The Policy Recommendation on Discovering a Green and Sustainable Crop Pest Management Solution for Rural Area Using AI-based IoT Strategy

APEC Policy Partnership on Science, Technology and Innovation

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KEY ABBREVIATIONS

Abbreviations	Meaning
AI	Artificial Intelligence
AIoT	Artificial Intelligence of Things
APEC	Asia-Pacific Economic Cooperation
BCG	Bio-Circular-Green
DNA	Deoxyribonucleic Acid
GDP	Gross Domestic Product
ICM	Integrated Crop Management
ICT	Information and Communications Technology
IDE	Innovation-Driven Enterprise
IPM	Integrated Pest Management
IRA	Inflation Reduction Act
ITRI	Industrial Technology Research Institute
M2M	Machine-to-Machine
MSMEs	Micro, Small, and Medium-sized Enterprises
R&D	Research and Development
SOPs	Standard Operating Procedures
STI	Science Technology Innovation
UAVs	Unmanned Aerial Vehicles
VOC	Volatile Organic Compound

1. Introduction

Agriculture remains the fundamental industry critical for providing food, the most essential human need. However, the sector is currently navigating a unique period characterized by immense structural challenges and unprecedented technological opportunities. Within the APEC region, pest and disease pressure represents a first-order threat to food security and rural livelihoods. The Food and Agriculture Organization (FAO) estimates that pests cause approximately 20%–40% of annual crop losses, translating into at least USD290 billion in economic damages globally. These risks are further compounded by the Asia-Pacific's high exposure to natural hazards—accounting for roughly 70% of global natural disasters—where the most severe impacts fall on developing economies and remote/rural communities that depend heavily on agriculture for income and exports.

The prevailing reliance on traditional pesticide-intensive approaches is increasingly viewed as inadequate and unsustainable. Overuse of chemical inputs not only harms ecosystems and soil biodiversity but also accelerates pesticide resistance and elevates occupational and food-safety risks. Moreover, the historical reliance on manual visual inspection for disease detection is labor-intensive and often results in delayed interventions. In this context, Integrated Pest/Crop Management (IPM/ICM) has become a vital strategic priority. By prioritizing prevention and data-based decisions over routine chemical applications, IPM/ICM offers a path to lower management costs and reduced resistance pressure—outcomes that are particularly critical in remote settings where labor and inputs are often constrained.

This crisis of sustainability is ushering in a new revolution in modern agriculture, following the historical milestones of chemical fertilizers, pesticides, and genetic breeding. We are now entering the era of "Smart Agriculture," where food production and crop health increasingly leverage advanced information technologies. By moving away from fragmented tools toward localized, deployable solutions, APEC economies can empower smallholders through an AI-based IoT/ICT strategy. This approach emphasizes practical "cyclic data management" and prediction capability—combining field-level sensing, open datasets from local meteorological agencies, and big-data analytics to support accurate pest forecasting and early intervention.

Building on this framework, this policy report focuses on the integration of technology advancement with robust STI (Science, Technology, and Innovation) policy development. The strategy explicitly centers on creating an integrated ecosystem that spans policymakers, technology providers, agricultural enterprises, and small farmers. By addressing key considerations such as data security and digital inclusion, this initiative commits to translating technological lessons into actionable policy recommendations. Ultimately, the goal is to enable sustainable and resilient agri-food systems across APEC economies, ensuring that the benefits of the AI-IoT revolution are accessible to the most vulnerable rural communities.

2. The Five Major Challenges of Pest and Disease Management in Remote and Rural Agriculture

2.1 Technological and Infrastructure Challenges

Remote and rural agricultural areas across the APEC region face deep-seated technological and infrastructure constraints that systematically hinder effective pest and disease prevention, monitoring, and control. A primary barrier is the "efficacy perception gap": preventive IPM/ICM approaches are frequently perceived by smallholders as less immediately effective or more complex to implement than routine, "calendar-based" chemical applications. This cognitive bias is exacerbated by the inherent logistical and biological limitations of alternative solutions. Specifically, many high-efficacy biopesticides exhibit slower action compared to synthetic counterparts and possess highly sensitive shelf lives [1-2]. The successful adoption of these microbial or botanical agents often necessitates localized fermentation units or specialized cold-chain storage to maintain stability—facilities that are typically unavailable or prohibitively expensive in remote areas [3-4]. Consequently, the lack of such supporting infrastructure reinforces a cycle of pesticide dependence despite well-documented risks of environmental degradation and pest resistance [5-7].

Furthermore, the "digital divide" remains a critical bottleneck for modernizing pest management. While AIoT-based systems offer transformative potential, unstable internet connectivity—characterized by low bandwidth in "last-mile" areas—and unreliable power grids severely hinder the deployment and long-term autonomous operation of real-time monitoring networks [8-9]. This digital infrastructure deficit is compounded by a chronic scarcity of scalable, high-quality agricultural data. Existing AI models often suffer from reduced accuracy under diverse real-world field conditions due to the "Small Data" challenge found in fragmented rural landscapes, where data collection is inconsistent [10-11].

Finally, engineering durable and resilient hardware presents a pivotal challenge for technology integration. On-farm IoT sensors and edge-computing devices are constantly exposed to severe environmental conditions, including extreme temperatures, high humidity, and pervasive dust, which significantly accelerate the physical wear and tear of critical components [12]. Such environmental stressors, combined with heavy precipitation, often lead to frequent equipment failure and necessitate recurring maintenance. For many remote communities and small-scale producers with limited technical expertise and financial resources, these ongoing operational expenditures and the high technical maintenance threshold pose a substantial barrier to the long-term viability of smart agricultural solutions [12].

2.2 Human Capacity and Knowledge Gaps

A critical bottleneck in rural agricultural resilience is the widening gap in human expertise and localized capacity. Many remote areas suffer from a severe scarcity of trained plant protection specialists and mobile diagnostic professionals, significantly limiting farmers' ability to detect and respond effectively to emerging or invasive pest risks in real-time [13-14]. At the farm level, the adoption of IPM/ICM frameworks is often hindered by their inherent complexity; these strategies require a high degree of technical knowledge, precise monitoring skills, and coordinated community-wide decision-making. Such a "cognitive burden" creates a steep learning curve for smallholders, many of whom lack formal technical training [13, 15-16].

This challenge is further intensified by a persistent disconnect between expert-generated recommendations and the realities of local farming practice. As the report notes, AI tools in agriculture depend heavily on localized data, language support, and content calibrated to local agroecological conditions. Without these elements, recommendations may remain too generic or inaccurate to be meaningfully integrated into daily field practices, particularly for smallholder farmers [17]. As AIoT technologies are introduced into agriculture, a new form of digital exclusion is becoming more visible. Many farmers, especially those with lower levels of digital readiness, may find it difficult to interpret data-intensive outputs or confidently use unfamiliar digital tools without adequate training and support. This can limit the effective uptake of AI-enabled solutions and reduce their practical value in day-to-day farm management. Policy responses should therefore prioritize not only technology deployment, but also usability, extension support, and capacity building for end users [16-17]. Without sustained investment in extension services and farmer-centered translation, training, and support mechanisms, even sophisticated pest management technologies are unlikely to achieve their intended on-farm effectiveness. Available evidence shows that practical impact depends not only on the technology itself, but also on trusted advisory channels, user-friendly delivery, local language adaptation, and continued farmer engagement [14].

