SMART AGRICULTURAL TRANSFORMATION IN ASIAN COUNTRIES

The Asian Productivity Organization (APO) is an intergovernmental organization that promotes productivity as a key enabler for socioeconomic development and organizational and enterprise growth. It promotes productivity improvement tools, techniques, and methodologies; supports the National Productivity Organizations of its members; conducts research on productivity trends; and disseminates productivity information, analyses, and data. The APO was established in 1961 and comprises 21 members.

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Smart Agricultural Transformation in Asian Countries

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FOREWORD

Agriculture throughout Asia must dramatically accelerate productivity growth in the next three decades to meet the demands of a growing population as well as the changing preferences of increasingly affluent, urbanized consumers. With the advent of the Fourth Industrial Revolution, smart technologies are becoming widespread throughout the economy, including in agriculture. "Smart agriculture" refers to the applications of those advanced technologies in agrifood systems.

Such applications offer tremendous promise for transforming agrifood systems. However, Asian economies vary widely in their readiness to adopt smart agriculture. The Smart Agricultural Transformation (SAT) Program of the Asian Productivity Organization (APO) aims at enhancing food security and meeting future food needs in the Asia-Pacific region through increased productivity, quality, and innovation in agrifood, leading to improved rural livelihoods, sustainability, and nutritional security.

The main objective of this research project was to determine the readiness of selected APO members for SAT and propose policy recommendations for its adoption and implementation. The results can be applied to increase their readiness for SAT, including the development of institutional capacity and improvement of mechanisms for reaping the benefits of SAT. They will also contribute to the creation of country-specific agricultural transformation frameworks.

The project developed a common framework for assessing SAT readiness based on a number of indicators. The framework was then applied in case studies of India, Indonesia, Pakistan, Thailand, and Vietnam. These developing economies have significant agricultural sectors and populations, with an urgent need for rapid productivity growth through SAT. They are in varying degrees of readiness for SAT, however, and therefore customized recommendations for achieving SAT readiness were made. This report includes a chapter on successful practices and case studies from a developed economy like the ROC that will serve as an example for other APO members to adopt and mainstream SAT.

The efforts of the team of experts who conducted the research and wrote this publication are very much appreciated. The APO expects that the publication *Smart Agricultural Transformation in Asian Countries* will serve as a useful guide to readers. Although the recommendations are specific to the selected five economies, they could be adapted to circumstances in other APO members and elsewhere. These in-depth assessments and accompanying recommendations offer guidance and insights to policymakers, agribusinesses, farmers' associations, consumers, researchers, and other stakeholders working toward smarter, more sustainable, productive agrifood systems in Asia.

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INTRODUCTION

Background and Rationale

With 60% of the world's population residing in Asia, a massive increase in food demand in the region is inevitable in the coming decades. As income grows and the ranks of the middle-class swell, households require safer and better-quality food. Conventional agriculture is not expected to deliver this quantity and quality of food equitably and sustainably.

Equitability has been neglected: Asia's economic development is leaving behind millions of smallholders and small-scale fishers in Asia's agriculture, exacerbating persistent inequalities. The urban-rural development gap remains prominent in developing Asia, driven to a large extent by growth in the non-agricultural sectors. The gap tends to narrow with growth in agriculture even though various Asian economies have seen agriculture fall behind in the past few decades [1].

Sustainability is also left behind, as natural ecosystems give way to expanding agriculture while receiving more pollutants in the form of agricultural nutrients, greenhouse gas emissions, organic wastes, and pesticide residues [2]. Half of nitrogen and phosphate fertilizers end up in water bodies. Around 80% of deforestation worldwide has been attributed to agriculture. Seventy percent of all freshwater use is siphoned off to agriculture; nonetheless, the rate of expansion of irrigated areas has been slowing down.

Over 40% of the world's rural population lives in water-scarce river basins [3]. Likewise, the fish stock is being decimated, with about 33.1% of the fish stock worldwide deemed overfished [4]. Also, conventional agriculture must contend with weather extremes and heat stresses associated with climate change: after 2050, continued increases in global temperatures will adversely impact crop production, especially near the equator. Climate trends are also altering the abundance and distribution of marine resources, such as coral reef fisheries, and fish stocks [5].

In the face of these new challenges, societies must adopt new pathways for the growth of food production. The next wave of agricultural transformation requires technologies that allow lower inputs and costs per unit output, better resilience to environmental shocks, and greater opportunities for higher incomes for smallholders and small-scale fishers.

Smart agriculture refers to the application of advanced technologies within the agrifood system. Important components of smart agriculture technologies are Big Data, digital technologies, and Artificial Intelligence (AI). Smart agriculture technologies encompass all stages of the agrifood system, from precision agriculture on the production side to the processing and distribution side like traceability. Smart agriculture offers great potential for continued agricultural transformation (AT) in developing Asia.

However, not every country can readily adopt all types of smart agricultural innovation. The Smart Agricultural Transformation (SAT) Program of the Asia Productivity Organization (APO) seeks to assist member governments to meet their sustainable agricultural productivity needs through smart transformation initiatives.

This research project aims to determine the readiness of selected APO member countries for SAT as well as to propose policy recommendations for its adoption and implementation. The specific objectives of this project are as listed.

- To assess the readiness of selected member countries for the adoption of SAT.
- To identify national institutional arrangements and mechanisms needed to reap the benefits of transforming into smart agriculture adopters.
- To generate a set of strategies and policy recommendations to speed up SAT.

The project involves conducting in-country research led by a National Expert, who will be responsible for collecting and analyzing data from their respective countries and preparing the country report. The countries covered under the project include India, Indonesia, Pakistan, Thailand, and Vietnam.

The SAT Framework

Agricultural Transformation

Throughout developing Asia, rural economies are already undergoing a dramatic transformation. The transformation is driven by the increase in the use of inputs on the same amount of land and biological innovations that have allowed additional inputs, primarily fertilizer and water, to be converted into incremental outputs. Transformation is also being driven by structural changes in the economy that are led by the overall increase in per capita income. Since rising wages outside agriculture are driving workers away from agriculture, those continuing with farming are being compelled to mechanize production, replacing draft animals and human workers.

Past waves of agricultural transformation have therefore involved the application of the more up-to-date technology of the time to agriculture. Currently, cutting-edge technologies increasingly involve "smart" applications. The private sector has been leading the way in many Asian countries in adopting smart applications in agriculture, towards increasing productivity, crop quality, and reducing cost [6].

Smart Agricultural Transformation

Applications in Production

Among the types of smart production technologies, drones might be a more cost-effective option for many farmers. Currently, drones have been widely used in pesticide and fertilizer spraying [7]. They help reduce the time and the hazardous effects associated with pesticide and fertilizer spraying, such as overuse of pesticides and pesticide exposure during spraying [8]. In India, for example, farmers in the Proddutur village in Telenanga State used drones to spray pesticides in their corn fields to protect their crops from pests. The charge for the service in 2019 was INR500 [9].

In an advanced country such as Japan, a variety of emerging technologies have been utilized to achieve the goal of improving agricultural production. Technologies like the Internet of Things (IoT), AI, and Big Data have been frequently deployed, often in combination with drone services. For example, OPTiM, a software company that provides IoT and AI platforms, has cooperated with a university in Japan and a local government to develop and test an agricultural drone capable of detecting pests and exterminating them with pinpoint pesticides or a zapper [10]. The functions of the agricultural drone were further extended to collect field and greenhouse images, and these images are analyzed by AI techniques to offer critical cultivation information to farmers [11]. For organic rice farming, the field image information provided by the drone has been used to assist farmers to determine the fields where more organic fertilizer must be used [12].

Similarly, an IoT-based platform jointly developed by PS Solutions, KCD, and Ericsson Japan enables remote control and monitoring services for field and greenhouse farming and has been offering the service since 2018 [13]. This platform combines sensors that measure various environmental parameters and those related to crop growth, and an AI-based cloud capable of machine learning to control different actuators. This ensures that crops can grow in a proper environment while the yield and quality of the crops can be improved. The platform has been used by rice fields in Yosano, Kyoto in Japan to improve their productivity while passing the cultivation knowledge to the younger generation [14].

Other large information technology (IT) companies also extend their services to the agricultural sector in Japan. For example, Fujitsu has offered a cloud-based food and agricultural AI service called Akisai [15]. Akisai uses various sensors and cameras to collect data generated from daily activities which are analyzed via the AI cloud. The results yield important information for agricultural production management, decision-making, planning, and worker management.

In addition to IoT- and AI-based systems, agricultural robots with Global Positioning System (GPS), together with satellite-enabled tractors, rice planters, and harvesters, have also been promoted in Japan. Kubota Corporation, a global giant in agricultural machinery, has introduced tractors, transplanters, and combine harvesters, with automatic steering functions [16]. For the transplanter, the technology involves the following steps: first, a map of the rice field is created by the machine using the GPS, as it is driven by a human around the perimeter of the field. The machine then automatically plants rice seedlings using the route calculated based on the map. OEM Off-Highway [17] describes the self-driving tractor equipped with AI technologies. The tractor can collect environmental data while operating, automatically sharing data with other machines at the same site to improve the efficiency of the operation.

Traceability and e-Commerce Applications

Smart technologies have been utilized not only to improve agricultural production but also to enable information exchange between the demand and supply sides of agricultural production. A good example is traceability systems for food and agricultural products. In the Republic of China (ROC), for example, the Agricultural Production and Certification Act and the Directions for Management of the Taiwan Traceability Label promulgated in 2007 have served as the basis for agricultural product labeling and traceability [18], [19]. Following these regulations, agricultural production and products are encouraged to be certified by an independent third party. The products that pass the certification process are allowed to be labeled as Traceable Agriculture Product (TAP) [20] or products that meet Certified Agricultural Standards (CAS) [21].

Organic products can also be certified by labeling them as CAS Organic or Taiwan Organic products [22]. Till 2015, over 6,000 label applicants were granted the Taiwan agricultural traceability label [23]. The number increased to approximately 40,000 by the end of 2018 [24]. A traceability platform, Taiwan Agricultural and Food Traceability System, set up by the government allow consumers to use a traceability barcode or a QR code to access product information and farming records to ensure the safety of the products The system also provides information about the amount of production of an agricultural product during a certain period to give consumers a better understanding of the overall agricultural production [25]. Since 2016, the government has encouraged public schools to use food and ingredients with certified labels to prepare lunch meals for students [26]. This initiative not only ensures the safety of the meals but also gives farmers more incentives to have their products certified.

Apart from the government-led promotion of agricultural and food traceability, some Taiwanese companies have begun to provide traceability services for farmers by integrating blockchain and other distributed ledger technologies into traceability systems. OwlTing, a Taiwanese e-Commerce platform provider, has connected over 1,500 farmers and food merchants in Taiwan via its platform [27]. The company also offers a map that shows dairy and fruit product profiles, together with geophysical information, as well as receiving orders from consumers. A dairy farm reported that its milk production increased by 15% after utilizing the platform for ten months [28]. In 2018, the company cooperated with a rice farm in Chishang, Taidong, which is famous for growing high-quality rice. Using an IoT-based monitoring system, the company installed illumination, temperature, and humidity sensors on the rice field to collect important environmental parameters that affect rice growth. These environmental data are transmitted to the blockchain platform and then analyzed. Consumers can use the platform to access the cultivation data of the rice [29]. In addition to information on the rice farm, the blockchain also includes data about a rice mill. Besides, the information about rice purchasing and quality classification done by the rice mill is recorded and can be browsed by consumers. With blockchain techniques, the traceability system can provide clear information about rice growth, production, and sales.

Most recently, Research, Development, and Demonstration (RD&D), a Taiwanese company specializing in cold chain logistics, used the service provided by OwlTing to ensure that proper temperature is maintained during the collection, transportation, and distribution of goods [30]. This service adopts IoT and blockchain technologies to track the temperature and delivery processes and record data in real-time to reduce the risk associated with cold chain delivery [31].

E-commerce for agriculture is increasingly widespread throughout Asia, with India being a prominent adopter. A study has shown that farmers in India have embraced e-commerce, but its practices are still in the infancy stage. The main purpose of e-commerce platforms for farmers in India is to train them, so they can learn to use the Internet and information available online.

In Thailand, e-Commerce practices have been promoted by the Ministry of Agriculture and Cooperatives. The ministry encourages people to sell and buy Thai agricultural products online in collaboration with local and international e-Commerce platforms. On the opening day of the initiative, 175 farmers applied for listing on the platforms, which shows that farmers are interested in selling their products online. And, farmers' revenue is expected to increase by at least 30% through the initiative [32].

SAT from the Perspective of Key Actors

Individuals and Enterprises

The preceding descriptions show a wide spectrum of technologies that can be referred to as "smart agriculture". The pace of adoption of smart technologies in agriculture depends on choices made by individual producers or enterprises in the agri-food system. This decision in turn depends on an economic comparison of benefits and costs. The cost of innovation in turn divides into a one-period time horizon or a multi-period horizon. An example of the former is advice from a mobile app to apply a specific pesticide within the current cropping season. For the latter, the system may involve the installation of an automatic sprinkler system for irrigation, for use over the lifespan of the system spanning multiple cropping seasons.

For the short-term, the adoption may involve a change in current cost (like the purchase of a new pesticide) and an expected change in returns, like realizing more harvest (compared to the case of not using pesticide), translating into more sales. A simple decision rule will be to adopt when the expected change in returns exceeds the change in current cost.

For the long-term, the adoption involves an increase in current costs (like the purchase of the system) and a stream of expected future returns. The standard method for comparing the two involves capital budgeting techniques, involving discounting the stream of future returns to compare with the current capital outlay. The criterion for adoption may involve the positive net present value, a benefit-cost ratio exceeding unity, or an internal rate of return exceeding the discount rate.

Hence, labeling the system "advanced" or pointing to other adopters will usually not be able to convince the producer to adopt new technology. Instead, producers must be convinced that the additional returns are worth the added cost. This is one reason why technology companies offer a new product with a steep markdown in price or the government steps in and provides a subsidy to farmers adopting new technologies.

Even if the expected discounted returns exceed the additional cost, the producer may still fail to adopt due to the following reasons.

- The expected returns may be higher but the producer is also wary of the remaining risk or uncertainty. In our example, the farmer may accept that in most cases the pesticide may work. However, even the slightest likelihood of it not working may be enough to dissuade farmers from purchasing the pesticide.

- The producer may be convinced, but does not have the cash on hand, or the means of financing, the acquisition of the new technology.

Risk and financing constraints are highly relevant to smallholders, small-scale fishers, as well as micro and small enterprises in the agri-food system, especially in developing Asia. It is the case though in developing Asia that small-scale farming is the norm [33]. In East Asia and the Pacific (except China) and South Asia, 50-60% of farm holdings were under 1.0 ha based on the most recent data. Nor is China much better. The average farm size in China in 2010 was just 0.6 ha and, unlike the rare wealthy farmer, the typical farmer in the country tends to be less capable of adopting new technologies. This further widens the inequalities from technological progress.

Public Sector

Based on official policy statements, nearly all governments in populous countries of developing Asia affirm social goals related to inclusive growth and rural development. This has translated to laws, regulations, rules, and expenditure programs, funded by taxes or public debt. In pursuit of these policy goals, the government has undertaken various actions for the agrifood system, including the following.

- Framing and enforcing laws and regulations related to the use of technology, like genetically modified organisms, agrichemicals, food safety systems, etc.

- Application of other rules and laws related to the operation of markets, many related to agriculture, such as price floors or price ceilings on agricultural products, limits on interest rates charged to farmers, rules on allocating a bank loan portfolio across sectors, including agriculture, etc.

- Exaction of charges on economic activity including corporate income tax, value-added tax, inspection fees, etc. Conversely, it can favor motivated commercial actors to behave in certain ways by offering tax breaks, i.e. tax incentives for agribusiness in a target rural zone.

- Designing, funding, and implementing various infrastructure projects such as public roads, bridges, ports, irrigation systems, power generation systems, etc. from small-scale like a fish port to large-scale like big hydropower dams In a few cases, some commercial actors are providing these (especially the smaller versions), but for the most part, such projects are usually public sector activity.

- Funding and implementation of activities in which the commercial sector is also active. These include the provision of credit, inputs, farm machinery, postharvest facilities, and processing equipment. It also comprises research and development to discover new technologies and introduce/disseminate these technologies to agri-food producers. The government may defray the cost of goods and services provided, all the way up to 100% subsidy (like free seeds and fertilizers or by offering R&D products in the public domain).

The government has played a fundamental role in agricultural transformation, from the funding of transformative research like the development of high-yielding varieties to policies affecting operations of markets, and investment in various rural infrastructures. This, however, does not imply that it is exclusively responsible for the transformation of the agricultural sector, which is an agri-food system comprising individuals and private actors. Governments can, however, provide a set of enabling conditions, or a favorable economic climate, for SAT to initiate or accelerate.

Method of Assessment

Overview

The issue of "readiness" for AT entails a recognition that agri-food systems will not transform automatically, as it were; but that there are certain prerequisites that mark out whether a process of SAT is likely to take place, or be sustained. This holds as well for the specific case of SAT, which involves widespread dissemination and adoption of advanced technologies, many of which are IT-based, or enabled by digital technology (e.g. bioinformatics as a driver of genomic technologies).

APO (2019) observes that the suitability of the various technologies is context-specific. Their adoption is dependent on the circumstances of the key actors in agricultural innovation, which in turn is conditioned by factors such as per capita GDP, the share of employment in the agriculture sector, and the state of basic rural infrastructure [6]. Such conditions depend on both demand-side factors and supply-side factors. The former corresponds to the willingness and capacity of farmers to adopt new technologies, support, and availability of downstream players in agribusiness and service providers, regulatory requirements, and consumer preference for quality and safety. The latter relates to the state of physical and technological infrastructure, as well as the availability of institutions for promoting smart technologies, such as farmer organizations, rural financial institutions, and active land markets for farm consolidation. Readiness for SAT depends heavily on the motivations of producers in the agri-food system, as well as the policies and capacities of governments. The assessment of readiness for SAT will then be utilized to develop comprehensive and multi-stakeholder national agricultural development plans and strategies, along with delivery mechanisms for translating plans into actual impacts on the ground.

Related Studies

Assessment of readiness for agriculture is relatively common in the literature. For instance, Zurek et al (2014) examines climate readiness in agriculture [34], Clarete and Villamil (2015) conduct a readiness assessment of Philippine agriculture and fisheries to the ASEAN Economic Community [35], Hendrix and Morrison (2017) look at workforce readiness in agriculture [36], and Phillips et al (2018) assess readiness for eAgriculture [37].

The study that most closely models the readiness assessment we plan to implement is Boettiger, Denis, and Sanghvi (2017) [38]. Their research on AT finds evidence that even a good development plan for AT will likely underperform unless certain "readiness" factors are in place. The readiness evaluation framework lists these factors; states the hypothesis linking these factors to transformation; and the source of data for quantification.

The readiness conditions are grouped into three clusters. The first cluster refers to factors most essential for AT. The second cluster refers to factors that can be changed in the short term and the third cluster relates to the underlying endowments of a country and may take a longer time to change. Respectively the clusters are denoted Enabling factors, Build immediately factors, and Build over time factors (see Table 1, Table 2, and Table 3.)

TABLE 1

ENABLING FACTORS FOR SAT.

Factor	Hypothesis	Source
High government expenditures on agriculture	Countries committed to AT will increase spending to drive transformation	ReSAKSS
AT is a high priority of the head of state	Head of state and other top leaders must show high commitment to transformation for true change to occur.	Expert survey
Agricultural policy is driven by evidence more than politics.	Commitment to agricultural transformation entails difficult trade-offs that may not be made if politics are the main decision driver.	Expert survey
The agricultural plan has basic building blocks	Several basic building blocks are critical components of an effective agricultural plan.	Assessment of agricultural plans
A high share of the agricultural budget disbursed	Countries committed to AT follow through on budgetary commitments.	FAO–MAFAP
Demonstrated commitment to policy stability	A stable policy environment is critical to support AT.	Expert survey
The governance model allows the agriculture ministry to make policy changes	The agriculture ministry needs a sufficient level of authority to change course when required	Expert survey

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Factor	Hypothesis	Source
Willingness to adapt transformation strategy based on evidence	AT relies on decision-makers open to external policy expertise to shape strategy based on evidence	Expert survey
Effective process to coordinate national and local agricultural strategy.	AT requires national and local alignment on strategic priorities	Expert survey

Note: ReSAKSS, Regional Strategic Analysis and Knowledge Support System; MAFAP, Monitoring and Analysis of Agriculture and Food Policies; FAO, Food and Agriculture Organization.

TABLE 2

BUILD IMMEDIATELY FACTORS FOR AGRICULTURAL TRANSFORMATION.

Factor	Hypothesis	Source
Performance tracking exists for agricultural strategy	For transformation to occur, consequences must exist when agricultural performance targets are not met	Expert survey
Effective delivery of agricultural goods and services	A civil service effectively delivering public goods and services is a key enabler of AT	MCC and expert survey
Consultation process across governments, donors, and private sector	The government, donors, the and private sector must work together to facilitate AT	Expert survey
The capacity of ministries to coordinate agricultural policies	A demonstrated ability to collaborate across ministries is a key enabler of AT	Expert survey
Ability to make evidence-based policy	Making evidence-based policy requires good agriculture sector data	WEF–GCI and expert survey
Presence of sufficient storage infrastructure	Adequate storage is a key enabler of AT	EIU
Attractive rural business environment	Businesses need to be able to grow and flourish to enable AT	IFAD
Good legal and regulatory framework for agricultural credit	Credit is an essential ingredient to growing rural businesses and linking smallholders to input and output markets	WB–EBA
Good legal and regulatory framework for agricultural seed	Smart seed regulation can ensure the timely introduction of improved varieties to the market	WB–EBA
Good legal and regulatory framework for agricultural credit	Smart fertilizer regulation can ensure the timely marketing of new fertilizers	WB–EBA

Note: EIU, Economist Intelligence Unit; GCI, Global Competitiveness Index; EBA, Ease of Doing Business; WB, World Bank; IFAD, International Fund for Agricultural Development; WEF, World Economic Forum.

TABLE 3

BUILD OVER TIME FACTORS FOR AGRICULTURAL TRANSFORMATION.

Factor	Hypothesis	Source
High rate of literacy	Basic education requirements are necessary to facilitate technology adoption and agribusiness development	UNESCO
High rate of rural electrification	Reliable electricity in rural areas is a key enabler of AT	WB–WDI
High rate of rural telephony infrastructure	The ability to stay connected in a rural setting is an enabler of AT	WB–WDI
Sufficient port infrastructure	As countries increase commercialization and exports, the transformation will slow if ports are poor	EIU
Sufficient road infrastructure	Inadequate transformation infrastructure will slow and stall transformation by retarding market performance	EIU

Note: UNESCO, United Nations Educational, Scientific, and Cultural Organization.

Framework for Assessing SAT Readiness

The AT readiness framework serves as a template for the SAT Readiness Assessment framework. For each factor, the national expert shall find relevant latest data and data for 2010. Based on the data, the expert will then assign a rating of High, Medium, or Low. Else the expert shall indicate that no data is available (ND). Obtaining data for two time periods permits an assessment of whether or not the country is showing increasing readiness for SAT.

The factors are clustered along the value chain of agriculture: Upstream factors, Production factors, Downstream factors, and Enabling factors. We extend the aforementioned AT framework beyond development to encompass digitization factors, given that our concern is SAT. The factors are listed by cluster in Tables 4 to 7. Each table has a hypothesis to guide the expert in assigning the readiness rating.

Upstream development factors (Table 4) relate to finance, insurance, extension system, and irrigation systems. Upstream digitization factors relate to the IT capacity of the extension system and IT utilization in agricultural insurance. The greater the capacity and utilization, the better prepared the agri-food system of the country for SAT.

Production development factors (Table 5) refer to regulatory frameworks, the degree of mechanization, the cost of labor, the demographic profile of the agricultural workers including the number of women in the agriculture sector, tenure profile, and agricultural productivity and productivity growth. There is only one digitization factor in production: the share of youth in rural employment, which is directly proportionate to the country’s readiness for SAT. Downstream development factors (Table 6) include food safety and traceability, infrastructure and logistics, and the storage indicator.

TABLE 4

UPSTREAM FACTORS IN THE SAT READINESS ASSESSMENT FRAMEWORK.

	Indicator	Hypothesis	2010	Latest
Development	Existence of laws and policies on agricultural finance	The existence of laws and policies improves the business climate for providing agricultural finance		
	Agricultural insurance penetration ratio	Insurance reduces agricultural risk and increases investment in and credit for agriculture		
	Share of borrowing smallholders and fishers who borrow from formal sources (%)	A shift from informal to formal borrowing reduces the borrowing rate		
	Technician-to-farmer ratio: public and private	The lower number of farmers per technician implies greater access to extension service		
	The proportion of agricultural land that is irrigated (%)	A shift from rainfed to irrigated technology raises cropping intensity and yields		
Digitization	Share of extension personnel who are computer-literate (%): public and private	Technicians who are computer-literature can disseminate IT-based services to farmers		
	Existence of IT-based agricultural insurance products (e.g. remote sensing)	The existence of such a product implies demand for risk instruments with the latest data technologies		

TABLE 5

PRODUCTION FACTORS IN THE SAT READINESS ASSESSMENT FRAMEWORK.

	Indicator	Hypothesis	2010	Latest
Development	Existence of a regulatory framework for seed	The existence a of regulatory framework improves the business climate for private sector investment		
	Existence of a regulatory framework for agrochemicals			
	Existence of a regulatory framework on agrimachinery			
	Tractors per 100 sq km of agricultural land	More tractors imply a greater spread of mechanization		
	Average monthly earnings in agriculture (dollars per day)	Higher agricultural earnings or wages increase the incentive to adopt farm machinery		
	Rural employment in youth employment (%)	A lower share implies a greater need to mechanize farm operations		

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	Indicator	Hypothesis	2010	Latest
Development	The average age of a farmer	Higher age implies a greater need to mechanize farm operations		
	Average farm size in hectares (ha)	Smaller average farm size implies a preponderance of smallholders		
	Share of smallholder (2 ha and below) who is owner-cultivator	Owner-cultivators are the relevant decision-making units for farm mechanization and digitization		
	Share of agricultural workers who are women (%)	A higher share implies greater participation of women in agriculture		
	Fertilizer utilization per ha	Greater utilization implies more soil nutrients towards higher productivity (but excess may be detrimental)		
	Pesticide application per ha	More pesticide application implies lower losses from pest infestation (but excesses may be detrimental)		
	Utilization of certified seeds, the share of total (%)	A higher share implies a better chance of reaching the potential yield		
	Agricultural Gross Value Added (GVA) per worker	Higher GVA per worker implies higher productivity and a degree of transformation		
	Agricultural Total Factor Productivity (TFP) growth	Higher TFP means a faster rate of technical progress in agriculture		
Digitization	Share of youth in rural employment (%)	A greater share implies a greater potential to adopt digital technologies		

TABLE 6

DOWNSTREAM FACTORS IN THE SAT READINESS ASSESSMENT FRAMEWORK.

	Indicator	Hypothesis	2010	Latest
Development	Existence of laws and policies on food safety, traceability	The existence of laws and policies upgrades the quality of the agri-food system		
	Infrastructure score, Global Competitiveness Index	A higher score implies a better state of infrastructure		
	Logistics performance index	A higher index implies better logistics performance		
	Rural road density (km per sq km)	Higher density implies greater connectivity from farms to markets		

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	Indicator	Hypothesis	2010	Latest
Development	Stocks-to-production ratio, milled rice equivalent	More stocks imply more storage facilities		
Digitization	Existence of laws and policies on e-Commerce	The existence of laws and policies improves the business climate in the e-Commerce platform		
	Share of e-Commerce in retail sales	Greater share implies more opportunity for marketing products		
	Existence of laws and policies on e-Commerce	The existence of laws and policies improves the business climate of e-Commerce platforms		
	Share of e-Commerce in retail sales	Greater share implies a greater opportunity for the marketing of products		

TABLE 7

ENABLING FACTORS IN THE SAT READINESS ASSESSMENT FRAMEWORK.

	Indicator	Hypothesis	2010	Latest
Development	Existence of laws and policies for agricultural Science and Technology (S&T)	The existence of laws and policies improves the flow of resources toward R&D		
	Share of public sector budget for agriculture in total (%)	A higher share implies greater priority placed on agriculture		
	The government budget for agriculture, per agricultural worker (USD)	A higher ratio correlates with more benefits per worker in agriculture		
	Government budget for agricultural R&D, ratio to agricultural GVA (%)	A higher ratio implies more resources for developing new technologies in agriculture		
	Literacy rate (working age population)	A higher rate correlates with the capacity to adopt the latest technologies		
	Average years of schooling (working age population)	More years correlate with the capacity to adopt the latest technologies		
	Prevalence of undernourishment	Lower prevalence implies a more responsive agri-food system		
	Food Security Index	A higher index implies a more responsive agri-food system		

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	Indicator	Hypothesis	2010	Latest
Digitization	Existence of laws and policies for the digitization of agriculture and related sectors	The existence of laws and policies implies a greater and more stable commitment to investing in digitization		
	Existence of laws and policies promoting eGovernance	The existence of laws and policies implies government commitment to adopt digital technologies		
	Existence of IT-based Disaster Risk Reduction and Management systems and early warning	Existence implies government commitment to adopt digital technologies		
	The government budget for the digitization of agriculture (USD)	A higher budget implies a higher commitment to adopting digital technologies in agriculture		
	Smartphone penetration ratio: total and rural	A higher ratio implies more readiness to adopt digital technologies		
	Internet penetration ratio: total and rural	A higher ratio implies more readiness to adopt digital technologies		
	Share of primary and secondary schools with access to the Internet (%)	Greater share correlates with greater digital literacy		
	Share of STEM graduates among college graduates (%)	Greater share implies more human resources available for adopting digital technologies		

Downstream digitization factors relate to e-Commerce. Lastly, enabling factors relating to development (Table 7) pertain to public policy on agricultural S&T, public spending on agriculture; and human capital indicators (including food security). Factors enabling digitization pertain to public policy on digitization, including eGovernment, disaster response, and public spending on the digitization of agriculture. It also includes general IT and communication technology readiness indicators such as smartphone and Internet penetration, the population with access to the Internet, and the share of technical field graduates among college graduates.

Assessment of SAT Readiness in Selected Asian Countries

Trends in Agricultural Transformation

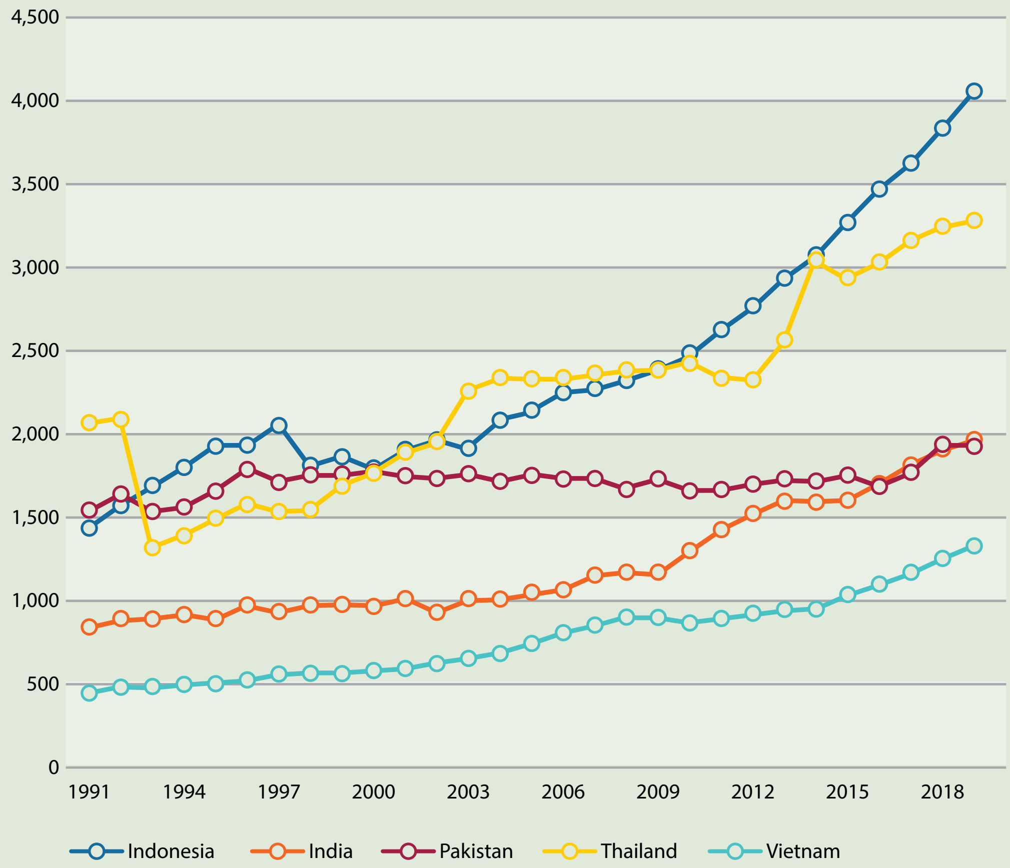
Structural change in an economy has led to a decline in the share of agriculture in GDP and employment while per capita GDP rises. This implies slower growth of agricultural GVA as compared to that of industry and services. However, this is compatible with the positive and vigorous growth of output per worker. IFAD adopts agricultural GVA per worker as a proxy of rural transformation [39].

Based on agricultural GVA per worker, agricultural transformation is most advanced in Indonesia and Thailand, and least in Vietnam, while India has recently caught up with Pakistan.

Compared with Vietnam's USD1,300 per year, agricultural output per worker in Indonesia is three times higher, while Thailand is 2.5 times higher (Figure 1). India and Pakistan are only 50% higher. However, Vietnam has shown a faster pace of growth of agricultural output per worker, at 4.1% per year, followed by Indonesia at 3.7% per year. Coming in third is India, allowing it to catch up with Pakistan, which had started 80% higher in 1991, but had suffered the weakest growth in agricultural output per worker (below 1% per year). Thailand, meanwhile, has had the most erratic performance in terms of agricultural output per worker.

FIGURE 1

AGRICULTURAL GVA PER WORKER, 1991–2016 (USD 2010).



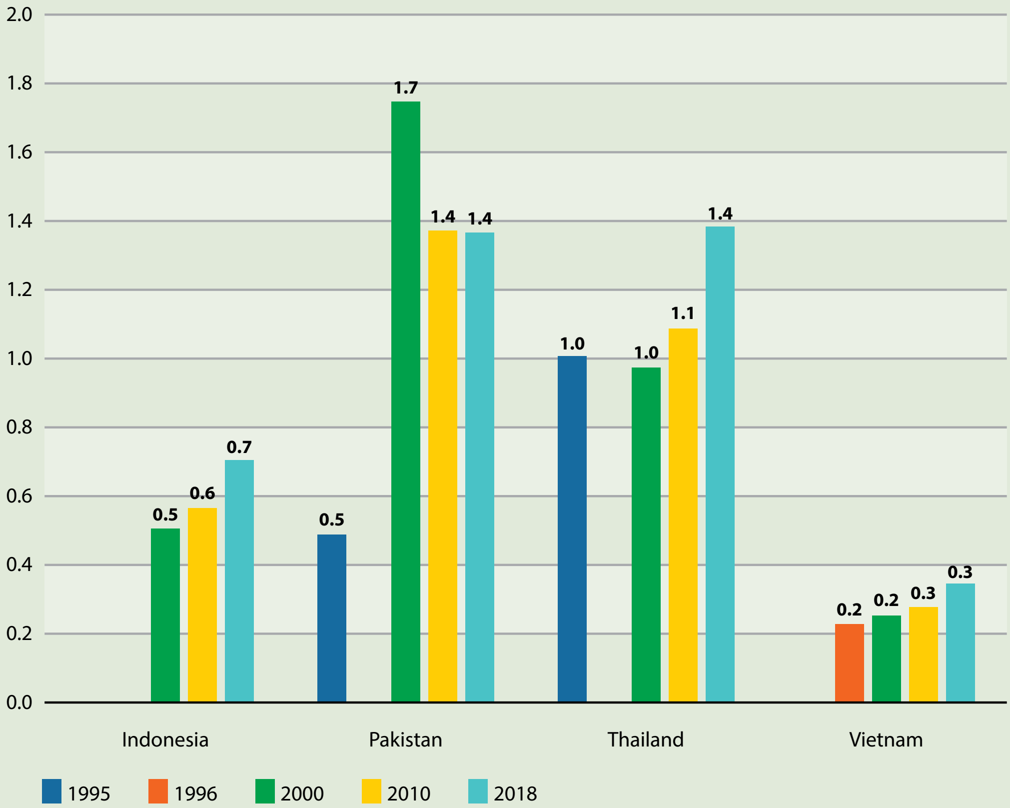
Source: World Bank (2020)[40].

Except for Pakistan, the number of agricultural workers per unit of land has been on a decline over the past few decades.

The legacy of structural change is the shift of labor out of agriculture. Despite the limited expansion of arable land throughout Asia, this is led to an increase in the hectare of arable land per agricultural worker in the selected countries. Unfortunately, data on agricultural workers are missing in the case of India (Figure 2). The fastest pace of increase has transpired in Vietnam, which has also enjoyed the fastest growth of output per worker. Over the course of structural change, there has been increasing adoption of machinery, allowing fewer workers to cultivate the same amount of land. However, land systems remain highly fragmented in Indonesia, Vietnam, and India. Note that land scarcity seems less of a problem in Thailand and Pakistan, which started with a larger endowment of arable land relative to their respective populations.

FIGURE 2

SIZE OF ARABLE LAND PER AGRICULTURAL WORKER, 1995/96–2018 (IN HECTARES).



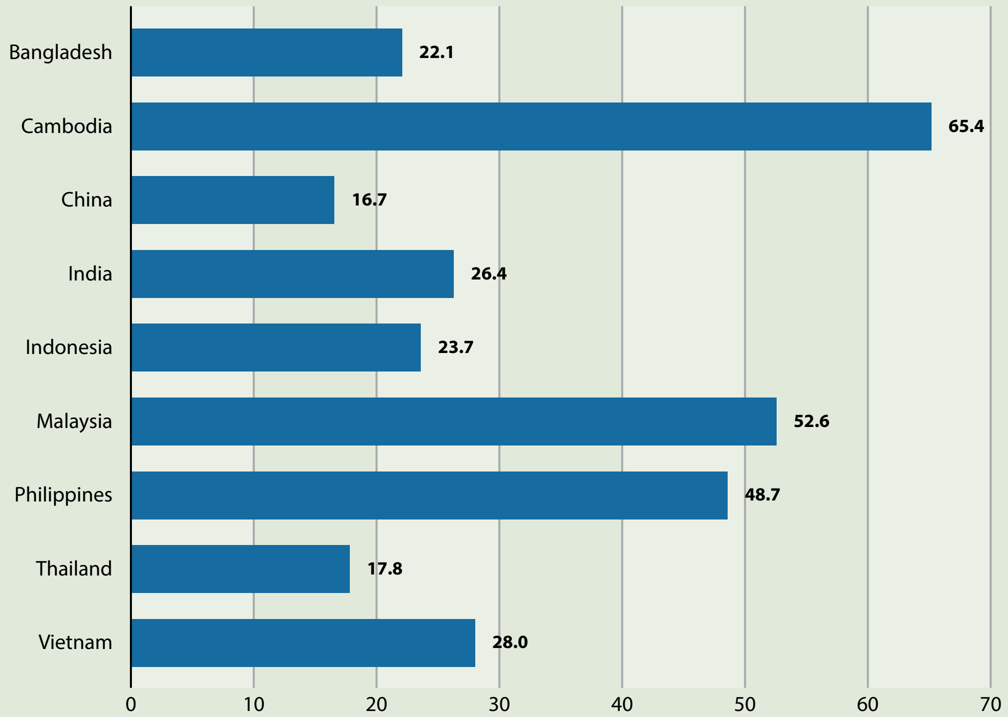
Source: FAO (2020) [41].

There remains much scope for continued agricultural transformation through the adoption of the latest innovations.

Despite decades of agricultural transformation, as seen by rising labor productivity in agriculture, there remains an enormous gap between labor productivity in agriculture and that outside. Figure 3 expresses GVA per worker in agriculture as a ratio to that in the industry (expressed in percentage). Here we add countries in addition to our limited selection, to highlight the generality of the pattern. The discrepancies are largest for China, the Philippines, and Thailand. Large disparities are also found in Indonesia, India, and Bangladesh. The productivity gap is the smallest (but still striking) for Cambodia and Malaysia.

FIGURE 3

THE RATIO OF GVA PER WORKER IN AGRICULTURE TO GVA PER WORKER IN THE INDUSTRY, IN USD 2010 (IN %).



Source of basic data: World Bank (2020) [40].

Applying the SAT Assessment Framework

The following is a highly abbreviated discussion of the findings from applying the SAT assessment framework discussed in Section 3 to the selected countries. A detailed exposition is provided in the associated chapters of this report.

Based on the defined framework, the degree of readiness at the upstream stage is mixed, though Indonesia tends towards the Medium-Low end and Thailand at the High-Medium end.

All the six countries reviewed as part of this study scored High for the existence of a law on agricultural finance. However, their ratings diverged for other indicators. Indonesia tends to have a Low score (based on Oxford Policy Management, 2017) for agricultural insurance penetration, and readiness of its extension system in terms of the number and quality of technicians [42]. It scores Medium only for the share of farmland irrigated. Similarly, Pakistan registers a low rating, scoring Medium only for the existence of policy on agricultural finance. In contrast, Thailand tends to score High for the upstream readiness indicators, dipping to Medium only for the share of irrigated farmland.

For insurance-related indicators, Vietnam scores Low, whereas India scores High to Medium in terms of insurance penetration and presence of IT-based insurance, respectively. Vietnam does much better in terms of its extension system, both in terms of the number of technicians and quality as compared to India where the computer literacy of technicians is rated Low. Both India and

Vietnam score High in terms of the proportion of farmers able to borrow from formal finance, though India scores lower for the share of farmland that is irrigated (Medium, as opposed to High for Vietnam).

Production factors are mostly in the Low/Medium range, with High scores only for policy indicators such as the presence of regulatory frameworks.

We have already discussed the indicator of agricultural output per worker. In the selected countries, scores were in the Low range for farm size, agricultural wage, age of farmers, the share of agricultural workers who are women, input application, and TFP. Each of the papers had an extensive discussion on the smallholder nature and continuing need for structural transformation and land consolidation in these countries, which accounts for the generally low scores for these indicators. Thailand though is more advanced along the structural transformation pathway and hence tends to score at least Medium for these indicators.

The countries, however, performed better in farm machinery per hectare and relied on certified seeds (Note however that there was difficulty in evaluating this parameter for Pakistan due to the absence of data). This suggests that farmers were well on their way to adopting more modern technologies. The countries did much better (with High scores all around) for regulatory frameworks whether for seeds, agrochemicals, or agromachinery, except for India which is missing the legal framework for regulating agrimachinery. Lastly, for digitization, the sole indicator is the share of youth in employment. While Thailand and Vietnam scored High on this, India and Indonesia got Low ratings largely due to the national experts' perception that agricultural employment is increasingly becoming an unattractive profession for young workers in these countries.

Downstream factors range from Medium-Low for India and High for Thailand.

The Low scores for India are for infrastructure, logistics performance, and road density. Likewise, Pakistan secures Medium only in road density. Countries in Southeast Asia on the other hand score Medium across most of the parameters. In contrast, Thailand has very High scores in most of the indicators. It is also promising that Indonesia and Thailand registered High scores for their share of e-Commerce in retail sales, though Vietnam has a Medium score for it. Given the relatively high penetration of e-Commerce among farmers in India, the Low rating of e-Commerce share in total retail is somewhat surprising. It, however, suggests that online selling for manufacturing (and even services) have fallen relatively behind.

Enabling factors for development and digitization range from mostly Low to Medium for India, up to Medium-High for Thailand, with Vietnam and Indonesia at the intermediate stage.

The selected countries were rated High for human resource indicators like literacy rate, average years of schooling, and nutrition/food security index. The exceptions were India where the literacy rate is rated Medium. Pakistan with 59% literacy was also rated Low on indicators like average years of schooling and nutrition. Note that Vietnam lacked explicit assessment of enabling factors, though it is safe to assess human resources at Medium-High.

Policy indicators are most advanced in Thailand, with enabling laws for digital transformation in place, as well as for agricultural science and technology. However, the policy was weakest in terms of budgetary commitment to agriculture and agricultural R&D, where Thailand was rated Low along with India and Indonesia. However, Vietnam had a possible rating of Medium on the policy front. For the other digitization indicators, the selected countries were rated Medium to High, except Pakistan which tends to score Low to Medium. Except for Pakistan, the Internet and smartphone penetration was rated High in other countries.

Strategies for SAT in Developing Asia

Summary

Throughout Asia, agriculture has been transformed by the widespread adoption of conventional machine and biological technologies.

Mechanization as well as biotechnologies have offered considerable benefits for developing Asia's agriculture. While much attention has fallen to smart applications and digital agriculture, there remains much scope for the continued adoption of conventional technologies. Simply being novel or innovative is not a legitimate reason to adopt new technology. Smart technologies should be adopted if they increase the long-run net income of the adopter. Additional reasons for adoption, from the social perspective, may be reduced usage of underpriced environmental resources and services.

The structure and characteristics of smallholder-based agriculture slow down the uptake of the latest technologies.

Developing Asian agriculture continues to be dominated by smallholder systems, where cultivation is done by an aging workforce; the better-educated rural youth cohort is increasingly attracted to nonagricultural work. Under these circumstances, large-scale economies accompanying some technologies disseminate at a slow pace, being mostly limited to medium to large-scale agribusiness companies in livestock, poultry, plantation crops, greenhouse vegetables, and the like.

The earliest adoption seems to be for small-scale technologies and e-Commerce.

Applications to production such as smart irrigation, robotics, and precision farming relying on a dense sensor network have not been as rapid compared to more affordable, small-scale technologies such as drones, remote sensing for mapping, agroclimatic/weather assessment, and e-extension advisory services. Another technology that is reaching out across the countryside is e-Commerce, which is introducing profound changes in the marketing landscape of agriculture. The case of Indonesia is interesting though as it involves the promotion of village enterprises (BUMDes), which seems to have been favorable for faster dissemination of smart technologies (in the Indonesia case study, the specific technology was drone spraying).

Governments have anticipated this next wave of innovation by putting into place SAT-promoting policy statements and legal frameworks.

Far from being neglected, smart technologies in agriculture have captured the attention of governments in developing Asia. Each has rolled out its experimental program on the Fourth Industrial Revolution, pursued promotional projects, and laid down legal and regulatory frameworks to address risks, uncertainty, or other bottlenecks to the adoption of smart technology. For instance, most countries have a regulatory framework for e-Commerce, biotechnology, and data privacy.

A significant constraint persists in terms of public investments in logistics-related infrastructure, agricultural R&D, and an IT-enabled extension system.

Nonetheless, the implementation of state policies favoring SAT leaves much to be desired. Whereas private investments have taken initiative for commercial applications, the underlying infrastructure normally the domain of the public sector like roads, bridges, ports, etc. have with few exceptions lagged in developing Asia. Other problems flagged in our case studies are agricultural R&D, as well as an extension system that is sufficient to reach smallholders, manned by personnel with adequate training in ICT and related technologies.

Implications

Based on the foregoing findings, implications for SAT based on an assessment of readiness can be drawn. The strategies are stated broadly, though hopefully with enough specifics to offer policy guidance.

1. The pursuit of SAT is complementary to policies towards sustainable agriculture and mitigation of climate change.

   Agriculture remains a major player in efforts to arrest environmental degradation, and greenhouse gas emissions, and promote inclusive growth. Programs that promote SAT are best accompanied by related environmental and inclusive growth policies for agriculture. For instance, water pricing incentivizes water-saving irrigation technology while tighter controls on pollution and methane emissions can support the adoption of smart biodigesters. Similarly, stricter pesticide maximum residue limits can encourage precision spraying. Even carbon pricing by making fossil fuels more expensive may cause farmers to save on fertilizers without sacrificing much output.

2. Inclusion of more smallholders in SAT (especially at the production stage), requires better rural organizations, better credit services, and improved insurance schemes.

   More than ever, inclusive development of agriculture in an era of SAT will require better organization of farmers to spread the initial cost of these systems, a realization supported by the case of BUMDES in Indonesia. In addition, applications may require some up-front investments, which entails expanded access to finance on the part of farmers and farmer organizations. Lastly, larger investments, even if supported by finance, imply an added risk for farmers, hence insurance can contribute towards mitigating such risk. Moreover, Big Data and sensor technologies (whether by satellite or other means) themselves can improve the attractiveness and affordability of agricultural insurance.

3. Government should continue to invest in the basics of agricultural transformation, including conventional rural infrastructure and R&D.

   Promoting rhetoric of SAT does not absolve the state of responsibility to provide for basic public goods. The obvious type of public good is ICT infrastructure; however, the strategy calls for investments even in basic rural infrastructure and scientific knowledge, which may be useful across a range of technologies, where such is lacking. Time and again though the commitment to agriculture faces difficult policy choices as alternative demands are made on government budgets, in our case studies, the national experts have deemed budgetary commitment to agriculture and agricultural R&D to be wanting in the selected countries. Budget priorities need serious re-evaluation to be able to accelerate SAT in developing Asia.

4. Investment in human resources of the rural workforce is key to SAT.

   Aside from hard infrastructure and S&T, upgrading the human resources of the rural workforce is another direction for the public sector. This involves the obvious education in agriculture and ICT; however, investments in improved nutrition, health, basic literacy, and numeracy, remain important for spreading widely the benefits of advancements in S&T.

5. Government should lead in SAT by moving towards eGovernance in its delivery of public services, including extension.

   The lack of extension personnel, and low proficiency in ICT among existing technicians, were highlighted in some of the case studies. Government leadership in SAT will materialize only if it leads the way by upgrading its human resource capability in e-extension. This need not be a standalone policy, but rather part of an overall transformation of the public sector towards a system of eGovernance. The ongoing pandemic provides a decisive impetus to orient public service away from traditional modes, towards access through online systems, with transactions recorded using Big Data and blockchain technology.

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CASE ANALYSIS
INDIA

India is the largest country in the world in terms of area under arable land. More than half of the workforce in India is engaged in agriculture and allied sectors. However, the contribution of the sector to the GDP of India has been declining and it has reached around 14% in 2018-19. It means half of India's population shares only 14% of national income. This has eventually led to a high level of unequal distribution of income. Another characteristic feature of Indian agriculture is the preponderance of smallholders and the purpose of cultivation, which is driven by subsistence and bare survival. It is one of the major bottlenecks of introducing technology and digitalization in agriculture.

There has been a shift in the policy paradigm in India from production orientation to doubling farmers' income by ensuring a fair price and improving post-production technologies. To strengthen the policy and to enable the enhancement of farmers' income, various market reforms were introduced. The basic components of the policy package comprise (i) digitalization of the trading process, (ii) promotion of online trading, (iii) "Uber-ization" of agricultural commodities, (iv) construction of e-markets with infrastructural facilities for specialized markets, and (v) formation of committees for specialized markets in every important agricultural production centers.

More than 50% of the essential components of readiness indicators for SAT are much below the desired level; however, 25% of the indicators are either non-existent or data for assessment is not available. The study concludeds that the transformation of agriculture into a smart technology mode demands active intervention from the government sector.

Introduction

Overview of the Indian Economy

India has been closely integrated with the global economy through its shift in development paradigm and growth strategy by the early 1990s [1]. India was the fifth largest economy in the world with a size of USD2.9 trillion in 2019 [2]. The world's output growth has decelerated from 2.9% since the financial meltdown in 2009, resulting in a reckless and unprecedented downturn in the domestic economy of India [2]. Uncertainties have driven major economic powers like China and the USA to resort to a protectionist regime further contributing to the slowdown in the growth performance of the Indian economy [2]. Amidst the weakened performance of global trade and manufacturing, the annual average growth rate of GDP registered the lowest growth rate of 4.8% during the first half of 2019-20. The deceleration in real GDP growth in India is attributable to supply and demand side variables. On the demand side, a decline in the growth of real fixed investment, induced by sluggish growth in real consumption and contraction of exports. Moreover, there has been a decline in the number of casual farm laborers by 31.93 million, from 109.52 million to 77.32 million during the period between 2011-12 and 2017-18 [2].

Although agriculture is one of the adequately researched areas in the Indian context, the research is mostly confined to the erstwhile policy paradigm of augmenting production and productivity along with assuring remunerative prices for farmers [3]–[5]. While emphasizing the importance of price factors in the promotion of agriculture in India, the post-production process and trade of agricultural commodities have not yet attracted adequate attention. However, the detailed study of India's agriculture and allied sectors by the Committee on Doubling Farmers' Income (DFI), is the first systematic attempt to place Indian agriculture in the global scenario by its emphasis on income augmentation through trade. The DFI Committee stressed the need for transforming Indian agriculture through technological change [1].

In a study of ten major e-markets in the state of Karnataka, Aggarwal, et al argued that the agricultural commodity markets in India need to be reformed more deeply with a focus on laying down rules and regulations, building up institutions and incentivizing the actors in the market by digitalizing trading through Electronic National Agricultural Market (e-NAM) [6]. In the study on the making of smart agriculture, Beriya and Saroja [7] observed that smart technology helped reduction in input costs and augmented the productivity of agriculture in Karnataka. However, smart agriculture has not yet addressed the issue of the fall in the prices of agricultural commodities in the state. The study also suggested that the digitalization of agriculture, particularly in marketing helps farmers to have a data-driven and customized decision support system. The study has spotted 25 indicators and associated hypotheses to gauge the degree of readiness for agricultural transformation. The study on the climate of smart agriculture in India underlines the importance of adapting to technological change and the use of different methods of advanced science in agricultural practices for better production and productivity [8].

Many developed and developing economies have shifted or are in the process of shifting from a price-based support policy to an income support policy. The growth strategy for the Indian economy shifted from inward-oriented import substituting to export-oriented growth by the 1980s. The export-led growth was incorporated into the main thrust of the development paradigm by the early 1990s with the introduction of economic reforms in June 1991. Ever since policy outlook has been fine-tuned to carve out a larger share in the external market and agriculture and allied sectors have been incorporated into the export orientation framework as one of the major drivers of growth. Although India occupies a leading position in the global trade of agricultural commodities, the value of agricultural export from India accounted for 2.15% of the world trade in agricultural commodities [9]. It is worth mentioning that both the volume and value of agricultural exports from India have significantly increased after trade liberalization, which is a part of the paradigm shift in the policy.

The export of agricultural commodities from India was valued at INR2,745,700 million while imports of agricultural commodities into India were valued at INR1,370,000 million in 2018–19 [2]. It may also be noted that the surplus trade in agriculture and allied sectors help the country to keep its trade balance at its present position. India has become a net exporter of agricultural commodities since 1991. On diversification of external markets for agricultural commodities, Bangladesh, Iran, Nepal, Saudi Arabia, and the USA continue to be major markets for India.

The underlying thrust of the policy shift is the swing away from improvement in production and productivity to income enhancement of farmers. The Prime Minister of India announced the shift in policy in his speech on 28 February 2016, at Rai Bareilly, which was translated into the mainframe of agricultural policy and action for DFI by 2022. Agriculture and allied activities, particularly crop production, have been transforming into economic enterprises. It is the net return, which determines the level of income of an entrepreneur. Overall, agriculture comprises two segments: production and post-production, where post-production is the source of value addition and income enhancement. In other words, the change in policy paradigm focuses more on the post-production and marketing of the products under the new economic paradigm for the agricultural sector in India.

There has been a renewed policy thrust to revive agricultural growth since the mid-2000s and for the revival, the government has initiated various development programs viz., interest subvention on crop loans, National Food Security Mission (NFSM), Rashtriya Krishi Vikas Yojana (RKVY), Pulses Development Programme (PDP), Soil Health Card Scheme, Pradhan Mantri Krishi Sinchai Yojana (PMKSY), National Agricultural Market for Electronic Trading, National Livestock Mission (NLM), and Pradhan Mantri Fasal Bima Yojana (PMFBY). Objectives of these projects are multi-pronged and they are broadly aimed at augmenting farmers' income through higher growth. The agricultural sector registered a revival by the turn of the present century. Various studies have also shown that diversification and output price have emerged as important drivers of output growth in recent years.

The sharp departure from the focus on production to the income approach has evolved from the perspective that the value realization from post-production activities is crucial for farmers' welfare. In other words, the shift in the approach needs promotion from "fork-to-farm" demand and price signals, rather than a "farm-to-fork" push. As the Indian farming system is mostly rain-fed and dependent on weather changes and a handful of other factors which are beyond the regulatory capacity of farmers, they may not earn a positive return from cultivation. The income approach considers output and its price and input used, and its price. To increase the net income of farmers, efficient monetization of production needs to be ensured. There is also a need to create an enabling environment for post-production activities and therefore post-production policy regime needs to be addressed from the perspective of what the markets demand. However, achieving the objective of promoting the post-harvesting process is fraught with various constraints and the first and foremost among the constraints is the preponderance of smallholders along with diversified crop production in small quantities. Moreover, there has not yet been a major breakthrough in production and post-harvesting technology since the 1960s.

Lack of rural infrastructure for the primary processing of harvested crops, lack of warehousing, inefficient system of marketing of agricultural produce, huge post-harvest losses, and a wide gap between the invention of technology and its adoption, continue to affect agriculture in India. Besides the structural rigidities that hold back India from transforming agriculture into a profit-making and sustainable enterprise, the country also lags due to the lack of adequate capacity in the system for effectively drought-proofing Indian agriculture through drought-resistant crop varieties and sustainable management of surface and groundwater resources.

An income support scheme for major agricultural produce alone would not be adequate to resolve the crisis that the sector is facing in India as much as terms of trade have turned against agriculture, neutralizing the gain in total factor productivity [1]. While acknowledging the positive effect of hiking administered prices through Minimum Support Price (MSP), a more effective intervention needs to be put in place by way of reforming the existing institutions for post-production processing and value realization through creating better marketing facilities.

Critical Assessment of Agricultural Transformation

There has been a decline in the share of agriculture and allied sectors in GVA in the country from 18.3% in 2013-14 to 16.1% in 2018-19. The decline in the relative contribution of agriculture and allied sector favored the service sector rather than manufacturing as envisaged in conventional economic theories [2]. However, to boost consumption, the government has taken measures, particularly for the agricultural sector, to increase the MSP for 2019-20 and provide assured income support of INR6,000 per year[1] to all farmers with landholdings.[2]

The average annual income of agricultural households from all components of income, including cultivation, livestock, non-farm business, and wages and salaries was INR77,976 in 2012–13 according to the country's National Sample Survey Organisation (NSSO) [1]. On the other hand, the average annual income is estimated at INR97,799 as per the estimation of the Indian Human Development Study (IHDS) by the National Council of Applied Economic Research (NCAER) for the year 2011-12. Although the income from cultivation is nearly the same as revealed by different data sources, there is a difference of INR3,000 in the case of non-farm business and INR4,000 in the case of livestock (higher in the case of NSSO). There is also a significant difference in the case of annual wage earnings and salaries per agricultural household, INR24,801 as per the NSSO's estimate and INR45,783 according to the IHDS data. These differences could be attributed to the sampling frames adopted by the two data sources or they could also be due to non-sampling errors. It has also been found that the share of income from cultivation increases with the size of landholdings. At the lower end of the spectrum of land size, wages, and salaries constitute the principal source of income. It may be noted that the shares of income from wages and salaries, non-farm business, and livestock decline as land sizes increase.

From a policy perspective, there is a wide variation in the average agricultural household income across regions in India. Moreover, there exist significant differences in agricultural income between the two agricultural crop seasons, the July-December Kharif season and the January-June Rabi season. The agricultural income during the Kharif season is higher than during the Rabi season. The all-India average of annual household income during the July-December season was USD302 while it stood at USD217 for the January-June season. The principal reason for the difference in agricultural household income between Kharif and Rabi seasons can be attributed to the fact that land is usually kept fallow during the Rabi season in many parts of India due to water scarcity and lack of irrigation. The average income per household from livestock also varies across states and agricultural zones in India and it shows that there is considerable scope for policy intervention to

augment income from livestock for households. The observed differences in the annual income of agricultural households across different sub-occupation within agriculture and allied sectors and across different states in India assume special significance and any policy approach to Indian agriculture needs to take those factors into account.

The recent debate on the economic slowdown in India is centered around the fall in consumption expenditure in rural India and it may be viewed from the perspective of stagnation in the agricultural

[1]Data on the number of workers in the agricultural and allied sector is collected by decadal population census and the last Census was conducted in 2011. The decadal population Census classifies agricultural workers into agricultural laborers and cultivators and both agricultural laborers and cultivators are again divided into main and marginal workers. Main worker is the one who records more than six months in cultivation or agricultural labor and the marginal is the one who works less than six months either as an agricultural laborer or cultivator. On the definition of farmer and agricultural household, different data collection agencies of the government define differently and so is the estimation of household income. India's Central Statistical Organisation (CSO) does not undertake periodic income surveys for agricultural households and the per capita income for agriculture workers comprising cultivators and agricultural laborers can be indirectly derived from GVA for the agriculture and allied sector. The NSSO, in its 70th Round, defined an agricultural household as one receiving income from agricultural activities, such as the cultivation of field crops, horticultural crops, fodder crops, plantation, animal husbandry, poultry, fishery, piggery, bee-keeping, vermiculture, and sericulture and among others with a reference period of 365 days preceding the date of field inquiry. For understanding the income of agricultural households in India, NSSO's 70th Round and IHDS 2011-12 conducted by NCAER can be clubbed together for comparison and to arrive at the data for understanding the income dimension of the farmer household.

[2]The analysis is based on the Report on DFI, Vol.2. Dalwai 2017.

sector since the early 2010s. Enhancement of income in the agriculture sector would drive down poverty and ensure better living standards and inclusive growth. In 2004, the government set up the National Commission for Farmers which submitted its final recommendation in October 2006.[3] Among its major recommendations, assurance of a minimum support price for crops, making agriculture a sustainable source of livelihood for people in rural India, and ensuring a remunerative income through adequate intervention in post-harvest issues were important. It is worth pointing out that land reforms, application of science and technology, especially soil testing, optimum use of water resources, augmenting productivity, and providing credit were some important recommendations of the Commission.

In 2016, the Government of India appointed a DFI committee shifting the core of concerted discussion on agriculture from production to income augmentation. The DFI Committee observed that 22.56% of farmers are still below the official poverty line primarily because the average monthly consumption expenditure of an agricultural household in India was INR6,223 as against the income of INR6,426. Further, the agriculture situation in India is fraught with several deficiencies due to the sheer negligence of scientific cultural practices in agriculture and allied sectors.

Scope of the Study

The analysis is focused on major crops and the animal husbandry sectors in India. In arid and semi-arid zones of India, the agriculture sector on average has to face drought every three years; in distress situations, farmers depend on milk production for survival and to make up for the loss in income from cultivation. The analysis is, therefore, confined to cultivation or crop production and animal husbandry sectors in India.

The trend and pattern in production, productivity, and area of major crops in India are analyzed for a period of more than 25 years, with a focus on the last decade from 2009-10 for comparison. The choice of the period for long-run analysis of basic indicators measuring the performance of the agricultural sector is influenced primarily by the introduction of new economic reforms in India in 1991. Under the new economic reform, restrictions on foreign trade of agricultural commodities have been withdrawn, allowing the sector and its major stakeholders to compete in the international market. For the assessment of readiness for Smart Agriculture, the year 2010 data was selected as the baseline to assess the progress made during the last nine years.

Analysis of the Current Situation

Introduction

The agriculture and allied sector in India is comprised of a handful of economic activities ranging from crop production to agribusiness. India has a gross cropped area of 198.36 million hectares of which 48.62% or 96.46 million hectares is irrigated. It is worth mentioning in this context that there have been severe agroclimatic constraints in augmenting the productivity of major crops and the area under irrigation in India. For the optimum use of scarce water, the government introduced the 'more crop per drop' initiative. Another major constraint of Indian agriculture for mechanization is the excessive dependence of the workforce on agriculture. Of the total workforce dependent on agriculture, 45% are cultivators (farmers) and 55% are agricultural workers. In the rural population, more than 75% of the workforce eke out a living directly or indirectly from agriculture and allied

[3]The National Commission on Farmers (NCF) was constituted on 18th November 2004. The NCF was constituted under the chairmanship of MS Swaminathan and the Commission was constituted to study the situation of farmers' distress in India. The beginning of the 21st century witnessed a massive spate of farmers' suicides in India.

activities. However, agriculture has failed to be a source of livelihood for people as about 50% of the workforce engaged in agriculture in the early 2000s indicated that they would prefer to abandon agriculture provided they had an alternative source of living [10].

The distress in agriculture was manifested in a spate of suicides, nearly 300,000 farmers in a decade in different parts of the country. Against this backdrop, the government observed: "Over the years, several new challenges have emerged before the sector with the fragmentation of agriculture holdings and depletion of water resources, ICT-based climate-smart agriculture can enhance agricultural productivity and sustainability. Smallholder farming can be a lucrative livelihood opportunity with the application of appropriate technologies and adoption of natural, organic, and Zero Budget Natural Farming" [9, p. 172].

The statement underlines the importance of transforming agriculture with a focus on active and user-friendly technological intervention. Another notable characteristic of the agricultural situation in India is its preponderance of small holdings (<2 hectares of land) in total operational holdings of agricultural land in India accounting for 85% in 2015-16. The semi-medium size of holdings (2-4 hectares) and medium size of holdings (4–10 hectares) accounted for 9.45% and 3.76% of total land holdings respectively. Large holdings (>10 hectares) accounted for only 0.57% of the land holdings in India. Conversely, there has been a marginal increase in the average size of holdings barring the marginal category of farmers. Table 1 shows the trend in the average size of holdings, relative share in the number of holdings, and area under a different type of holdings.

TABLE 1

RELATIVE SHARE OF LAND HOLDINGS AND AVERAGE SIZE OF HOLDINGS (2010-11 AND 2015–16).

Category of Holdings	Number of Holdings (%)		Area (%)		Average Size of Holdings (Hectare)	
	2010-11	2015-16	2010-11	2015-16	2010-11	2015-16
Marginal	67.1	68.52	22.50	24.16	0.39	0.38
Small	17.9	17.69	22.1	23.19	1.42	1.41
Semi-medium	10	9.45	23.60	23.65	2.71	2.70
Medium	4.20	3.76	21.2	19.96	5.76	5.72
Large	0.7	0.57	10.6	9.04	17.38	17.1

Source: Agriculture Census 2015-16, Phase 1, Ministry of Agriculture, Cooperation and Farmers Welfare, Government of India.
Note: Land use statistics are collected in India on a quinquennial basis by the Ministry of Agriculture, Cooperation and Farmers Welfare, Government of India. The latest data is available for the year 2015-16.

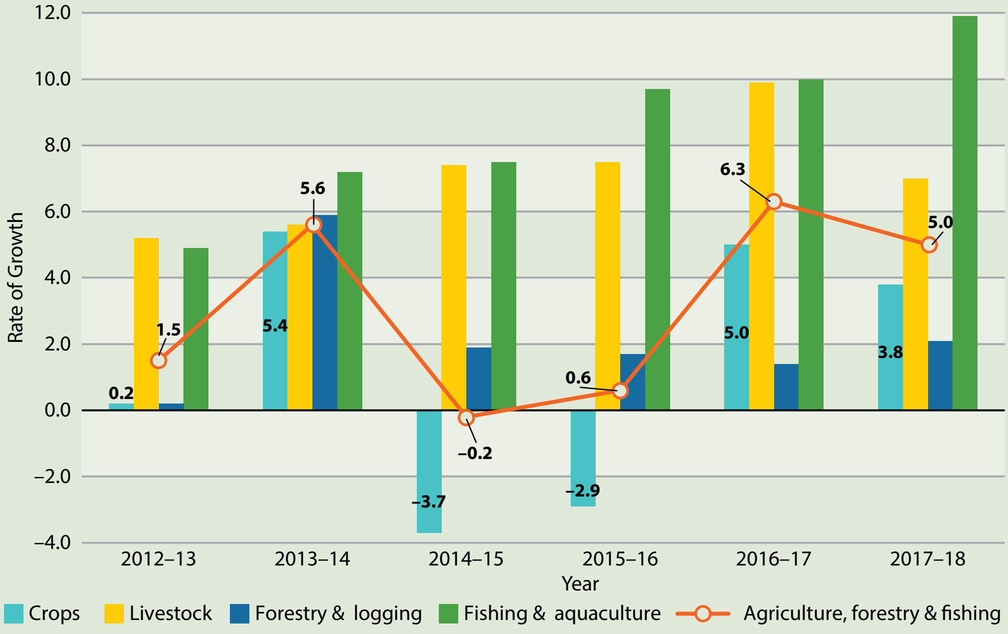
Performance of Agriculture and Allied Sectors

The growth rate in the GVA of agriculture and allied sectors shows that it has been volatile since the stagnation in agriculture in 2013. Figure 1 shows the trend in the annual growth rate of different sub-sectors from 2011-12 to 2017-18. The crop production sector registered the lowest growth rate and the rate of growth turned negative twice during eight years since 2011-12.

It may also be noted that the agroclimatic conditions do vary across states and the number of crops cultivated in the country is diverse. For the sake of brevity of analysis, we can broadly classify the crops into the following categories like food grains, oil seeds, other cash crops, pulses, and fruits and vegetables.

FIGURE 1

GROWTH OF GVA IN AGRICULTURE AND ALLIED SECTORS AT 2011–12 PRICES.



Source: Economic Survey, Government of India, 2019–20.

Table 2 shows India's position in the world map of agriculture and allied activities. It is rather clear that India ranks first in several items of agricultural production and ranks second or third in most other items. However, the issue that assumes importance in this context is low productivity. For instance, India is the second largest country in cattle and first in buffalo population. However, the productivity of cattle and buffalo is on the much lower side. Table 3 shows the productivity of major agricultural and dairy products in India and compares it with world productivity.

TABLE 2

INDIA'S POSITION IN THE WORLD AGRICULTURE (2016).

Item	India	World	India's Share in the World and Rank
Arable land (million hectares)	156.46	1423.79	10.99 (1)
Rural population (2011 population census in India)	867.27	3370.28	25.73 (1)
Total cereal production (million tonnes)	297.85	2909.20	10.24 (3) After China and USA
Pulses (million tonnes)	18.15	83.46	21.75 (1)
Oilseeds Production (million tonnes)			
Groundnut (in shell)	7.46	44.91	16.62 (2)
Rapeseed	6.80	68.09	9.98 (3)

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Item	India	World	India's Share in the World and Rank
Commercial Crops Production (million tonnes)			
Sugarcane	348.45	1861.18	18.72 (2)
Tea	1.25	5.91	21.14 (2)
Coffee (green)	0.35	9.32	3.73 (7)
Jute	1.90	3.31	57.31 (1)
Cotton (lint) 2013	6.05	24.77	24.43 (2)
Tobacco (unmanufactured)	0.78	6.40	12.23 (2)
Fruits and Vegetables (million tonnes)			
Vegetable primary and lemon	123.63	1229.51	10.06 (2)
Fruits primary	88.47	710.50	12.45 (2)
Potatoes	43.42	374.25	11.60 (2)
Onion (dry)	20.93	94.94	22.05 (2)
Livestock (in million)			
Cow	186.04	1488.96	12.49 (2)
Buffalo	112.57	199.39	56.46 (1)
Milk (million tonnes)	165.33	809.80	20.42 (1)

Source: Agriculture Statistics at a Glance 2018, FAOSTAT, 2019; P. 221–222.

TABLE 3

PRODUCTIVITY (KG/HA) OF PRINCIPAL CROPS IN INDIA AND THE WORLD (2016).

Item	India	World	India's Share in the World Production (%)
Paddy	3,790	4,577	21.65
Wheat	3,034	3,401	12.32
Maize	2,616	5,632	2.35
Pulses	588	958	21.75
Sugarcane	70,394	70,134	18.72
Groundnut (in shell)	1,287	1,606	16.62
Tobacco	1,698	1,795	2.67

Source: Agriculture Statistics at a Glance 2018, FAOSTAT, 2019; P. 221-222.

Trends in Production and Productivity of Major Crops in India

A brief history of Indian agricultural growth since the onset of the Five Year Plans in 1951, underlines that economic growth is driven by the performance of agriculture and allied sectors. The current economic slowdown in India is attributable to sluggishness in the crop production sector. The annual average growth rate of agriculture and allied sector in India has remained constant at 2.88% during 2014-15 to 2018-19 and it is much below the targeted growth rate for the sector to achieve the avowed objective of doubling farmers' income by 2022. However, fluctuations in agricultural output growth have substantially reduced as measured in terms of coefficient of variation (0.8%) from 2005 to 2018. The relative share of agriculture and allied sectors in GVA of India has been declining over the years and contributed only 16.3% in 2020-21. It is clear from Table 4 that the relative share of crops has declined from 11.5% to 9.0% during the period 2012-13 to 2020-21.

TABLE 4

CONTRIBUTION OF AGRICULTURE AND ALLIED SECTORS IN GDP AT CONSTANT PRICE IN 2011–12 (IN %).

Sector and Sub-sector	2012–13	2013–14	2014–15	2015–16	2016–17	2017–18	2018–19	2019–20	2020–21
Agriculture, forestry, and fishing	17.8	17.8	16.5	15.4	15.2	15.3	14.8	15.0	16.3
Crop	11.5	11.4	10.3	9.2	9.0	8.9	8.2	8.4	9.0
Livestock	4.0	4.0	4.0	4.0	4.1	4.1	4.2	4.4	4.9
Forestry and logging	1.5	1.5	1.4	1.3	1.3	1.3	1.3	1.2	1.3
Fishing and aquaculture	0.8	0.8	0.8	0.9	0.9	1.0	1.0	1.0	1.1

Source: Economic Survey, Government of India, 2022-23.

Animal Husbandry Sector

India is the largest producer of milk in the world with a production of 187.7 million tonnes in 2018-19 and it has registered an annual growth rate of 4% for more than a decade. The per capita availability of milk in India was 394 grams per day in 2018. Animal husbandry or livestock is the second largest sector in agriculture and allied sectors in India. The contribution of the animal husbandry sector was 4% of the GVA in the country while the crop production sector contributed 10.33% to GVA in India. The livestock sector has registered a growth rate of 7.9% during the last five years. The government has launched National Animal Disease Control Programme (NADCP) with a financial outlay of INR13,430 million for the period 2019-24. The purpose of the program is to increase milk production and productivity with the long-term objective of enhancing export earnings from the sector. However, India's yield as a percentage of other countries is on the much lower side and it has a significant bearing on the competitiveness of the Indian dairy sector in the international market (Table 5). Another important issue with the milk production sector in India is the significant differences in average yield per animal across different states in India (Table 6).

TABLE 5

MILK YIELD PER ANIMAL IN INDIA AND OTHER COUNTRIES.

Country	India's Yield as % of Other Countries
European Union	19
Australia	21
Mexico	28
Argentina	24
New Zealand	33
Russian Federation	29
Ukraine	37
Brazil	100
Pakistan	93
China	39

Source: Dairyman.

TABLE 6

AVERAGE MILK YIELD PER ANIMAL PER DAY IN 2018 (IN KG).

States	Buffalo	Cow (Exotic)	Cow (Indigenous)
Andhra	4.73	7.42	2.08
Bihar	3.95	6.11	2.94
Gujarat	4.87	8.94	4.07
Haryana	7.54	8.37	5.22
Karnataka	2.70	6.11	2.35
Kerala	3.28	3.00	0.59
Madhya Pradesh	3.98	7.38	2.52
Maharashtra	4.35	7.08	1.76
Punjab	8.72	11.04	6.59
Rajasthan	5.76	7.75	3.68
Tamil Nadu	4.42	6.87	2.71
Uttar Pradesh	4.45	7.09	2.59
West Bengal	5.42	3.58	2.65
India	4.91	6.78	2.50

Source: Economic Survey, Government of India, 2018-19.

Government Expenditure, Capital Formation, and Agriculture Sector in India

Given that 85% of landholding in India is marginal and small (<2 hectares), farmers are incapable of making large investments and therefore public sector investment in agriculture is a pre-condition.

TABLE 7

GROSS CAPITAL FORMATION IN AGRICULTURE AND ALLIED SECTORS.