2.3 Economic and Business Model Constraints

In remote and rural agriculture, economic constraints are not limited to technology affordability alone; they are rooted in the low and often unstable margins under which many farm households operate, especially smallholders and family farms, whose investment decisions are shaped by cash flow, market access, production risk, and limited access to financing and productive assets [18]. New agricultural technologies may offer clear technical benefits, but their adoption is frequently constrained by high upfront costs, the need for complementary infrastructure or services, and the scale requirements needed to make them economically sustainable [19-20]. In practice, many digital and precision agriculture tools exhibit strong economies of scale and scope, which means that limited uptake keeps per-unit costs high, slows diffusion, and reinforces a "Low Adoption–High Cost Trap," particularly for small farmers in remote areas who face additional barriers in communications infrastructure, literacy, and service access [19-20]. At the same time, larger farms and agri-food firms are generally better positioned to exploit scale-dependent technologies, comply with regulations, access export markets, and mobilize the human and financial capacity needed for innovation, which can bias prevailing market incentives toward commercially stronger segments and established production pathways rather than toward solutions tailored to marginal areas or sustainability-oriented transition needs [21]. As a result, farmers in remote and rural settings often find single-point technologies difficult to adopt, especially when those technologies add cost without reducing transaction burdens or improving market integration. Under such conditions, adoption is more likely when technologies are delivered through bundled or system-level models that combine technical tools with advisory support, business services, market linkage, and other integrated forms of coordination that reduce risk and improve practical usability [18-20].

2.4 Institutional and Policy Fragmentation

Institutional and Policy Fragmentation. Remote and rural agriculture is further constrained by institutional and policy fragmentation. Within agricultural systems, specialized disciplinary silos—such as soil management, fertilization, and pest control—often produce interventions that appear effective in isolation but fail to generate satisfactory outcomes at the whole-farm or system level. For example, even an effective pest management measure may deliver limited results if it is not aligned with crop nutrition, soil health, water management, or broader agronomic conditions. This reflects the fundamental reality that agriculture functions as an integrated ecological system, in which soil, plants, water, microbes, and management practices interact continuously, rather than as a set of discrete technical components [22]. At the policy level, many agricultural initiatives are well-intentioned and strategically sound in design, yet their practical impact often remains constrained because implementation details are decisive, and policymakers may not fully grasp the operational realities, trade-offs, and time pressures faced on farms. In addition, weak coordination across ministries, agencies, and program portfolios can further reduce policy coherence, create fragmented support mechanisms, and limit the effectiveness of otherwise promising agricultural interventions.

2.5 Environmental and Climate-related Vulnerabilities

Environmental and Climate-related Vulnerabilities. Remote and rural agriculture is increasingly exposed to environmental and climate-related vulnerabilities that heighten production risk and weaken the stability of local farming systems. Soil and land degradation, water scarcity, climate change, and the growing frequency and intensity of extreme weather events are placing mounting pressure on already fragile agricultural landscapes [23-25]. These pressures can increase the unpredictability of pest and disease occurrence, disrupt seasonal production patterns, and reduce the reliability of conventional control and management measures under increasingly variable field conditions [24, 26]. At the same time, climate-related shocks such as droughts, floods, heat stress, and severe water shortages can trigger broader food-system disruptions, including yield losses, livelihood instability, and increased rural vulnerability [24-26]. Farmers in remote and rural areas are particularly at risk because many smallholders operate with limited assets, weak risk-buffering capacity, and constrained access to services, infrastructure, and adaptive support [23-24, 26]. As a result, adaptive capacity often remains insufficient to keep pace with escalating environmental stress, reinforcing cycles of yield instability, income insecurity, and livelihood risk in climate-sensitive rural production systems [24, 26].

3. Current Situation and Key Challenges of Remote and Rural Agriculture across APEC Economies

3.1 Australia [27-29]

I. Rural Agricultural Landscape

Australia's agricultural sector is characterized by a strong export orientation and large-scale operations, with approximately 70% of produce exported and 99% of farms remaining family-owned and operated. While agriculture accounts for about 2.4% of the economy's GDP, it utilizes 55% of the economy's land and 70% of its freshwater resources. The most critical challenge is the increasing frequency of extreme droughts driven by climate change, which has caused a 23% decline in average annual farm profits over the past two decades. Furthermore, rural Australia faces a severe labor shortage—projected to reach 25,000 workers by 2030—and escalating biosecurity threats (e.g., Varroa mite). Combined with high logistical costs due to geographic isolation, these stressors are compelling the sector to transition toward climate-resilient automated systems.

II. Technology (AIoT & ICM) Integration Trends

To mitigate acute water scarcity and climate volatility, Australia leverages AIoT as a cornerstone of its "Digital Foundations for Agriculture Strategy". Australian farms have extensively deployed soil moisture sensors and automated irrigation systems that utilize real-time data to optimize water distribution, significantly enhancing crop survival during droughts. The implementation of "edge-of-field monitoring" and big data analytics allows producers to track resource efficiency, with digital technologies projected to add over AUD20 billion annually to the sector's output. Regarding Integrated Crop Management (ICM), Australia maintains a world-leading low chemical and fertilizer footprint. Notably, 85% of grain farms practice "stubble retention" to preserve soil moisture, integrating this with AI-driven precision spraying and biological controls. This deep synthesis of digital precision and water-conservative agronomy has become essential for Australia to maintain its global export competitiveness amidst extreme climatic variability.

3.2 Indonesia [30-32]

I. Rural Agricultural Landscape

Agriculture remains a vital cornerstone of Indonesia's economy, contributing 12.4% to the economy's GDP and employing approximately 29% of the total workforce. However, rural regions face persistent structural bottlenecks; according to the 2023 Agricultural Census, over 60.8% of farming households are "fragmented smallholders" (Petani Gurem) operating on less than 0.5 hectares. The sector is also grappling with acute demographic aging and high sensitivity to climate volatility, where extreme weather events in 2024 led to a significant shortfall of 4 million tons in rice production. Consequently, in 2026, the government designated "Food Self-Sufficiency" as a top-tier domestic security objective to mitigate import dependency and address the widening infrastructure gap in remote archipelagic regions.

II. Technology (AIoT & ICM) Integration Trends

To escape productivity stagnation and advance toward "Agriculture 4.0," Indonesia is accelerating the integration of digital innovation and "Farmer Corporatization" under the National Agricultural Development Planning 2025–2029. In terms of AIoT adoption, large-scale plantations have extensively deployed Unmanned Aerial Vehicles (UAVs) and IoT sensors for precision irrigation and real-time pest monitoring. For smallholders, centralized big data platforms provide critical climate alerts and optimized planting guidance. Regarding Integrated Crop Management (ICM), the government is enforcing the Indonesian Sustainable Palm Oil (ISPO) certification, which institutionalizes digital traceability across the value chain. Empirical evidence indicates that implementing ICM technology packages—including smart fertigation and mechanization—can increase rice yields by 16% to 37% while significantly reducing chemical dependency. This synthesis of digital precision and sustainable governance is central to Indonesia's strategy for rural revitalization and ensuring long-term food security.

3.3 Japan [33-37]

I. Rural Agricultural Landscape

Japan's agricultural landscape is profoundly shaped by its mountainous geography, with only 20% of land suitable for cultivation, leading to fragmented and small-scale operations predominantly located in rural and "hilly and mountainous" areas. Consequently, the industry's status directly mirrors the economic vulnerability of rural communities. As of 2017, the sector contributed only 1.1% to the GDP, and domestic food self-sufficiency remains at a critical 38%. The most pressing structural challenge is extreme demographic aging, with the average age of farmers exceeding 67. This has resulted in a sharp labor decline, causing extensive farmland abandonment and the collapse of essential rural community functions, such as the maintenance of shared irrigation systems. Furthermore, skyrocketing input costs since 2021 and persistent wildlife damage in remote regions have further strained farm profitability and threatened domestic food security.