Year	GCF in Agriculture and Allied Sectors at 2011-12 Prices (INR million)			GVA in Agriculture and Allied Sectors at 2011-12 Prices (INR million)	GCF in Agriculture and Allied Sectors as % of its GVA		
	Public	Private	Total		Public	Private	Total
2012-13	3,60,190	21,50,750	25,10,940	1,52,42,880	2.4	14.1	16.5
2013-14	3,39,250	25,04,990	28,44,240	1,60,91,980	2.1	15.6	17.7
2014-15	3,71,720	23,54,910	27,26,630	1,60,57,150	2.3	14.7	17.0
2015-16	4,25,220	19,51,270	23,76,490	1,61,61,460	2.6	12.1	14.7
2016-17	4,77,670	21,93,860	26,71,530	1,72,60,040	2.8	12.7	15.5
2017-18	4,60,315	22,62,895	27,23,210	1,84,00,220	2.5	12.3	14.8
2018-19	5,34,934	24,31,377	29,66,311	1,87,85,983	2.8	12.9	15.8
2019-20	4,70,395	25,46,317	30,16,712	1,98,23,029	2.4	12.8	15.2
2020-21	4,67,281	27,98,046	32,65,327	2,04,80,318	2.3	13.7	15.9

Source: CSO, MoSPI.

In public sector investment, 2018-19 the outlay on research and education for the farm sector assumes special significance. It is found that the expenditure share for research and education in the agricultural promotion and extension activities remains less than 0.5% of the GVA (Figure 3). Another important factor influencing the performance of the sector is the relative share of actual expenditure budgeted and expended for the agricultural sector. There are two aspects to budget outlays for agriculture and allied activities. The share of agriculture in the total budget outlay has declined from about 5% in the late 1990s to around 4% in 2017-18. The actual expenditure in agriculture and allied sectors in the budget outlay has been declining and reached 2%. Figure 4 shows the actual expenditure on agriculture and allied activities in the budget allotted for the same during the period between 1991-92 and 2017-18. The more worrisome is the fact that more than 20% of the budget allotted for agriculture remains unspent.

Trends in Foreign Trade of Agricultural Commodities in India

There has been a consistent increase in the foreign trade of agricultural commodities from India since the introduction of economic reforms in 1991. The trade in agricultural commodities received a stimulus with the announcement of DFI by 2022 as the thrust of agricultural policy in 2016. In the external trade of agricultural commodities, trade in agricultural commodities in India constituted only 2.15% of the world agricultural trade (2018). Moreover, there is little diversification of trade in agricultural commodities in India as the USA, Saudi Arabia, Iran,

FIGURE 2

CONTRIBUTION OF PUBLIC AND PRIVATE SECTOR IN TOTAL GCF IN AGRICULTURE AND ALLIED SECTORS (IN %).

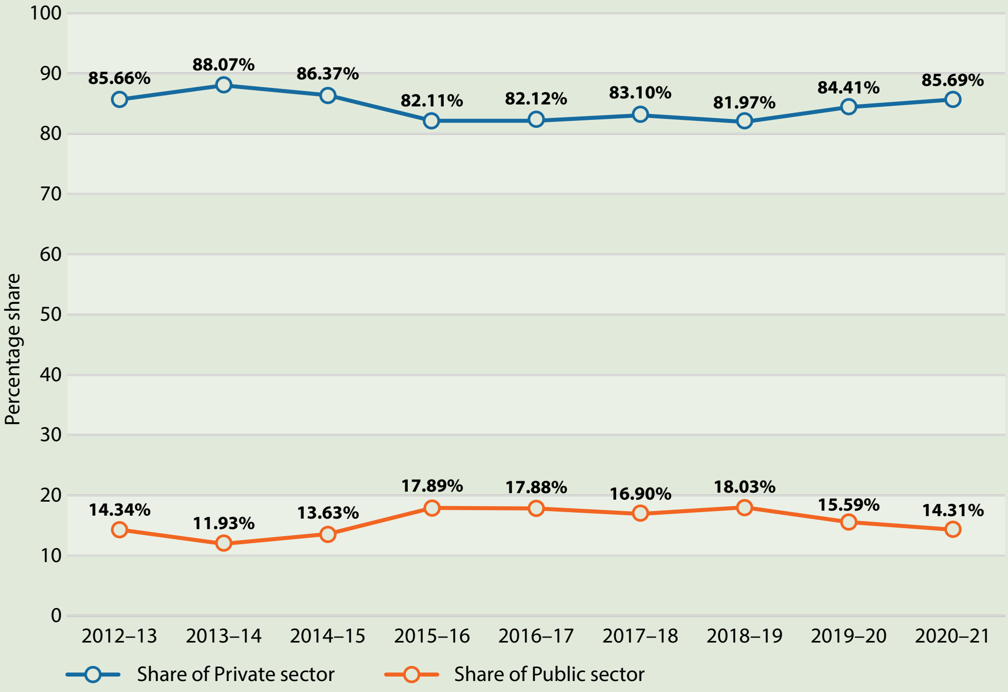
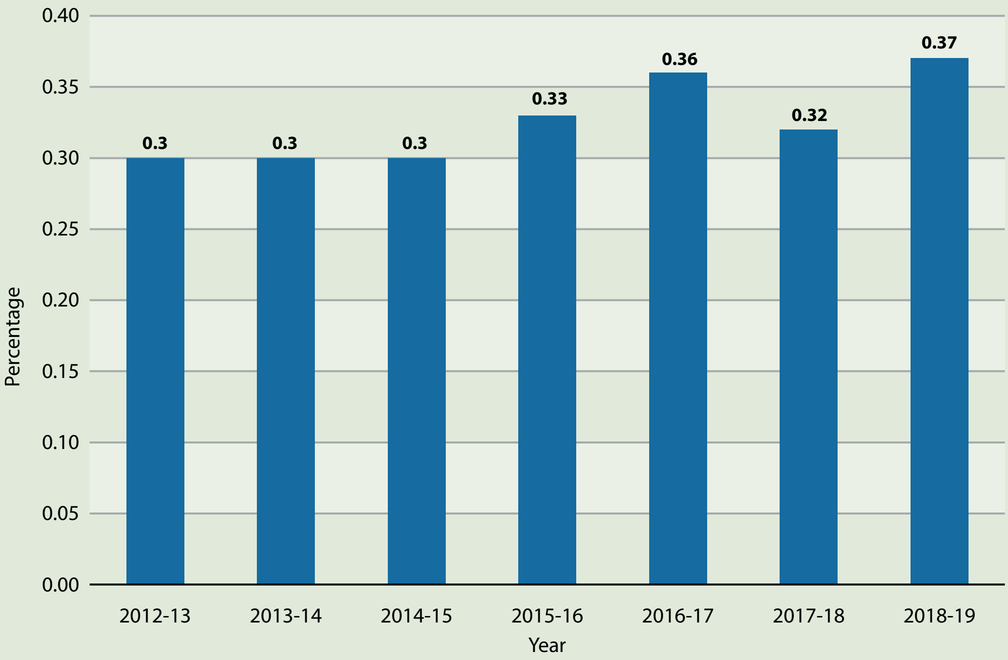


FIGURE 3

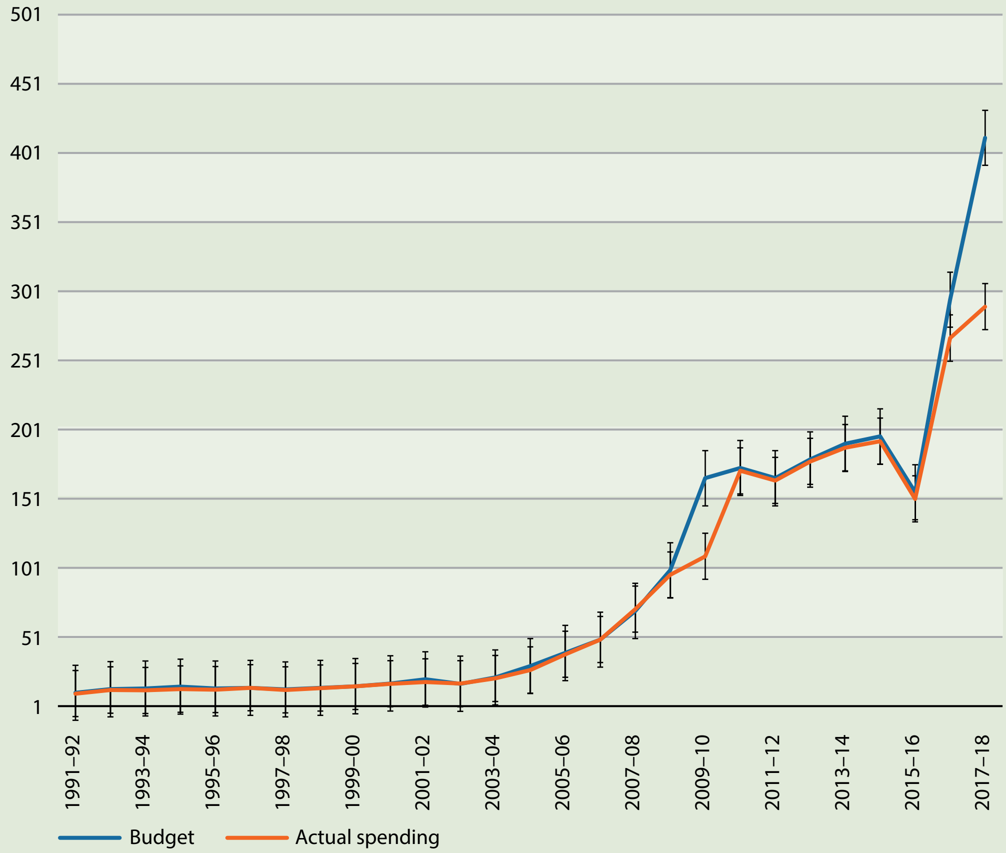
SHARE OF EXPENDITURE ON AGRICULTURE RESEARCH AND EDUCATION IN AGRICULTURAL GVA (IN %).



Source: Economic Survey, Government of India, 2018-19.

FIGURE 4

BUDGET ALLOCATION AND ACTUAL EXPENDITURE FOR DEPARTMENT OF AGRICULTURE COOPERATION AND FARMERS WELFARE IN INDIA (1991–92 TO 2017–18; IN INR BILLION).



Source: Agriculture Statistics at a Glance 2017.

Nepal, and Bangladesh continue to be the major destinations of exports from India. In 2018-19, India exported INR2,700 billion worth of agricultural commodities against an import of INR1,370 billion. Important items of exports of agricultural commodities from India include rice, spices, cotton, oil meals, sugar, castor oil, tea, coffee, and fresh vegetables of which rice and spices constitute more than 25% of the total value of exports. The Government of India initiated an agricultural trade policy to double agricultural exports and integrate Indian farmers with the global value chain.

The agricultural credit in India across different regions shows that there exists significant variation in agricultural credit disbursement. The amount of credit disbursed to the agricultural sector increased from INR2,860 billion to INR18,630 billion between 2009-10 and 2021-22 [11]. To provide comprehensive coverage of risks from pre-sowing to post-harvest against natural non-preventable risks, the country has been running the Pradhan Mantri Fasal Yojana (PMFBY) program 2015-16. The PMFBY covers 23% of the gross cropped area in the country under insurance and it is expected to increase the insurance by 50%. The Government has created a national insurance portal for agricultural insurance. It is a web-based integrated IT platform that provides an interface for all stakeholders to access data related to farmers insured under PMFBY and

Restructured Weather Based Crop Insurance Scheme (RWBCIS). In 2018-19, applications of over 56.45 million farmers covering an area of 51.77 million hectares were insured for a total of INR2,356.42 billion. In 2019, under PMFBY, INR177.56 billion was claimed and INR167.63 billion was disbursed. Overall, 23 out of 28 states in India implemented the program in 2017-18.

Status of Major Policy Initiatives for Agricultural Transformation

Table 8 shows the status of the adoption rate of extension services by farmers from different sources. An important conclusion that emerged from the table is the adoption rate of farmers and its success rate is also very high. It shows the willingness of farmers to receive advanced technology in agriculture if it is supplied.

TABLE 8

THE PROPORTION OF HOUSEHOLDS ADOPTING ADVICE FROM DIFFERENT SOURCES.

Sources	Households Adopting Advice During the Jan-June 2013 Season (in %)	Households that Reported the Advice as Useful During the Jan-June 2013 Season (in %)
Extension agent	86	94
Krishi Vigyan Kendra	79	98
Agricultural universities and colleges	81	93
Private commercial agents, including drilling contractors	87	96
Progressive farmer	92	97
Radio/TV/newspaper/Internet	64	95
Veterinary department	92	98
NGO	85	99
Any agent	85	NA

Source: Economic Survey, Government of India, 2019-20.

Table 9 and Table 10 explain the current status of schemes and programs for SAT in India. Most such programs were introduced in 2017, hence a constructive assessment would be rather difficult. All these programs are ongoing and, in a few cases, they were introduced in the last two years.

FIGURE 5

POLICY INITIATIVES.

Production	• Contract farming • Soil health card • Water efficiency • Farmers credit card • Crop insurance • Pension scheme • PMKisan
Post harvesting	• Upgradation of village market • Minimum support price • e-NAM

TABLE 9

AGRICULTURAL TRANSFORMATION INITIATIVES (AS OF 2019 DECEMBER).

Programs and Schemes	Year and Outlay (INR million)	Main Objective and Physical and Financial Achievement	Constraints and Challenges
e-NAM-National agricultural marketing	2016 Outlay: 1,960 (2019–20)	• To promote better marketing facilities for farmers by integration and quality assurance • 585 agricultural markets from 18 provinces were developed into electronic marketing systems • e-Trade provided for 150 commodities with tradable parameters • Inter-state trade in 12 states started • 1.27 lakh traders joined the scheme from different states and specialized markets • 16.50 million farmers registered under the scheme	• Inadequate number of labs for quality assessment • Lack of Internet connectivity and other infrastructure for e-NAM
Gramin agricultural markets (GrAMs)	2018-19 20,000 (2019-20)	• To Develop and upgrade agricultural markets in villages by providing basic and supporting infrastructure and marketing infrastructure • 707 rural markets were developed with basic infrastructure and MGNREGA • INR20,000 million Agri Market Infrastructure Fund has been created	• Lack of information on rural agri markets • Coordination with state and local governments becomes difficult • Fewer takers of AMIF from provinces
Integrated scheme for agricultural marketing (ISAM)	2019–20 4,080 (2019–20)	**To Develop Agricultural Market Infrastructure** • Provide innovative technologies in post-harvest • Encourage collective farm-level processing through FPOs • Provide quality certification • Provide integrated value chain **Project Components** • AMI: Integrated Scheme for Agricultural Marketing • MRIN: Integrated Scheme for Information Network • SAGF: Strengthening of AGMARK Grading Facility • VCA: Venture Capital Assistance • NIAM: National Institute of Agricultural Marketing	• Provinces in certain parts of the country do not respond positively to the program, particularly the North-Eastern region • It needs to be closely probed
Farmers producers organization (FPO)	2011-12 There is no plan outlay but depends on states to suggest FPO formation under Annual Action Plan for RKVY	• Mobilizing farmers into 15-20 members at the village level • Enhance productivity through capacity building • Encourage usage of quality inputs and services and form cluster competitiveness. provide quality certification • Ensure remunerative price through market aggregators **Achievements** • 819 FPO registered to date	• Lack of professional support for FPOs • Lack of infrastructure for FPOs • Banks are reluctant to extend credit to FPOs • Interest rate is higher for FPOs • There are no cold-chain management programs for FPOs

Source: Discussion with officials in the Ministry of Agriculture, Marketing Division, Government of India, 2019.

TABLE 10

MAJOR SCHEMES FOR ENHANCING PRODUCTION AND PRODUCTIVITY OF CROPS IN INDIA.

Scheme	Objectives
Sub-Mission on Agricultural Extension (SMAE) was implemented under Nation Mission on Agricultural Extension and Technology (NMAET). Introduced in 2014-15, SMAE has been subsumed as a sub-scheme of the umbrella scheme, Green Revolution Krishonnati Yojana from 2017-18	**SMAE includes the following components** • Support to Extension Programme for Extension Reforms • Mass media support for Agricultural Extension • Agri Clinics and Agri Business Centres (ACABC) • Extension support to central institutes • Strengthening and promoting the Agricultural Information system, including the Kisan Call Centers (KCC)
AGMARKNET	**Launched in March 2000** • To provide electronic connectivity to the wholesale markets of the country • To collect, analyze and disseminate market information to the farmers, traders, policymakers, and other stakeholders • More than 3,200 markets are covered under the scheme and more than 2,700 markets are reporting data on the Agmarknet portal • More than 350 commodities and 2,000 varieties are covered under the scheme
Horticulture Mission for Integrated Development of Horticulture (MIDH)	• Scheme for the holistic growth of the horticulture sector • The Government of India contributes 85% of the total outlay for developmental programs while 15% is provided by the state governments
Online Pesticide Registration Computerized Registration of Pesticides (CROP)	• Online Application for Registration of Pesticides • Online status checking • Frequent email notification to the applicant at certain milestones of the registration process till deficiency reporting and approval • Online application for grievances
Plant Quarantine Clearance	• Plant Quarantine Information System facilitates importers to apply online for import permits • Online application for Import Release Orders and Phyto-sanitary Certificates for exporters
DBT in Agriculture	• Direct Benefit Transfer (DBT) portal for agriculture and store all the Beneficiaries with Scheme information at a national level
Pradhanmantri Krishi Sinchayee Yojna (PMKSY)	• To ensure access to the means of protective irrigation to all agricultural farms in the country • To produce 'More Crop per Drop'
Kisan Call Centre	• The scheme was launched in January 2004. • The main aim of the scheme is to answer farmers' queries on a telephone call in their language. • These call centers are working in 21 different locations in the country covering all the States and UTs
m-Kisan	• It is an SMS Portal for farmers to give information, services, and advisories to farmers by SMS in their language, preference of agricultural practices, and location
Jaivik Kheti	• Jaivik Kheti portal is a unique initiative of the Ministry of Agriculture (MoA), Department of Agriculture (DAC) along with MSTC to promote organic farming globally • It is a one-stop solution for facilitating organic farmers to sell their organic produce and promoting organic farming and its benefits

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Scheme	Objectives
e-Nam	• It is a pan-India electronic trading portal that networks the existing APMC mandis to create a unified national market for agricultural commodities
Soil Health Card	• Soil Health Card Scheme is a scheme launched by the Government of India on 19 February 2015 • The Soil Health Card is used to assess the current status of soil health and, when used over time, to determine changes in soil health that are affected by land management
Pradhan Mantri Fasal Bima Yojana (PMFBY)	• Launched on 18 February 2016 for insurance coverage and financial support to the farmers in event of any crop failure due to natural calamities, pests, and diseases • To stabilize the income of farmers to ensure their continuance in farming • To adopt innovative and modern agricultural practices and to ensure the flow of credit to the agricultural sector

Identification of Key Stakeholders for Digitalization of Agriculture

The first and foremost stakeholders in the digitalization of agriculture in India are the smallholders who constitute more than 85% of total landholdings in the country. Many smallholders are organized into Farmers' Producers Organisations (FPOs), Farmers' Cooperative Societies, Banks for credit supply as well as digitalization of trading practices, online traders in agricultural commodities, National Agricultural Marketing Committees or what is called Specialised Markets, Self Help Groups and other information and formal groupings of farmers.

Agricultural labor is the second important stakeholder of digitalization. The agricultural labor force in India remains relatively unskilled and there is a need to substantially improve their level of computer literacy and awareness of SMART technology since they are the ones who can take the digitalization process to the field.

Input vendors, manufacturers, traders, commission agents, and exporters are also key players in the agricultural value chain. As farmers depend mostly on the private sector for fertilizers, pesticides, artificial insemination of cattle and buffalo, and marketing, the trading agents in villages disseminate knowledge about cultural practices and the application of inputs, pesticides, and agricultural implements. They have to be trained along with farmers. A process of certification needs to be put in place to ensure the quality of inputs sold by private vendors.

An important driver of the digitalization process is the government at various layers, including local governments. The role of the central government in introducing schemes and programs is pivotal while the provincial governments play an important role in implementing them.

Readiness Assessment and GAP Analysis

Introduction

The concept of SAT is different for countries and its modalities and application also vary within the country. SAT includes three components: smart, agriculture, and transformation. There has been a shift in India's agricultural policy paradigm from the earlier production orientation to marketing by 2017. In this context, transformation refers to changes in the structure, functions, and role of institutions and functionaries enabled by a collective political enabling environment to address the objective of augmenting farmers' income per unit of time, energy, and finance expended on it. The word "smart" refers to the application of modern technology in every sphere of agriculture to achieve the objective of augmenting income per unit of investment. There was a set of enabling factors for SAT to come into existence and such enabling factors do vary across countries and regions within the country. Broadly, such enabling factors include core elements of planning and delivery [12] Those enabling factors are grouped to form Readiness Indicators and a country's SAT status is measured in terms of the level of such indicators.

Gaps in Agricultural Transformation

Gaps can also be construed as important challenges for the Indian agricultural and allied sectors in achieving its long-term goal of sustainable and market-driven growth. The gaps may be discussed in the context of the initiatives on the marketing side as a method to enhance farmers' income. There exist significant productivity differences across different states in India and there are agroclimatic limitations in addressing the augmentation of productivity.

The availability of data for comparison from authorized sources in public space is considered an important indicator of the development of the sector. The data available on different indicators of readiness assessment shows that information on digitalization is not available for several indices at the national level.

(i) More than 85% of holdings are under smallholders with an average size between 0.38 hectares and 1.41 hectares.

(ii) About half of the area under cultivation is rain-fed and the Climate Smart Agriculture has not yet been practiced sufficiently by most smallholders.

(iii) A large segment of farmers remains unaware of the programs and schemes on technological upgradation and the importance of digitalization of agriculture and e-marketing facilities.

(iv) Family labor-based farms still constitute a major chunk of the production scenario and, therefore, commoditization of agriculture is low.

(v) Penetration of risk cover among farmers and its adequate adoption remain a major challenge.

(vi) Productivity of major crops remains much below the average productivity of major producers in the world. It affects the competitiveness of Indian farmers in the international market.

(vii) Research and Development (R&D) fund for agricultural and allied sectors constituted only 0.3% of the GVA of the sector. It is a major challenge and needs to be raised substantially.

(viii) Gross Capital Formation (GCF) in agriculture is relatively low and it constitutes only 16% of GVA. In the GCF, the share of the public sector is still abysmally low at 2.5% of GVA. It poses a major threat.

(ix) Markets for agricultural commodities are not adequately digitalized to ensure free and fair trade.

(x) Trade in agricultural commodities in India is only 2.5% of the world trade and remain stagnant for a long time. Rules and regulations on trade in agricultural commodities need to be changed from the perspective of enhancing income for farmers.

Case Study

For assessing the readiness for Smart Agriculture Transformation, a study of two important e-markets for agricultural commodities in Rajasthan and Gujarat were selected. The study focused on Unjha Market in Gujarat and Ramganj Market in Rajasthan along with farmers of two major export-oriented seed spices, cumin, and coriander (which account for 25% of spice exports of India) cultivated in these two states. The primary objective of the study is to assess the adoption of smart technology in the production process and the effectiveness of e-markets created under agriculture transformation in India. The analysis revealed that farmers continue to use the traditional methods of cultivation in the production process but they make use of smart technology for gathering market information and it helps them fetch a better price for the produce. However, the density of specialized markets is very low and it dissuades farmers from selling the produce on e-NAM. There is a significant price difference between local markets and platforms and the e-NAM price is always higher than the local market price.

For SAT, infrastructure facilities in the market to ensure a fair deal for enhancement of income to the farmers is important. Table 11 shows the availability of different market infrastructure facilities and corresponding quality ratings by farmers. Based on the quality rating of facilities, an Index has been constructed for cumin and coriander. Table 12 shows the Market Infrastructure Index availed by farmers of two representative crops considered in the analysis. The table shows that 35% of cumin farmers do not avail any type of infrastructure facility available in the market. It appears to be rather realistic because cumin is grown in the desert and agriculturally backward regions of Rajasthan and Gujarat. Moreover, the specialized market for the crop is located far away from the production centers and, therefore, farmers are compelled to sell the standing crops to agents of specialized markets or sell at the nearby local market. It also points out that 11% of coriander farmers and 3% of cumin farmers have made use of all infrastructure facilities available in the market. Coriander-growing farmers avail more infrastructure facilities in the market as compared to cumin and it is often attributed to the stage of development of farmers cultivating coriander in Rajasthan. Besides, 10%-20% of the market infrastructure is used by both coriander and cumin farmers.

Meanwhile, Table 13 shows the source from where farmers access technical and extension services for crop production and marketing. However, farmers reported that they get to know about the price either from the traders in the main market or online and newspapers and accordingly bargain by setting the floor price.

TABLE 11

FARMERS RESPONSE AS A PERCENTAGE OF TOTAL FARMERS MARKET INFRASTRUCTURE FACILITIES.

Grading	Not Available		Bad		Average		Good	
Weights	0		0.5		1		2	
Facilities	Cumin	Coriander	Cumin	Coriander	Cumin	Coriander	Cumin	Coriander
Godown facilities	59	8.33	3.5	3.92	33	74.02	4.5	13.73
Auction agreement	60.5	29.90	4.5	2.45	31	50.49	4	17.16

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Grading	Not Available		Bad		Average		Good	
Weights	0		0.5		1		2	
Facilities	Cumin	Coriander	Cumin	Coriander	Cumin	Coriander	Cumin	Coriander
Supervision of sale	62	31.86	1.5	1.47	31	50.49	5.5	16.18
Loading facilities	37.5	7.35	1	3.43	46	50.49	15.5	38.73
Sorting and grading facilities	71.5	55.39	3.5	0.49	17.5	27.45	7.5	16.67
Cleaning facility	66.5	44.61	5.5	0.49	20.5	37.25	7.5	17.65
Weighting facilities	38	6.37	2	0.98	29	51.47	31	41.18
Packing facilities	62.5	37.25	0	21.57	14.5	40.69	23	0.49
Banking facilities	62	39.71	2	0.98	14.5	25.49	21.5	33.82
Motorable roads	38.5	4.90	8.5	5.39	29	48.53	24	41.18
Computer facilities	62	60.29	2	1.47	15.5	13.73	20.5	24.51
Internet facilities	66	62.75	2	0.49	14	12.25	18	24.51

Source: Primary Survey.

TABLE 12

COMPREHENSIVE INDEX OF MARKET INFRASTRUCTURE FOR CUMIN AND CORIANDER.

MII Score	Farmers Availing Facility (%)	
	Cumin	Coriander
0	35.38	2.11
01 – 05	18.47	16.02
05 – 10	7.69	19.72
10 – 15	17.95	25.34
15 – 20	17.43	25.36
20 – 25	3.08	11.27
Total	**100**	**100**

Source: Primary Survey.
Note: The maximum score possible from a farmer is 24 based on weights. To maintain the class interval width, 20-25 is given.

TABLE 13

ACCESSIBILITY TO TECHNICAL ADVICE FOR THE CULTIVATION OF CUMIN AND CORIANDER.

Source of Technical Advice	Accessed by Cumin Farmers (in %)	Accessed by Coriander Farmers (in %)
Agriculture supervisor (G.P)	19.5	41.50
Extension agent/officer from spices board	2.50	5.00
Krishi Vigyan Kendra	13.50	15.50
Agricultural universities/colleges	2.00	0.00

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Source of Technical Advice	Accessed by Cumin Farmers (in %)	Accessed by Coriander Farmers (in %)
Private agricultural experts	61.50	35.50
Progressive farmer	93.50	96.50
Radio	2.00	9.00
Television	5.50	24.50
Newspaper	20.50	46.50
Internet/computer	2.00	7.00
Smartphones	3.00	8.00
Mobiles	21.50	29.00
Farmers organizations	3.50	3.00
Others	1.50	3.00

Source: Primary survey.
Note: Column total exceeds 100 because a farmer may avail technical advice from more than one source.

Assessment of SAT Readiness

Readiness for SAT is assessed based on data on different indicators (Table 14) For each of the indicators, the author has assigned a qualitative score of High (H), Medium (M), and Low (L), to more systematically assess SAT readiness of Indian agriculture.

(i) Some caveats in evaluating the indicators are as follows: Relevant data are not available for several important indicators to assess the Readiness Indicators.

(ii) In those cases where the data is available, the latest figures are not available or have not yet been extrapolated at the official level for policy purposes.

(iii) Most of the indicators in 2010 are either low meaning data/is non-existent and even if the data is existent, it is inadequate to come to any meaningful assessment.

(iv) Since the middle of 2010, after the introduction of the DFI policy in India, data on e-NAM and digitalization are available in the ministry, but such data may take a few more years to be systematically presented in the public domain.

Table 15 summarises the Readiness Index for SAT. The following observations can be made from the table.

(v) In the Upstream Index for the year 2010, there were seven indicators of which four are Medium, one is High and two are Low. For the latest year, there were three Highs, two Mediums, and two Lows, signifying improvement over time.

(vi) In the case of Production indicators, as compared to 2010, there is an improvement in the number of High ratings from 3 to 4, but Medium and Low ratings remain unchanged implying the absence of significant change during the last 10 years.

(vii) For Downstream Indicators, there is a deterioration in the case of readiness indicators as the number of Medium ratings declined from 2 to 1, while the number of Low ratings increased from 5 to 6.

(viii) In the case of enabling factors, there is an improvement in readiness toward SAT.

(ix) Overall, indicators with High ratings have increased from 4 to 9 between 2010 and 2018, or the latest year for which data is available. For the Low ratings, there has also been an increase from 24 to 22, owing to a decline in rating for previously Medium-rated indicators.

TABLE 14

READINESS ASSESSMENT INDICATORS AND RATING.

	Indicator	2010	Latest	Rating (2010)	Rating (latest)
	Development				
Upstream	Existence of laws and policies on agricultural finance	Yes	Yes	M	H
	Agricultural insurance penetration ratio	1.21%	25.96% (2017-18)	M	H
	Share of borrowing smallholders and fishers who borrow from formal sources (%)	69	78	H	H
	Technician-to-farmer ratio: public and private	ND	ND	L	L
	The proportion of agricultural land that is irrigated (%)	45%	49% (2016)	M	M
	Digitization				
	Share of extension personnel who are computer-literate (%): public and private	ND	ND	L	L
	Existence of IT-based agricultural insurance products (e.g., remote sensing)	Yes	Yes	M	M
	Development				
Production	Existence of a regulatory framework for seed	Yes	220 hybrids, 93 horticultural crops	M	H
	Existence of a regulatory framework for agrochemicals (fertilizer and pesticide)	Yes	Yes	M	H
	Existence of a regulatory framework on agrimachinery	Nil	Nil	L	L
	Tractors per 100 sq km of arable land	ND	27 tractors per 1,000 hectares of agricultural land (2015)	M	H
	Agricultural wage (dollars per day)	USD3.51 per day	USD5.46 per day	M	L
	Rural employment in youth employment (%)	76.32	72.28 (2018)	H	L
	The average age of a farmer	ND	46	L	L

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	Indicator	2010	Latest	Rating (2010)	Rating (latest)
Production	Average farm size (ha)	1.15 hectare	1.08 hectare (2015)	M	L
	Share of smallholder (2 ha and below) who is owner-cultivator	85% (farmers) 44.6 % (area)	86.21% (farmers) 47.38% (area)	H	H
	Share of agricultural workers who are women (%)	25.8%	27.9% (2015-16)	M	M
	Fertilizer utilization per ha	128.58 kg/ ha	128.02 kg/ha (2017-18)	M	M
	Pesticide application per ha	32.17 (2001-02)	43.67 (2011-12)	H	H
	Utilization of certified seeds, the share of total (%)	117.39 availability as % of requirement (2012-13)	86.46 availability as % of requirement (2016-17)	M	M
	Agricultural GVA per worker (constant USD 2010)	1239.991	1712.622 (2018)	L	L
	Total factor productivity (TFP)	121 (index)	140 (2016)	M	M
	Digitization				
	Share of youth in rural employment (%)	17.99	12.46 (2018)	L	L
Downstream	**Development**				
	Existence of laws and policies on food safety and traceability	Yes	Yes	M	M
	Infrastructure score in Global Competitiveness Index	3.5 (1-7) rank 86	68.1 (2019) rank 70	L	L
	Logistics performance index	3.12	3.18 (2018)	L	L
	Rural road density (km per sq km)	0.03km/ sq.km (2010-11)	0.041 km/ sq.km (2015-16)	L	L
	Stocks-to-production ratio, milled rice equivalent	0.213	0.181 (2017)	M	L
	Digitization				
	Existence of law and policy on e-commerce	Yes	Yes	L	L
	Share of e-Commerce in retail sales	ND	ND	L	L
Enabling Factors	**Development**				
	Existence of law and policy for agricultural S&T	Yes	Yes	L	L
	Share of public sector budget for agriculture in total (%)	2.34%	5.08% (2020)	L	L
	The government budget for agriculture, per agricultural worker (USD)	ND	ND	L	L

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	Indicator	2010	Latest	Rating (2010)	Rating (latest)
Enabling Factors	Government budget for agricultural R&D, ratio to agricultural GVA (%)	0.49%	0.40 % (2018-19)	L	L
	Literacy rate (working age population)	69.3 (2011)	69.3 (2011)	M	M
	Average years of schooling (working age population)	5.4 (HDI)	6.5 (2018)	L	L
	Prevalence of undernourishment	ND	ND	L	L
	Food Security Index (GFSI)	45.0 (66 rank) 2012	58.9 (72 rank) 2019	M	M
	Digitization				
	Existence of laws and policies for the digitization of agriculture and related sectors	Yes	Yes	L	L
	Existence of law and policy promoting eGovernance	Yes	Yes	L	L
	Existence of IT-based Disaster Risk Reduction and Management systems and early warning	Yes	Yes	L	L
	The government budget for the digitization of agriculture (USD)	ND	Yes	L	L
	Smartphone penetration ratio: total and rural	ND	ND	L	H
	Internet penetration ratio: total and rural	ND	ND	L	H
	Share of primary and secondary schools with access to the Internet (%)	ND	ND	L	L
	Share of STEM graduates among college graduates (%)	ND	ND	M	M

Rating: H, High or Existing; M, Medium; L, Low or non-existent; ND, no data available.

TABLE 15

SUMMARY OF SAT READINESS INDEX.

Indicators	No of Indices					
	Ratings 2010			Ratings Latest		
	High	Medium	Low	High	Medium	Low
Upstream	1	4	2	3	2	2
Production	3	9	4	4	9	3
Downstream	0	2	5	0	1	6
Enabling factors	0	3	13	2	3	11

A modern technology driven processing centre for making coriander powder in Rajasthan, India, 2019

An exporter's warehouse in an e-market in Rajasthan, India, 2019

A coriander and cumin auction market in Gujarat, India (2019)

Modern agricultural commodity market in Rajasthan, India, 2019 (commodity auction process)

An agricultural market in Rajasthan, India, 2019

Coriander cleaning process using cleaning machine in an agricultural market in Rajasthan, 2019

Coriander processing in a factory in Rajasthan, India, 2019

Traditional cleaning of Isabgol (psyllium) in an agricultural market in Rajasthan, India, 2019

Conclusion

India is the largest country in the world in terms of area under arable land. More than half of the workforce in India is engaged in agriculture and allied sectors. However, the contribution of the sector towards the GDP (GVA since 2013-14) has been declining, touching around 14% in 2018-19. It means about half of India's population shares only 14% of national income and it has eventually led to a high level of unequal distribution of income. After the introduction of economic reforms and trade liberalization in 1991, the market for agricultural commodities in India has become highly volatile, forcing the farmers to stop cultivating some of the crops. The fact that the majority of smallholders operate at a bare subsistence level also severely constrains the adoption of new technologies and digitalization.

There has been a shift in policy paradigm in India from production targets to income targets, by ensuring a fair price and improving post-production technologies. The basic component of the renewed policy package is: (i) digitalization of the trading process, (ii) promotion of online trading, (iii) Uber-ization of agricultural commodities, (iv) setting up of e-markets with infrastructural facilities for specialized markets, (v) formation of committees for specialized markets at important agricultural production centers.

An analysis of different indicators for assessing readiness for SAT in India reveals that more than 50% of the essential components of Readiness Indicators for SAT are much below the desired level. Besides, 25% of the essential indicators are either non-existent or data for assessment is not available in the public domain. Broadly, it indicates that agricultural transformation and digitalization need to go deeper and wider for both production and marketing. Recent reforms in agriculture and allied activities in India, particularly after the implementation of the Dalwai Committee Report, have focussed more on post-harvest issues rather than production. Major stakeholders of agricultural transformation, particularly smallholders and agricultural laborers, small traders, and marketing agents need to be adequately equipped to adopt technological changes and digitalization. This will be the primary step towards transforming agriculture in India.

Recommendations

- A SWOT analysis of major policy initiatives, programs, and schemes for agriculture and allied sectors should be done with the active participation of farmers and other stakeholders. The inputs from the SWOT analysis of SAT may be used for strengthening the program.

- It is important to have a critical and constructive review of e-NAM and eAgriculture in India. Also, clearly defined and replicable indicators should be developed for review of existing enabling factors for e-enabled production, exchange, and distribution. Such programs and schemes must be subjected to detailed scrutiny by major stakeholders before they are implemented. Based on the critical assessment of the programs, India should decide to go ahead and prepare the country for SAT.

- The thrust on transformation in agriculture and allied sectors in India is aimed at doubling the farmers' income by ensuring a lucrative price for farm produce. A major bottleneck that holds the sector from excelling in the international market is the lack of competitiveness as compared to other major producers of crops. It can be addressed by augmenting productivity through the modernization of agricultural production and trade. Technological fatigue in production must also be overcome.

- For productivity enhancement, enabling factors need to be strengthened. In this case, primary importance needs to be given to establishing warehouses, cold storage, assurance of maximum farm gate price, and production augmenting infrastructure like roads and transport systems at affordable prices to farmers.

- SAT in India is focused more on the post-harvesting stage, marketing. The role of SAT in other aspects of the agricultural value chain like production and processing should be examined.

- A major policy initiative, e-NAM needs to further step up its process as there is resistance to its adoption from farmers and traders. The resistance is because of the predominance of small farmers in the crop production sector.

- In milk production, 80% of the trade takes place in the informal sector and a rural network of cooperatives connects the farmers. However, it is confined to the collection of milk. The production and extension of milk need to be strengthened for transformation.

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CASE ANALYSIS

INDONESIA

The agricultural sector was the second-highest among the sectors contributing to Indonesia's GDP in the third quarter of 2019. However, its growth decreased by 3.66% from the previous year. The decline in the number of farmers during the last five years, limited agricultural land, and the high cost of production are the reasons why SAT is important for the country. Smart agriculture utilizes agricultural technology to optimize the management of farming systems for more efficiency. This study aims to (i) assess the readiness of Indonesia for adopting SAT, (ii) identify national institutional arrangements and mechanisms needed to reap the benefits of smart agricultural practices, and (iii) define strategies and policy recommendations to speed up SAT in the country. This study is experimental research strengthened by a literature study that was analyzed using mixed methods. The research was conducted in Kepuh Village, Sukoharjo Regency, Central Java, in collaboration with government and private institutions. The analysis unit of this study included Village-Owned Enterprise (BUMDes) farmers and institutions. This research analyzes Indonesia's progress toward adopting Smart Agricultural Transformation and suggests an institutional strategy to ensure the sustainability of the use of advanced technology in the village. It can be used as a policy recommendation to the Ministry of Agriculture (MoA) and Ministry of Village (MoV), and as a technical reference to farmer groups, BUMDes Directors, and the village government.

Overview and Background

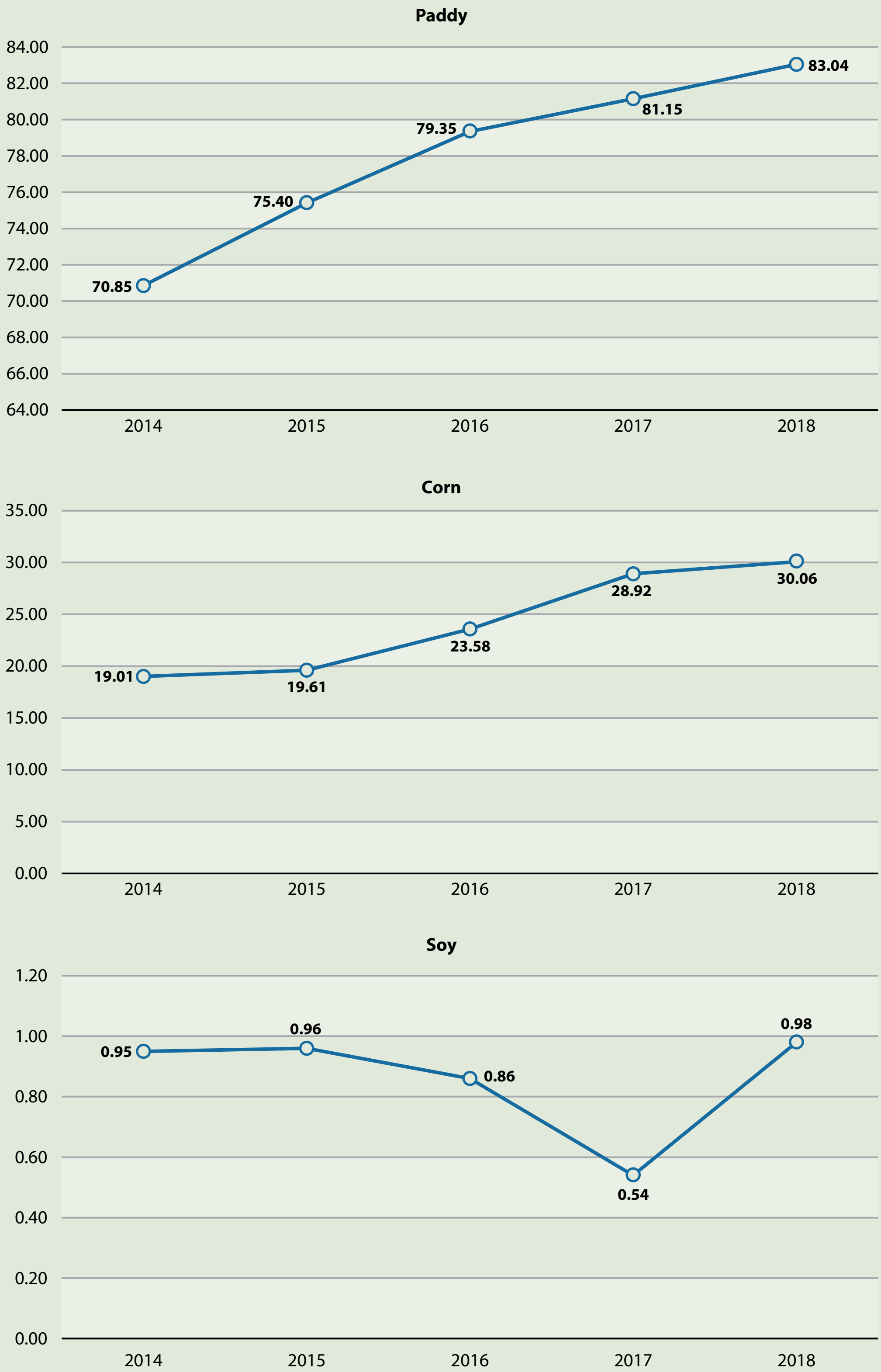
Indonesia is one of the countries included in the tropics, which has potential resources for large agriculture, including abundant germplasm, with the second largest terrestrial biodiversity in the world after Brazil. The country also has considerable land potential. The land area of Indonesia is around 191.1 million ha, divided into 43.6 million ha of wetlands and 144.5 million ha of dry land [1]. Indonesia is inhabited by nearly 260 million people, most of them living in rural areas that can potentially support agricultural development.

The agricultural sector is a mainstay of the economic drivers in Indonesia, with a contribution of 13.5% to the national GDP. Indonesia also has a target of food self-sufficiency and becoming the world food barn by 2045. The concept of a food granary is developed on the concept of food self-sufficiency. The state fulfills domestic food needs independently and sustainably and strengthens the competitiveness of the national food for export opportunities in the global market. The top three priorities are rice, corn, and soybeans. The production of strategic commodities in Indonesia is explained below in Figure 1.

Existing agricultural resources need to be utilized on an optimal basis by utilizing technological innovation. Unfortunately, not all sophisticated agricultural technologies can be adopted by farmers due to various stumbling blocks like limited capital, institutional weakness, relatively small business scale, and uneven spread of technology at the farm level.

FIGURE 1

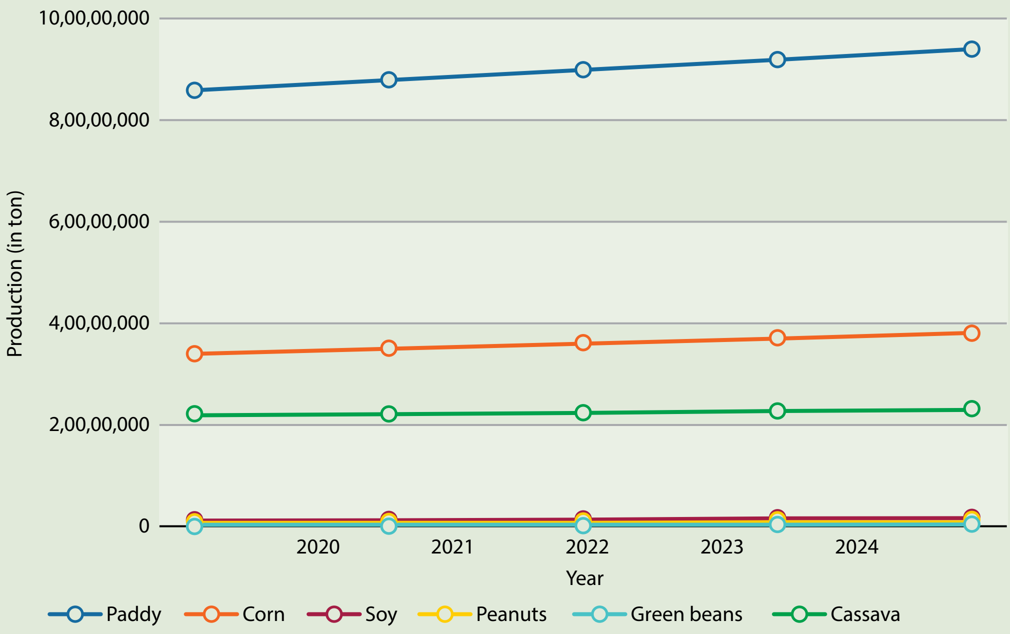
PRODUCTION OF THREE STRATEGIC INDONESIAN AGRICULTURAL COMMODITIES (IN MILLION TONNES).



Source: Ministry of Agriculture, 2018.

FIGURE 2

PRODUCTION GOALS FOR FOOD CROPS, 2020–2024.



Source: Ministry of Agriculture, 2019.

MoA has followed up on Presidential Regulation No. 91 of 2017, concerning the Acceleration of Business Implementation, by adjusting 241 Regulations and Decrees of MoA and revoking 50 of them. The Government of Indonesia carried out the deregulation and trimming of licenses to improve the agricultural investment climate. One of the significant policies is MoA Regulation No. 5 of 2019, which relates to licensing procedures for the agriculture business. As a result, investments in the agriculture sector increased by 42.94% from 2017 to 2018. The regulations also had an impact on the agricultural GDP by 27.14%, as illustrated in Table 1 below.

TABLE 1

INDICATORS OF GROSS DOMESTIC PRODUCT AND INDONESIA'S AGRICULTURAL INVESTMENT VALUE IN THE LAST FIVE YEARS (IN IDR TRILLION).

Year	GDP on Agriculture	Investment
2015	906.80	43.10
2016	936.40	45.40
2017	969.80	45.90
2018	1,005.40	61.60
2019	1,043.60	89.00

Source: Ministry of Agriculture, 2019.

The absorption of labor in the agricultural sector is among the highest as compared to other economic sectors in Indonesia, covering 33.5 million people of the total workforce employed in February 2019. However, the number of workers engaged in agriculture has been on a decline during the last five years. The country's Inter-Census Agriculture Survey (SUTAS) indicates that the number of farmer-owned households has decreased by 1% [2].

Indonesia is also experiencing the problem of aging farmers. During the last five years, the overall percentage of farmers aged 65 years and above increased from 12.75% in 2013 to 13.81% in 2018. On the other hand, the number of farmers below 35 years decreased by 337,000. Most of them (73.97%) have formal education only till elementary school. In 2018, over 82.77% of the rural population was still dependent on the agricultural sector for income and was classified as inferior. This is because most households in Indonesia cultivate on small landholdings of less than 0.5 hectares, where the input costs of seed, fertilizer, and pesticide prove expensive and lead to low profitability. This has prompted the search for innovative solutions, such as smart agricultural technology. Previous research indicates that smart agricultural technology requires qualified management to be used sustainably by farmers.

Focus and Scope of Analysis

The Government of Indonesia has been facilitating the adoption and use of smart agricultural technology through assistance schemes and grants. Even though technical guidelines and instructions enable the return of unutilized agricultural machinery tools (Alsintan), only a few types of agricultural machinery have been adopted. It then led to the hypothesis that the push for the adoption of smart agricultural technology in the villages should be accompanied by sufficient farming knowledge as well as precise and proper management. The objective of this research is:

1. To assess the readiness of selected member countries for the adoption of smart agricultural transformation or SAT.

2. To identify national institutional arrangements and mechanisms needed to reap the benefits of transforming into smart agriculture adopters.

3. To generate a set of strategies and policy recommendations to speed up SAT.

The additional objective of this research is to answer the role that BUMDes can play to bring about smart agricultural transformation in the villages in Indonesia.

This study began by describing the current conditions for the adoption of agricultural technology. It is interesting to analyze how efficient the use of agricultural technology is for farmers and how technology has been managed so far. It is important to note that though the BUMDes are still being set up and they are yet to determine their business units, they should be empowered to support the economy of farmers in the village. The study also made efforts to understand the perceptions of each actor in the village and map the relationship between actors in using and managing agricultural technology. Based on the findings, a strategy for managing intelligent agricultural technology was developed through BUMDes.

Analysis of the Current Situation

Agricultural Regulation

Law Number 22 of 2019 on Sustainable Agriculture Cultivation Systems is a new Law that revokes and replaces Law Number 12 of 1992 related to Plant Cultivation Systems. Sustainable Agriculture

Cultivation System is the management of biological natural resources in producing agricultural commodities to meet human needs better and sustainably, by preserving the environment. The aim is to increase and expand the diversification of agricultural products, to meet the needs of food, clothing, housing, health, domestic industries, and increase exports, increase farmers' income and living standards, and encourage the expansion and equitable distribution of business opportunities and employment opportunities.

Sustainable Agriculture Cultivation System (see Appendix 1) in principle, is a paradigm of management of agriculture, that integrates four elements, namely environmental, social, cultural, and economic aspects so that the benefits of agriculture can be enjoyed for a long time. A sustainable agriculture cultivation system is carried out by taking into account the carrying capacity of ecosystems, mitigation, and adaptation to climate change, as well as environmental sustainability, to realize an advanced, efficient, resilient, and sustainable agriculture system. Implementation of agricultural cultivation can be carried out through extensification, intensification, and diversification, by considering climate change that is inseparable in the framework of the overall agribusiness system at different stages, namely (1) land use and/or other planting media, (2) seedlings, (3) planting, (4) removal and entry of plant seeds, (5) utilization of water, (6) protection and maintenance of agriculture, (7) harvest, and (8) postharvest.

Agriculture Development Program by Related Ministries

Ministry of Communications and Informatics (MCI)

Integrated Broadband Village (DBT)

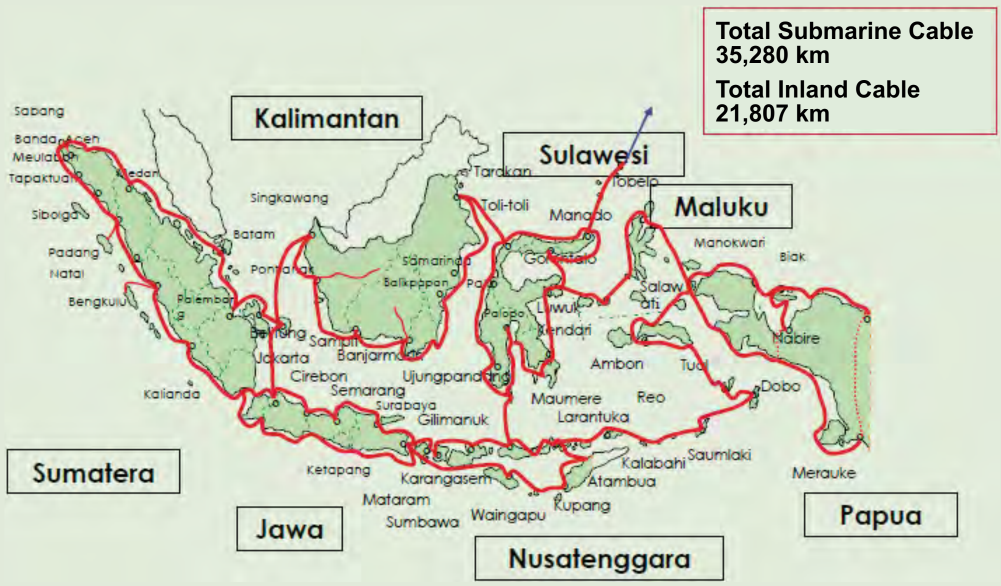
The survey by the Indonesian Internet Service Users Association [3] shows that out of the 264.16 million population, 171 million people use the Internet in Indonesia, a massive increase since 2010 when the Internet penetration number was only 50 million. This shows a threefold increase in ICT penetration in less than a decade. However, the spread of Internet access has not been evenly distributed, especially in disadvantaged areas. The digital divide is defined as the gap between individuals, households, businesses, and geographical areas at different socio-economic levels related to their opportunities to access ICTs and their use for various activities [4]. MCI inaugurated the DBT development program in several locations by the Regulation of the Head of the National Border Management Agency No. 1 of 2015.

IBV is equipped with Internet access, end devices, and applications tailored to the conditions of the rural population to empower village potential. It not only focuses on providing technology and information infrastructure but has the provision of technology and information ecosystems to improve the competency of human resources. The program is specifically designed for farming, fishing, and 3T villages (lagging, outermost, and outermost). While the pilot project was started in 2015 across 50 villages, an initiative was also taken in 2016 to test the mobile-based application in three villages namely Meskom Village (Riau), Fatukbot Village (NTT), and Panca Karsa I Village (Gorontalo). In 2019 there were already 225 DBT and 20 champions of BUMDes as well as Joint Village-owned Enterprises (see Appendix 2).

The Palapa Ring Project is the first Public Private Partnership (PPP) project in the telecommunications sector that implemented a service availability payment scheme. This scheme was initiated by the Ministry of Finance and funds were sourced from the Universal Service Obligation (USO) contribution fund. The project is expected to serve as the backbone of the national telecommunications system that connects all districts and cities in Indonesia. Besides bringing in equity and providing information technology access to service providers for national

FIGURE 3

PALAPA RING PROJECT.



Source: Ministry of Communication and Informatics, 2020.

security, the Palapa Ring Project is also expected to spur economic growth. Overall, 91% of the total 6,878 kilometers of optical fiber are so far connected. Meanwhile, the implementation of the 2,275-km West Palapa Ring and the 2,995-km Middle Palapa Ring has been completed last year, while the work for rolling out the Palapa Ring Timur project is being pursued.

It is projected that the available supporting infrastructure will enable the Internet speed to reach 10 Mbps in rural areas and 20 Mbps in urban areas. This will help the villagers use the Internet for better utilization of appropriate technologies and to sell agricultural products. Market access will be wide open, thereby increasing the welfare of rural communities.

Ministry of Agriculture

The Development of Asian 4.0

The level of agricultural mechanization in Indonesia increased from 0.14% in 2014 to 1.68% in 2019. The Ministry of Agriculture, through the Agency for Agricultural Research and Development (Balitbangtan), began research and engineering related to Alsintan technology based on IoT, cyber-physical systems, and management information systems in 2018. Several advanced Alsintan, prepared by the Central Mechanization of Agriculture, the Ministry of Agriculture, are ready to be used by farmers soon [5]. These include the following.

Seed Dispersing Drone: Seed dispersing drones can sow seeds in one hectare of land in an hour, with the existing capacity of sowing 50-60 kg seeds per hectare. These seed-dispersing drones can work independently by following the patterns or paths created using an Android device and guided by the GPS. These drones can carry out the operations automatically, such that delayed operations can be resumed without overlap. It can operate for 20 minutes with a maximum carrying capacity of 6 kg of rice seeds, with each hectare of land requiring around 25 kg of seeds.

Rice Planting Robot: The rice planting robot (Rotap) can be used to plant rice seeds in paddy fields with a communication system using the IoT and GPS. The other advantage of Rotap is that it can work independently, without a need for operator assistance. A Rotap can have specifications like a 30 cm planting width, six rows of planting, and a 2 km per hour working speed. This robot, with a width of 1.8 m, has a working capacity of 0.36 ha per hour.

Autonomous Tractor: The unmanned tractor is a 4.0 generation Alsintan being developed since 2018. This tool is an unmanned four-wheeled tractor that can be controlled by an Internet-of-Things navigation system (IoT). The autonomous tractor can help in land management by following the planning map and can move as per the instructions from the user with the help of GPS.

Integrated Rice Harvesting Machine Tool: The tool can do harvesting and tillage together in one operational process. The technology has been developed based on the previously used combine harvester, which is capable of planting rice saplings, separating the grains of rice from their stems, and packaging them in sacks. The latest generation of the combine harvester, however, is equipped with a land processor using a rotary engine.

Compared to conventional equipment, the Integrated Rice Harvesting Machine Tool can improve worktime efficiency by 51% to 82%, while the cost efficiencies range between 30% and 75%. The efficiency of Alsintan is visible in its usage; a reduction in harvesting time from 320-400 hours per hectare to 4-6 hours per hectare. Hence, the machine is 97.4% more efficient and saves work costs by up to 40%, bringing it down to IDR1.2 million per hectare compared to the previous IDR2 million per hectare. The use of Alsintan also affects the allocation of labor, which further saves costs. Based on tests conducted by the MoA, mechanization can reduce production costs in Indonesia by around 30% and increase land productivity by 33.83%.

Kostratani

The formation of the Strategic Command for Agricultural Development (Kostratani), which was initiated by the Minister of Agriculture in 2019, is expected to be one of the revivals of the extension agents for assisting farmers during farming. It is the center of agricultural development activities at the sub-district level, which optimizes the duties, functions, and roles of the Agricultural Extension Center by utilizing information technology for understanding national food sovereignty. Kostratani is an agricultural extension center equipped with information technology 4.0. There is a growth in the number of millennial farmer entrepreneurs. The guidance for KUR or Micro Credit Program is the main capital that is driving the people's economy, the agricultural sector. Kostratani has also been designed to serve as a network center so that in the future, farmers' associations can become business associations that can plan to plant, process, and market agricultural produce together.

Agricultural Extension Center (BPP) in the region cooperates with other agencies, non-commissioned village supervisors (Babinsa), members of the police appointed as supervisors of security and public order (Babinkamtibmas), and the Ministry of Villages through the Village Facilitator. Kostratani provided 100 packages consisting of a computer, handphone, LED TV, and drone to 100 districts across Indonesia. The IBV program initiated by the MCI also supports the rolling out of Kostratani in Indonesia by ensuring the provision of the Internet in the village. The following steps need to be taken to strengthen the BPP as a Kostratani Command Post.

1. Procurement of infrastructures, such as computer networks, Internet networks, drones, and LCDs.

2. Strengthening institutions such as village agricultural extension post (Posluhdes) and Farmer's Economics Institution.

3. Improvement of agricultural human resources such as admin and IT, as well as extension workers and other functional officers.

4. Improving operations, such as strengthening data and information, agribusiness services, and strengthening brigades.

Agriculture War Room

Currently, an Agriculture War Room (AWR) is being built at the MoA's Headquarters, which will serve as the center for agricultural development control.

FIGURE 4

SOFT LAUNCH OF THE AGRICULTURE WAR ROOM.

Source: Sasongko, 2020.

The AWR will enable the Minister and officials of the MoA to monitor and communicate with extension workers, officers, and officials who handle Kostratani at all levels. It will also help access the data on planting area, crop condition, and harvest area on a real-time basis. The AWR uses six Android-based applications to collect data. These include (1) e-Reporting District, (2) e-Reporting Province, (3) e-Reporting Instructor, (4) e-Reporting OPT-DPI Officer, (5) e-Reporting OPT-DPI Public, and (6) Farm Price-Officer [6]. That data can be recorded at any time using the drones available at each Kostratani. The general public can also access information related to the development of each Kostratani through the Agricultural Counseling System.

Ministry of Villages, Disadvantaged Regions, and Transmigration

Directorate General of Development of Disadvantaged Regions (PDT)

Smart Farming 4.0: Digitalization of agrotechnology-based governance and land use is needed as a framework for the economic development of the community, especially in disadvantaged areas. Taking this forward, the PDT through the Directorate of Development of Resources and the Environment has made a paradigm shift in the development and utilization of land, from the conventional method to a technology-based approach. To support the digitalization of governance and technology-based land use, the government has begun providing Internet access in villages by setting up base transceiver stations there. The initiative has been taken under the MCI program.

Smart farming utilizes technology for input efficiency, time effectiveness, and measurable data, to increase agricultural production with improved quality. PDT 2018 introduced the concept of Smart Farming 4.0 in collaboration with PT Mitra Sejahtera Membangun Bangsa (MSMB). It mainly uses four technologies including an agri-drone sprayer, drone surveillance, soil and weather sensor, and water debit sensor.

TABLE 2

PDT'S SMART FARMING ACTIVITIES IN 2018.

Region	Date	Activity
Sleman	3 September 2018	• Drone sprayer trials conducted on a cornfield
Wonogiri	3 September 2018	• Review of soil and weather sensors in the area
Sumbawa	9 September 2018	• Samota Maritime Expo in Sail Moyo Tambora • Drone sprayer and soil and weather sensor testing in the rice fields
Sumbawa Timur	10 September 2018	• Testing of the drone sprayer, soil, and weather sensor in the rice fields
Situbondo	24 September 2018	• Launch of Smart Farming 4.0
Badung	18 October 2018	• Appropriate Technology Exhibition
Tabanan	22 October 2018	• Testing of drone sprayer, drone surveillance, soil and weather sensor, and water debit sensor

Source: Ditjen PDT, 2019.

In 2019, PDT promoted and facilitated the digitalization of technology-based governance and land use through the concept of Smart Farming in eight underdeveloped districts of Alor Regency, Pasaman Barat Regency, West Sumbawa Regency, Central Sumbawa Regency, Buol Regency, North Gorontalo Regency, West Nias Regency, and Bima Regency. Situbondo Regency was chosen as one of the pilot projects because it has great agricultural potential, with large tracts of land. The pilot project was carried out on 250 hectares of land, with the support of a unit of soil and weather sensors. Following the success of the pilot project, PT MSMB along with Bank Negara Indonesia (BNI) continued further with the model to develop precision agriculture in Situbondo and to roll out Agriculture 4.0. The Movement to Welcome Agriculture 4.0 in Situbondo Regency was the fourth activity that was carried out in the region. It was previously held at Garut, West Pasaman, and Sukabumi Regencies.

The use of the Smart Farming 4.0 method goes beyond the application of technology and includes measurable data. Drone sprayers, for example, are used to spray fertilizers and pesticides with more precision to ensure that excess plant nutrients or antibiotics are not given. The results of mapping from drone surveillance are used by farmers to find out the condition of plants on their land. The data obtained from soil and weather sensors are also capable of measuring air and soil moisture, temperature, soil pH, water content, and estimated harvest time. If integrated with Android, a warning will be given if there are changes in the land conditions, and recommendations for handling will be provided[1].

Directorate of Rural Economic Business Development (PUED)

Village-owned Enterprises (BUMDes)

According to Law 6/2014, "BUMDes is a business entity that entire or most of the capital is owned by the village through direct participation from village assets that are separated to manage assets, services, and other businesses for the maximum welfare of the village community". The establishment of BUMDes is adjusted to the abilities, needs, and local conditions of the village. Hence it must be oriented to the following:

i. Joint ownership (village and community government) to encourage economic independence of the village and improve the welfare of the community through its participation in carrying out economic activities and enjoying the results of these economic activities.

ii. Move beyond financial benefits such as taxes and Village Original Income to provide broad economic benefits such as employment and a sustainable economy.

iii. Providing services and organizing public benefits for rural communities.

BUMDes capital investment does not have to originate from the transfer of Village Funds but is allocated through the Village Budget (APBDes). Besides, BUMDes business can be set up in the form of a social business, brokering, trading, financial business, and holdings. Businesses can provide agricultural technology on a rental basis to villages in the national rice barn area. So far, the rentals at BUMDes are limited to transportation equipment, tractors, party equipment, buildings, and village-owned land.

Around 61% of the total villages throughout Indonesia already had BUMDes by 2019. However, of the 46,000 BUMDes, very few had businesses in the agricultural sector. This study tries to calculate the number of agricultural BUMDes in the ten national rice barn provinces namely East Java, Central Java, West Java, South Sulawesi, South Sumatra, Lampung, North Sumatra, Banten, Yogyakarta Special Region, and West Nusa Tenggara. Overall, there are 1,971 BUMDes across these ten locations, with different business types in the agricultural sector. However, only 5.28% of these, or 104 BUMDes operate rental business units [7].

MoV Research and Development Center

Experimental Research Drone Sprayer in Kepuh Village, Sukoharjo

To analyze the gap in the preparation for the transformation of smart agriculture in Indonesia, especially in villages, the writer, as a researcher from the Research and Development Center of the Ministry of Villages, conducted experimental research. The location was purposefully chosen in Kepuh Village, Sukoharjo Regency in Central Java because it is the second largest national rice barn, after East Java and Sukoharjo Regency. With 53% of agricultural land, the Regency serves as a food buffer district in

[1] Details of the technical specifications, data collection, transmitting mechanism, and output received by the farmers are clearly explained in the video on the website https://msmbindonesia.com/.

Central Java. Since the New Order era, agricultural technology has been introduced to farmers in Sukoharjo, which has slowly changed the pattern of agriculture in the region.

FIGURE 5

AREA OF AGRICULTURAL LAND IN SUKOHARJO REGENCY.

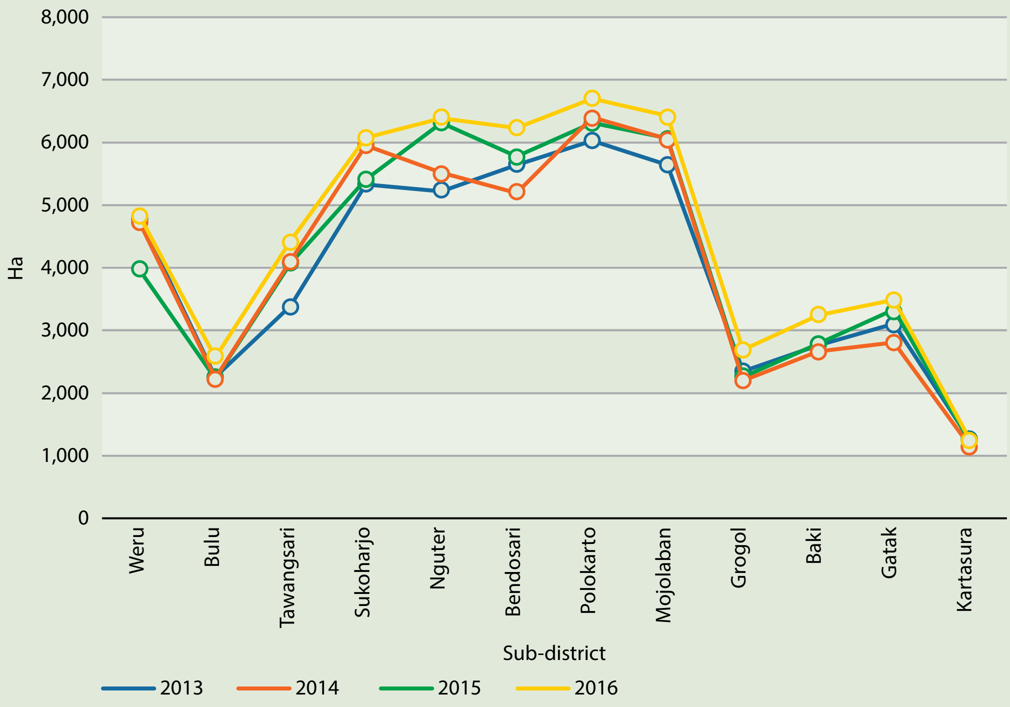


Figure 5 indicates that the agricultural use of land in Sukoharjo Regency has been increasing over the years. However, the growth in agricultural land usage is not accompanied by an increase in the number of workers. Data from the Sukoharjo Regency (2015) shows that of the total workforce of 79,543 in the region, only 299 people worked in the agriculture, animal husbandry, forestry, hunting, and fishery sectors. To ensure that Sukoharjo Regency continues to serve as one of the mainstays of rice producers in the province, and nationally, the region needs to use intelligent agricultural technologies and maintain its rice production levels.

In the village of Kepuh, trials were conducted on a one-hectare rice field to test the spraying of fertilizers using a drone sprayer. The trial was conducted by the Research and Development Center in MoV, the Institute of Aviation and Space (LAPAN),[2] and its collaborator AeroTerraScan[3]. Spraying of liquid fertilizer was done four times during the early months of August to mid-October 2019 and the harvest was carried out on 30 October 2019.

The unit of analysis in this study is farmers and BUMDes. The data used in this study consists of primary and secondary data. Primary data was collected through field trials, observations, and interviews with the Kepuh Village Head. Secondary data, in the form of documents related to the research substance, was collected from Statistics Indonesia (BPS), the Ministry of Agriculture website, Village Profiles, and other related scientific references, including electronic media. The

[2] More information about the institution can be accessed at https://www.lapan.go.id/.
[3] More information about the company can be accessed at https://www.aeroterrascan.com/.

FIGURE 6

GENERAL DESCRIPTION OF KEPUH VILLAGE.

Land Area of Kepuh Village
Kepuh Village in Nguter District has an area of **+ 395,3 ha** with 169.7 ha of paddy land and 225.6 ha of dry land.

Geographical Location
The distance of Kepuh Village from the center of the District is +3 km, while the distance of the Village Kepuh from the center of the Regency +6 km.

Village Cash Land
Kepuh Village Cash Land (2015) included 103 fields comprising a total area of + 29.25 ha.

Source: Primary data, 2019.

data obtained were processed using a mixed approach and analyzed by concurrent embedded. The quantitative approach was carried out with descriptive statistics, to calculate the efficiency of using intelligent agricultural technology, by comparing conventional production costs, i.e., fertilizing rice fields with farmer labor and using a drone sprayer.

FIGURE 7

TESTING OF 20L DRONE SPRAYER FROM AEROTERRASCAN.

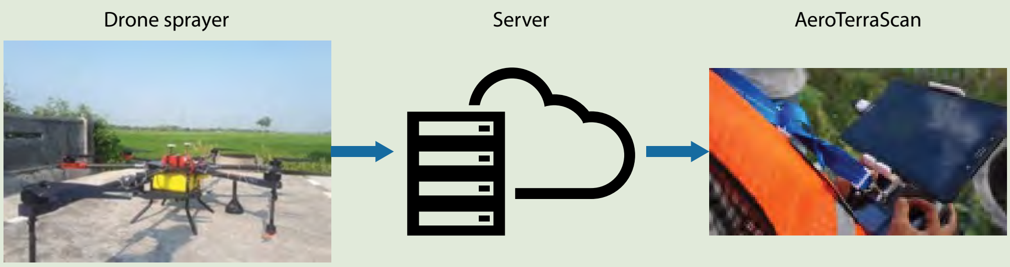


FIGURE 8

DURATION OF SPRAYING FERTILIZER IN 1 HA RICE FIELD.

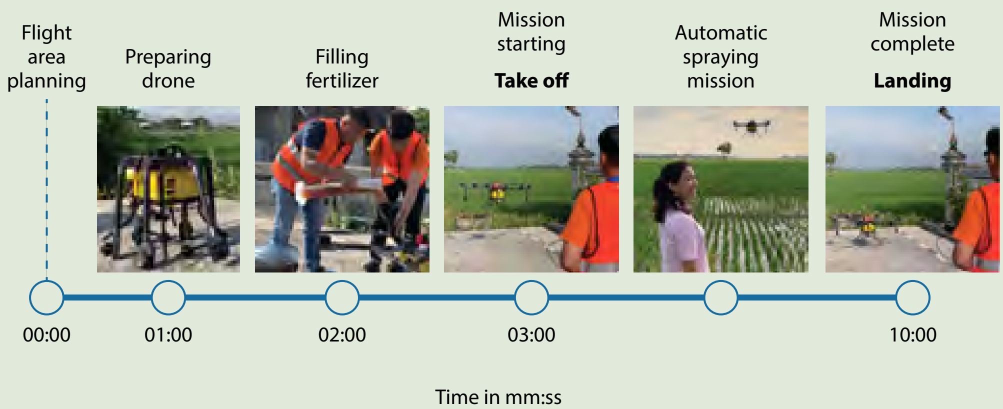


FIGURE 9

PROGRESS OF RICE GROWTH AFTER SPRAYING FERTILIZER USING DRONE.


Spraying 2


Spraying 3


Spraying 4

Figure 9 illustrates that the yellow indicator installed in the paddy field checks that spraying has been done evenly by the liquid fertilizer particles attached to it. Conventionally, farmers usually consider the range of spraying fertilizer with a feeling, this is, at the same time, entertaining to farmers, that the automation of the drone sprayer can reduce the possibility of overlapping fertilization, as compared to backpack sprayers. The results of the test were very encouraging with a yield of 116 bags of unhusked rice of 67 kg each.

FIGURE 10

COMPARISON OF BACKPACK VS. DRONE SPRAYER EFFICIENCY.

Backpack		Drone Sprayer
12L (water + liquid organic fertilizer)	**Tank capacity**	10L (water + liquid organic fertilizer)
1L Fertilizer mix with 120L water	**Dosage**	1L Fertilizer mix with 60L water
14 Tanks (168 Liter) for 1 HA	**Total use**	**2 Tanks** (20 Liter) for 1 HA
1 HA = **1–2 Days**	**Spraying time**	1 HA = **12–15 Minutes** Flight
Farmer **USD 7**/day/person Liquid fertilizer **USD 7.4**	**Cost**	**No farmer needed** Liquid fertilizer **USD 1.63**

Figure 10 explains that the use of a drone sprayer is more effective in terms of the time spent on spraying the fertilizer and more efficient in terms of the quantity of liquid fertilizer used. As compared to backpack sprayers that may require one full day of work by 1-2 farmers to spray fertilizers in a one-hectare paddy field, the drone sprayer can do the same work with one operator in 12 minutes.

Readiness Assessment and Gap Analysis

Digital transformation of agriculture requires readiness for transformation such as institutional, governance, and political environment. It also requires high-quality national agricultural development plans or strategies and good implementation to translate plans into impacts on the ground. The focus of SAT is to promote the application of advanced technologies, especially digital technologies, in agricultural operations, sustainable management of resources, identification of climate change-resistant agriculture models, and value-added agriculture.

Level of Readiness Towards Smart Agricultural Transformation

(Rating: H, High or Existing; M, Medium; L, Low or non-existent; ND, no data available). Note that wherever data is not available, the author has used expert judgment in assigning ratings.

TABLE 3

SAT READINESS ASSESSMENT FOR UPSTREAM LEVEL.

INDICATOR	2010	Currently
	Development	
Existence of the laws and policies on agricultural finance	**M** Regulation of The Minister of Finance and Minister of Agriculture Number 416/ Kpts/ HK.060/ 6/ 2006 and Number 47/ PMK.02/ 2006 concerning Fund Management for Development of Agricultural Financing Services Scheme	**H** Minister of Agriculture Regulation No. 12 of 2020 concerning Facilitation of People's Business Credit in the Agricultural Sector
Agricultural insurance penetration ratio	**ND** The Agricultural Insurance Program has formally commenced since the issuance of Law No. 19 of 2013 concerning Farmer Protection and Empowerment	**L** In 2019, only 39% of the land area covered with the realization claims paid IDR10.94 billion from the total premium of IDR70.67 billion
Share of borrowing smallholders and fishers who borrow from formal sources (%)	**M** Total agriculture sector credit in 2009 was only 26.6% of the total realization of People's Business Credit distribution with 613,780 debtors [8]	**H** The realization of agriculture KUR 2020 until the end of May reached IDR18 trillion with 669,598 debtors [9]
Technician-to-farmer ratio: public; private	**ND**	**ND**
The proportion of agricultural land that is irrigated (%)	**M** 61.25%[4]	**M** 70.3%[5]
	Digitization	
Share of extension personnel who are computer-literate (%): public and private	**ND**	**L**
Existence of IT-based agricultural insurance products (e.g., remote sensing)	**ND**	**L**

[4] The Agricultural Crop Statistics Report, Statistics Indonesia, 2011 shows that the area of irrigated rice fields is 4.9 million hectares out of a total of 8 million hectares of land.