II. Technology (AIoT & ICM) Integration Trends

To revitalize these regions and enhance productivity, Japan is aggressively promoting the integration of AIoT and Integrated Crop Management (ICM) under a comprehensive legal and strategic framework. A cornerstone of this effort is the "Act on Promoting the Utilization of Smart Agricultural Technology," enforced in 2024, which aims for over 50% adoption of smart technologies by 2030. The economy's "WAGRI" platform serves as a data-driven nexus, harmonizing weather, soil, and growth datasets to optimize decision-making and harvesting precision. In hilly terrains, robotics and Unmanned Aerial Vehicles (UAVs) are deployed to alleviate the labor burden of steep-slope operations. This digital shift is coupled with the "MIDORI Strategy," which targets a 50% risk-weighted reduction in chemical pesticides and a 30% reduction in fertilizers by 2050. Through "MIDORI Checks" (cross-compliance), environmental sustainability is mandated as a prerequisite for government support, driving a transition toward a resilient, carbon-neutral, and value-added agricultural food system.

3.4 Malaysia [38-40]

I. Rural Agricultural Landscape

Agriculture remains a vital component of Malaysia's economy, with oil palm contributing a dominant 36.8% to the sector's value in 2024. However, rural agriculture faces critical structural vulnerabilities, particularly an insufficient food self-sufficiency level—most notably rice, which stands at approximately 70%—and a heavy dependence on foreign manual labor. The rural workforce is characterized by extreme aging and a significant technical gap, with the sector struggling against a shortfall of tens of thousands of workers. Furthermore, Malaysia's rural areas are increasingly prone to climate-driven disasters; a single flood event in 2022 resulted in agricultural losses exceeding MYR150 million. These compounding stressors necessitate an urgent strategic shift toward resilient management to safeguard rural livelihoods and domestic food security.

II. Technology (AIoT & ICM) Integration Trends

To mitigate labor scarcity and boost productivity, Malaysia is accelerating its transition toward Agriculture 4.0 under the "National Agrofood Policy 2.0 (DAN 2.0)" and the "Digital AgTech" initiative. As of early 2025, over 600 digital systems have been deployed economy-wide, training more than 30,000 agropreneurs to adopt IoT and AI technologies. Key implementations include AI-powered smart fertigation, Unmanned Aerial Vehicles (UAVs) for plantation monitoring, and AI-driven pest detection, which have collectively increased productivity and income by 20% while reducing operational costs by 30%. Regarding Integrated Crop Management (ICM), Malaysia emphasizes the "Malaysian Sustainable Palm Oil (MSPO)" standard, integrating digital traceability with precision management to meet global green requirements. This synergy of digital innovation and sustainable practice is also designed to attract younger generations back to rural areas, transforming the sector into a high-value, tech-driven industry.

3.5 New Zealand [41-43]

I. Rural Agricultural Landscape

Agriculture remains a vital cornerstone of New Zealand's economy, contributing 15.3% to the economy's GDP in 2024 and achieving a record NZD60.4 billion in export revenue by mid-2025. However, rural regions face a critical demographic challenge, with over 50% of the agricultural workforce now aged 55 or older, leading to acute labor shortages and succession gaps. Environmentally, producers must navigate an increasing frequency of adverse weather events, such as severe droughts and floods. Furthermore, the sector is under immense pressure to comply with stringent domestic regulations regarding water quality, biodiversity loss, and greenhouse gas emissions. These structural and environmental stressors are compelling traditional pastoral and cropping systems to accelerate their transition toward more resilient operational models.

II. Technology (AIoT & ICM) Integration Trends

To maintain its global competitive edge, New Zealand is aggressively fostering "Climate-Smart Agriculture" and the deep integration of AI-driven technologies. While personal digital device adoption among farmers is high, the deployment of dedicated Machine-to-Machine (M2M) and AIoT infrastructure for production remains an untapped frontier, currently shifting toward the use of remote sensing and big data for optimized pasture management. Regarding Integrated Crop Management (ICM), the focus is on merging time-tested practices with modern innovations, such as AI-powered breeding and microbial solutions. By utilizing real-time soil and water monitoring to facilitate precision nutrient application and soil health restoration, New Zealand aims to balance profitability with environmental stewardship. This synthesis of digital innovation and sustainable management is essential for preserving the "grass-fed" brand's integrity while meeting economy's biosecurity and 2030 sustainability targets.

3.6 Peru [44-47]

I. Rural Agricultural Landscape

Agriculture in Peru operates on a stark dualistic model: while a high-tech coastal strip leads the world in blueberry and grape exports (projected to exceed USD22 billion by 2025), the Andean and Amazonian regions remain dominated by smallholders facing a 27.6% rural poverty rate. The sector employs 25% of the economically active population, yet structural gaps—such as fragmented land ownership and limited access to credit—persist. Furthermore, high vulnerability to El Niño-driven climate shocks poses a constant threat to the economic resilience of nearly four million small-scale producers. This disparity underscores a critical need for rural transformation that balances export growth with social and environmental sustainability.

II. Technology (AIoT & ICM) Integration Trends

To bridge the productivity gap, Peru is accelerating its transition through the October 2025 launch of the "AgroDigital" mobile platform and the

"Agricultural Producers Registry (PPA)," which utilize geolocation and satellite monitoring to provide real-time climate alerts and market intelligence. A pivotal technical shift is driven by the 2026 enforcement of the EU Deforestation Regulation (EUDR); Peru is deploying blockchain-based traceability for coffee and cacao to certify deforestation-free production. Additionally, the government has committed USD74.8 million in public funding for climate-smart irrigation to optimize water use in arid coastal zones, merging AI-driven precision with biological pest controls managed by SENASA. These initiatives aim to integrate rural smallholders into high-value global supply chains while fostering a low-carbon agricultural future.

3.7 The Philippines [48-50]

I. Rural Agricultural Landscape

Agriculture remains a cornerstone of the Philippines' economy, contributing approximately 10% to the economy's GDP and employing 24% of the workforce. In 2025, the sector achieved a 2.6% growth in output value, its fastest pace in eight years. Despite this rebound, rural regions face profound structural challenges, including highly fragmented landholding patterns (99.2% of agricultural businesses are MSMEs), significant infrastructure deficits (e.g., inadequate farm-to-market roads and post-harvest facilities), and extreme climate vulnerability—facing an average of over 30 cyclones annually. Furthermore, aging demographics and volatile input costs render smallholders acutely susceptible to global price shocks and the intensifying impacts of El Niño and La Niña events, necessitating a transition toward more resilient production models.

II. Technology (AIoT & ICM) Integration Trends

To enhance climate resilience, the Philippines is aggressively accelerating the integration of "Climate-Smart Agriculture" and digital platforms. The digital agriculture platform market is projected to reach USD1.1 billion by 2025, with an estimated 70% of rural farmers utilizing mobile devices for agricultural management. Regarding AIoT integration, the strategic priority lies in deploying soil moisture and microclimate sensors for "Smart Irrigation" and the widespread adoption of Unmanned Aerial Vehicles (UAVs) for precision spraying and real-time monitoring. In terms of Integrated Crop Management (ICM), the government-led "Masagana Rice Industry Development Program" synthesizes Integrated Pest Management (IPM) and biological controls to reduce chemical dependency and restore soil health. This synergy of satellite tracking, AI-driven decision support, and sustainable farming practices is central to the Philippines' strategy for rural transformation, the generation of "green jobs," and ensuring long-term domestic food security.

3.8 Chinese Taipei [51-57]

I. Rural Agricultural Landscape

Chinese Taipei’s mountainous terrain across tropical and subtropical zones supports diverse crops but remains highly vulnerable to typhoons and extreme weather events. As agricultural production is concentrated in rural areas, the industry's status directly defines the economic resilience of rural communities. The sector is characterized by small-scale farming with an average landholding of 0.72 hectares. According to 2024 statistics, primary agriculture accounts for 1.5% of GDP and 4.3% of employment. However, the broader "Agri-food Chain" contributes 7.2% to GDP and employs 17.1% of the workforce, meaning one out of six workers is engaged in agri-food activities. Despite this footprint, rural regions face acute structural challenges: pronounced rural aging (averaging over 62 years old) leads to severe labor shortages and technical succession gaps. Exorbitant land prices and fragmented ownership severely limit economies of scale and automation efficiency. Furthermore, costs for inputs like seeds and fertilizers exceed international benchmarks, and wide price spreads between production and retail compress farmers' real income, while incomplete digital integration further hinders sustainable development space in rural areas.