[5] The government-verified Sustainable Food Agriculture Land in October 2019 reached 5 million hectares from a total of 7.1 million hectares of paddy fields.

The Agricultural Financing Services Scheme (SP-3) is an agricultural financing scheme, to encourage financing or credit in micro and small-scale agricultural enterprises by implementing banks, providing guaranteed service facilities, and for credit risk. SP-3 is 60-80% allocated to guarantee facilities of micro-businesses and 20-40% for small businesses. SP-3 is conducted through the Executing Bank with Executing Pattern, namely, direct financing from the Executing Bank to Farmers or Farmer Groups, with the decision to extend credit to the Executing Bank. Implementation of the SP-3 program through banking, with banking provisions, continued to be difficult for farmers to access because banks require collateral, which is usually difficult for farmers to provide. But the idea continued with a People's Business Credit (KUR), which was disbursed by the President of Indonesia on 5 November 2007. The agricultural finance was carried out by the Directorate of Agricultural Financing towards the Minister of Agriculture Regulation No. 61/ Permentan/ OT.140/ 10/ 2010. Overall, it had four main activities[6].

1. Optimizing lending in the form of Food and Energy Security Credit (KKP-E), Bio Energy Development Credit and Agricultural Revitalization (KPEN-RP), Cattle Breeding Business Credit (KUPS), and People's Business Credit (KUR).

2. Facilitating farmer financing through direct community support to farmer groups (Gapoktan) and Rural Agribusiness Development (PUAP).

3. Growth and development of Agribusiness Microfinance Institutions (MFIs).

4. Compilation of agricultural insurance policies and cooperation with Islamic Financial Institutions.

The agricultural credit scheme also needs to be improved by developing farmers' institutions as channeling agents. In 2020, the financing aspect focused on protecting farming through agricultural insurance, People's Business Credit (KUR), and the initiation of an agricultural bank. The MoA targets agriculture sector financing, absorbed through the KUR scheme, to reach IDR50 trillion, almost double the realization of the KUR agriculture sector in the previous year [10].

Laws relating to agricultural insurance are followed up with Regulation of the Minister of Agriculture (Permentan) No. 40 of 2015, concerning Agricultural Insurance Facilitation to provide a sense of security and prevent losses in the event of drought, flood, or crop failure. The Government of Indonesia has also subsidized agricultural insurance with a claim of IDR6,000,000/HA/ MT. Insurance premiums are set at IDR180,000/Ha/ MT with the government paying IDR144,000 and farmers contributing IDR36,000[7] towards it.

TABLE 4

REALIZATION OF RICE FARMING BUSINESS INSURANCE FOR THE LAST FIVE YEARS.

Components	2015	2016	2017	2018	2019
Number of farmers (people)	401,408	929,945	1,550,389	1,446,399	676,455
Land area (from target 1,000,000 HA)	233,499	518,507	997,961	901,421	392,649

(Continued on next page)

[6] Strategic Planning Document (RENSTRA) of Directorate of Agricultural Finance, Directorate General of Facilities and Infrastructure, Ministry of Agriculture 2010-2014.
[7] Minister of Agriculture Decree Number: 30/ Kpts/ SR.210/ B/ 12/ 2018 about Guidelines on Rice Farming Premiums Assistance.

(Continued from the previous page)

Components	2015	2016	2017	2018	2019
Premium	IDR42 billion	IDR93.33 billion	IDR179.63 billion	IDR161.73 billion	IDR70.67 billion
Claims paid	IDR124.8 million	IDR55.5 billion	IDR149.64 billion	IDR73.16 billion	IDR10.94 billion

Source: OJK, 2019.

The main challenge in the adoption of smart agriculture technology in villages is the availability of human resources who understand IT and can disseminate information on modern farming methods to farmers. The number of registrants for the Agricultural Development Polytechnic increased from 7,097 in 2017 to 13,111 in 2018 but the distribution of agricultural polytechnic graduates has not been even across the villages [11]. Therefore, there is an urgent need to provide vocational education in villages to boost the competitiveness of agricultural human resources.

TABLE 5

SAT READINESS ASSESSMENT FOR PRODUCTION LEVEL.

Indicator	2010	Currently
	Development	
Existence of a regulatory framework for seed	**M** Minister of Agriculture Regulation No. 70 of 2007 concerning Amendment to the Regulation of the Minister of Agriculture Number 38 / Permentan / OT.140 / 8/2006 concerning Seed Import and Export	**H** Minister of Agriculture Regulation No. 12 of 2018 concerning Production, Certification, and Circulation of Plant Seeds
Existence of a regulatory framework for agrochemicals (fertilizer and pesticide)	**M** Minister of Agriculture Regulation No. 28 of 2009 concerning Organic Fertilizers, Biofertilizers, and Land Enhancers	**H** Minister of Agriculture Regulation No. 1 of 2020 concerning the Highest Allocation and Retail Price of Subsidized Fertilizer in the Agriculture Sector
Existence of a regulatory framework on agrimachinery	**M** Minister of Agriculture Regulation No. 65 of 2006 concerning Guidelines for the Supervision of Procurement, Distribution, and Utilization of Agricultural Tools and Machinery	**H** Minister of Agriculture Decree No. 6 of 2019 concerning Technical Guidelines for Procurement and Distribution of Agricultural Equipment and Machinery Assistance for the 2019 State Budget
Utilization of farm machinery, and tractors per 100 sq km of agricultural land	ND	ND

(Continued on next page)

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Indicator	2010	Currently
Average monthly earnings in agriculture (dollars per day)	**L** USD2.68 per day (December 2010)	**L** USD3.84 per day (April 2020)
Rural employment in youth employment (%)	**M** 58.4% (Statistics Indonesia, 2010)	**M** 45.3% (Statistics Indonesia, 2019)
The average age of a farmer	**L** 52 years old (Statistics Indonesia, 2010)	**L** 27% aged 45 to 54, 21% aged 55-64, and 13% over 65 years
Average farm size (ha)	**L** <0.5 ha	**L** 0.8 ha
Share of smallholder (2 ha and below) who is owner-cultivator	**L**	**L**
Share of agricultural workers who are women (%)	**L**	**M** 24.04% (2018)
Fertilizer utilization per ha	**L** 181.5 kg	**L** 231.37 kg (The World Bank, n.d.)
Pesticide application per ha	**M**	**M**
Utilization of certified seeds, the share of total (%)	**L**	**M**
Agricultural GVA per worker	**L** USD2,463	**M** USD4,052
Agricultural Total Factor Productivity (TFP) growth	**L** 0.01%	**L** 0.01%
Digitization		
Share of youth in rural employment (%)	**M**	**L**

Globally, Indonesia ranks 95 among 173 countries in terms of agricultural GVA per worker and 37 out of 162 countries in fertilizer utilization per hectare [12]. In Indonesia, pesticides play a major role in saving agricultural production from pest and plant diseases, especially when reaching the control threshold. However, pesticides also lead to risks and concerns about human safety and the environment. Hence, the government is obliged to regulate permits, distribution, and the use of pesticides more responsibly. The use of fake and illegal pesticides also complicates the export of agricultural products because destination countries are concerned about the maximum residue limit (MRL). The government enacted Minister of Agriculture Regulation No. 43 of 2019, concerning the Registration of Pesticides, to refine the previous rules, especially on the procedure for application set by the director general and the extension of the trial permit.

Other than regulations relating to the protection of agricultural land, the government also encourages the application of technology in farming. Providing agricultural equipment and machinery was one of the priorities in 2019. It aimed to increase agricultural production as well as farmers' welfare. The assistance included the facilitation of two-wheeled tractors, water pumps, four-wheeled tractors, cultivators, and excavators.

Facilitation and utilization of assistance, through the Department of Agriculture, are based on the specific needs of the location in each region. The central government and the province consider several criteria before providing aid.

1. Prioritization of the production centers of food crops, horticultural, plantation, and livestock.

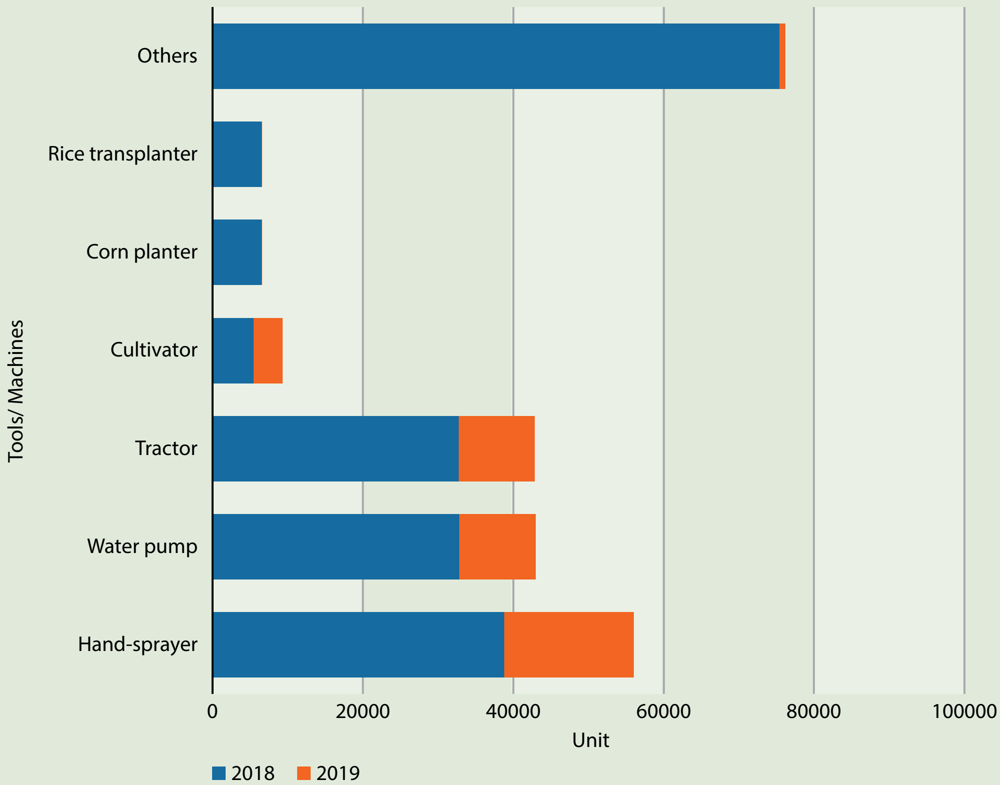
2. The needs of specific Alsintan and local conditions that technically meet the requirements for the operation of agricultural machinery and equipment.

3. The level of commitment to support increased agricultural production programs.

A comparison of the realization of the distribution of agricultural equipment and machinery in the 2018 and 2019 fiscal years can be seen below.

FIGURE 11

NUMBER OF ALSINTAN DISTRIBUTED IN 2018 AND 2019.



Source: Ministry of Agriculture, 2019.

Decreasing the agricultural budget has resulted in a reduction in the number of agricultural tools and machinery distributed. In 2019, the budget for Alsintan was only IDR771 billion, which decreased dramatically from IDR2.85 trillion in the previous year. The ratio of agricultural equipment and machinery also decreased from 6.6 per village in 2018 to 3.16 in 2019.

Data from the Agricultural Extension and Human Resources Development Agency, Ministry of Agriculture, states that 90% of the total number of farmers in Indonesia have entered the less productive phase.

"Currently, there are 33.4 million farmers in Indonesia, whom 2.7 million farmers are millennial and 30.4 million are colonial." - Chairman of the Youth Farmer from The Indonesian Farmers Association (HKTI), Rina Saadah Adisurya.

The current urbanization also descends young people migrating to urban areas. Amenities that relatively accompany urban completion are progress education, diversity of employment, and access to technology, which attract youth. Urbanization has become the locomotive of towing the country's growth. Not surprisingly, more than half of the youth in Indonesia live in cities (57.94%). The percentage of rural youth who work is higher as compared to urban youth, 54.61%, and 53.36%, respectively. This is one of the consequences of lower educational attainment in the countryside. The low average length of the school and high dropout rates in rural areas automatically encourages rural youth to come into the job market early.

Statistics Indonesia also shows that in rural areas only around 4% of young people aged 15-23 are interested in taking up farming. The rest chose to work in the industrial sector, the small-medium industrial sector, or the urban informal sector because they were seen as having more potential to guarantee future welfare. Overall, there are less than three million young farmers in Indonesia, even as the agricultural land area has expanded to 7.78 million hectares [13]. Therefore, involving the younger generation is key and modern agriculture is the solution to attracting young people to get involved in agriculture-related business.

According to the business field, youth who work in the manufacturing sector, including the mining, industrial, electricity, construction sectors, and services have the highest average working hours, 43 hours a week, which is higher than the agricultural sector with an average of 31 working hours per week.

TABLE 6

SAT READINESS ASSESSMENT FOR DOWNSTREAM LEVEL.

Indicator	2010	Currently
	Development	
Existence of the laws and policies on food safety, traceability	**M** Minister of Agriculture Regulation Number 20 of 2010 concerning the Quality Guarantee System of Farm Products	**H**
Infrastructure score in Global Competitiveness Index	**L**	**M**
Logistics performance index	**M** 2.76	**H** 3.15 (2018)

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Indicator	2010	Currently
Rural road density (km per sq km)	**L** 25.6 km per 100 sq. km land area	**M**
Stocks-to-production ratio, milled rice equivalent	**L**	**M**
Digitization		
Existence of the laws and policies on e-commerce	ND	**M**
Share of e-commerce in retail sales	**L**	**H**

In the Global Competitive Index 2019, Indonesia stands at 50th position among 141 countries in the world, down five ranks from the earlier position. According to the World Economic Forum report of 2019, the three main factors that led to the decline of Indonesia's ranking include, the adoption of information and communication technology, health, and the product market. Meanwhile, Indonesia's Logistic Performance Index in 2018 stood at 3.15 and the country was ranked fifth among the ASEAN countries. This is due to Indonesia's nature as an island nation that requires massive infrastructure development for connectivity.

TABLE 7

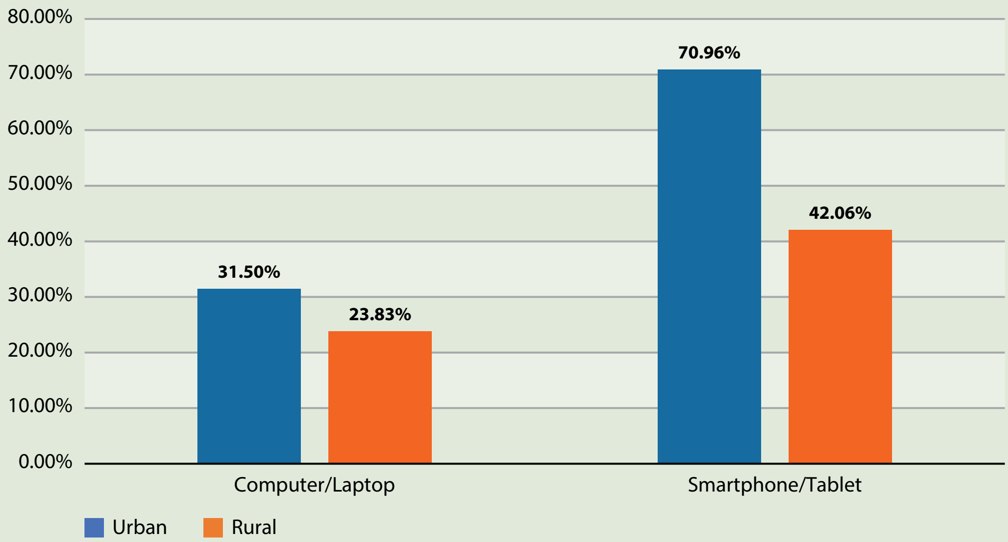
SAT READINESS ASSESSMENT FOR ENABLING FACTORS.

Indicator	2010	Currently
Development		
Existence of the laws and policies for agricultural S&T	L	M
Share of public sector budget for agriculture in total (%)	L	L
The government budget for agriculture, per agricultural worker (USD)	L	L
Government budget for agricultural R&D, ratio to agricultural GVA (%)	L	L
Literacy rate (working age population)	L	H
Average years of schooling (working age population)	L	M
Prevalence of undernourishment	H	M
Food Security Index	L	M
Digitization		
Existence of the laws and policies for the digitization of agriculture and related sectors	M	H
Existence of the laws and policies promoting e-governance	M	H
Existence of IT-based Disaster Risk Reduction and Management systems and early warning	M	H
The government budget for the digitization of agriculture (USD)	L	M
Smartphone penetration ratio: total and rural	L	H
Internet penetration ratio: total and rural	L	H
Share of primary and secondary schools with access to the Internet (%)	L	M
Share of STEM graduates among college graduates (%)	L	M

Indonesia, the fourth most populous country in the world with 70% mobile phone penetration (McKinsey Report, 2018), has the potential to be prepared to undergo SAT. One of the parameters is device ownership in the villages, as can be seen below.

FIGURE 12

DEVICE OWNERSHIP IN THE VILLAGES.



Source: APJII, 2018.

Agricultural technology assistance can reduce farmers' operational costs by 35% to 48% while increasing the value added due to fast processing and harvesting. In the present situation, agricultural equipment and machinery provided by the government are managed by the Alsintan Service Rental Business (UPJA) under Minister of Agriculture Regulation No. 25 of 2008. UPJA is positioned as a technical solution for managing narrow agricultural land, lack of farmers, and reducing the cost of agricultural production. UPJA's performance has declined because many agricultural tools and machinery were damaged and the government was unable to replace them. The performance of the use of agricultural mechanization shows problems in developing agricultural tools and machinery, namely, limited purchasing power and unorganized management. Some examples of agricultural technology cases are stalled because the village government and farmers are not able to manage them technically and materially. Therefore, this research seeks to explore aspects of sustainability and efficient utilization of intelligent agricultural technologies and the management potential of BUMDes.

From the facts and data above, it can be concluded that there are several challenges in implementing the SAT in Indonesia. First, not all areas of Indonesia have Internet access, even though technology is an essential part of agriculture transformation. Palapa Ring, a fiber-optic network development project, is expected to build a network that covers remote areas. Second, digital literacy among young people is not equal to young people's interest to become farmers. Agriculture in Indonesia is still dominated by aged farmers who find it challenging to adopt technology in farming activities. Third, SAT certainly requires sophisticated technology equipment that requires a lot of capital. Various credit schemes from banks and non-bank are difficult for small farmers to access. The

Internet's utilization through financial technology (fintech) is still burdensome for farmers because the interest tends to be high. Coordination and participation of all stakeholders are needed to overcome all challenges to achieve the SAT.

Lesson Learned and Insight from Case Analysis

Policy Recommendation

- **Literacy and Competency Building:** To ensure the sustainability of intelligent agriculture, it is necessary to increase the literacy and capacity of farmers, and also village escort. MoA has compiled an occupation map for the Indonesian agricultural sector qualification framework, in cooperation with the Ministry of Manpower, Ministry of National Development Planning, National Professional Certification Agency (BNSP), and Indonesian trade. The occupancy in the key qualification framework of agricultural technology now includes the operators of pre-farm machinery and equipment, operators of repair equipment and agricultural machinery, maintenance technicians, and manager of equipment workshops and agricultural machinery.

  In October 2019, MoA began the construction of the four-hectare Indonesian Agricultural Engineering Polytechnic (PEPI) campus in Serpong, Banten. PEPI is the first as well as only vocational education institution based on agricultural engineering in Indonesia [14]. The establishment of the PEPI campus is in line with the transformation of traditional agriculture into modern agriculture and the building of skilled and international-class agricultural human resources. PEPI should be able to make Indonesia more than just an agricultural machine tool operator. If now, Indonesia has been able to produce tractors with 100% local material, it is hoped that PEPI can create superior human resources capable of assembling sophisticated agricultural equipment so that Indonesia is no longer dependent on imports of machinery or components.

- **Supporting Agriculture from Village Fund:** The proportion of the budget allocated by the government to the Ministry of Agriculture is generally under 1% of the total state budget. From 2004 to 2014, the MoA's budget allocation ranged between 0.71-0.84%. In 2015, the budget allocation for MoA increased to 1.65%, followed by 1.33% in 2016 and 1.06% in 2017.

FIGURE 13

AGRICULTURAL BUDGET IN INDONESIA.

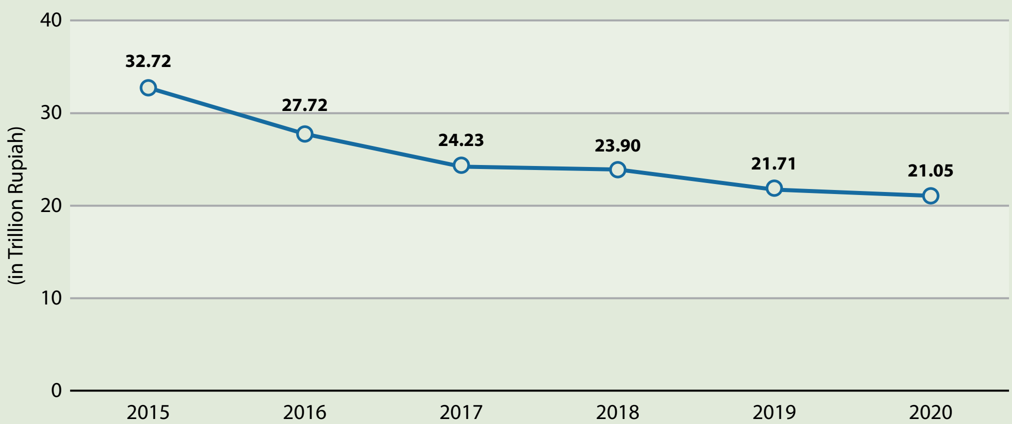


Figure 13 points out that the provision of agricultural technology cannot rely solely on the State Budget (APBN) for agricultural allocation in the Ministry of Agriculture. There needs to be another mechanism, both financially and institutionally, that guarantees the use of sustainable agricultural technology. In article 80 of the Village Law, it is explicitly stated that the program priorities are highly related to agriculture and the development of productive economies of agriculture, and the development and use of appropriate technology for economic progress. Since all of these are related to agriculture, these can help build a strong foundation through the proper allocation of Village Funds for the development and modernization of agriculture.

- **BUMDes for Agriculture:** Every year, MoV enacts the Village Minister Regulation, concerning Priority of the Use of Village Funds, which mandates that the Village Fund must be used for procurement, construction, development, and maintenance of economic facilities, and infrastructure of rural communities, including economic activities in agricultural cultivation (productive on-farm and off-farm), including production, distribution, and marketing. It also includes the use of appropriate technology for economic progress with a focus on the formation and development of superior products in villages and rural areas, including the use of technology for agricultural production. It also outlines that training programs can be conducted to improve the quality and capacity of rural communities and to enable the development of superior products, agricultural business, and digitization. The policy is the basis for the transformation of intelligent agriculture in national rice barns throughout Indonesia.

  The above regulation also explains how the Village Fund can be used to strengthen BUMDes even though it does not specifically mention agricultural BUMDes. However, if Village Conference agrees on the use of the Village Fund to purchase agricultural technology as an investment for the BUMDes business unit, this is permitted. In addition to opening new business unit options, agricultural equipment rentals also open up new jobs for rural communities as operators and are paid regularly. This is expected to attract young people to return to the village and develop the agricultural sector, without worrying about conventional farming systems and income uncertainty. Smart agricultural technology is not only talking about technology and natural resources but also human and institutional resources. Therefore, within the Ministry of Village itself, there needs to be good collaboration between the Research and Development Center as a think-tank, the Directorate of Resources and Environmental Development, the Directorate of Appropriate Technology as a technical unit, and the Directorate of Village Economic Business Development as a catalyst for BUMDes.

- **Joint Ministerial Decree on SAT:** Synergy across the Ministry of Communication and Informatics (MCI), MoA, MoV, and LAPAN, towards smart agricultural transformation, must be formalized in a joint ministerial decree. Regarding the readiness assessment and ongoing program related to modern agriculture in each institution, it is important to set short- and long-term goals, map the roles, and build a mechanism to measure the progress. The presence of the Internet in the village, the competency of agricultural instructors in promoting the benefits of food crop production technology, the certification of drone operators in the village, and the establishment of BUMDes with agricultural equipment rental business units, are concrete contributions to developing the economy of rural communities while achieving the ideals of a 2045 world food barn. Besides, the National Professional Certification Agency (BNSP) can play an important role in formulating standards, training, and certification of agriculture technicians and operators.

Strategies and Ways Forward

From the results of the experimental research in Kepuh Village, Sukoharjo, the study recommends the use of a rental model to make drone sprayers available to the villages through BUMDes. The calculation technique used includes gross margin per ha, which is the total value of output per ha minus the total variable costs per ha. Variable costs in farming are the intake of seeds, liquid fertilizer, fuel, and labor costs. The calculation results are processed together with qualitative data in the field which is in the form of observation and discussion notes.

TABLE 8

CALCULATION OF DRONE SPRAYER INVESTMENT AND OPERATIONAL COSTS.

Hybrid Drone Sprayer	
Motor electric for drone	
Power source generator fuel	
Purchase cost: USD27,500	
Per Flight	
Spraying dosage	20 L/ha
Spraying capacity	20 L
Spraying area	1 ha/flight
Flight duration	15 minutes
Operation Per Day	
Flight start – flight end	6 AM – 4 PM
Flight hours (with lunch break)	9 hours
Flight minutes	540 minutes
Flight times	36 flight/day
Occupancy (moving base)	70%
Estimate real flight times	25 flight/day
Flight times x flight duration	375 minutes/day (6.25 hours)
Hectare sprayed	25 hectare/day
Maintenance per	50 hours
Changing components on generator	USD7
Operation Cost	
Number of operators	2
Pilot cost	IDR1.7 per flight hour
Copilot and helper cost	IDR1.5 per flight hour
Pilot cost	IDR10.6 per flight/day

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Copilot and helper cost	IDR9.4 per flight/day
Fuel	
Fuel cons	0.5 L/flight
Fuel mix for generator cost	IDR1 L
Fuel cost	IDR0.5 per flight/times
Fuel cost	IDR3.1 per flight/day
Assumption	
Aerial spraying with drone	IDR10 per ha
	IDR250 per day
Operation Per Month	
Flight hours (with lunch break)	270 Hours
Flight minutes	16,200 minutes
Flight times	1,080 flight/day
Occupancy (moving base)	80%
Estimate real flight times	750 flight/month
Flight times x flight duration	11,250 minutes/month (187.5 hours)
Hectare sprayed	750 hectare/ month
Maintenance per	50 hours
Changing components on generator	USD7
Operation Cost	
Pilot cost	USD318.8 flight/month
Copilot and helper cost	USD281.3 flight/month
Fuel cost	USD93.8 flight/month
Aerial spraying with drone	**USD7,500 per month**

Source: Primary data analysis, 2019.

The simulation below illustrates the initial investment needed if a hybrid drone sprayer was purchased at a mass scale (500 units), each for USD14,000. As indicated, the drone rental fee is USD10 per ha for an aerial spray of 750 ha per month. However, on the economies of scale, if the size of a rice field that needs spraying of fertilizer is bigger, the per ha cost of renting a drone can be cheaper. Thus, experiments can be conducted at BUMDes in the top ten provinces of the National Rice Barn.

Based on the simulations above, it can be concluded that if the drone rental costs USD10 per ha, then the BEP for the investment of one drone unit will be reached in the third month. Determination of the rental price can be agreed upon in the village consultation (Musdes), which is held every year by the various farmer groups. The mechanism and renting fee is new and yet quite interesting for the group of farmers, as long as it is facilitated by the BUMDes and is affordable. By their request, the renting scheme through BUMDes can be carried out as follows.

TABLE 9

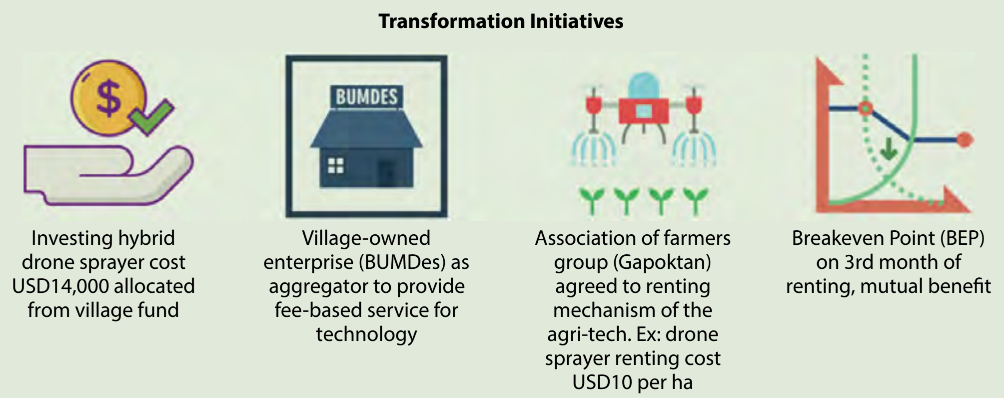
SIMULATION OF PROFIT CALCULATION AND BEP DETERMINATION.

Calculation	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8	Month 9	Month 10
Flight hours accumulation	270	540	810	1080	1350	1620	1890	2160	2430	2700
Aerial sprayed accumulation (ha)	750	1500	2250	3000	3750	4500	5250	6000	6750	7500
Revenue per month (in USD)	7,500.00	7,500.00	7,500.00	7,500.00	7,500.00	7,500.00	7,500.00	7,500.00	7,500.00	7,500.00
Revenue accumulation (in USD)	7,500.00	15,000.00	22,500.00	30,000.00	37,500.00	45,000.00	52,500.00	60,000.00	67,500.00	75,000.00
Cost (in USD)										
Operator per month	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00
Fuel	93.80	93.80	93.80	93.80	93.80	93.80	93.80	93.80	93.80	93.80
Maintenance	38.00	37.80	37.80	37.80	37.80	37.80	37.80	37.80	37.80	37.80
Profit per month (in USD)	6,768.50	6,768.50	6,768.50	6,768.50	6,768.50	6,768.50	6,768.50	6,768.50	6,768.50	6,768.50
Profit accumulation (in USD)	6,768.50	13,536.90	20,305.40	27,073.80	33,842.30	40,610.70	47,379.20	54,147.60	60,916.10	67,684.50
Checked BEP	Not Yet BEP	Not Yet BEP	Break Even Point	Break Even Point	Break Even Point	Break Even Point	Break Even Point	Break Even Point	Break Even Point	Break Even Point
Profit gain (in USD)	(7,231.60)	(463.10)	6,305.40	13,073.80	19,842.30	26,610.70	33,379.20	40,147.60	46,916.10	53,684.50
Total profit gain (in USD)										**2,20,580.30**
Gain times (in USD)										**15.75573214**

Source: Primary data analysis from calculation result of tech-provider and farmers, 2019.

FIGURE 14

BUMDES RENTING SCHEME FOR DRONE SPRAYER.



Source: Primary data analysis, 2019.

One of the ideas of the BUMDes business unit is to run a rental business to serve the needs of the local community and at the same time to obtain village income. Business activities in this field have been running for a long time in many villages, especially those in Java, including the leasing of agricultural equipment and machinery. In the Regulation of the Minister of Village Number 7 of 2020, concerning the Determination of Priority for the Use of Village Funds, it is stated that based on the conditions and potential of the village, the Village Funds sourced from the state budget can be used for the establishment and development of BUMDes. In addition, Article 11 makes it clear that the use of Village Funds is for the empowerment of village communities and can support the economic activities developed by BUMDes, including the agricultural business unit.

Conclusion

In a period of two years (2016-2018), the declining number of farmers in Indonesia has increased quite significantly by over four million. Out of 33.4 million farmers, around 30.4 million or 91% are those who are approaching the age bracket of 50-60 years while there were only 9% or 2.7 million young farmers aged between 19-39. The lack of interest in millennials to be involved in agriculture indicates that the sector is no longer considered profitable. This situation could also have unfavorable implications for the government's target to make Indonesia a world food barn by 2045. Farmer regeneration is one of the key factors for the advancement and modernization of agriculture in Indonesia.

The mechanization of agriculture in Indonesia has been an ongoing process since 1960. The use of agriculture machine tools is intended to increase the area and intensity of planting, accelerate work, reduce costs, reduce losses, and increase production. However, program effectiveness and usage of Alsintan in the field have not been optimal due to the decline in the agricultural budget, the distribution of equipment that is not per the needs, and the institutional preparation of the recipient farmers.

SAT is expected to improve the efficiency of farming by reducing production costs and increasing productivity and competitiveness. These conditions will again make agriculture a sector of interest for the young population by promising higher income. To deal with low budget allocations by the government for agriculture, the country can optimize the use of village funds to finance agricultural technologies that can meet the village's needs.

Village-owned Enterprises (BUMDes) are the best options to ensure that agricultural technologies are sustainably maintained to earn revenue for the village. The scheme for renting agricultural equipment as a business unit of BUMDes, as proposed, is worth being tested and evaluated for its effectiveness. This paper suggests the three main ministries, namely the MoA, the MoV, and MCI, collaborate and facilitate smart agricultural transformation, from upstream to downstream.

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Appendix 1. Agricultural Regulation

Inquiry matters in Law Number 22 of 2019 on Sustainable Agriculture Cultivation Systems are:

a. Agriculture cultivation planning

b. Agricultural land use

c. Land use

d. Seedlings and nurseries

e. Planting

f. Removal and entry of plants, seeds, and animals

g. Protection and maintenance of agriculture

h. Harvest and post-harvest

i. Agricultural cultivation facilities and infrastructure

j. Agricultural cultivation business

k. Guidance and supervision

l. Research and development

m. Human resource development

n. Information system

o. Community participation

p. Penalty

Other related regulations include:

1. Law Number 41 of 2009 concerning the Protection of Sustainable Agricultural Land
2. Regulation of the Minister of Agriculture No. 9 of 2019 concerning Guidelines for the Movement of Agriculture Human Resources Development towards the World Food Barn 2045
3. Regulation of the Minister of Agriculture No. 22 / PERMENTAN / SM.200 / 5/2018 concerning Levels of the Indonesian National Qualifications Framework for Agricultural Sector Workers
4. Regulation of the Minister of Agriculture No. 18 / PERMENTAN / RC.040 / 4/2018 concerning Guidelines for the Development of Farmers-based Agricultural Areas

5. Regulation of the Minister of Agriculture Number 07 / PERMENTAN / LB.200 / 2/2018 concerning Guidelines for Agricultural Technology Transfer

6. Minister of Agriculture Regulation Number 03 / PERMENTAN / SM.200 / 1/2018 concerning Guidelines for Implementing Agricultural Counseling

7. Regulation of the Minister of Agriculture Number 67 / PERMENTAN / SM.050 / 12/2016 concerning the Development of Farmer Institutions

8. Regulation of the Minister of Agriculture No. 41 / PERMENTAN / OT.140 / 3/2014 concerning Guidelines for E-Planning Based Agricultural Development Planning

9. Regulation of the Minister of Agriculture Number 16 / PERMENTAN / OT.140 / 2/2008 concerning General Guidelines for the Development of Rural Agribusiness Enterprises

10. Decree of the Minister of Agriculture No. 01 / KPTS / SR.130 / 1/2006 concerning Recommendations for N, P, and K Fertilization on Site-Specific Rice Fields

Appendix 2. Champions of Integrated Broadband Village (IBV)

No.	Village-Owned Enterprise(s)	Village	Province
1.	Panca Mandala	Mandalamekar	West Java
2.	Prakarsa Galuh	Cupunagara	West Java
3.	Maju Bersama	Cikadu	West Java
4.	Gunung Simpang	Puncakbaru	West Java
5.	Gerbang Lentera	Lerep	Central Java
6.	Ngaprah Sejahtera Bersama	Ngaprah	Central Java
7.	Muda Meupakat	Gampong Cot Baroh	Aceh
8.	Sarilamak	Nagara Sarilamak	West Sumatera
9.	Bumi Dipasena Jaya	Bumi Dipasena Jaya	Lampung
10.	Bokor Mandiri	Bokor	Riau
11.	Hilir Sehati	Hilir	Kepulauan Riau
12.	Panua Mandiri	Malango	Gorontalo
13.	Pasitoruang	Torosiaje	Gorontalo
14.	Sungai Nibung Sejahtera	Sungai Nibung	West Kalimantan
15.	Pancasila	Sungai Enau	West Kalimantan
16.	Bangket Barage	Kaliau	West Kalimantan
17.	Yotowawa	Wonreli	Maluku Barat Daya
18.	Dua Rato	Dua Rato	East Nusa Tenggara
19.	Weimpele	Kampung Saonek	Papua
20.	Persatuan	Kampung Persatuan	Papua

Appendix 3. GSM and Internet Signal Based on Village Potential

Province	Blank Spot	2.5G/E/GPRS	3g/H/H+/EVDO	4g/LTE	No Internet Signal
Aceh	112	967	3590	1628	209
Sumatera Utara	189	1003	2536	1156	553
Sumatera Barat	39	149	595	214	48
Riau	27	363	885	279	53
Jambi	54	204	663	398	80
Sumatera Selatan	53	630	1395	638	160
Bengkulu	24	250	744	241	82
Lampung		381	1114	891	60
Kepulauan Bangka Belitung	1	24	169	113	2
Kepulauan Riau	13	94	106	28	34
Jawa Barat	17	257	2557	2415	66
Jawa Tengah	10	377	3521	3846	55
Di Yogyakarta		25	182	185	
Jawa Timur	7	484	3816	3318	96
Banten	6	80	702	432	18
Bali	2	16	279	339	
Nusa Tenggara Barat	10	83	402	457	43
Nusa Tenggara Timur	197	716	1408	145	582
Kalimantan Barat	327	402	614	171	524
Kalimantan Tengah	232	443	459	56	244
Kalimantan Selatan	61	216	948	568	71
Kalimantan Timur	57	113	352	182	137
Kalimantan Utara	59	95	87	27	179
Sulawesi Utara	83	193	539	493	198
Sulawesi Tengah	207	253	776	348	258
Sulawesi Selatan	93	241	1130	664	127
Sulawesi Tenggara	152	222	940	428	227
Gorontalo	19	79	289	223	47
Sulawesi Barat	137	71	175	80	112
Maluku	190	145	229	109	529
Maluku Utara	183	176	203	151	353
Papua Barat	824	263	147	119	539
Papua	3343	481	322	147	1163

Source: Statistics Indonesia, 2019 (processed by R&D Center of MoV).
Note: Colored provinces are National Rice Barns.