II. Technology (AIoT & ICM) Integration Trends

To bolster industrial resilience and product competitiveness in rural regions, Chinese Taipei is promoting "Smart Agriculture 4.0," integrating AIoT deeply into production processes. Sensors are extensively deployed to monitor microclimates and soil dynamics, channeling data via wireless networks to cloud platforms. In practice, UAVs are widely used for precision spraying and disaster assessment, while AI image recognition enables early pest warnings. Farmers utilize mobile apps for real-time remote monitoring, transforming fragmented data into visualized management tools to optimize decision-making. Regarding Integrated Crop Management (ICM), progress is centered on the "Ten-Year Action Plan for Halving Chemical Pesticide Risks". Key measures include a real-name pesticide purchase system and the 2024 "Plant Clinicist Act," which certified professionals to provide precision control advice. With subsidies for biopesticides and 42 crop-specific IPM guidelines established, overall pesticide risk has decreased by

37%, and highly toxic pesticide use fell by 71.2% as of 2024, fostering a sustainable production model that balances safety with economic efficiency in rural areas.

3.9 Thailand [58-61]

I. **Rural Agricultural Landscape**

Often hailed as the "Kitchen of the World," Thailand maintains agriculture as its socio-economic backbone, contributing approximately 8.7% to the economy's GDP and employing nearly 30% of its total workforce. The sector is dominated by smallholder farmers (averaging 4 hectares per farm) who maintain a leading global position in exporting rice, natural rubber, cassava, and tropical fruits. However, rural regions face critical structural bottlenecks: a rapidly aging farming population (averaging over 59 years) coupled with high input and labor costs, as well as widespread household debt that limits capital investment. Environmentally, Thai agriculture is acutely sensitive to climate change, where frequent droughts and floods—particularly in the arid Northeast—severely threaten the stability of traditional farming practices.

II. **Technology (AIoT & ICM) Integration Trends**

To escape the low-value commodity trap, Thailand is aggressively promoting the "Bio-Circular-Green (BCG)" economic model and the "Agriculture 4.0" initiative launched in 2026. Regarding AIoT integration, the government utilizes the "Agri-Map" system to harmonize land and resource big data, while accelerating the deployment of Unmanned Aerial Vehicles (UAVs) for precision spraying to bridge rural labor gaps. Sensor networks and automated irrigation are increasingly piloted in high-value durian plantations to facilitate remote environmental monitoring. In terms of Integrated Crop Management (ICM), Thailand emphasizes the economy-wide scaling of "Good Agricultural Practices (GAP)" certification, aiming to shift from low-price commodities to high-safety, premium products. By optimizing fertilizer and pesticide application through digital technology, Thailand seeks to maintain its lead in the global food safety chain while achieving long-term sustainability goals.

3.10 United States [62-65]

I. **Rural Agricultural Landscape**

The United States' agricultural landscape is characterized by extensive industrial-scale operations and a high degree of economic concentration, with just 6% of large-scale farms contributing 75% of the total agricultural output value. While the average farm size has expanded to 463 acres, the total number of farms has decreased to roughly 1.9 million, reflecting a continuous shift toward industrial consolidation. Rural communities are currently grappling with a severe labor crisis and a widening technical succession gap, as the average age of producers has reached 58.1 years. Furthermore, although 79% of farms have basic internet access, the persistent lack of high-speed rural broadband remains a critical infrastructure bottleneck for deploying sophisticated AIoT solutions in remote areas. This structural vulnerability is exacerbated by the increasing frequency of extreme weather events, which directly threaten the stability of global food supply chains.

II. Technology (AIoT & ICM) Integration Trends

To mitigate the impact of rural depopulation, the U.S. leverages "industrial-scale AIoT" as a vital force multiplier for agricultural productivity. Adoption of precision agriculture is projected to reach 60-65% by 2025, driven by the integration of Variable Rate Technology (VRT), satellite monitoring, and 24/7 autonomous tractors that compensate for the dwindling labor pool. Regarding Integrated Crop Management (ICM), the USDA's domestic initiative targets a 75% coverage rate for Integrated Pest Management (IPM) practices across all cropland. This effort is bolstered by USD19 billion in funding from the Inflation Reduction Act (IRA), specifically allocated to incentivize climate-smart agricultural practices that enhance soil health and resource efficiency. By synthesizing generative AI for planting simulations and molecular-level precision fertilization, the U.S. is transforming vast rural acreages into a highly automated, low-carbon industrial system that ensures food security and resilience despite a shrinking rural workforce.

3.11 Concluding Summary

A comprehensive analysis of the selected APEC economies reveals a shared imperative for digital and sustainable transformation, though pathways diverge based on operational scale and developmental stages. Industrialized economies prioritize "industrial-scale AIoT" to offset labor scarcity and enhance climate resilience, while land-limited economies with aging demographics focus on precision technologies and policy frameworks to sustain high-value management. Simultaneously, emerging economies are leveraging bio-economic models and digital traceability to integrate smallholders into global value chains. Despite these diverse approaches, the synergy between AIoT-driven precision and Integrated Crop Management (ICM) serves as a universal nexus across the Asia-Pacific. This integration of data-driven productivity and eco-friendly governance is transforming rural vulnerabilities into resilient, high-value, and carbon-neutral agricultural systems, ensuring long-term regional food security.

4. Technical Framework: Empowering Rural Agriculture through AI-based IoT Systems

4.1 The Digital Revolution Pathway [66-69]

I. Technological Background

Modern agriculture is currently undergoing a unique revolutionary period, transitioning from traditional input-reliant methods toward the era of "Smart Agriculture". This shift represents a significant industrial evolution following the historical introduction of chemical fertilizers, pesticides, herbicides, and genetic breeding through recombinant DNA. In this new landscape, food production, quality, and processing are increasingly integrated with advanced information technologies to meet the fundamental human need for food security. By leveraging sophisticated AI-based IoT systems, agricultural management becomes more precise and environmentally sustainable. These technologies provide automated, timely, and accurate monitoring solutions that are essential for early pathogen detection and swift intervention, which are critical for mitigating crop losses in field operations.

II. Key Driving Forces

The momentum behind this digital transformation in rural regions is sustained by several integrated technological and social opportunities:

- Sensor Proliferation and Affordability: A wide array of sensors for detecting pathogens and pests—including optical, thermal, and acoustic varieties—is now available at relatively low costs, enabling non-invasive and real-time monitoring.
- Computing and Analytics Capabilities: The rise of affordable computers and sophisticated software enables big data analysis for individual farmers, allowing for data-driven decision-making rather than a sole reliance on traditional visual inspection.
- Network and Information Infrastructure: Mature IoT architectures and fluent information flow via the internet promote the sharing of management experiences across remote regions and the continuous monitoring of environmental conditions.
- Mature Technical Ecosystem: Both hardware and software for data collection and transfer have reached a high level of sophistication, supporting continuous field surveillance and real-time response systems.
- Social and Regulatory Demands: Growing public concern regarding food safety and stricter governmental regulations regarding "organic" or reduced-chemical production methods exert significant pressure on the sector to adopt smarter, more sustainable management strategies.

4.2 Multidimensional Monitoring [66-67, 69]

I. Comprehensive Monitoring Framework

The core of the AI-based IoT framework lies in its ability to perform continuous, non-invasive surveillance of crop health. Unlike traditional manual inspection, this system integrates diverse sensing technologies to detect biological threats at early stages—often before visual symptoms appear. The system is designed to identify and monitor four primary categories of threats: viruses, bacteria, fungi, and pests.