CASE ANALYSIS
PAKISTAN

The Islamic Republic of Pakistan is one of the ten most populated countries in the world, with a population exceeding 212.2 million. It is the 33rd-largest country by area, spanning 881,913 sq km. Pakistan's agriculture benefits from the good quality of soil suitable for the cultivation of a large number of fruits and vegetables including cotton, grains, and others crops like sugarcane, for domestic consumption as well as export. Agriculture of Pakistan is supported by the nature with the four seasons, namely winter, autumn, spring, and summer.

Like other countries of the world, agriculture is considered the most important sector of Pakistan, critical for feeding the increasing population. Even though the yield per hectare is sufficient at the moment, a higher yield is needed to meet future requirements, which indicates that there is a need to implement smart agriculture. Improved cultivation methods like tunnel farming, hydroponic farming, and dense plantation, supported by different types of drip irrigation systems are necessary. These are all part of smart agriculture to get the maximum yield potential from contemporary crops using available arable lands.

SAT will play a critical role in the preharvest and postharvest life cycles of agricultural produce, which will help improve food safety and security. A better preharvest strategy is essential to produce quality food followed by postharvest technology, which is a fundamental unit of agriculture products' supply and value chain.

Introduction and Background

The projected increase in world population from 7.6 billion in 2018 to over 9.8 billion in 2050 has received a lot of attention influencing the world's demand for food. Although the existing food system, with more than 570 million smallholder farms worldwide along with agriculture and food production that accounts for 28% of the entire global workforce produces enough food to feed the world, an estimated 821 million people still suffer from hunger. To answer the question of how to feed nine billion people by 2050, the world urgently needs to transform the agri-food system at an extraordinary speed and scale up [1].

Like the rest of the world, Pakistan faces a similar question. As a developing nation, the country is undergoing a low pace of growth and also faces various crises, unsustainability being one of them. The percentage of poverty in the rural areas of Pakistan is very high because of low incomes, causing deprivation in clothing, housing, healthcare, sanitary facilities, education, and human rights. Around 65.9% of the country's population lives in rural areas and their main source of income is agriculture. Besides, there is increasing pressure on arable land in Pakistan to produce more food to meet the country's growing demands, even as it faces issues like land degradation, an increase in demand for water resources, and inadequate infrastructure.

SAT is the best way to utilize available natural resources to obtain food for the growing population. It is not feasible to increase the area of arable land, but it is possible to maximize the benefits from the available arable land under the umbrella of smart agriculture. There is a need to develop an understanding among the farming community that farming decisions based on smart agriculture lead to higher yields. Even the Prime Minister of Pakistan has stated that Pakistan needs to avail maximum benefits from modern technologies in agriculture, and SAT should be the focus of future policies on agriculture.

Focus and Scope of Case Analysis

Agriculture is still the main source of employment and income for the majority of people in Pakistan. Nevertheless, its performance has been uneven, both in terms of the rate of growth and commodity balance, despite the slow but steady structural transformation of Pakistan's economy in recent times.

The state of agriculture in recent years has improved compared to other sectors, particularly in production and trade. The objective of the government is to achieve an agriculture growth rate of 7.5% annually by the fiscal year 2027-2028 (FY28), led and sustained by producer-owned integrated market-based value chains, which aims to incentivize producers to continue investing in modern and climate-smart production technologies, expansion of the cultivated land area, and value-added activities.

The other overarching goal of the government is to create policies that can boost agricultural exports, accelerate rural-development-driven economic growth, reduce rural poverty, enhance finances, and inclusion of gender in the agricultural sector.

It may be argued that since big farmers have sufficient financial support from their other businesses and the government, the agriculture transformation initiative is led by and under the control of large farmers. The government of Pakistan is planning to accelerate the pro-poor growth strategy, focusing on the agriculture transformation of the business model of the 7.4 million smallholder farmers, who cultivate 48% of the total cultivable land. In the present scenario, the government is focusing on the following:

- Special initiatives for Baluchistan, South Punjab, KPK, and Tharparkar
- Agriculture Climate Change Insurance Pool (Farmer Risk Transfer Mechanism/Satellite-based Crop Reporting)
- Establishment of Agriculture Development Authority for Coordination of Reform Implementation
- Linkages with Ehsaas, Kamyab Jawan, and China–Pakistan Economic Corridor (CPEC)
- Incentives for promoting investment in warehousing, contract farming, and farmers' produce organizations

Pakistan ranks in the World's Top 10 list in terms of the production of several crops as shown in Table 1.

TABLE 1

PAKISTAN'S GLOBAL RANKING ACROSS CROPS.

Crop	World Ranking Among Producing Countries
Chickpea	3
Apricot	6
Date Palm	5
Mango	4
Kinnow, Mandarin, Oranges, Clementine	6
Onion	7
Wheat	7
Rice	11
Sugarcane	5
Cotton	4

Despite having one of the best alluvial soils worldwide, diversified weather conditions, the best irrigation system, assiduous farmers, and proximity to the high-end market in the Middle East, Central Asia, China, and the rest of countries, the performance is not up to the mark. The disconnect between researchers and agriculture stakeholders leads to slack in the use of agricultural technology, resulting in stagnant yields. Poor management of agricultural produce at the post-harvest level and little processing of agricultural commodities have further reduced the compatibility of the sector in international markets. These factors also lead to a low return for farmers and other entrepreneurs in agricultural business, causing widespread poverty in rural areas. To achieve the potential of the sector, transformation is required in agriculture from a supply-driven to a demand-oriented job.

There is great potential for modernizing agriculture and enhancing its competitiveness through developing and strengthening agriculture transformation. It can be envisioned that improving the adoption of state-of-the-art techniques in production and processing (preharvest and postharvest) at the village level, can augment the yield and reduce post-harvest losses. It would enhance agriculture exports by introducing modern agricultural processes in the value chain, such as grading, packing, processing, certification, traceability, etc.

The objective of the study is to convey the existing scenario of agriculture in Pakistan to the rest of the world.

Analysis of the Current Situation

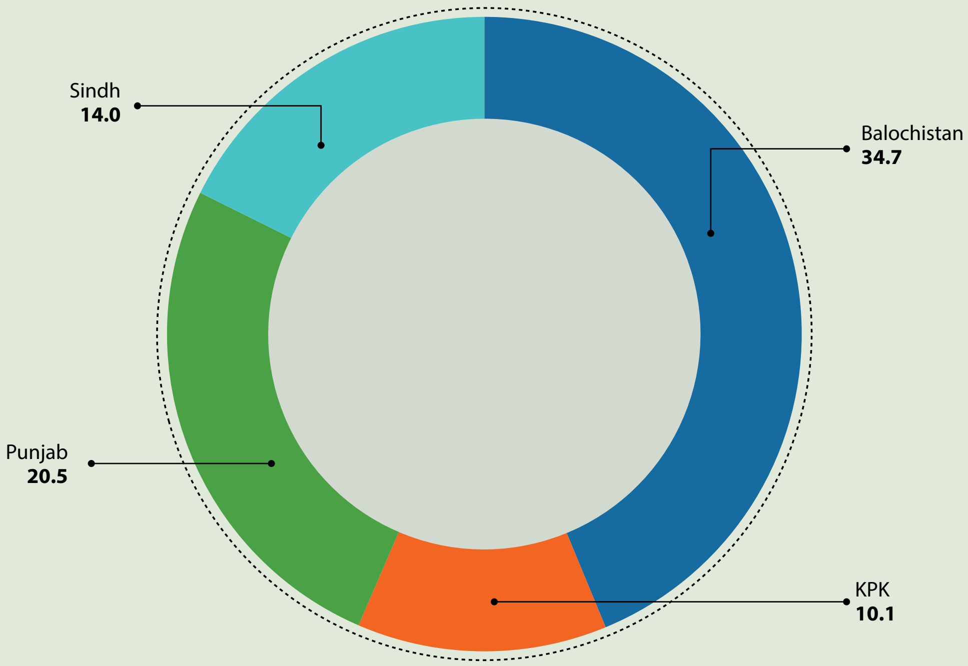
State of the Agriculture

Natural Resources for Farming

Situated in South Asia, the total area of the Islamic Republic of Pakistan is 79.6 million hectares. The country is divided into four provinces: Baluchistan, Khyber Pakhtunkhwa, Punjab, and Sindh. The land share of each province is shown in Figure 1. Baluchistan is the biggest province by area, followed by Punjab, Sindh, and Khyber Pakhtunkhwa (KPK). A significant area of agricultural land is available in the Baluchistan province, including land for date palm, apples, and cherry, besides vegetables like tomato, and condiments like onion and garlic. Potential for expansion in agricultural land is present in the other provinces.

FIGURE 1

LAND SHARE OF PROVINCES (IN %).



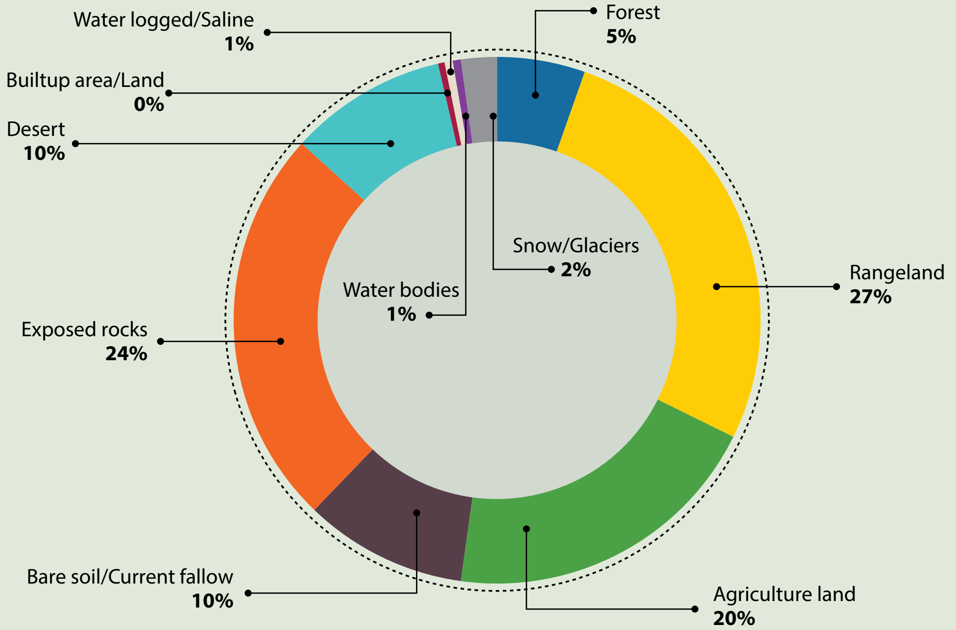
Pakistan has nearly 23.3 million hectares of agricultural area and a forest cover of over 4.6 million hectares. The rest includes culturable waste, densely populated forests, and rangelands. The classification of land in Pakistan is shown in Figure 2. This classification shows that Pakistan has versatile lands endowment, and these are being used in adaptable ways for different types of agriculture, livestock, and fishery.

Pakistan has significant freshwater sources ranging from rivers, canals, and groundwater. These sources feed into the world's largest contiguous irrigation system, which irrigates almost 80% of the cultivated area [2]. A wide variety of soils are found in the country, hence different farming approaches are needed to optimally and sustainably use this resource, which can be facilitated by smart agriculture technologies. Optimal use of resources would ensure continued availability of food for the increasing population.

The country's climate varies from tropical to temperate, with arid conditions in the coastal south. The country also has coastal, desert, plain, and mountainous regions. The monsoon season sees heavy rainfall while the temperature is quite high during the summer. Pakistan has two cropping seasons. Kharif is the first season, where sowing takes place from April-June, and harvesting is done from October-December. Rice, sugarcane, cotton, and maize are Kharif crops. The other season is Rabi, where sowing takes place from October-December and harvesting is done between April-May. Wheat, gram, lentil, tobacco, barley, and mustard are Rabi crops. The other important crops are potato, tomato, chili, onion, carrot, dates, mango, citrus, and melon. Agricultural productivity is dependent upon the timely availability of water, with other essential inputs [3].

FIGURE 2

LAND DISTRIBUTION IN PAKISTAN.



Profile of Agriculture

According to the Pakistan Economic Survey 2016-17, agriculture contributes 19.5% to Pakistan's GDP, employs 42% of the labor force, constitutes 65% of export earnings, and provides livelihoods to 62% of the population of the country. Agroclimatic conditions of Pakistan which range from tropical to temperate favor the cultivation of 40 different kinds of vegetables and 21 types of fruits. The major vegetables grown in Pakistan include potatoes, onions, chilies, melons, cucumber, tomato, turnip, okra, and peas. Besides, citrus, date, mango, guava, apple, banana, apricot, grape, almond, peach, plum, and pomegranate are the main fruit crops.

Agriculture is the backbone of Pakistan's economy. Natural resources like arable land and water are available for agriculture. During the year 2018-2019, agriculture accounted for about 18.5% of Pakistan's GDP and employed about 38.5% of the labor force. The developments in the agriculture sector of Pakistan have created optimism for increasing the food supply for the growing population. Increasing food supply also boosts economic growth and increases food supplies for the world population via exports. The China-Pakistan Economic Corridor opens market opportunities for fresh as well as processed products.

Figure 3 shows the major crops in Pakistan, which indicates that little change has been seen in the areas under crop and production between 2014 and 2018 for some crops, while others show an increasing trend in both area and production. It is now time to intensify the adoption of new technologies and practices under the umbrella of smart agriculture according to the values of the farming community of Pakistan [4].

Wheat is a staple crop, and Pakistan always needs its high yield to feed its population. In 2016-2017, the area under production was less than it was in 2014-2015, however, production was higher, implying the yield was improved. The potential for a higher yield is present, and even higher levels can be attained by using smart agriculture practices in agronomic management.

FIGURE 3

MAJOR CROPS IN PAKISTAN.

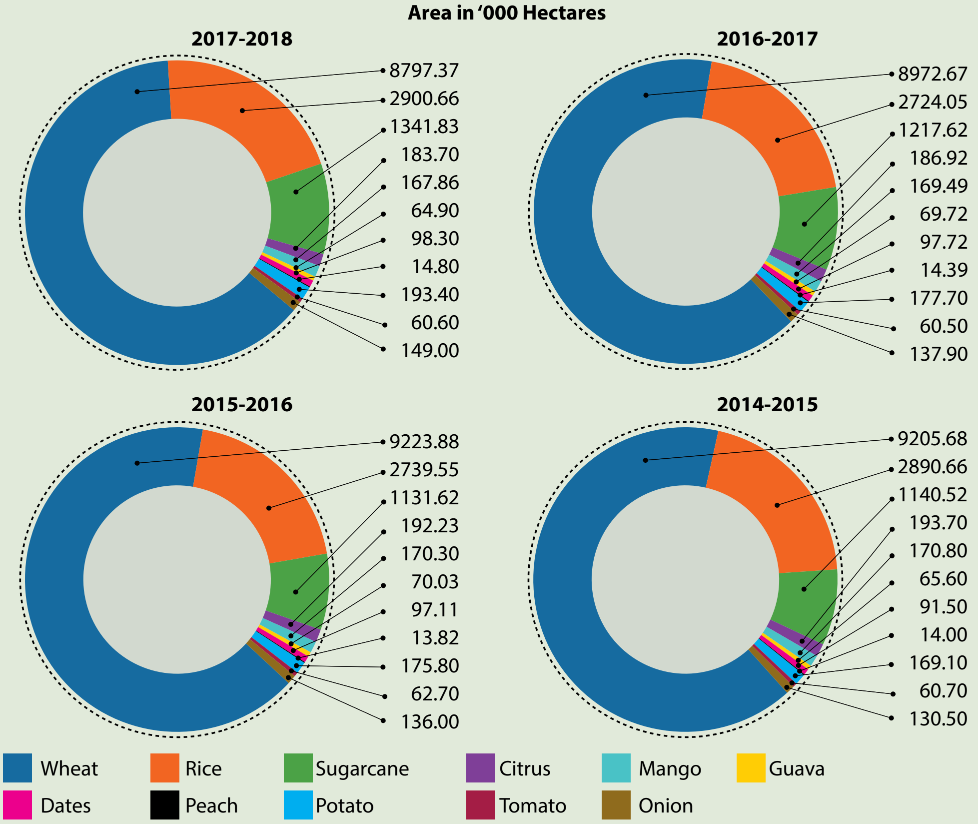


Table 2 shows the production of eleven crops over 40 years, in which the area under production is converted into hectares. These trends show that Pakistan has had a great track record in growing its agricultural sector. Smart agriculture can provide a way to enhance the agricultural productivity of Pakistan through the development of improved adaptable techniques in the sector of preharvest and postharvest, which are the two main stages of the agricultural value chain.

TABLE 2

PRODUCTION OF ELEVEN CROPS FOR FORTY YEARS.

Year	Wheat	Rice	Sugarcane	Citrus	Mango	Guava	Dates	Peach	Potato	Tomato	Onion
Area Under Cultivation in Hectares											
1970–71	5977700	1503400	636300	43550	55400	11300	18500	890	20200	ND	23400
1980–81	6983900	1933100	824700	94500	57200	17300	24200	1100	38000	11500	43200
1990–91	7911700	2112700	883800	173300	85400	46900	42000	2150	72000	20800	58600
2000–01	8181100	2376600	960800	198700	97000	63400	78600	5500	101500	28300	105600
2010–11	8884800	2365300	987600	194500	171900	64000	90050	15200	159400	52300	147600
Production in '000 Tonnes											
1970–71	6474.0	2199.7	23167.0	445.3	519.2	88.3	157.3	8.1	228.6	ND	246.9
1980–81	11474.0	3123.2	32359.4	926.2	546.6	123.6	194.1	10.1	394.3	92.1	447.6

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Year	Wheat	Rice	Sugarcane	Citrus	Mango	Guava	Dates	Peach	Potato	Tomato	Onion
1990–91	14565.0	3260.8	35988.7	1609.1	776.0	355.3	287.3	21.8	751.3	231.5	702.4
2000–01	19023.7	4802.6	43606.3	1897.7	989.8	525.5	612.5	32.9	1666.1	269.8	1563.3
2010–11	25213.8	4823.3	55308.5	1982.2	1885.9	546.6	522.2	52.6	3491.7	529.6	1939.6

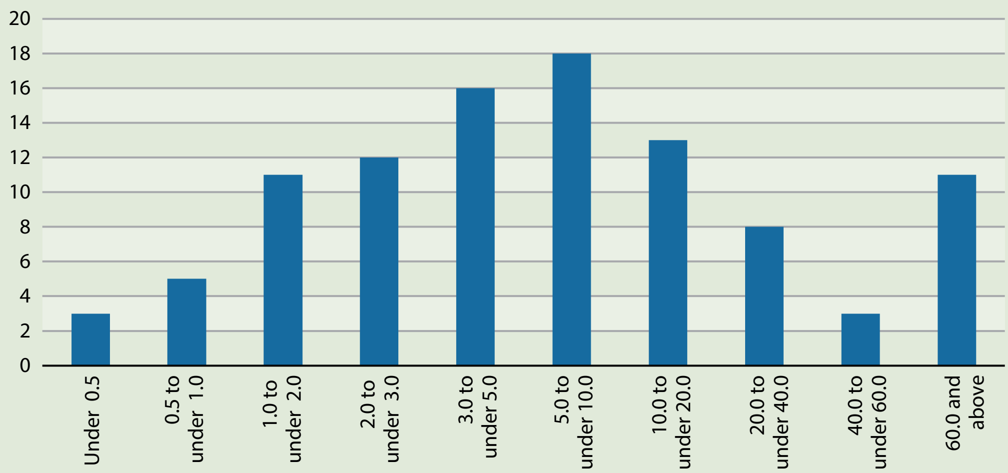
The agriculture sector in Pakistan, however, has been facing several challenges. The performance of this sector has been less than its potential in recent times, with low 3.3% growth during the last decade. Besides, agricultural growth has failed to benefit the rural poor to the extent it was expected. Major factors underlying this underperformance include the slow rate of technological innovation, problems with the quality, quantity, and timeliness of input supply, and inadequate extension services and technology transfer. The agricultural sector in Pakistan has also been suffering due to marketing and trade restrictions, pest and disease problems, a limited amount of credits for agricultural production and processing, and a lack of agriculture-specific loan products [5].

Agricultural farms in Pakistan vary in size. However, the majority of the farms in the country are of small and medium scale with limited resources. Hence, they cannot afford to make large investments to improve their farming system. Figure 4 indicates that about 18% of all farms in Pakistan fall within the 5-10 hectare range and 47% of farms are in the 0.5-5.0-hectare range. The small landholding size limits the farmer's financial resources and they face a lot of problems while adopting new technologies. These farmers are looking for smart yet affordable agricultural technologies for enhancing crop production. They have the skill and experience but do not have the resources to access better technologies for the preharvest and postharvest phases.

At present, most farmers in Pakistan are using conventional agronomic practices for cultivation, starting from seed selection, sowing method, and irrigation of major crops like wheat, maize, sugarcane, and cotton, as well as vegetables and fruits. The use of technology in agriculture is very constrained due to limited resources depending on the farmer's income.

FIGURE 4

FARM SIZES BY AREA IN PAKISTAN IN HA (%).



Machinery plays a big role in getting a higher yield through suitable utilization. Table 3 lists the types of machinery used by farmers. Farmers in Pakistan, usually in the medium and big categories, use very simple machinery for agriculture.

TABLE 3

TYPE OF MACHINERY IN USE BY FARMERS IN PAKISTAN.

Size of Farm "Hectares"	Farms Reporting Use of Important Agriculture Machinery by Size of Farm																
	All Farms	Farms Reporting Use of															
		Tractors		Tubewell/Pump		Thresher		Sheller		Combined Harvester		Reaper Harvester		Drill		Spray Machine	
		Owned	Rented	Owned	Rented	Owned	Rented	Owned	Rented	Owned	Rented	Owned	Rented	Owned	Rented	Owned	Rented
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Under 0.5	1255	10	1171	32	406	5	922	1	102	1	43	1	49	6	186	80	272
0.5 to under 1.0	2342	45	2203	176	879	18	2099	3	205	4	124	3	163	30	514	322	874
1.0 to under 2.0	1754	98	1600	232	608	39	1595	6	167	4	123	8	163	43	438	327	658
20 to under 3.0	1132	24	974	207	370	53	989	5	104	5	94	9	122	47	300	228	4281
3.0 to under 5.0	917	182	711	216	252	85	756	8	77	6	75	15	96	65	229	230	428
5.0 to under 10.0	561	157	390	145	128	81	429	10	48	5	53	16	66	59	146	156	175
10.0 to under 20.0	211	79	127	56	35	47	135	6	16	3	19	8	21	30	34	65	51
20.0 to under 40.0	67	29	37	17	9	19	36	3	4	1	6	5	5	11	7	22	13
40.0 to under 60.0	13	6	6	3	2	4	6	1	1	0	1	1	1	3	1	4	2
50.0 and above	13	5	9	3	1	3	6	0	1	0	1	1	1	2	2	3	2
Total	**8264**	**738**	**7208**	**1086**	**2710**	**354**	**6973**	**42**	**725**	**28**	**539**	**69**	**687**	**295**	**1857**	**1438**	**6756**

Rapid urbanization and reduction in farmland sizes are some of the main reasons that make the adoption of modern technology critical, especially for small and medium landholders. Public and private sectors are looking for the latest, yet socially-oriented appropriate technologies. The cultivated lands have the potential to produce more if smart agriculture is introduced. Small or medium size landholdings may be open to the adoption of smart agriculture, but operators do not have the funds or the operational knowledge. Mutual understanding is a must among farmers and service providers.

SAT in the Agricultural Crop Cycle

The life cycle of any agricultural crop consists of two stages. The preharvest stage includes operations like preparation of the land, sowing and planting, use of fertilizer, and management of diseases and pests. The stage ends just before the harvest stage, including the determination of the maturity level of the crop. The second phase or postharvest stage generates financial benefits for the farmer, as well as supplies consumers with preferably safe food. The adaptation of smart agriculture at both the preharvest and the postharvest stages will boost the yield and also help supply safe and good quality products to the consumers through the food system.

The ultimate goal of agriculture is to achieve food security for people. This requires good practices from the start, such as the selection of quality seed/nursery plants, land preparation, time of sowing, sowing methodology, agronomic practices, irrigation, and ends at harvesting.

Common problems at the preharvest stage include unhealthy seed and nursery plants, uneven land preparation, poor water management, uncontrolled pests and diseases, and inappropriate cultural practices of pruning, fertilizing, and spraying pesticides. Unsuitable harvesting methods, inadequate storage facilities, and lack of proper processing and packaging facilities are also some of the problems impacting the postharvest phase. These factors lead to lower yield and increase food loss. With good harvesting practices, the postharvest life of the produce is better assured.

Food loss refers to food that is spilled, spoiled, suffers a reduction in quality, or otherwise is lost before it reaches the consumer. Food loss is the unintended result of an agricultural process, as well as the technical limitation in the postharvest stage owing to inferior handling, storage, infrastructure, packaging, or marketing [6]. Despite many technical improvements in production, harvesting, and postharvest management since the 1970s, when food losses were first measured by FAO, the wastage of food continues to be significant to date. More than one-third of food is lost or wasted in postharvest operations.

On-farm losses, throughout Africa, Asia, and the Middle East range from 23%-39%. When converted into calories, global food loss and waste amount to approximately 24% of all the food produced. The use of scientific storage methods can reduce these losses to as low as 1%–2%. An integrated system approach, which should consist of engineering, economic, and biological principles, might help in increasing the food supply by 10%-30% around the world.

In Pakistan, all efforts are focused on enhancing the yield. However, not much emphasis has been given to the supply chain from harvesting to the consumer’s doorstep. Therefore, tremendous losses are associated with these crops after the harvest. Enormous losses during postharvest processes, in terms of quantity and quality, are occurring both in wheat and rice, as well as other major food commodities. A comprehensive study has been carried out on postharvest losses of food grains in all four provinces of Pakistan. The study includes losses occurring during harvesting, threshing, cleaning, drying, milling, storage, processing, cooking, and consumption.

The aggregate losses during various postharvest operations in Pakistan are 17.1% in paddy, 15.3% in wheat, and 12.6% in maize [7]. World Food Program reported that approximately 12.5% of wheat is wasted on its way from the field to the consumer [8]. To protect resources and ensure sufficient food supplies for the population, priority should be given to adopting postharvest technology to avoid food loss.

Emerging Agricultural Technologies

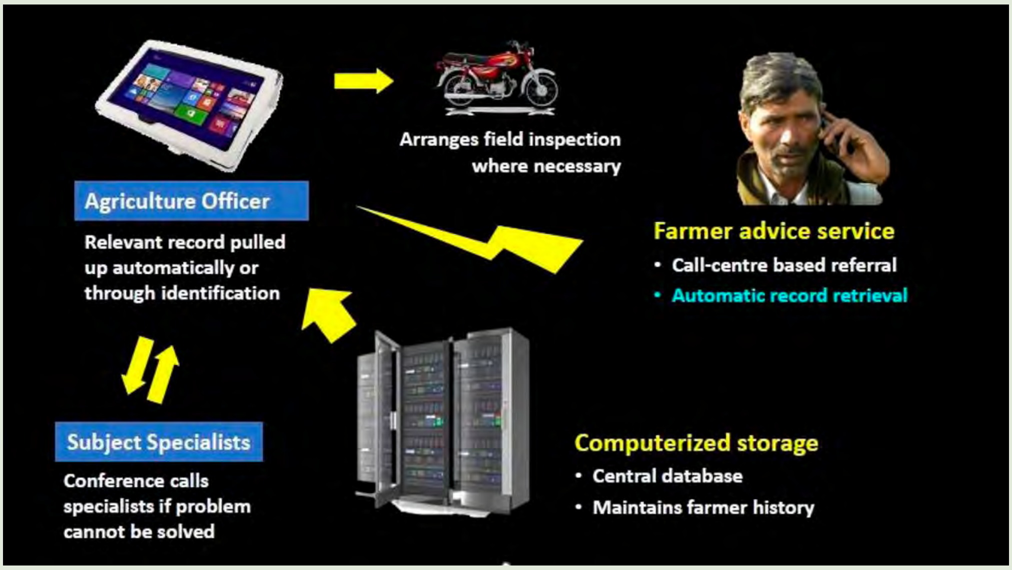
Digital Technologies

The basic principle of smart agricultural transformation is to assist the agrifood system, including the adoption of precision agriculture, enhancing production, increasing food safety through traceability, and optimization of the whole agricultural system to make it sustainable and efficient. This can be achieved by using cutting-edge, system-wide, digital technologies in primarily agricultural systems and processes [9].

Extension services are very important in collecting data, as well as rendering technical services to the farming community. The extension system in Pakistan has recently started assisting farmers with the help of information technology (Figure 5). The country also recently introduced the use of drones for farming, especially for soil and field analysis, crop monitoring, irrigation, and spraying on crops. While the technology offers several benefits, it is primarily being used to improve agronomic practices and maximize yield. The use of drones in Pakistan is in its initial phase due to a lack of concrete policies, as it is a sensitive issue related to security.

FIGURE 5

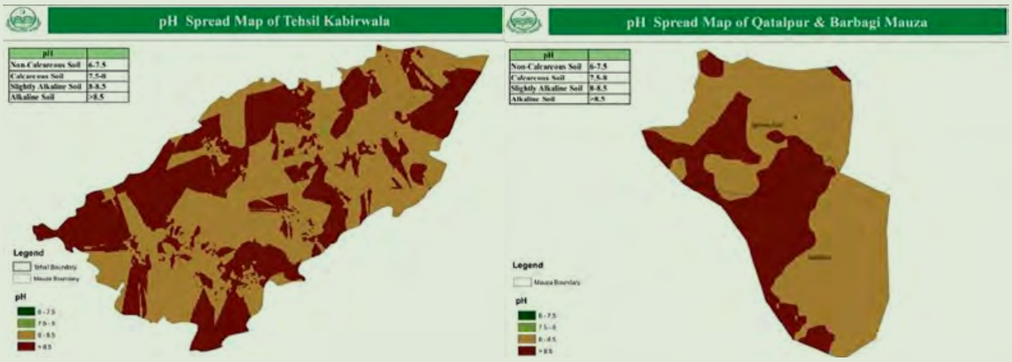
TECHNOLOGY EXTENSION SERVICES.



Digitalization of information, regarding land classification of various pH levels, as shown in Figure 6, together with weather forecasting, soil characterization (soil type and texture, moisture contents, irrigation requirement, fertilizer requirement, and application), pesticide requirements and application, and disease control is the key information required to support farmers through their decision for smart farming.

FIGURE 6

THE SPREAD MAP FOR pH.



Tunnel Farming

An example of a new appropriate technology is tunnel farming, which involves the cultivation of off-season crops in a modified atmosphere inside polythene tunnels (Figure 7). Tunnel farming is an emerging cultivation technology for many vegetables. It needs skilled personnel to operate, with the help of supporting scientific gadgets. Farmers are getting quality produce in better quantity for domestic as well as export markets. In Pakistan, tunnel farming is normally adopted for the off-season cultivation of summer vegetables. It is not possible to grow summer vegetables in open fields from December to February, due to low temperatures and high frost levels, so these are grown inside the polythene tunnels.

Tunnel farming is the source of higher yields and earlier production, and this earlier and quality produce enables farmers to earn a better profit. Due to this motivation, modern and progressive farmers of Pakistan are adopting this advanced mode of farming at an increasing pace. Tunnel farming is accomplished amongst educated farmers, as it provides them with an opportunity to save inputs by using less than 40% water, fertilizer, and other resources compared with conventional farming.

FIGURE 7

TUNNEL FARMING IN PAKISTAN.

Certified Seed

Planting of certified seed is mandatory, otherwise, the farmer cannot get a high yield. In Pakistan, some industries are working in the seed sector, but they are not able to meet the demand of the farmers. Hence, there is a need for technology to produce a higher volume of quality seeds.

Sowing and Plantation Geometry

Crop and plant geometry refers to the space available for individual plants. It influences the crop yield through its influence on light interception, rooting pattern, and moisture extraction pattern. Crop and plant geometry is altered by changing inter and intra-row spacing, row-to-row, and plant-to-plant distance. Some examples can be seen in Figure 8. Appropriate application of geometry helps in increasing the plant population which subsequently increases the quality yield. The dense population needs a lot of labor or machinery to manage field practices right from sowing to harvesting.

FIGURE 8

CROP AND PLANT GEOMETRY.

Wheat sowing on beds

Dense cultivation of Mangoes

Ninety percent of water from irrigation is used for agriculture in Pakistan, mainly because farmers flood their fields to irrigate their crops. Between 1990 and 2015, the amount of water available per person dropped from 2,172 cubic meters to 1,306 cubic meters [10]. An old irrigation system is shown in Figure 9, which is still used to irrigate most of the crops and orchards. Some water channels and canals are lined with fields to minimize water seepage. Previously there was no lining and a lot of water seepage would occur during the irrigation process.

FIGURE 9

AN OLD IRRIGATION SYSTEM: A LINED WATER CHANNEL.

There is a need to overcome water scarcity through the application of appropriate technologies like sprinklers and drip irrigation systems. Adequate distribution of irrigated water to each plant in the field is also an important technology. Plain, furrowed, and bedded fields have separate practices of irrigation, but they should be based on minimum water loss. Irrigation is considered the lifeline of agriculture which is very genuine.

Modern systems of irrigation are required to make irrigated water available for other crops. At present, different irrigation methods are being used for different crops as per their water requirement, as shown in Figure 10.

FIGURE 10

DIFFERENT DRIP IRRIGATION METHODS.

Drip irrigation

Tractor-driven drip irrigation

The adoption of solar irrigation systems, as shown in Figure 11, is in the developing stage as a green approach, but due to the high installation expenditure, small to medium farmers are reluctant to accept it. They are waiting for the development of low-cost solar technology for irrigation purposes to make the investment more affordable.

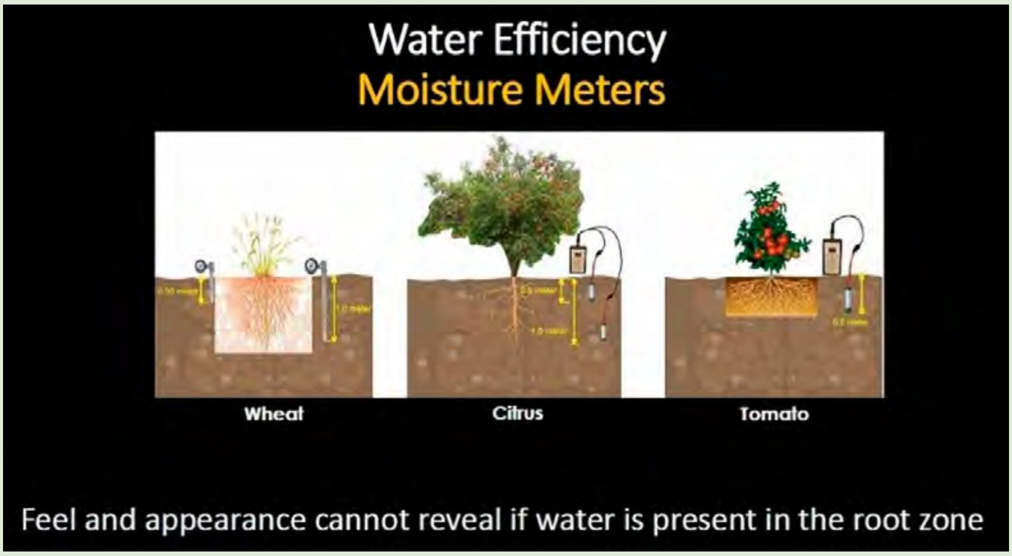
FIGURE 11

SOLAR IRRIGATION SYSTEM.

Appropriate time of irrigation significantly impacts the yield as well as saves water. This can be easily achieved by using water sensor systems, presently being used in the farming community. Figure 12 shows some examples of adopting moisture meters to improve the efficiency of water use.

FIGURE 12

MOISTURE METERS THAT INCREASE THE EFFICIENCY OF WATER USE.



Land Leveling

There is a need to adopt advanced practices which require less water, for effective irrigation on leveled lands. Leveling arable land is one of the major issues in Pakistan. Well-leveled land facilitates the water flow for irrigation. Farmers still use basic machinery and need better technology for leveling arable land in the country (Figure 13).

FIGURE 13

A LASER LAND LEVELING UNIT.

Weather Station

Agriculture depends on the climate and weather conditions. Early information and forecast about the weather condition can be very helpful to the farmers, enabling them to manage their farms and crop according to the weather conditions. It also helps to determine the crop maturity level, by calculating the daily temperature range in terms of TDD and GDD, as discussed earlier, for the intended use of the produce. A weather station that measures important weather parameters is shown in Figure 14.

FIGURE 14

A WEATHER STATION POWERED BY SOLAR PANEL.

Degree Days

The growth rates of most agriculture commodities are controlled primarily by weather conditions, especially temperature. The growth rate is predominantly under temperature control and its rate of development can be characterized by using the system of growing-degree days, which is also known as Total Degree Days. With climate change, it has become more necessary to understand the direct impact of solar radiation on crops from flowering to their maturity. Table 4 shows the relation between TDD/GDD and the life cycle of corn maturity. The data helps determine the proper maturity stage for harvesting a crop. The quality and quantity of produce that can be stored after harvesting, depends on this information.

TABLE 4

TDD AND GDD FOR CORN.