1. Detection of Viral Pathogens

   Viruses often cause subtle metabolic changes in plants. The framework utilizes high-resolution optical sensors, including hyperspectral imaging and chlorophyll fluorescence sensors, to detect shifts in photosynthetic efficiency and leaf reflectance patterns. These sensors can identify specific "spectral signatures" associated with viral infections such as mosaic viruses, enabling rapid isolation of infected plants to prevent field-wide outbreaks.

2. Monitoring of Bacterial Infections

   Bacterial pathogens frequently alter the plant's volatile organic compound (VOC) emissions and leaf surface characteristics. The system employs gas sensors (Electronic Noses) to "smell" early bacterial decay or specific VOC biomarkers. Additionally, ion-selective electrodes are used to monitor nutrient imbalances in the soil or plant sap that may indicate systemic bacterial colonization, such as wilt-inducing bacteria.

3. Monitoring of Fungal Diseases

   Fungal outbreaks, such as powdery mildew or rust, significantly impact canopy temperature and moisture levels. The framework leverages thermal sensors to monitor canopy heat signatures, as fungal infections often disrupt transpiration. Multispectral sensors are also deployed to track the "Normalized Difference Vegetation Index" (NDVI) and other physiological indices to distinguish between fungal lesions and abiotic stress (e.g., drought).

4. Pest Identification and Management

   For insect pests like aphids, mites, or borers, the system employs a dual-tracking approach:

   - Acoustic Sensors: Highly sensitive microphones detect the specific vibrations and sounds produced by larvae or adult insects during feeding or movement within the plant tissue.
   - Image-Based AI: RGB cameras coupled with Edge-AI algorithms perform real-time identification of pest species and population density on leaves and traps, allowing for the precise application of biological controls rather than broad-spectrum chemical spraying.

4.3 Analytical Empowerment [66, 68-69]

I. Transition to Data-Driven Agriculture

The integration of AI-based IoT systems marks a pivotal shift in agricultural management, moving away from a sole reliance on traditional visual observation toward a sophisticated data-driven paradigm. Historically, farmers in remote regions depended on their experience and physical inspection to identify crop stress or disease. However, the current era of smart agriculture leverages relatively affordable computers, software, and high-speed internet to enable comprehensive big data analysis for individual farmers. This technological empowerment allows for the processing of vast amounts of field data, transforming raw sensor inputs into actionable intelligence.

II. Personalized Decision Support

By utilizing these accessible IT resources, individual farmers can now receive precise, farm-specific decision support. The system analyzes environmental variables and pathogen detection data in real-time, providing tailored recommendations for intervention. This analytical capability is crucial for:

- Early Diagnosis: Identifying potential threats before they escalate into widespread outbreaks, based on statistical patterns rather than waiting for visible symptoms.
- Optimized Resource Allocation: Assisting farmers in making informed decisions about the exact timing and necessity of biological or chemical applications, thereby enhancing cost-effectiveness.
- Risk Mitigation: Using historical and real-time data to forecast pest and disease trends, allowing individual producers to implement preventive measures more effectively.

III. Promoting Experience Sharing and Fluency

Furthermore, the analysis performed at the individual farm level contributes to a much more fluent information flow across the agricultural network. This digital connectivity promotes experience sharing among farmers, as data-driven insights can be easily communicated and compared. By empowering individual farmers with professional-grade analytical tools, the framework helps bridge the knowledge gap in rural areas, ensuring that modern management techniques are accessible to all, regardless of their geographic location.

4.4 Knowledge Connectivity [69-70]

I. Revolution in Information Fluency

One of the most significant opportunities in the era of smart agriculture is the achievement of "much fluent information flow." Historically, farmers in remote and rural regions have been isolated from timely expert advice and market insights.

However, the maturation of internet infrastructure and specialized software has revolutionized how agricultural data is moved and utilized. This technological connectivity ensures that critical information—ranging from real-time environmental monitoring to pathogen outbreak alerts—can reach individual producers regardless of their geographic location.

II. Facilitating Experience Sharing

The AI-based IoT framework serves as a powerful platform for "experience sharing" among farmers, researchers, and policymakers across the APEC region. By leveraging information technology advantages, the system enables:

- Peer-to-Peer Learning: Individual farmers can share their successful pest management strategies and data-driven insights with others, effectively bridging the localized knowledge gap.
- Collaborative Risk Management: As data flows more freely between farms and central analytical hubs, successful intervention experiences can be scaled rapidly to protect broader agricultural zones.
- Synchronized Response: The fluency of information facilitates a more coordinated effort between rural communities and governmental institutions, ensuring that local management practices are aligned with regional biosecurity goals.

III. Bridging the Knowledge Gap

By empowering individual farmers with the tools to both receive and contribute to a collective body of knowledge, this framework promotes a more inclusive agricultural ecosystem. The ability to access and exchange professional management experiences via affordable digital channels is essential for transforming rural agriculture from a traditionally labor-intensive sector into a highly informed, collaborative, and resilient industry.

4.5 Socio-Technical Accessibility [68]

I. Breaking the Barriers of Affordability

The success of smart agriculture in remote regions hinges not only on technical precision but also on economic accessibility. The AI-based IoT framework addresses the long-standing capital constraints of rural agriculture by leveraging the current era’s technological dividends. A pivotal opportunity identified in this strategy is the availability of "inexpensive sensors" for detecting various pathogens and pests. These low-cost hardware solutions enable non-invasive, continuous monitoring without the prohibitive capital investment historically required for high-end agricultural technology. By making field-level surveillance financially viable, the framework ensures that even small-scale producers can participate in the digital transformation.

II. Democratizing Big Data and Analytics

Beyond hardware, the software and analytical components of the system are designed around "relatively affordable computers and software." This accessibility is essential for achieving digital inclusion among individual farmers who have traditionally been marginalized from advanced information technology. By utilizing cost-effective IT resources, the system transforms big data analysis from an elite scientific endeavor into a practical, everyday tool for rural producers. This democratization of data ensures that sophisticated management experiences and expert-level insights are no longer restricted by a farmer's financial standing or geographic isolation.

III. A Foundation for Digital Inclusion

Ultimately, the integration of affordable technology fosters a "fluent information flow" that bridges the digital divide in rural areas. The ability to monitor environmental conditions and pathogen threats in real-time—at a cost that matches the economic reality of remote communities—is the key to achieving a green and sustainable agricultural revolution. By ensuring that smart solutions are socio-technically accessible, APEC economies can promote a more equitable agricultural landscape, where technology serves as a catalyst for resilience, food safety, and the revitalization of rural livelihoods.

5. Policy Recommendations

Building on the challenges identified in earlier chapters, the economy-level review across selected APEC members, and the technical analysis of emerging AI-based IoT and IPM/ICM solutions, this chapter proposes a policy package centered on agri-industrial integration and ecosystem enablement to strengthen pest and disease management in remote and rural agriculture across APEC economies. As the preceding analysis has shown, the constraints facing remote and rural agriculture are interconnected, spanning infrastructure gaps, human capacity limitations, weak commercialization pathways, institutional fragmentation, and rising environmental pressures. Despite major differences in scale, income level, and production structure, many APEC economies face a common policy challenge: how to translate promising digital and sustainable agricultural technologies into solutions that are practical, affordable, and scalable under real rural conditions.