Phase	Development Stage	GDD
Vegetative	Planting	0
	Two leaves fully emerged	200
	Four leaves fully emerged	345
	Six leaves fully emerged (growing point above the soil)	476
	Eight leaves fully emerged (tassel beginning to develop)	610
	Ten leaves fully emerged	740
	Twelve leaves fully emerged (ear formation)	870
	Fourteen leaves fully emerged (silks developing on the ear)	1,000
	Sixteen leaves fully emerged (tip of tassel emerging)	1,135
Reproductive	Silks emerging/pollen shedding (plant at full height)	1,400
	Kernels in blister stage	1,660
	Kernels in the dough stage	1,925
	Kernels denting	2,190
	Kernels dented	2,450
	Physiological maturity	2,700

Note: Growing-degree day requirements for different phenology stages of a 2,700 GDD hybrid.
Source: Neild and Newman. Growing season characteristics and requirements in the Corn Belt. National Corn Handbook.

Optimum Harvest Time

Postharvest is the phase, where all measures are adopted for food safety and security in terms of saving the yields from the field, after the efforts put in day and night by the farmer, up to the consumption of the produce. Decision on the timing of harvest is a critical issue as any incorrect decision may increase postharvest losses. Many studies are available to determine the level of maturity in various crops. The level of maturity is quite varying in tomatoes for fresh consumption, as shown in Figure 15; similar considerations also hold for potatoes. For the marketing of mango, the maturity level for harvesting is different for closer markets than it is for distant ones. Even storage life is dependent on the maturity of the commodity/produce.

FIGURE 15

TOMATOES AT DIFFERENT MATURITY LEVELS.

Harvesting Technologies

Harvesting techniques help in minimizing postharvest losses and maintain the quality of the produce for fresh consumption and short- or long-term storage. On smaller farms, with minimal mechanization, harvesting is the most labor-intensive activity. On large mechanized farms, harvesting utilizes the most expensive and sophisticated farm machinery, such as the combine harvester and digger with a grader. Specialized harvesting equipment like secateurs, grip scissors, and gentle cutting and gripping tools are used for fruit harvesting (see images in Figure 16).

FIGURE 16

HARVESTING TOOLS AND MACHINERY USED BY LARGE MECHANIZED FARMS.

Harvesting with grip secateurs

Tractor-driven potato harvester and grader

Tractor-driven harvester

After harvesting, produce collection is started in the field. Conventional practices tend to increase postharvest losses, hence farmers need advice on how to properly handle them through field training. There is also a need for R&D studies on how to avoid postharvest losses. Some examples of proper handling techniques are given in Figure 17.

FIGURE 17

POST-HARVESTING PRACTICES AND TRAINING.

Field-handling crate in 1990 — Field-handling crate in 2015

Jute bag filling — Training on the benefits of using net bag for packaging — Net bag filling

Storage Technologies

The purpose of the storage is to save the produce, without disturbing its quality and quantity. It helps to stabilize the market price. Cold storage (Figure 18), is mostly used for the storage of fruits and vegetables. For grains, several storage techniques are used in Pakistan (Figure 19). In traditional 'Ganji' storage, jute bags holding 100 kg wheat are placed in piles of 9,000-13,000 bags, protected with tarpaulin cloth. It is not an efficient way of grain storage and results in considerable postharvest losses.

Instead, farmers and traders need to adopt hermetic storage, which is an effective system for controlling grain moisture content and insect activity in a tropical climate, without resorting to pesticide application. This type of storage helps to meet the rising demand worldwide for high-quality and safe food, which must be free of chemical as well as physical contaminants and pathogens. Hermetic storage, also termed sealed storage or sacrificial sealed storage, or air-tight storage, involves the bio-generation of an oxygen-deficient and carbon dioxide-enriched atmosphere, in a sealed storage ecosystem. This environment could control insect infestations, and preserve the quality and quantity of the grains.

FIGURE 18

CONTROLLED ATMOSPHERIC COLD STORAGE FACILITY.

FIGURE 19

VARIOUS GRAIN STORAGE TECHNIQUES.

Grain storage in jute bags

Wheat storage in jute bags

Grain storage silos

Hermatic grain storage

Transportation Technologies

Transportation of agricultural produce is also a sensitive subject as improper transportation chain may cause huge losses to fruits, vegetables, as well as, grains. In the case of fruits and vegetables, the reefer container is the appropriate mode of transport. For grains, the closed container is preferred (Figure 20).

FIGURE 20

TRANSPORTATION OF FRUIT, AND VEGETABLE.

Keeping the vegetables cool using ice during transportation in summers

Mobile air blast cooling unit cum reefer container

Government and Agriculture

Various public departments directly serve the farming community in Pakistan. These multi-disciplinary departments help in the groundwork for crops and related activities and are supported by other departments like agri marketing, crop reporting, information, cooperatives, etc. Here is the list of the major departments supporting agriculture in Pakistan.

1. National Agriculture Research Center, Islamabad
2. Nuclear Institute for Agriculture and Biology, Faisalabad
3. National Institute for Biotechnology and Genetic Engineering, Faisalabad
4. Nuclear Institute for Food and Agriculture, Peshawar
5. Nuclear Institute of Agriculture, Tandojam
6. Agriculture Department (Research & Extension) Punjab, Lahore
7. Agriculture Department (Research & Extension) Sindh, Hyderabad
8. Agriculture Department (Research & Extension) Baluchistan, Quetta
9. Agriculture Department (Research & Extension) KPK, Peshawar
10. Agriculture Department (Research & Extension) Gilgit Baltistan, Gilgit

Educational institutions, as listed, produce a large number of agriculture graduates, diploma holders, and professionals.

1. The Islamia University of Bahawalpur, Bahawalpur
2. Bacha Khan University, Charsadda
3. Gomal University, Dera Ismail Khan
4. University of Agriculture, Faisalabad
5. Lasbela University of Agriculture, Water and Marine Sciences, Uthal, Lasbela
6. Hazara University, Mansehra
7. Abdul Wali Khan University, Mardan
8. Bahauddin Zakariya University, Multan
9. Muhammad Nawaz Sharif University of Agriculture, Multan
10. The University of Agriculture, Peshawar
11. Khawaja Fareed University of Engineering and Information Technology, RY Khan
12. University of the Poonch, Rawal Kot
13. Pir Mahar Ali Shah Arid Agriculture University, Rawalpindi
14. University of Sargodha, Sargodha
15. Mir Chakar Khan Rind University, Sibi
16. University of Swabi, Swabi
17. Shaheed Benazir Bhutto University, Sheringal Upper Dir
18. Sindh Agriculture University, Tandojam
19. In-Service Agricultural Training Institute, Sargodha
20. In-Service Agricultural Training Institute, Rahimyar Khan
21. In-Service Agricultural Training Institute, Rawalpindi
22. In-Service Agricultural Training Institute, Layyah
23. Agricultural Training Institute, Sakrand

Qualified individuals from these institutions are employed in various public and private departments and NGOs working in the agriculture sector across the country, with the mandate to assist the farmers and provide them with solutions for the problems they are facing during their day-to-day work. These employees are supporters and working partners of the farmers.

Public departments absorb manpower produced by academia and work in accordance with government policy. Professional agriculturists and farmers are more proficient in their subject for tangible results. Unfortunately, many agricultural service departments in the country are headed by non-agriculture professionals. Moreover, an administrative appointment is time specific, which changes on the arrival of a new incumbent. However, every new administrative appointee may have a different thought process for driving development in the agriculture sector.

Both public and private sectors recognize that Pakistan is an agricultural country, but their efforts are not fully supportive of the farmers. The policymakers usually give preference to industrialists instead of agriculture, while most of the industry is looking towards farmers for their raw materials.

A root cause of poverty among farmers is the misuse of public funds. There are multiple reasons for the poor economic performance and corruption in Pakistan. Moreover, various regulations on farm businesses waste time and resources, causing more problems rather than facilitating solutions. Besides, very few from the farming community are involved in policymaking. Since farming in Pakistan is mostly done by small and medium landholders, they have almost no representation and say in the policy formation process. Big farmers and bureaucrats, with some input from experts, determine the agricultural policy in Pakistan. There is a need to reform the bureaucracy and involve trained professionals in both administration and operations to facilitate SAT.

Readiness Assessment and Gap Analysis

TABLE 5

SAT READINESS ASSESSMENT.

Rating: H: High or Existing; M: Medium; L: Low or non-existent; ND: no data available

Indicator		Hypothesis	2010 or Five Years Before the Latest	Latest
	Development			
Upstream	Existence of laws and policies on agricultural finance	No online database	L	M
	Agricultural insurance penetration ratio	No online database	ND	L
	Share of borrowing smallholders and fishers who borrow from formal sources (%)	No online database	ND	L

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	Indicator	Hypothesis	2010 or Five Years Before the Latest	Latest
Upstream	Technician-to-farmer ratio: public and private	https://www.g-fras.org/en/world-wide-extension-study.html for number of public agri extension workers	8842	ND
	The proportion of agricultural land that is irrigated (%)	http://www.fao.org/faostat/en/#data/RL (Land Use Database)	1.14:1	1.14:1
	Digitization			
	Share of extension personnel who are computer-literate (%): public and private	No online database	ND	L
	Existence of IT-based agricultural insurance products (e.g., remote sensing)	No online database	ND	L
Production	**Development**			
	Existence of a regulatory framework for seed	No online database	L	M
	Existence of a regulatory framework for agrochemicals (fertilizer and pesticide)	No online database	L	M
	Existence of a regulatory framework on agrimachinery	No online database	ND	L
	Tractors per 100 sq km of arable land	https://data.worldbank.org/indicator/AG.LND.TRAC.ZS?view=chart	145	ND
	Average monthly earnings in agriculture (dollars per day)	https://www.ilo.org/ilostat/faces/oracle/webcenter/portalapp/pagehierarchy/Page32.jspx?locale=EN&subject=EAR&indicator=EAR_4MTH_SEX_ECO_CUR_NB&datasetCode=A&collectionCode=YI&_afrLoop=1440882128312155&_afrWindowMode=0&_afrWindowId=null#!%40%40%3Findicator%3DEAR_4MTH_SEX_ECO_CUR_NB%26_afrWindowId%3Dnull%26subject%3DEAR%26locale%3DEN%26_afrLoop%3D1440882128312155%26datasetCode%3DA%26collectionCode%3DYI%26_afrWindowMode%3D0%26_adf.ctrl-state%3D1dhs9vxm6p_156	ND	ND

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	Indicator	Hypothesis	2010 or Five Years Before the Latest	Latest
Production	Rural employment in youth employment (%)	https://www.ilo.org/ilostat/faces/oracle/webcenter/portalapp/pagehierarchy/Page32.jspx?locale=EN&subject=EAP&indicator=EAP_TEAP_SEX_AGE_NB&datasetCode=A&collectionCode=YI&_afrLoop=1440808963924880&_afrWindowMode=0&_afrWindowId=null#!%40%40%3Findicator%3DEAP_TEAP_SEX_AGE_NB%26_afrWindowId%3Dnull%26subject%3DEAP%26locale%3DEN%26_afrLoop%3D1440808963924880%26datasetCode%3DA%26collectionCode%3DYI%26_afrWindowMode%3D0%26_adf.ctrl-state%3D1dhs9vxm6p_110	ND	ND
	The average age of a farmer	No online database	ND	ND
	Average farm size (ha)	No online database	2.6	ND
	Share of smallholder (2 ha and below) who is owner-cultivator	No online database	64	ND
	Share of agricultural workers who are women (%)	https://data.worldbank.org/indicator/SL.AGR.EMPL.FE.ZS?view=chart	74.09	62.18
	Fertilizer utilization per ha	https://data.worldbank.org/indicator/AG.CON.FERT.ZS?view=chart	138.305	155.993
	Pesticide application per ha	No online database	0.7	11.5
	Utilization of certified seeds, the share of total (%)	No online database	ND	ND
	Agricultural GVA per worker	https://data.worldbank.org/indicator/NV.AGR.EMPL.KD	ND	ND
	Agricultural Total factor productivity (TFP) growth	https://www.ers.usda.gov/webdocs/DataFiles/51270/AgTFPindividualcountries.xlsx?v=6612.3	ND	ND
	Digitization			
	Share of youth in agricultural employment (%)	http://data.un.org/Data.aspx?q=population+datamart%5bPOP%2cGenderStat%5d&d=POP&f=tableCode%3a321	ND	ND

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	Indicator	Hypothesis	2010 or Five Years Before the Latest	Latest
Downstream		**Development**		
	Existence of laws and policies on food safety, traceability	No online database	L	L
	Infrastructure score in Global Competitiveness Index	http://reports.weforum.org/global-competitiveness-report-2018/	ND	4
	Logistics performance index	https://lpi.worldbank.org/international/global	2.53	2.59
	Rural road density (km per sq km)	No online database	M	M
	Stocks-to-production ratio, milled rice equivalent	http://www.fao.org/economic/est/publications/rice-publications/rice-market-monitor-rmm/en/	ND	ND
		Digitization		
	Existence of laws and policies on e-commerce	No online database	NE	L
	Share of e-commerce in retail sales	No online database	NE	NE
Enabling Factors		**Development**		
	Existence of laws and policies for agricultural S&T	Existence of laws and policies improves the flow of resources toward R&D.	M	M
	Share of public sector budget for agriculture in total (%)	A higher share implies greater priority placed on agriculture	M	M
	The government budget for agriculture, per agricultural worker (USD)	A higher ratio correlates with more benefits per worker in agriculture	L	L
	Government budget for agricultural R&D, ratio to agricultural GVA (%)	A higher ratio implies more resources for developing new technologies in agriculture	L	L
	Literacy rate (working age population)	A higher rate correlates with the capacity to adopt the latest technologies	ND	59.1
	Average years of schooling (working age population)	More years correlate with the capacity to adopt the latest technologies	ND	10

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	Indicator	Hypothesis	2010 or Five Years Before the Latest	Latest
Enabling Factors	Prevalence of undernourishment	Lower prevalence implies a more responsive agri-food system	ND	20
	Food Security Index	A higher index implies a more responsive agri-food system	ND	52.1
		Digitization		
	Existence of laws and policies for the digitization of agriculture and related sectors	Existence of laws and policies imply a greater and more stable commitment to investing in digitization	L	L
	Existence of laws and policies promoting e-governance	Existence of laws and policies imply government commitment to adopt digital technologies	L	L
	Existence of IT-based Disaster Risk Reduction and Management systems and early warning	Existence implies government commitment to adopt digital technologies	L	L
	The government budget for the digitization of agriculture (USD)	A higher budget implies a higher commitment to adopting digital technologies in agriculture	L	L
	Smartphone penetration ratio: total and rural	A higher ratio implies more readiness to adopt digital technologies	L	M
	Internet penetration ratio: total and rural	A higher ratio implies more readiness to adopt digital technologies	L	M
	Share of primary and secondary schools with access to the Internet (%)	Greater share correlates with greater digital literacy	L	M
	Share of STEM graduates among college graduates (%)	Greater share implies more human resources available for adopting digital technologies	ND	ND

Lesson Learned and Insight from Case Analysis

Need for New Agricultural Technologies

Pakistan's agriculture contributes to food safety and security of feeding the population of the world, a role achieved through the export of many food products. However, many of today's growers are inappropriately using toxic pesticides, excess fertilizers, hormones, and bad quality irrigated water, thereby threatening the health of the consumers as well as their own. Therefore, every effort must be taken to develop technologies and methods that are safe for farmers, consumers, and the environment. Adaptation of modern technology can ensure food safety and security, all the way to consumers' tables.

Preharvest Innovations

Practices in the preharvest phase towards food productivity and food safety include disease-free quality seed, appropriate and recommended use of fertilizer, quality of irrigated water, integrated spray scheme for diseases and insecticides, and harvesting at appropriate maturity level. There is a need for a practical framework, such as training centers to conduct different training programs, access to small loans, and other useful services for farmers that will help them to increase production, without harming the natural resources.

The regulatory framework for new digital technologies is only now being developed. For example, the Prime Minister has recently ratified the establishment of the Civil Drone Authority leading to an increase in the production of drones. Currently, the Pakistan government and the higher education commission are focusing on the exchange of agricultural development, particularly the transfer of technology from China under the CPEC. It is high time the country demands technologies like drones, remote sensing, modern and efficient harvesting technology, and postharvest technology, for use across branches of agriculture including crops, fruits, vegetables, poultry, dairy, and agricultural machinery.

Innovative technologies, such as insect barriers and pheromone traps are significantly reducing the threat and sometimes, eliminating the need to spray pesticides. The disease-resistant varieties are another natural means that millions of farmers use to reduce the need for applying pesticides.

The farming community of Pakistan has the skill and enthusiasm to get more from their arable lands, but unfortunately, they do not have the appropriate agriculture implements and face limited access to machinery such as tractors, combine harvesters, reaper harvesters, threshers, shellers, drills, tube well and pumps, and spray machines. Plenty of opportunity is available to introduce state-of-the-art machinery for use in the agriculture sector in Pakistan. It is also essential to get optimum yield from arable land and even tunnel farming.

Pakistan is experiencing a golden era of water management through the construction of the canal irrigation system. Precision Land Leveling has proven highly beneficial because it minimizes the cost of operation, ensures a better degree of accuracy in much lesser time, saves irrigated water, ascertains uniform seed germination, increases the efficiency of fertilizer, and resultantly, enhances crop yields, which can be supported through smart agriculture transformation. However, better information on climate change and how agriculture can adapt to the changing climate is needed.

Postharvest Innovations

Postharvest losses directly depend on the level and stage of the maturity of produce. One cannot store fully ripe produce like tomatoes, mango, guava, and strawberry. Higher levels of moisture in cereals and grains cause major losses during storage.

The level of maturity plays a critical role in the consumption and storage life of a crop. Different physical characteristics are used to determine the appropriate level of crop harvesting. The common factor for all crops is the calculation of the heating units as TDD/GDD. It seems like a more suitable tactic in this climate change scenario for farmers and growers to safeguard their end product from being wasted.

Storage facilities are necessary for any agriculture-based country. Low-temperature storage is required for fresh fruits and vegetables, while silos and hermetic stores are indispensable for grain and cereal produce. Low-temperature, energy-efficient storage chambers, having a capacity of

5,000-10,000 kg, can help the farmers to safeguard their commodities and sell them at a competitive market price. It would also help to minimize postharvest loss. Low-cost silos and hermetic storage systems would be helpful to maintain the quality and quantity of grain and cereal storage. Low cost is a must in both cases because small- and medium-scale farmers do not have enough capital to construct these systems. Modern storage facilities with improved management effectively minimize the losses of food and retain their quality for a longer storage period. Solar energy can provide an edge in their operational cost. Pakistan has a longer summer season and a storage system working on 15-25 kw can support the farmers in the storage of their produce.

Marketing is one of the factors that determine the success or failure of a farmer's success in generating earnings. Elements of marketing include sources of information, traders, time to sell, use of information technology, and approach to potential markets. Marketing practices vary in different locations. Farmers sell the products with a special commitment in many cases. In these wholesale markets, commission agents play the role of a third party between the farmer and the consumer, subsequently declining the earnings of the farmers.

Data collection on the different addressable issues is also very important to achieve reality-based development. However, the quality of data collection in Pakistan is not very good. There is a need to use advanced technology for data collection on different issues and parameters in the agriculture sector. Data is a key tool in the formulation of new projects under planning and development objectives.

Conclusion

Smart agriculture is the essence of modern farming. Several methods have been introduced in agriculture to increase yield and improve its safety and preservation. Modern farming is growing and developing for the commercialization of crops. Smart farming is a modern concept that uses the Internet, soil scanning, and data management to increase production. Shade net and greenhouse farming is a part of modern farming and is used extensively, supporting farmers and helping them in selecting the right farming method, depending on the weather or water requirements and other cultural practices. Smart agriculture further tackles the interlinked problems of food security and climate change, and supports smallholder farmers by improving the productivity of inputs, such as energy, seeds, and fertilizers, and increases food security. Smart farming practices also help in protecting natural resources for future generations by preserving the ecosystems.

Pakistan is a developing country that is slowly moving towards SAT. Currently, there is no cooperative farming system and farmers cannot shift their agriculture to SAT due to small holdings and financial issues. Nevertheless, SAT can play a critical role in the development of agriculture in Pakistan. It, however, needs full support from the public sector because small and medium farmers do not have the financial resources to adopt SAT and hence, still prefer to use low-cost technology.

Productivity, quality, and innovation require planned investment, and socio-economic development in agriculture is conceivable through the smart agriculture transformation in preharvest and postharvest phases of agriculture produce. Smart agriculture will open up many new horizons, and provide the foundation and confidence in food production and safety. Food for more people is the necessity of the time and modern technologies are very helpful in this regard.

Maximum farm holdings in Pakistan are small to medium in size and there are relatively lesser numbers of large farms. There is a need to address the issues impacting small and medium farms, including the lack of access to modern agriculture practices, as they are the main player in raising the productivity levels of food crops.

Smart agriculture in Pakistan is conducted at a very small scale as compared to the scale of the agriculture sector in the country. Pakistan needs to implement modern and advanced technologies, especially to support small- and medium-scale farming, without ignoring the big farms. The involvement of public and private partnerships in R&D and financial support to the small and medium farming community would produce more effective results in the agriculture sector. The most important issue, which should be addressed in Pakistan is to change the structure of the agriculture department.

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CASE ANALYSIS
THAILAND

This case study examines Thailand's readiness in terms of implementing innovative agricultural and digital technology and thus, transforming the agricultural industry. This will improve agricultural efficiency and productivity, as well as the technical skills of Thai farmers. In this context, the SWOT, readiness assessment, and GAP analysis showed that the government policy is strong enough to drive agricultural transformation during the next decade. Many factors, especially enhanced research and development (R&D) on farm mechanization, the promotion of digital agriculture, and the government policy on developing Agriculture 4.0 for Thailand 4.0, suggest that farmers are ready to adapt and meet the requirements of high-level technology for agricultural transformation. Although political instability, rapid advances in technology, and difficulty in adapting to them are some of the constraints, these obstacles are unlikely to hinder the high-tech agricultural industry from penetrating the agriculture sector of Thailand.

Introduction and Background

Agriculture has always been the mainstay of the Thai economy. Over time, farmers have strived to provide enough food for the Thai people and also, for export. Owing to the benign tropical climate and abundance of fertile soils, the country has become a leading producer of agricultural commodities. From a global perspective, Thailand will continue to be a leading exporter of agricultural produce, especially rice.

Thailand has a total area of 51.2 million hectares (Mha) and approximately 41% is used for agricultural production, and 32% of the population (22 million people) is engaged in the sector. In 2014, the revenue from agriculture amounted to USD46 billion, accounting for 10.5% of the nation's gross domestic product (GDP). However, in 2018, the value of exported agricultural products dropped to USD44.4 billion [1]. The country can be divided into five regions (Table 1) with around 42% of total rice cultivation coming from the Northeast; the Central region has the highest productivity due to its effective irrigation systems. The Ministry of Agriculture and Cooperatives (MOAC) lists the following 15 major crops that are cultivated by Thai farmers- rice, sugarcane, cassava, corn, rubber, palm oil, mung bean, soybean, peanut, sunflower, pineapple, durian, coffee, onion, and garlic.

However, owing to globalization and the world's rising population, the demand for agricultural products continues to rise. The Food and Agriculture Organization (FAO) of the United Nations has indicated that the global demand for agricultural commodities is expected to increase at a rate of approximately 1.4% per annum until 2030, and subsequently at 0.8% until 2050. This means an increase of 40% from 2018 to 2050 [2]. Under this scenario, the shortage of arable land may become a global crisis. While untapped arable land can be sourced in due course, the area of new cultivable land will be insufficient for keeping pace with demand. As a result, improving productivity and yield rates is the key to ensuring future food security for the planet.

Rice is the most important crop in Thailand and it plays a crucial economic role as an export. Rice exports in 2014 amounted to 1.3% of the GDP. Half of the country's cultivated area is used for rice production. The average farm size is around four hectares per household. Rice fields are located in both highland and lowland areas. The most famous strain of rice in Thailand is Jasmine rice (Khao Dawk Mali 105). The other important crops besides rice include cassava, corn, sugarcane, oil crops, perennial trees such as para rubber, and orchards. Cassava is a major export commodity, with Thailand supplying approximately 70-75% of the world's cassava exports [3]. Tables 1 and 2 show different aspects of land utilization nationwide.

TABLE 1

LAND UTILIZATION IN THAILAND BY REGION FROM 2014-2017 (IN HECTARES).

Region	Year	Total Land Area	Forest Land	Agricultural Land Use	Farm Size (rai/ household)	Non- agricultural Land Use
Overall Thailand	2014	51,311,502	16,365,664	23,876,031	4.04	11,069,806
	2015	51,311,502	16,358,557	23,878,783	4.04	11,074,162
	2016	51,311,502	16,347,969	23,881,625	4.04	11,081,908
	2017	51,311,502	16,345,016	23,880,595	4.03	11,085,891
North	2014	16,964,429	9,045,997	5,198,782	3.98	2,719,649
	2015	16,964,429	9,039,502	5,200,010	3.99	2,724,917
	2016	16,964,429	9,029,438	5,200,775	3.97	2,734,216
	2017	16,964,429	9,020,705	5,201,067	3.96	2,742,656
Northeast	2014	16,885,434	2,519,829	10,214,993	3.72	4,150,612
	2015	16,885,434	2,505,626	10,217,576	3.72	4,162,231
	2016	16,885,434	2,503,651	10,218,531	3.74	4,163,251
	2017	16,885,434	2,504,888	10,217,300	3.74	4,163,245
Central	2014	10,390,120	3,030,321	4,979,670	5.92	2,380,099
	2015	10,390,120	3,041,588	4,981,038	5.94	2,367,494
	2016	10,390,120	3,042,586	4,982,001	5.89	2,365,533
	2017	10,390,120	3,045,287	4,982,550	5.82	2,362,283
South	2014	7,071,519	1,769,516	3,482,556	3.42	1,819,446
	2015	7,071,519	1,771,841	3,480,158	3.43	1,819,520
	2016	7,071,519	1,772,293	3,480,317	3.41	1,818,908
	2017	7,071,519	1,774,135	3,479,677	3.42	1,817,707

Source: Royal Thai Survey Department, and Royal Forest Department.

Rice cultivation is highly laborious and there is a need for new technology to alleviate the hard work of the farmers. Thailand has an established agricultural mechanization industry that is knowledge and technology-based. With the number of farm laborers dwindling because of urban migration as well as an aging society, farm mechanization and digitalization are likely to play an important role in agricultural transformation in the next decade.

TABLE 2

AGRICULTURAL LAND USE BY REGION FROM 2014-2017 (IN HECTARES).

Region	Year	Agricultural Land Use					
		Total Agricultural Land	Paddy Land	Upland Field Crops	Fruit Trees and Perennial Trees	Vegetables, Cut Flowers, and Ornamental Plants	Others
Overall Thailand	2014	23,876,031	11,193,434	4,984,005	5,586,863	223,643	1,888,085
	2015	23,878,783	11,194,258	4,986,546	5,585,555	223,836	1,888,587
	2016	23,881,625	11,193,597	4,987,247	5,587,289	224,255	1,889,237
	2017	23,880,595	10,996,526	4,917,444	5,909,140	224,160	1,833,324
North	2014	5,198,782	2,526,411	1,630,937	647,853	71,405	322,176
	2015	5,200,010	2,526,674	1,631,607	647,969	71,480	322,280
	2016	5,200,775	2,526,604	1,631,823	648,471	71,544	322,332
	2017	5,201,067	2,520,412	1,645,437	641,390	71,530	322,297
Northeast	2014	10,214,993	6,839,524	1,910,325	690,749	50,853	723,541
	2015	10,217,576	6,840,247	1,911,498	691,344	50,863	723,624
	2016	10,218,531	6,840,104	1,911,829	691,908	50,898	723,792
	2017	10,217,300	6,679,521	1,831,447	944,446	50,887	710,996
Central	2014	4,979,700	1,631,654	1,441,083	1,182,776	81,046	643,139
	2015	4,981,038	1,631,770	1,441,784	1,183,018	81,116	643,350
	2016	4,982,001	1,631,628	1,441,935	1,183,270	81,405	643,762
	2017	4,982,550	1,631,910	1,438,882	1,186,583	81,225	643,950
South	2014	3,482,556	195,845	1,660	3,065,483	20,339	199,228
	2015	3,480,158	195,568	1,657	3,063,224	20,376	199,333
	2016	3,480,317	195,260	1,670	3,063,639	20,408	199,351
	2017	3,479,677	164,682	1,678	3,136,719	20,517	156,080

Sources: 1) Royal Thai Survey Department; and 2) Royal Forest Department.

TABLE 3

VALUE OF EXPORTS, IMPORTS, AND BALANCE OF TRADE FROM 2014–2018 (IN USD MILLION).

Items	2014	2015	2016	2017	2018
Total exported	235,615	232,879	243,153	257,982	260,867
Agricultural products	42,191	39,402	40,317	46,296	44,799
Food and agricultural products	33,5549	32,153	33,166	36,331	36,856
Agricultural products for agro-industry	8,642	7,250	7,151	9,966	7,942
Non-agricultural products	193,424	193,476	202,836	211,686	216,068
Total re-exported	265	246	457	326	254
Agricultural products	12	21	41	51	23
Food and agricultural products	12	21	41	51	23
Agricultural products for agro-industry	n.s.	0.1	0.7	0.03	0.03
Non-agricultural products	252	226	416	275	231
Total imported	238,874	222,812	222,235	244,785	261,271
Agricultural products	14,459	15,059	16,090	16,419	16,550
Food and agricultural products	13,536	14,320	15,431	15,720	15,825
Agricultural products for agro-Industry	923	739	659	700	725
Non-agricultural products	225,706	207,753	206,145	228,366	244,721
Balance of trade	–2,994	10,313	21,375	13,523	–150
Agricultural products	27,744	24,363	24,268	29,928	28,272
Food and agricultural products	20,026	17,853	17,776	20,661	21,054
Agricultural products for agro-industry	7,719	6,511	6,493	9,266	7,217
Non-agricultural products	–30,739	–14,051	–2,894	–16,404	–28,422

Note: 1 USD = 30.995 THB.
Source: Cooperation between the Office of Agricultural Economics and the Customs Department.

Table 3 reveals that between 2014 and 2018, agricultural products comprised approximately 17% of the total export values, and the main customers are China, Japan, and the USA, as is evident from Table 4.

TABLE 4

EXPORT VALUE OF AGRICULTURAL PRODUCTS TO MAJOR CUSTOMERS FROM 2014-2018 (IN USD MILLION).

	2014	2015	2016	2017	2018
Value of agricultural products	42,191	39,402	40,317	46,296	44,799
China	8,517	8,135	7,762	10,099	9,174
Japan	5,093	5,005	5,190	5,430	5,219
USA	3,929	3,878	4,275	4,380	4,122
Vietnam	1,246	1,093	1,441	2,461	2,298

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	2014	2015	2016	2017	2018
Malaysia	2,070	1,821	1,729	1,958	1,950
Indonesia	1,295	1,307	1,667	1,541	1,875
Myanmar	1,071	1,155	1,230	1,340	1,351
Cambodia	896	792	951	1,146	1,258
Philippines	728	816	912	784	1,204
United Kingdom	1,181	1,125	1,107	1,033	1,073
Others	16,163	14,273	14,052	16,091	15,274

Note: 1 USD = 30.995 THB.
Source: Cooperation between the Office of Agricultural Economics and the Customs Department.

Focus and Scope of the Case Study

Thailand has been a food exporting country since the 13th Century (~800 years ago). The country's agricultural production expanded during the 1960s and 1970s following the governmental policy to open up more arable land and reduce the number of unemployed farm laborers. Between 1962 and 1983, the agriculture sector grew by 4.1% per year, peaking in 1980 when it employed over 70% of the working population. Agriculture continued to grow at a rate of 2.2% per annum between 1983 and 2007. By 2021, Thailand had become an aging society with 20% of the population over 60 years old. This is leading to a shortage of farm labor in the agriculture sector. It has also served as a stimulus for introducing more on-farm mechanization and digitalization. In a similar context, the National Statistical Office (NSO) reported that in March 2018 approximately 11.8 million people were working in the agriculture sector, which decreased to 10.58 million by February 2019 [4]. However, Thailand still leads the world in the production and export of agricultural commodities. Major exports include rice, cassava, rubber, sugar, tapioca, mung bean, pineapple, other fruits, ready-to-eat food, shrimp, chicken, pork, crab, tuna, and sardine. In fact, Thailand can produce enough food to feed its population fourfold and is the world's largest exporter of rice.

Under the government policy to evolve Agriculture 4.0 for Thailand 4.0, the development of smart farming is a key component. This is part of the 20-year road map to enable Thailand to pass through the middle-income trap. Five S-curve and Six new S-curve industries have been established to promote national economic growth. The government has highlighted opportunities and investment trends in 11 targeted industries that are divided into two categories. The first Five S-Curve industries include next-generation automotive, intelligent electronics, advanced agriculture and biotechnology, and food processing and tourism. These industries have been selected to use technological innovation to strengthen the sectors and enhance Thailand's competitiveness. The six new S-Curve industries that were added in 2018 comprise the digital sector, robotics and automation, aviation and logistics, biofuel, and biochemical, medical hub, and dual-use technology. These were added to develop additional industries that can accelerate one new industrial base growth. The agriculture and food industries are the two most important S curves to facilitate an upstream and downstream flow. Under the policy, the government has been attempting to convince the private sector to invest in R&D and increase its percentage by up to 1% of the national GDP.

However, there is a need for the development of cutting-edge farm mechanization and to establish concomitant training programs for smart farmers so they can efficiently use and manage the new technology under local conditions during the next decade. While promoting this technology thrust, the country also needs to address the increased production, the issue of aging farmers, and the farm labor shortages nationwide.

Rice farmers are constrained and discouraged due to fluctuating productivity levels, low prices, drought, labor shortages, and so on that they have not experienced in the past at this level. Statistical data reveals that Thailand is a net producer of agricultural commodities for export. Approximately 11 Mha of land is used for rice cultivation while the yield of rice is falling to 3 tonnes per ha as shown in Table 5. Irrigation has a highly significant role in producing satisfactory rice yields because cultivation in rain-fed areas, especially in the Northeast, is affected by drought and infertile soils that impede sustainable harvests.

TABLE 5

RICE PRODUCTION OF FIRST AND SECOND CROPS IN THAILAND FROM 2009-2018.

Year	Planted Area (1,000 ha)	Harvested Area (1,000 ha)	Production (1,000 tonnes)	Yield Per ha (kg)	Farm-gate Price (in USD/tonne)	Farm-gate Value (in million USD)
2009	11,635	11,140	32,398	2,906	322	10,424
2010	12,908	12,119	36,004	2,969	349	12,557
2011	13,345	11,956	38,102	3,187	382	14,556
2012	12,966	11,956	38,000	3,181	366	13,925
2013	12,341	11,684	36,762	3,142	325	11,961
2014	11,080	10,665	31,617	2,962	299	9,464
2015	10,112	9,628	27,420	2,850	303	8,318
2016	11,056	10,712	31,857	2,975	270	8,590
2017	11,406	10,720	32,899	3,068	286	9,701
2018	11,343	10,398	31,977	3,062	356	11,378

Note: 1 USD = 30.995 THB.

Rice Cultivation in Thailand: The Current Situation

Upland rice and lowland rice cultivation are the two farming methodologies used in Thailand. For lowland rice, which has available irrigation, germinated seed broadcasting after land preparation had been favored by farmers for a long time.

However, because of farm labor shortages, demand for higher productivity, and lower cultivation costs, the use of mechanized rice transplanters is now more popular. For upland rice, which is rain-fed, farmers opt for dried seed broadcasting after land preparation. Upland rice yields are generally low due to perennial droughts. Normally, the farmer plants the rice seedlings in the rainy season when water is available. In some upland areas, which are prone to water shortage, dry direct broadcasting is employed. As for lowland rice, rented rice transplanters are becoming popular. Once again, this highlights the aging society and labor shortage issues of the farms that are influencing the trends toward farm mechanization. The following photographs show rice cultivation using modern farm machinery in Thailand.

FIGURE 1

RICE CULTIVATION USING MODERN FARM MACHINERY IN THAILAND.

Mechanized land preparation

The use of walking tractors for land preparation

Training session on seedlings preparation

Rice transplanter in action

Water management in rice fields

Local combine harvester in operation

A New Approach to Rice Cultivation in the Digital Era

For several years now, training for young and smart farmers on land preparation technologies, such as real-time kinematic positioning (RTK) and global navigation satellite system (GNSS), for reforming rice and other field crops cultivation methodology is being promoted to increase crop productivity. The reforming of crop cultivation includes land leveling, irrigation systems, mechanization, and digital technology. The use of a multispectral camera mounted on an unmanned aerial system (UAS) for specific farm management and yield prediction has also been tested and evaluated by public as well as private organizations [5]. These technologies not only help boost production but also empower smart farmers to make optimum use of their land. It is hoped that they will be disseminated nationwide in due course. The following photographs depict new rice cultivation technologies being promoted in Thailand.

FIGURE 2A

NEW RICE CULTIVATION TECHNOLOGIES PROMOTED IN THAILAND.

Land leveling equipment in operation

Rice field observations after land leveling

The use of precision equipment for agriculture

Farmers in Thailand using robotic rice transplanter

FIGURE 2B

NEW RICE CULTIVATION TECHNOLOGIES PROMOTED IN THAILAND.

A precision rice transplanter

Precision tools attached to a rice transplanter


Control pad of an agri-UAV


Agri-UAV evaluation in operation


Agri-UAV demonstration in a rice field

This methodology has proved in practice, that the production of rice increases in this specific field experiment as compared to the conventional method. Less time and labor are also required for the operations on the field.

For upland rice fields, where water is scarce, mechanized rice seeders that dispense dried seed or germinated seed have been promoted by public and private organizations, to mitigate labor shortages. They also help in minimizing the damage from drought, particularly in the Northeast.

Farm Mechanization Training

Training on farm mechanization has been initiated for farmers' groups by many organizations in Thailand, such as the MOAC, and also through cooperation between the public and private sectors. The farmers learn about soil and water management, land leveling, land preparation, seedling preparation, pesticide and herbicide equipment use, and how to use machinery such as rice combine harvesters. The training also encompasses animal husbandry, aquaculture, and irrigation management. Agricultural digital technology has also been taking farmers' perspectives into account. The MOAC reported that 57,125 smart and young smart farmers were trained in 2017 [6]. They were empowered to meet the requirements for agricultural transformation in the near future. The following photographs show different training activities.