In response, the proposed approach treats technology development and commercialization as a coupled mechanism. Solutions should be co-designed, co-developed, and field-validated through structured collaboration between the agricultural sector, which defines demand and field scenarios, and the industrial sector, which contributes sensing technologies, equipment, digital platforms, and system-integration capabilities. The guiding requirement is that solutions must be fit-for-purpose, impact-validated, and affordable within farmers' ability to pay. To make this feasible in dispersed and resource-constrained settings, the package emphasizes holistic, system-level solution bundles that reduce farmers' coordination burden, lower the total cost of pest and disease management, and remain workable under last-mile conditions. This requires foundational support such as rural internet connectivity, power reliability, and practical low-barrier tools suited to uneven infrastructure and varying levels of digital readiness.

The policy package also recognizes that commercialization in agriculture cannot rely on technology transfer alone. Because agricultural production is highly diverse and biologically complex, innovation rarely creates value as a stand-alone technical component; it must be adapted and integrated with diagnostics, advisory services, field operations, and market delivery. For this reason, IDE-based agricultural startups should be supported as an important commercialization mechanism. Compared with incumbent firms, which are often tied to existing input-based product lines, and public-sector entities, which typically operate through project-based mandates, startups are often better positioned to integrate cross-disciplinary technologies, iterate with farmers, and develop bundled service-oriented solutions that can be continuously improved over time.

Building on workshop discussions and the cross-economy observations presented in this report, the policy package recommends enabling scalable and sustainable deployment through ecosystem-driven business models and a clear set of market-enabling tools and delivery mechanisms. These include public–private coordination platforms to bridge the R&D-to-commercialization gap, shared-service models such as leasing, subscription, and managed services to reduce upfront investment barriers, and stronger plant health extension and localized diagnostics to translate technical outputs into actionable IPM/ICM practices. In parallel, the package prioritizes data governance and interoperability, including platform-level data exchange standards and, where appropriate, cross-economy data-sharing arrangements, to support earlier warning, more precise targeting, and continuous improvement. Taken together, these recommendations aim to shorten response time, improve decision quality, reduce pest-management input costs, and increase farm value creation through yield and quality gains, while also addressing commercialization and deployment barriers so that integrated crop management solutions can be continuously delivered, improved, and adopted across remote and rural communities.

5.1 Macro Policy Recommendation Framework: Agri-Industrial Integration And Ecosystem Enablement

Building on the challenges identified in earlier sections, the economy-level review across APEC members, and the technical opportunities presented by AI-based IoT and IPM/ICM approaches, this report proposes a macro policy recommendation framework to enable sustained and scalable pest and disease management in remote and rural agriculture across APEC economies. As illustrated in Figure 1, the framework is structured around the interaction of two mutually reinforcing policy gears: Agri-Industrial Integration and Ecosystem Enablement. This architecture reflects a central finding of the report: in remote and rural agriculture, technical effectiveness alone is insufficient. To generate real public value, solutions must not only work in the field, but also be deployable, affordable, and continuously supported under diverse rural conditions.

The first gear, Agri-Industrial Integration, focuses on solution readiness. It begins with demand-led co-design, in which actual field constraints, crop-specific risk scenarios, and farmer decision needs are translated into technical requirements. These requirements are then co-developed with industrial actors, including providers of sensing systems, equipment, digital platforms, and system integration capabilities. Rather than promoting fragmented tools, this framework emphasizes integrated solution development and field validation through demonstration sites and production-scale testing, so that outputs can be converted into replicable workflows and practical standard operating procedures (SOPs). In line with the challenges discussed in previous chapters, particularly those related to affordability, low digital readiness, and fragmented farm conditions, all solutions should meet a common threshold: they must be fit-for-purpose, impact-validated, and affordable within farmers' ability to pay.

The second gear, Ecosystem Enablement, focuses on commercialization and scaling. The review across APEC economies shows that even when promising technologies exist, rural adoption is often constrained by weak delivery systems, limited integration capacity, and inadequate commercialization pathways. To address this, the framework calls for ecosystem-level mechanisms that align system integrators, niche providers, extension actors, finance channels, and relevant public institutions. This includes public–private coordination platforms to bridge the R&D-to-market gap, holistic solution packages and delivery models that reduce farmers' coordination burden, and market-enabling tools such as procurement mechanisms, incentives, standards, and risk-sharing finance. It also includes efforts to remove scaling barriers for sustainable alternatives, including biological or lower-risk solutions that may face weak market channels or regulatory uncertainty despite their field relevance.

A defining feature of this framework is the feedback and iteration loop connecting the two gears. Agri-industrial integration improves solution quality and fitness for use, while ecosystem enablement improves the conditions for uptake, service delivery, and continuous deployment. As adoption expands, learning from implementation can be fed back into design refinement, cost reduction, and delivery improvement. This dynamic is especially important in remote and rural agriculture, where high diversity in farming practices, environmental conditions, and service access means that solutions must evolve through repeated field learning rather than one-time deployment. In practical terms, this mutual reinforcement is intended to support sustained adoption by lowering the total cost of pest and disease management while improving usability, delivery continuity, and commercial viability.

The framework is supported by four enabling conditions that strengthen policy and system capacity. First, data governance and interoperability standards are needed to support platform-level data exchange, APIs, privacy protection, and cybersecurity, thereby improving the quality, trustworthiness, and continuity of digital pest-management systems. Second, last-mile infrastructure and shared services—including connectivity, reliable power, and service models such as leasing, subscription, or managed services—are essential for making technology usable in dispersed rural environments. Third, talent and localized extension/diagnostics capacity remain indispensable for translating technical outputs into actionable decisions, particularly through plant doctors, lead farmers, and locally accessible communication channels. Fourth, cross-ministerial coordination and public–private funding alignment are required to reduce institutional fragmentation, sustain joint governance, and mobilize long-term financing mechanisms, including PPP arrangements where appropriate.

Together, these two policy gears and four enabling conditions are designed to generate three forms of public value that respond directly to the problems identified earlier in this report: faster response and better decisions, through earlier warning and more timely diagnostics; lower pest-management input costs, through reduced unnecessary inputs and better targeting; and higher farm value creation and resilience, through yield and quality gains under IPM/ICM-aligned, climate- and pest-resilient production systems. In this sense, the framework is not only a conceptual model for policy coordination, but also a practical architecture for aligning innovation, commercialization, and delivery in ways that are responsive to the realities of remote and rural agriculture across APEC economies.

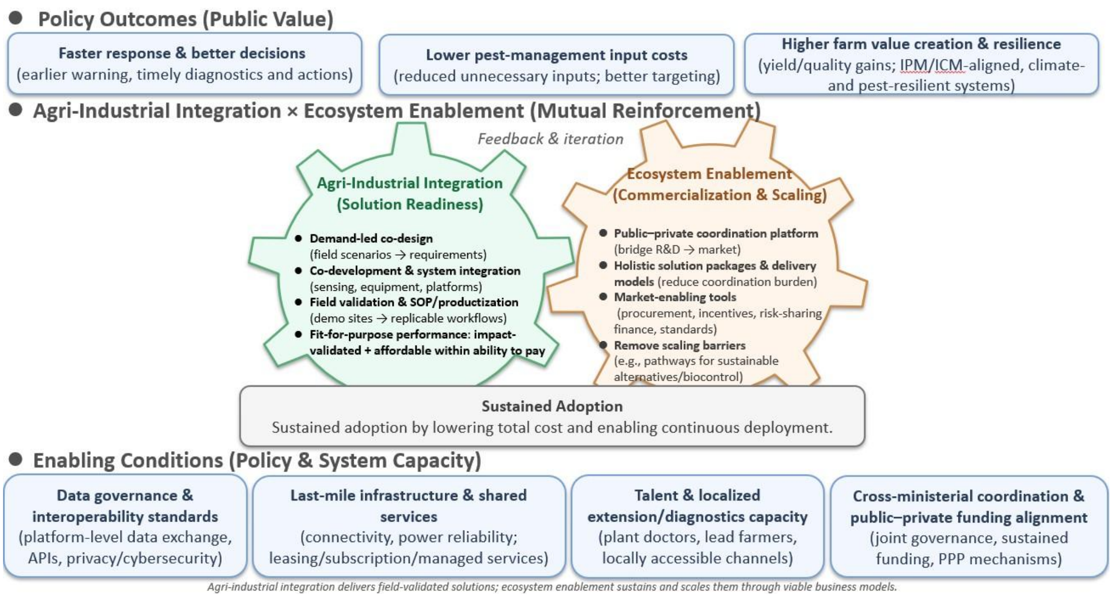

Figure 1. Marco Framework of Policy Recommendation

5.2 Micro-Level Delivery Mechanism: Operationalizing the Macro Policy Architecture

Drawing on workshop outcomes and implementation experience across APEC economies, this section sets out the micro-level delivery mechanism for operationalizing the macro policy architecture presented in Figure 1 in remote and rural contexts. While the macro framework defines the policy logic, effective implementation depends on whether economies can translate that logic into a practical delivery pathway that works under real field conditions. In remote and rural agriculture, pest and disease management is not only a technical issue, but also a coordination, service-delivery, and commercialization challenge shaped by weak infrastructure, fragmented farming systems, limited extension reach, and uneven private-sector incentives.

For this reason, the micro-level mechanism is presented as a sequence of operational functions rather than as a broad institutional narrative. The purpose is to help APEC economies identify who should do what, at which stage, and with what outputs. A key implementation principle is that governments should lead where public-good functions are essential—such as early-stage coordination, field validation, standards, extension capacity, and enabling infrastructure—while creating conditions for enterprises, startups, producer organizations, and service providers to assume stronger roles in solution refinement, delivery, and scale-up. In practical terms, this means moving from fragmented pilots toward a more structured pathway for developing, validating, packaging, and scaling integrated pest and disease management solutions under IPM/ICM principles.

I. Agri-Industrial Integration: Demand Confirmation and Translation

Under Agri-Industrial Integration, the first delivery function is Demand Confirmation and Translation. This step is essential because many agricultural technologies fail not due to weak technical performance, but because they are developed without a sufficiently precise understanding of real farm demand. APEC economies are therefore encouraged to begin with a structured process for identifying priority crops, major pest and disease risks, current management bottlenecks, and the most binding delivery constraints in remote and rural areas. This process should involve agricultural authorities, extension systems, plant health services, producer organizations, and representative farmers, so that field realities are translated into operational requirements rather than left as general policy intentions.

The translation process should go beyond identifying "what technology is needed" and also define decision scenarios: who needs to decide, what information is required, when that information must arrive, and what practical actions should follow. This is particularly important in remote agriculture, where timing, labor availability, and affordability can determine whether a technically sound recommendation is actually usable. A practical output from this step should be a standardized requirements dossier covering use cases, target users, infrastructure assumptions, affordability thresholds, service expectations, and basic SOPs for data capture and advisory delivery. To improve implement ability, economies may also consider requiring that this dossier be updated each production cycle based on field feedback, rather than treated as a one-time planning document.

II. Agri-Industrial Integration: Integrated Development

Once field demand has been translated into operational requirements, the next function is Integrated Development. At this stage, the objective is to convert verified demand into a deployable solution package through coordinated collaboration among research institutes, industrial partners, startups, extension services, and public agencies. Rather than promoting stand-alone tools, APEC economies are encouraged to support co-development of integrated configurations that combine sensing, diagnostics, advisory logic, field operations support, and user-facing communication channels. This reflects the report's earlier finding that agricultural value is rarely created by a single technical component in isolation.

Integrated Development should also explicitly incorporate cost, maintainability, and delivery feasibility as design criteria from the outset. In remote and rural settings, solutions that depend on highly specialized maintenance, uninterrupted connectivity, or frequent hardware replacement are unlikely to remain sustainable. Governments can play a catalytic role here by using public R&D programs, challenge funds, or co-development grants to ensure that affordability, robustness, and simplicity are treated as core design requirements. One practical way to strengthen this stage is to require each development consortium to include at least one field-facing actor—such as an extension body, cooperative, or local service partner—so that solution design remains grounded in actual delivery conditions rather than drifting toward laboratory optimization alone.

III. Agri-Industrial Integration: Field Validation & Productization

The third function is Field Validation & Productization, which converts prototypes into solutions that can be confidently deployed beyond pilot settings. APEC economies are encouraged to implement this phase through multi-site, production-scale demonstration trials that cover a full production cycle and reflect different agroecological, infrastructure, and farmer-capacity conditions. Validation should follow farmers' real workflows, rather than idealized test scenarios, so that the resulting solution is evaluated against actual constraints such as response time, maintenance burden, usability, labor fit, and affordability.

A key principle at this stage is that farmers should be treated not only as end users, but also as co-testers and co-refiners. Their participation helps capture practical feedback that technical teams may otherwise overlook, while also building familiarity and trust that lower future adoption barriers. The expected outputs from this phase should include: verified field-performance data; standardized SOPs; training materials; service protocols; and procurement-ready specifications with tiered options for different levels of connectivity and service readiness. To improve policy usefulness, APEC economies may also consider establishing a simple validation framework with a small set of common performance indicators—such as timeliness of response, reduction in unnecessary input use, yield/quality effect, uptime, and farmer usability—so that demonstration outcomes can be compared more systematically across projects and sites.

IV. Ecosystem Enablement: Ecosystem Roles & Governance (Orchestration for Scaling)

The first delivery function under Ecosystem Enablement is Ecosystem Roles & Governance, which addresses the coordination challenge that often emerges once a technology has been validated but not yet scaled. Because integrated pest and disease management solutions typically involve multiple actors, no single institution can deliver the full value chain alone. APEC economies are therefore encouraged to establish public–private coordination platforms that define functional roles across the ecosystem, including system integrators, niche technology providers, startups, extension services, local diagnostics actors, finance partners, producer organizations, and relevant ministries or public agencies.

The primary goal of this platform is not to create another discussion forum, but to reduce fragmentation and ensure that the different parts of the delivery system are aligned around implementation. This means clarifying who is responsible for system integration, who provides local advisory support, who handles farmer onboarding, who manages service continuity, and how data-sharing, interoperability, and accountability will be governed. In practical terms, economies may improve orchestration by assigning a lead convening entity with clear authority to coordinate across agencies and delivery actors, rather than relying on purely informal collaboration. This is especially important where remote and rural deployment depends on synchronized action across connectivity, agriculture, extension, and financing functions.

V. Ecosystem Enablement: Packaging & Delivery Models (Holistic Solution Packages)

Validated tools must then be translated into Packaging & Delivery Models that are understandable and usable at the farm level. The report's earlier analysis shows that farmers in remote and rural areas often lack the time, technical knowledge, or integration capacity to assemble multiple technologies and services on their own. For this reason, APEC economies are encouraged to support holistic solution packages that reduce coordination burdens and present farmers with a clearer pathway to action. These packages should integrate the necessary technical, advisory, and service elements into a coherent offering rather than expecting adoption through fragmented components.

In practice, packaging should be tiered and modular. A basic package may consist of locally adapted SOPs, offline advisory protocols, and extension-supported diagnostics. A more advanced package may include real-time sensing, app-based decision support, subscription-based diagnostics, or bundled service delivery through producer groups or channel partners. This flexibility is important because infrastructure readiness, digital literacy, and crop value differ significantly across APEC economies and within rural regions of the same economy. To strengthen implementation, economies may also consider promoting delivery through Bn2F2B-type pathways (Figure 2), in which agribusinesses, buyers, or farmer organizations help organize adoption and create demand pull, especially for specialty crops or market channels where quality differentiation and safer production practices can be rewarded.

VI. Ecosystem Enablement: Market-Enabling Tools & De-risking (Scaling Instruments)

The next function is Market-Enabling Tools & De-risking, which addresses the gap between successful pilots and sustained adoption. In many cases, technologies do not fail because they lack technical merit, but because adoption risk, financing barriers, and business-model uncertainty remain unresolved. APEC economies are therefore encouraged to deploy a set of market-enabling instruments that make it easier for validated solutions to move into regular use. These may include public procurement pathways, targeted incentives, risk-sharing finance, concessional funding windows, leasing or managed-service models, interoperability standards, and PPP-based support for scale-up.

Particular attention should be given to business models that reduce the burden of upfront investment for smallholders and rural communities. Shared-service approaches—such as subscription, leasing, or local managed-service delivery—may often be more feasible than ownership-based models, especially where technologies require maintenance or periodic calibration. In addition, sustainable alternatives, including lower-risk biological or integrated management solutions, may require tailored support because they do not always fit established input-market channels. To improve execution, economies may consider linking de-risking tools to verified field-performance milestones, so that public support helps crowd in private investment while maintaining accountability for real delivery outcomes. In parallel, APEC economies may also use this stage to cultivate longer-term commercialization capacity by supporting early-stage IDE-based agricultural ventures through incubation, seed-stage de-risking, and, where appropriate, regulatory sandbox mechanisms for emerging integrated solutions.

VII. Interface for Sustained Adoption: Feedback, Iteration, Cost Reduction, and IDE Startup Formation

The interface between Agri-Industrial Integration and Ecosystem Enablement is where sustained adoption is generated. In remote and rural agriculture, adoption should not be understood as a one-time deployment outcome, but as a continuous process in which field learning feeds back into product refinement, service improvement, cost reduction, and institutional adjustment. This iterative loop is especially important in agriculture because production conditions are highly heterogeneous across crops, locations, seasons, and farming practices, while commercial returns are often slower than in many other technology sectors due to lower value density and longer biological production cycles.

For this reason, APEC economies should also treat IDE-based agricultural startup formation as an important mechanism within the sustained adoption interface. In many cases, the actors best positioned to carry technologies through repeated iteration, field adaptation, and business-model refinement are not conventional input suppliers or public research institutions acting alone, but dedicated ventures capable of linking research outputs with practical delivery, market testing, and continuous improvement. Given the long payback periods and public-good characteristics of agriculture, government support is particularly important in the early stages of such ventures.

A practical policy approach is to encourage spin-off formation from government-supported research institutes, public laboratories, and universities. This may include using public project funding to support startup teams during market discovery, customer validation, and early business formation; establishing dedicated startup offices within public research organizations or universities; and providing complementary support in areas where technical teams are often weaker, such as business development, market strategy, regulatory navigation, and organizational formation. In the agricultural sector, governments and originating public institutions may also consider participating through technology equity contributions, while keeping ownership shares at levels that preserve entrepreneurial flexibility and commercial responsiveness. Early-stage seed support, incubator-style assistance, and milestone-based public financing can help these ventures bridge the gap between research success and market readiness.

Where appropriate, APEC economies may further strengthen this pathway through regulatory sandboxes or controlled pilot frameworks that temporarily lower selected regulatory barriers for qualified startup teams while maintaining necessary safeguards. This can be particularly useful for integrated crop management solutions, biological alternatives, digital advisory models, and service-based delivery innovations that may not fit neatly within existing regulatory categories. If designed well, this approach allows governments to play a catalytic role similar to an accelerator: supporting high-potential agricultural ventures at the early stage, sharing in long-term economic upside where appropriate, and reinvesting those gains into future innovation, entrepreneurship, and public-interest agricultural development. In a sector such as agriculture—where economic, environmental, and public-health benefits are broadly shared—such support can generate returns that extend well beyond firm-level growth alone.

Concluding Operational Note

Taken together, this micro-level delivery mechanism provides an operational pathway for translating the macro policy framework into practice across APEC economies. It clarifies how governments, industrial partners, startups, extension systems, local service actors, and producer organizations can be sequenced and aligned to move from field needs to sustained deployment. By structuring implementation around demand confirmation, integrated development, field validation, ecosystem orchestration, delivery packaging, market-enabling and de-risking instruments, and continuous feedback-driven refinement, the mechanism offers a practical basis for moving beyond fragmented pilots toward durable IPM/ICM-aligned pest and disease management systems in remote and rural agriculture. It also underscores that sustained adoption requires more than validated technology alone: it requires supportive public leadership and viable commercialization vehicles, including IDE-based agricultural startups, that can translate research and field learning into continuously improved products and services.

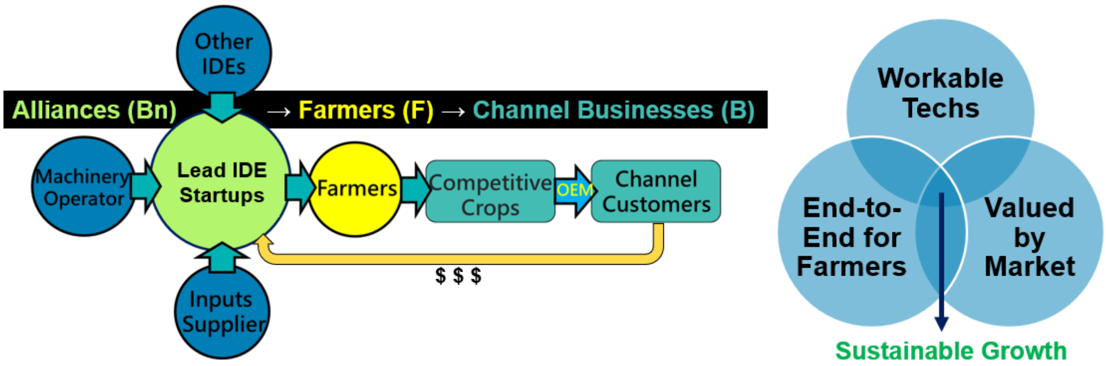

Figure 2. The Bn2F2B Business Model: A Framework for Sustainable Growth

5.3 Summary of Policy Recommendation

This report recommends that APEC economies adopt a policy approach centered on agri-industrial integration, ecosystem enablement, and practical rural delivery capacity to strengthen pest and disease management in remote and rural agriculture. Based on the challenges, economy-level observations, and technical analysis presented in this report, six policy priorities emerge:

1. **Institutionalize demand-led co-design and field validation**

   Establish mechanisms for co-design, co-development, and field validation so that solutions are fit-for-purpose, impact-validated, and affordable under real rural conditions.

2. **Prioritize holistic solution packages over stand-alone technologies**

   Promote integrated packages that combine sensing, diagnostics, advisory support, field operations, and delivery models, rather than fragmented single-point tools.

3. **Strengthen last-mile enabling conditions**

   Invest in rural connectivity, power reliability, interoperable data systems, and shared-service infrastructure to make AIoT- and IPM/ICM-based solutions deployable in dispersed rural areas.

4. **Reinforce localized extension and diagnostics capacity**

   Strengthen plant health extension, localized diagnostics, and farmer-facing translation mechanisms so that technical outputs can be converted into actionable IPM/ICM practices.

5. **Deploy ecosystem-based commercialization and de-risking tools**

   Use public–private coordination platforms, shared-service models, incentives, procurement tools, and risk-sharing finance to move validated solutions beyond pilot projects into sustained deployment.

6. **Support IDE-based agricultural startups as strategic commercialization**

vehicles

Encourage incubation, seed-stage support, spin-off formation, and regulatory sandboxes for agricultural startups, especially those emerging from public research and academic institutions, to sustain field iteration, commercialization, and long-term value creation.

Taken together, these six recommendations provide APEC economies with a practical policy pathway to accelerate earlier warning, improve on-farm decision quality, reduce unnecessary pest-management costs, and strengthen the resilience, productivity, and long-term sustainability of remote and rural agriculture.

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