FIGURE 3

TRAINING ON FARM MECHANIZATION IN THAILAND.

Explaining seeder components

Differentiating seeders

Machinery practice for farmers

Farm Mechanization Manufacturing Industry: From Local to Global

Until recently, the Thai farm mechanization manufacturing industry has served locally only, producing basic farm machinery such as land preparation equipment, walking tractors, and rice threshers. More sophisticated farm machinery is being imported to increase agricultural production. Several private companies are also becoming involved now in the production of more complex machinery such as rice combine harvesters, tractors, and sugarcane harvesters. Table 6 shows that the average growth rate in the export value of this domain to the members of the Association of Southeast Asian Nations (ASEAN) community from 2010-2014 was around 28.24%. Today, the industry is not only targeting the local and ASEAN markets but also other countries in South Asia and Africa. Table 7 identifies the export value of farm machinery categories and shows the percentages of exported farm machinery, which indicate the growth of this industry. The import-export and trade balance of Thailand's agricultural machinery is shown in Table 8. The increasing trend of the import and export value to the ASEAN members and other countries can be observed and it can be implied that the quality of Thailand's agricultural machinery products has been accepted by the customers and it also shows a significant level of mechanization in this part of the world.

TABLE 6

EXPORT VALUE OF THAI AGRICULTURAL MACHINERY TO ASEAN MEMBERS FROM 2010-2014.

Year	Export Value (in USD million)	Growth (%)
2010	146	
2011	240	64.4
2012	304	26.7
2013	339	11.5
2014	470	38.6
CAGR: 2010–2014		**28.24**

Source: UN Comtrade, 2015.

TABLE 7

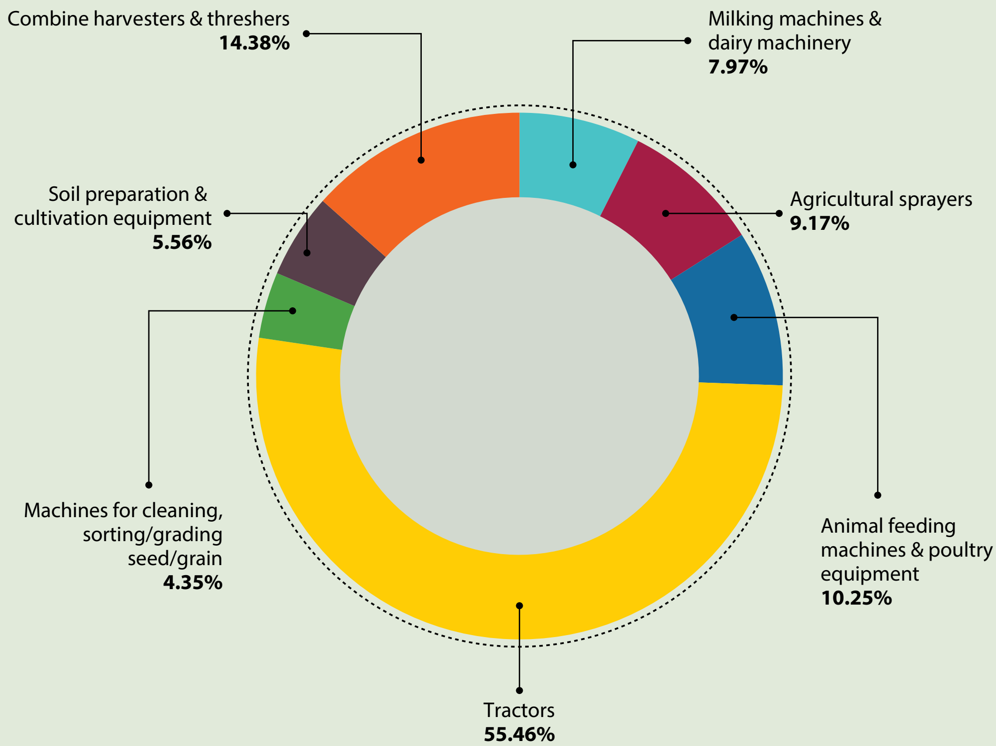
EXPORT VALUE ACCORDING TO MACHINE TYPE (IN USD).

Machine types	2010	2011	2012	2013	2014
Tractors	71,917,503	112,529,726	125,464,455	157,500,117	223,320,386
Combine harvesters and threshers	25,779,486	39,462,855	63,784,105	69,986,060	93,810,635
Soil preparation and cultivation	15,439,568	27,298,837	30,236,793	31,551,023	35,786,297
Equipment, agricultural sprayers	597,522	926,755	903,625	1,206,672	1,446,703
Milking machines and dairy machinery	3,151,161	237,824	323,063	2,079,049	1,395,417
Animal feeding machines and poultry equipment	2,389,247	3,837,429	6,661,579	7,696,641	7,121,369
Machines for cleaning, sorting, or grading seed or grain	898,382	696,899	1,548,371	958,325	1,157,730
Total	120,172,869	184,990,325	228,921,991	270,977,887	364,038,537

Source: UN Comtrade, 2015.

FIGURE 4

PERCENTAGE OF EXPORTED FARM MACHINERY.



Source: UN Comtrade, 2015.

TABLE 8

IMPORT-EXPORT AND TRADE BALANCE OF THAILAND AGRICULTURAL MACHINERY (MILLION USD)

	2012	2013	2014	2015	2016	2017	2018	2019
Import	1,125	1,147	1151	1,153	1,207	1,237	1,152	1,210
Export	595	655	818	974	1,100	1,119	1,168	1,077
Trade balance	–530	–492	–333	–179	–107	–118	16	–133

Note: 1 USD = 30.995 THB.
Source: https://news.isit.or.th:8080/isit/website.

Digital Infrastructure for Agricultural Transformation

Figure 5 shows that Thailand has a total population of approximately 69.11 million, 51.3% of which are female and 48.7% male. There is an annual 0.2% change in demographic size. Per capita GDP is around USD16,946 and general literacy is around 97%. More than half of the population (53%) is urban-based. Figure 6 demonstrates that the penetration of Internet use is around 82% or 57 million people have access to it. There are 93.61 million mobile telephone subscribers and 67% actively use social media. In 2015, the Provincial Electricity Authority reported that 80,062 villages or 99.99% of villages nationwide had access to electricity [7]. Such data on this important infrastructure indicate that facilitating the digital transformation of agriculture nationwide is unlikely to be hindered.

FIGURE 5

POPULATION AND ECONOMIC INDICATORS OF THAILAND.

Source: Hootsuite, 2018.

FIGURE 6

KEY DIGITAL STATISTICAL INDICATORS FOR THAILAND.

Source: Hootsuite, 2018.

Figure 7 illustrates that about 78% of the population has a bank account but only 4% make online purchases and use smartphone applications for conducting their daily lives. Figure 8 explains the daily life activities that people can manage with smartphones.

FIGURE 7

FINANCIAL INCLUSION FACTORS FOR THAILAND.

Source: Hootsuite, 2018.

FIGURE 8

SMARTPHONE LIFE MANAGEMENT ACTIVITIES IN THAILAND.

Source: Hootsuite, 2018.

Figures 9 and 10 also address the trends in e-commerce in Thailand. The data reveals that traveling, electronics and physical media, and fashion and beauty items score high on e-commerce platforms. Around 11.92 million people purchase consumer products through e-commerce platforms with the total annual sales revenue touching USD2.962 billion in 2018.

FIGURE 9

TOTAL ANNUAL E-COMMERCE SPEND BY CATEGORY.

Source: Hootsuite, 2018.

FIGURE 10

OVERVIEW OF THE E-COMMERCE MARKET FOR CONSUMER GOODS IN THAILAND.

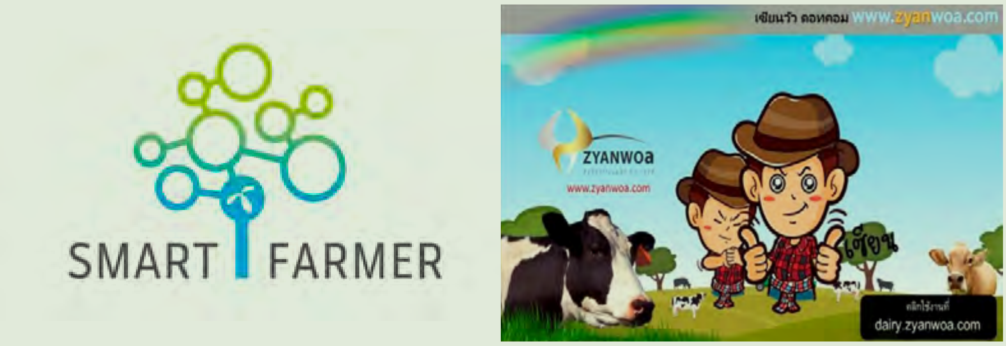
Source: Hootsuite, 2018.

Mobile Applications for Smart Farmers

Smart applications for agriculture have recently been developed in Thailand, as shown in Figure 11, by academia and private companies. These applications can report data via smartphones and also by using cloud-based systems. They not only address field crops, animal husbandry, dairy industry, weather forecasting, and the use of pesticides but also help in soil and water management in the local area of cultivation, among other sectors. They aim to support farmers in enhancing cultivation and agricultural activities such as increasing the yield, reducing crop damage, and increasing the income of the farmers with the ultimate objective of modernizing the national agriculture system [8]. In the case of ZYANWOA, a mobile application for dairy cows and cattle beef, it is now very useful for dairy and cattle farms. The farmers can use this mobile application for recording the farm data such as farm registration, breeding, fattening, veterinarian calling, and milk recording. Overall, 6,608 of the 170,000 dairy farmers have been using this application [9]. These mobile applications backstop the provision of a suitable national agricultural infrastructure, to prepare for the transformation of agriculture to digital agriculture in the coming decade.

FIGURE 11

MOBILE APPLICATIONS FOR SMART FARMERS.



Source: Total Access Communication Public Company Limited website; https://www.dtac.co.th/sustainability/en/project/Project-SmartFarmer.

Analysis of the Current Situation

To assess the current situation for digital transformation in the agriculture sector, strengths, weaknesses, opportunities, and threats (SWOT) analysis, readiness assessment, and GAP analysis were conducted to identify the national index for this study. The results can be used to inform the policy development discussion about Agriculture 4.0 (A4.0) for the country. Details are provided in Table 9.

TABLE 9

SWOT ANALYSIS OF THE CURRENT STATUS OF AGRICULTURAL TRANSFORMATION.

Strengths	Opportunities
• Strong supply chain from the local farm mechanization (FM) industry • Plentiful raw materials for agricultural production • Skilled labor working in the FM industry. • Strong local agricultural production capacity • Agglomeration of the local FM industry to support technology and knowledge sharing • Specific local industrial standards for FM to support local development	• The aging society and labor shortages increase the incentive to invest in A4.0 • Growing local demand for hi-tech digital technology for machinery • Government policy aimed at promoting A 4.0 • Attractive direct investment incentives, maximum corporate income tax holiday of 8 years • Reliable infrastructure including electricity, fixed broadband Internet, and 4G technology • Dedicated local R&D institutes and extension centers to promote FM and digital transformation in A4.0

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Weaknesses	Threats
• FM manufacturing processes are still not advanced • Lack of access to funding among farmers to upgrade to hi-tech digital technology for machinery • Some older farmers are not familiar with A4.0	• Political uncertainty may cause the discontinuation of the A4.0 policy • Lack of integrated and holistic cooperation to implement the smart farmer policy • Large players in the market may create barriers for new entrants • Rapidly changing technology • Commodity prices are volatile, downturns in price may lower future demand • Climate change impacts lead to a decline in farmers' income, which lowers farmers' purchasing power • Fluctuations in international currency exchange rates

The strengths (e.g. good infrastructure, plentiful raw materials for production) and weaknesses (e.g. labor shortage, aging society) in the SWOT analysis indicate that the Agriculture 4.0 policy will be the driving force for agricultural transformation in Thailand via the adoption of innovative technology. However, political instability, a slow adaptation of technology by conservative farmers, limited funding, rapidly changing advances in technology that are hard for the farmers to catch up to, and global warming impacts on the yield and field practice will be significant constraints for the development of the agriculture sector in Thailand.

The Readiness Assessment and GAP Analysis

The readiness assessment and GAP analysis evaluated the level of preparedness in the agriculture sector for transformation. A rating system (H = high or extant, M = medium, L = low or non-existent, ND = no data) for indicators and hypotheses were used to rank downstream, upstream, and enabling factors. The results are given in Table 10.

TABLE 10

READINESS ASSESSMENT AND GAP ANALYSIS.

	Indicator	Hypothesis	2010	Latest
	Development			
Upstream	Existence of law and policy on agricultural finance	Having a law and policy improves the business climate for providing agricultural finance	M	H
	Agricultural insurance penetration ratio	Insurance reduces agricultural risk, increases investment, and credit for agriculture	M	H
	Share of borrowing smallholders and fishers who borrow from formal sources (70%)	The shift from informal to formal borrowing reduces the borrowing rate	L	M
	Technician-to-farmer ratio: public and private	Lower numbers of farmers per technician imply greater access to extension services	M	H

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	Indicator	Hypothesis	2010	Latest
Upstream	The proportion of agricultural land that is irrigated (16.7%)	The shift from rain-fed to irrigated technology raises cropping intensity and yields	L	M
		Digitalization		
	Share of extension personnel who are computer-literate (95%): public and private	Technicians who are computer-literature can disseminate IT-based services to farmers	M	H
	Existence of IT-based agricultural insurance products (e.g., remote sensing)	The existence of such products implies demand for risk instruments with the latest data technologies	L	M
Production		**Development**		
	Existence of a regulatory framework for seed	Existence of a regulatory framework that improves the business climate for private sector investment	M	H
	Existence of regulatory a framework for agro-chemicals (fertilizer and pesticide)		M	H
	Existence of a regulatory framework on agri-Machinery		L	M
	Utilization of farm machinery, in horsepower per hectare	More horsepower implies a greater spread of mechanization	M	H
	Agricultural wage (10 dollars per day)	Higher agricultural wages increase incentives to adopt farm machinery	L	M
	Rural employment in youth employment (7%)	A lower share implies a greater need to mechanize farm operations	L	M
	The average age of farmers (60 years)	Higher age implies a greater need to mechanize farm operations	M	H
	Average farm size (4 ha)	Smaller average farm size implies a preponderance of smallholders	M	M
	Share of smallholders (2 ha and below) who are owners-cultivators	Owners-cultivators are the relevant decision-making units for farm mechanization and digitalization	L	M
	Share of agricultural workers who are women (50%)	A higher share implies greater participation of women in agriculture	M	M

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	Indicator	Hypothesis	2010	Latest
Production	Fertilizer utilization per hectare	Greater utilization implies more soil nutrients leading to higher productivity (but excess may be detrimental)	M	H
	Pesticide application per hectare	More pesticide application implies lower losses from pest infestation (but excesses may be detrimental).	H	M
	Utilization of certified seeds, the share of the total (90%)	A higher share implies better chances of reaching the potential yield	M	H
	Agricultural gross value added (GVA) per worker	Higher GVA per worker implies higher productivity and a degree of transformation	L	M
	Total factor productivity (TFP)	Higher TFP means a faster rate of technical progress in agriculture	L	M
	Digitalization			
	Share of youth in rural employment (7%)	A greater share implies a greater potential to adopt digital technologies	L	H
Downstream	**Development**			
	Existence of laws and policies on food safety and traceability	The existence of laws and policies upgrades the quality of the agri-food system	M	H
	Infrastructure score in the Global Competitiveness Index	A higher score implies a better state of infrastructure	M	H
	Logistics performance index	A higher index implies better logistics performance	M	H
	Rural road density (kilometer per square kilometer)	Higher density implies greater connectivity from farms to markets	M	H
	Stocks-to-production ratio, milled rice equivalent	More stocks imply more storage facilities	M	H
	Digitalization			
	Existence of law and policy on e-Commerce	The existence of laws and policies improves the business climate for investors in the e-Commerce platform	M	H
	Share of e-commerce in retail sales	Greater share implies a greater opportunity for online marketing for agricultural products	M	H

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	Indicator	Hypothesis	2010	Latest
	Development			
	Existence of laws and policies for agricultural science and technology	The existence of laws and policies improves the flow of resources towards R&D	M	H
	Share of the public sector budget for agriculture in the total (3-4%)	A higher share implies greater priority placed on agriculture	L	M
	The government budget for agriculture, per agricultural worker	A higher ratio correlates with more benefits per worker in agriculture	L	M
	The government budget for agricultural R&D, ratio to agricultural GVA (0.25%)	A higher ratio implies more resources for developing new technologies in agriculture	L	L
	Literacy rate (working age population)	A higher rate correlates with the capacity to adopt the latest technologies	H	H
	Average years of schooling (working age population)	More years correlate with the capacity to adopt the latest technologies	M	H
Enabling Factors	Prevalence of undernourishment	Lower prevalence implies a more responsive agri-food system	L	L
	Food Security Index	A higher index implies a more responsive agri-food system	H	H
	Digitalization			
	Existence of laws and policies for the digitalization of agriculture and related sectors	The existence of laws and policies implies a greater and more stable commitment to investing in digitalization	M	H
	Existence of laws and policies to promote e-Governance	The existence of laws and policies implies government commitment to adopt digital technologies	M	H
	Existence of IT-based disaster risk reduction and management system and early warning	Existence implies government commitment to adopting digital technologies	M	H
	The government budget for the digitalization of agriculture (USD)	A higher budget implies a higher commitment to adopting digital technologies in agriculture	L	M
	Smartphone penetration ratio: total; rural	A higher ratio implies more readiness to adopt digital technologies	M	H

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	Indicator	Hypothesis	2010	Latest
Enabling Factors	Internet penetration ratio: total; rural	A higher ratio implies more readiness to adopt digital technologies	M	H
	Share of primary and secondary schools with access to the Internet (100%)	Greater share correlates with greater digital literacy	L	H
	Share of science, technology, engineering, and mathematics (STEM) graduates among college graduates (33%)	Greater share implies more human resources available for adopting digital technologies	L	M

The readiness assessment and GAP analysis indicate that Thailand is relatively well-prepared for medium and high-level technological adaptation (digitalization). The Thai agricultural industry has all the enabling downstream to upstream factors in place in terms of inventories, stocks, financing, human resources, conversion technology, and infrastructure. These factors play a very important role in motivating local farmers to use the new technologies and eventually transform the agricultural industry. However, the ratio of agricultural GVA is low and therefore, might be a hindrance to the transformation of agriculture. Recently, research funding organizations in the country have been promoting the collaboration framework for a research grant for Agriculture 4.0, supported by the government policy and also, the implementation to drive the digital transformation of agriculture.

Lessons Learned, Insights, and the Way Forward

From the data and information collection, this study shows and indicates the technology readiness level of Thailand for agricultural transformation using digital technology and innovative farm mechanization to drive the modern agricultural industry. A development constraint is an inadequate and overlapping collaboration among related organizations. The government should encourage agencies such as the Ministry of Agriculture and Cooperatives to take a lead for Agriculture 4.0. The Ministry of Labour and Ministry of Digital Economy and Society, as well as all the research entities, should be encouraged for providing a training course on the digital transformation of agriculture 4.0. Private and industrial sectors should also take the lead in agriculture industry 4.0. Banks and financing institutions should learn and prepare for the new policy. The road map of the agricultural sector development should focus on human resource development, such as training courses for the smart and young smart farmer, or course syllabus of precision agriculture for graduate students, and increased funding and soft loans from formal sources for farmers to access farm machinery and digital technology to increase the agricultural productivity and assure food security. For example, in the agricultural industry, Sunsweet Public Co., Ltd, has adopted digitalization for field cultivation of sweet corn plantations in the North of Thailand. The use of digitalization, solar pump, weather station, soil moisture sensor, certified seeds, and UAVs for agriculture has been promoted to increase the productivity of sweet corn [10]. The productivity of sweet corn increased from 9.375 tonnes/ha to 15.625 tonnes/ha leading to an increase in the farmers' income to around USD1,000 per hectare. These results showed that digitalization of the agriculture sector can help farmers considerably, by providing information on the management of soils, plants, and water, and also on crop disease prevention, weather forecasting, and crop yields. It also enables the dissemination of information on other aspects of farm management and how to optimize cultivating conditions to achieve higher crop yields. This can lead to the transformation of Thailand's agriculture sector in the coming decade.

Conclusion

Thailand has great potential in this regard due to enabling factors such as infrastructure, human resource development, and government policy. More investment by the private sector in R&D as well as funding for local farmers are supporting factors driving growth. Additionally, the strong industrial sector, aging society, and lack of labor will drive the agricultural industry of Thailand to more sophisticated technological levels. Under this particular study, infrastructure and conditions that show the readiness of Thailand for the transformation of the agricultural industry include strong and well-prepared agricultural machinery, digitalization, lack of labor, an aging society, low-interest business loans, R&D, and support of private sector in R&D. These factors exhibit a high degree of readiness from Thailand for agricultural transformation from a basic agricultural industry to a high-tech one. Digitalization of the agricultural sector will help farmers in many aspects including providing information on soil, plants, diseases, weather, crop yield, etc., managing farming activities, and optimizing the cultivating conditions to achieve the highest crop yield. This will lead to an essential transformation of the agricultural sector in Thailand for the next decade.

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CASE ANALYSIS
VIETNAM

Agriculture, forestry, and fishery play an important role in Vietnam's economy. Together, they contributed 13.96% of the country's GDP in 2019. The three sectors are also the main source of raw materials and inputs for economic and social development and employ 35.4% of the labor force from among the 65% population that lives in its rural areas. Although the agricultural sector in Vietnam has achieved significant success, it is faced with several challenges that hinder its initiatives toward Smart Agriculture Transformation. This research and case analysis aims to determine the readiness level of Vietnam for SAT and provide scientific recommendations for pushing the process forward.

The research utilizes both qualitative and quantitative methods (scoring) to assess SAT readiness at three levels: upstream, production, and downstream. The results show that despite a clear improvement in the country's SAT readiness at all three levels over the years, it needs to pay more attention to certain areas like IT-based agricultural insurance, land accumulation for large farm size, labor training, agricultural TFP and GVA per worker, the share of e-commerce, and performance of the logistics sector. The research suggests that the SAT readiness for Vietnam is at a medium level and there is still a gap between policy development and the actual implementation to support the transformation process.

The SAT readiness assessment is an important and necessary step toward developing an appropriate roadmap for the adoption of the smart agricultural process. There has been a paradigm shift towards sustainable, high value-added, and effective use of natural resources and agricultural inputs, in the context of increasing scarcity of resources employed in agriculture production. This shift is presented clearly in the Agriculture Restructuring Proposal (ARP) of Vietnam, approved by the Prime Minister in 2013.

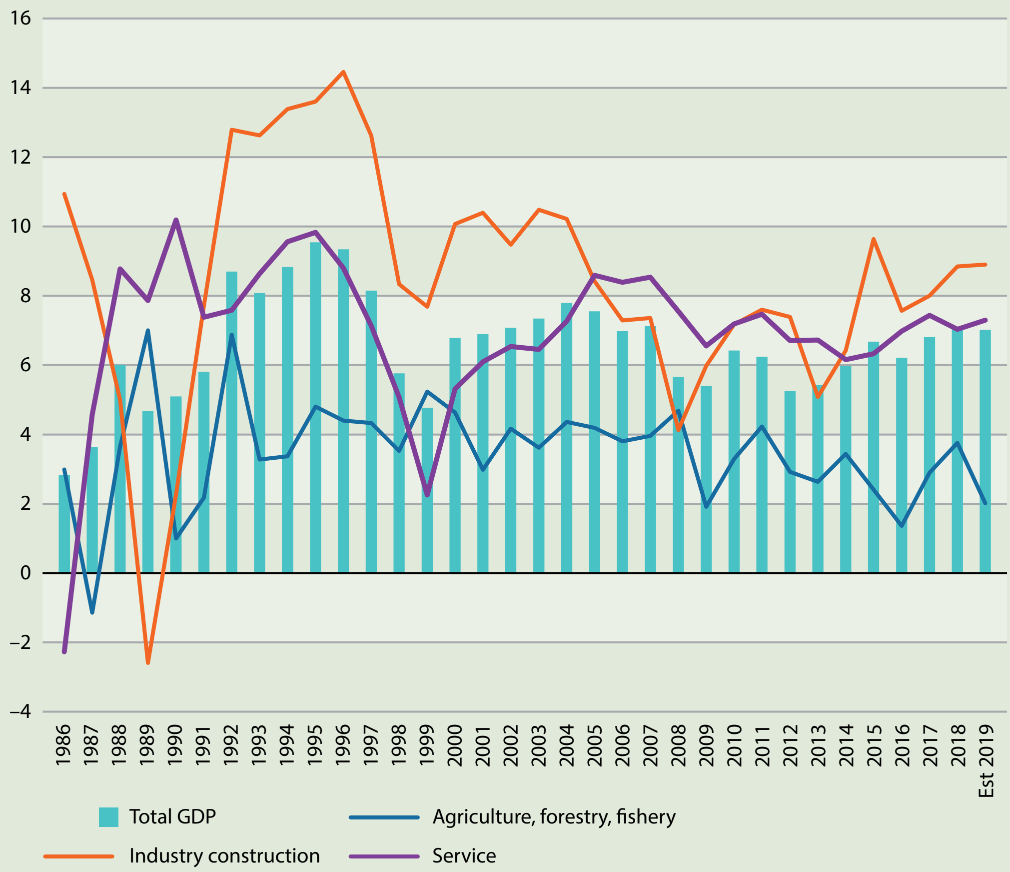
Introduction and Background

During the last 30 years, Vietnam has done astonishingly well on the economic growth front, with an average annual GDP growth of 6% [2], the highest among other growing economies in the world. The country's agricultural sector has also made enormous progress, which along with the forestry and fishery sectors play an important role in Vietnam's economy. Together, the three sectors employ 35.4% of the labor force from among the 65% population that lives in rural areas [3]. A larger percentage of the population in Vietnam still depends on the agricultural sectors for livelihood, including informal labor [3].

Steady advances in smallholder farm productivity and intensification through the 1990s and beyond have played a central role in Vietnam's successes in reducing poverty and ensuring national food security and social stability. The agricultural sector in Vietnam has evolved in a relatively short time making Vietnam a major global supplier of agricultural and food products.

FIGURE 1

GDP GROWTH OF DIFFERENT ECONOMIC SECTORS IN VIETNAM (%).



Source: General Statistics Office, Ministry of Planning and Investment, Vietnam.

During the past three decades, the service sector has been the largest contributor to national output, accounting for over 40% of total GDP. It is followed by the industry sector and then agriculture which contributes the least at an average of about 16% of the total GDP (see details in Figure 3). However, agricultural production has kept a stable growth rate of around 3% annually (see Figure 1). Even though the annual rate slowed down in recent years, it has maintained rates higher than most countries in the region [3]. However, the slowdown trend might be taken as a warning signal that the earlier sources of the sector's boom might not be sustainable. While rice remains, by far, the most important commodity, there has been an important change in the composition of production, away from staple foods to other commodities, perennial crops, and livestock production in particular. This reflects the strong orientation toward the export of perennial crops and changes in consumers' preferences for higher-value products [2]. While production of the best-performing crops is driven by exports, livestock products are destined almost exclusively for the domestic market and their production growth reflects the growing demand from domestic consumers.

Vietnam has experienced food shortages and hunger in the past, but its per capita food availability at present ranks among the top tier of middle-income countries. It has also become one of the top exporters of rice, rubber, coffee, pepper, cashew nuts, wood products, and fisheries of the world. The agricultural sector has always traded surplus, even through the hardest period (see Appendix

1). The export turnover of the agricultural sector hit a record, crossing over USD41.3 billion in 2019. Nevertheless, most of Vietnam's agricultural export products have not taken full advantage of the market opportunities for generating value addition. Even though Vietnam is among the five leading exporters for most of the export commodities, both in volume and value, those products are sold mainly based on cost arbitrage at much cheaper prices in comparison to the competition with other global leaders [4].

During recent decades, the expansion and intensification of Vietnam's agriculture have led to environmental exploitation and intensive and inefficient use of inputs [4]. As arable land is relatively scarce[1], with just 0.34 ha per capita, and agriculture is dominated by small farms and widespread subsistence farming[2], the pressure on the land is further exacerbated by its low quality. Moreover, in Vietnam, agricultural production accounts for up to 95% of total water withdrawals [5], and the sector faces growing competition for land and water from the industry as well as services sectors.

TABLE 1

EXPORT OF AGRICULTURAL PRODUCTS IN VIETNAM.

Commodity	World Export (in USD billion)	Market Share of Vietnam (in %)	Ranking on Export Value	Ranking on Export Price
Rice	20.1	11.3	3	10
Vegetable and fruits	177.6	2.1	19	15
Coffee	30.9	10.5	2	10
Black pepper	4.7	23.9	1	8
Cashew nuts	7.5	46.8	1	6
Rubber	170.2	11.4	3	10
Tea	7.3	2.2	9	10
Shrimp	18.6	16.9	1	2
Catfish (pangasius)	1.8	95.0	1	1
Furniture/wooden	127.8	6.0	2	4

Source: Trademap-ITC [6], General Statistics Office (GSO) [2].

More than 11 million tonnes of fertilizer have been used in a year, at nearly 300kg/ha. The application use rate in Vietnam is nearly double that of other Southeast Asian countries. Pesticide use also seems to have increased sharply since the mid-2000s, perhaps due to the increased pressure of pest control from high-intensive production and the development of pesticide resistance [4]. Frequent and late chemical spraying on crops has contributed to the growing concerns about pesticide residues. As a result, achievements in agricultural growth come with environmental consequences.

Vietnam is among the most vulnerable countries impacted by climate change. Among the 84 coastal developing countries that are heavily affected by rising sea levels, Vietnam ranks first in terms of

1 The size of arable land is about half to three-quarters the average land size in Cambodia, Myanmar, and the Philippines.
2 Out of 11.3 million agricultural land users, 69% are currently cultivating less than 0.5 hectares, while only 6.2% of households own two hectares or more of land.

consequences to population and GDP performance and second in terms of influence on land area and agricultural production [5]. In addition, associated unpredictable extreme weather events such as droughts, floods, tropical storms, and heat waves, together with changing rural demographics like outmigration of youth to urban have exacerbated problems and challenges faced by the agriculture and food systems of the region.

Agribusinesses, particularly small and medium enterprises (SMEs), play an essential role in the economy of Vietnam. According to GSO statistics, in 2017, Vietnam had 517,924 enterprises and the trend continues to increase in both quantity and quality. Over 98% of the enterprises are small and medium. Enterprises in the agricultural, forestry, and fishery sectors account for just 1% of the total. Of these, only 2.6% are large enterprises, while 0.9% are medium, 35.7% small, and 60.8% are micro enterprises [6].

Although Vietnam's agricultural sector has achieved significant success, it is also faced with a lot of challenges. Questions and concerns related to the quality and sustainability of Vietnam's agricultural development, such as the low profitability of smallholder farmers, low productivity of agricultural workers, low-value addition, food safety, and climate change, are raised. In this context, smart agriculture, with new and advanced technologies, like automation, the Internet of Things (IoT), and Big Data is expected to open new opportunities for transforming traditional production towards higher productivity and product quality, higher added value, and sustainability. In addition, it could also help address many challenges, especially resource scarcity (land, water, biodiversity, natural energy, etc.), and mitigate climate change. The SAT will also transform farming practices and make them more environmentally friendly, to meet the increasing demands from consumers for high-quality standards and traceability. The SAT is expected to happen at all stages of the agricultural value chains, from production (seed technology, mechanization, and automation), processing (new technologies, deep processed products, etc.), and consumption (traceability, mode of distribution, and logistics services). Therefore, agriculture transformation is an indispensable requirement, and smart agriculture is considered inevitable for creating opportunities to help the sector make breakthroughs.

Focus and Scope of Case Analysis

In the Strategic Planning Session of the Agricultural Committee of the APO, the urgency of developing the SAT Framework to promote innovation and technology-led agricultural transformation was agreed upon. The research on SAT readiness in Vietnam is an initial part of this developing process that is being conducted. This research aims to determine the readiness of Vietnam for SAT, as well as to propose policy recommendations for its adoption and implementation in the country. It also aims to make policy recommendations adaptable to circumstances in other APO member economies.

Analysis of the Current Situation

Country Level

As defined by the APO in 2019, smart agriculture is the use of new and advanced technologies within the agriculture and food system, to promote sustainable productivity by allowing farmers and other stakeholders to make more informed, appropriate decisions. Existing and emerging technologies like Big Data, online meteorological data, digital technologies, and analytics are important components of smart agriculture technologies [7]. However, SAT is context specific and the adoption is dependent on the stages of economic development of each APO member economy like Vietnam.

According to Global Innovation Index 2017[3] (GII 2017), Vietnam was ranked 47 out of 127 countries and economies on innovation in agriculture and food. This is the highest ranking that Vietnam has ever achieved, up by 12 positions from that in 2016. Vietnam is considered to be quite an open economy, with participation in more and more global and regional value chains. Of the 27 countries in the lower-middle income group, Vietnam jumped to the number one rank, up from the third position in 2016. The country also ranked ninth in the region, including Southeast Asia, East Asia, and Oceania, while it stood at number three within ASEAN, just behind Singapore and Malaysia [8].

TABLE 2

VIETNAM INNOVATION INDEX.

Indicator	2013	2014	2015	2016	2017
	Ranking/141 Economies			Ranking/128 Economies	Ranking/127 Economies
Sub input group index of creative innovation	89	100	78	79	71
1. Institutional organization	122	121	101	93	87
2. Human resources, research	98	89	78	74	70
3. Infrastructure	80	99	88	90	77
4. Market development level	73	92	67	64	34
5. Business development qualifications	67	59	40	72	73
Sub-output group index of creative innovation	54	47	39	42	38
6. Technology and knowledge output	51	49	28	39	28
7. Innovative output	66	58	62	52	52
Effectiveness of creative innovation	**17**	**5**	**9**	**11**	**10**
Creative innovation index	**76**	**71**	**52**	**59**	**47**

Source: The Global Innovation Index 2017 [8].

Vietnam's quality of human resources is low at 3.79 points out of 10 while it scored just 3.39 points on the human resources competitiveness index. Another Employers Survey, conducted in 2012 by Vietnam's Central Institute for Economic Management (CIEM), also pointed out the mismatch between the supply and demand of skilled laborers. Around 47% of the firms claimed that the education system failed to meet the skills needed for the workplace [9]; 66% of international firms and 36% of local firms indicated that there was a mismatch. Indeed, the rapid change in demand for skilled labor has not been met by the market supply [3].

Recent research conducted by the World Bank, in cooperation with the Institute for Policy and Strategy for Agriculture and Rural Development (IPSARD), to assess the agricultural transformation of Vietnam pointed out that the country's trajectory of shifting from an agriculture-based country to a transition country in 15 years from the mid-1990s to 2010–2011, was relatively rapid [10].

[3] GII 2017 is the 10th annual ranking report implemented by Cornell University (USA), the Institute of European Administration (INSEAD), and the World Intellectual Property Organization (WIPO). The report aggregates 81 sub-indicators in the fields of institutions, organizations, human resources and research, infrastructure, market development, business development, technology and knowledge outputs, and innovative results. It provides detailed data on 127 economies, which account for 92.5% of the world's population and 97.6% of the global GDP.

There was high consensus on the importance of proactive participation in the fourth industrial revolution (4IR). The Government of Vietnam is aware of the opportunities that 4IR brings and the challenges the country faces. Therefore, it has been propagating to the business communities and people via building a legal corridor and creating favorable conditions to join 4IR. On 4 May 2017, the Prime Minister of Vietnam issued Directive 16, confirming that 4IR has a strong impact on all aspects of socio-economic life and directed all government organizations, especially related ministries, and agencies, to focus on developing IT infrastructure, encourage enterprises to innovate technologies, accelerate the start-up movement, and to take full advantage by participating in this revolution.

Sectoral Level

At the sectoral level, agricultural transformation in Vietnam has made significant progress over the last decade. The mechanization in agriculture and application of post-harvest technologies has developed and brought about successes in increasing productivity and reducing post-harvest losses, contributing to economic restructuring and agricultural production, towards developing commodity production. Many stages of agricultural production have been highly mechanized, such as rice land preparation, planting (sowing), harvesting and milling, sugarcane harvesting, and processing, which creates an important foundation for SAT in Vietnam and contributes to the modernization of Vietnam's agriculture in recent years.

According to the Department of Agro-product Processing and Market Development, automotive machines applied in agricultural production have reached an average of 2.4 horsepower per ha across the country [12]. The number of agricultural machinery and equipment increased by 45.5% in 2016, as compared to the average during the period from 2011 to 2016. Big tractors with a capacity of more than 35 horsepower increased by 92.4%, while medium-sized tractors of 18 to 35 horsepower jumped 31.3%, and small tractors with less than 12 horsepower increased by 53.5%. This increased the combined harvesters by 77.1%. Similarly, agricultural dryers and kilns increased by 25.8%, animal feed processing machines increased by 90.6%, aquatic food processing machines increased by 2.2 times, and pesticide spraying machines went up by 3.1 times [11].

An agricultural product processing system has been formed and developed, with a processing capacity of about 120 million tonnes of agricultural raw materials a year and more than 7,500 enterprises associated with exporting key agricultural products[4] . In addition, there are thousands of small and micro agricultural processing facilities and households, performing preliminary processing and processing-related activities for domestic consumption [11]. However, the mechanization rate is low compared to the demand and is not comprehensive. While domestic manufacturing capacity can meet about 33% of the value, the infrastructure planning fails to meet the demand for machinery application in production. Besides, mechanisms and policies on mechanization and processing have not yet been synchronized and there is a lack of consistency and ineffective implementation. Also, while several policies were made, resource allocation for implementation is lacking [12].

For Crop Production

Some stages of the mechanization process in crop production have reached a high level. For example, machinery used in land preparation for rice cultivation increased from 75% in 2008 to 94% in 2018 and even 100% in the Mekong River Delta (MRD). Similarly, sowing and transplanting increased from 5% in 2008 to 25% in 2018, with Red River Delta (RRD) 25% and MRD at 45%.

[4] Vietnam has identified 14 key agricultural commodities with a total export turnover of more than USD 1 billion annually, which include rice, coffee, tea, cashew nuts, black pepper, rubber, mangoes, shrimp, and pangasius fish.

Crop management and plant protection increased by 55% in 2008 to 75% in 2018 (RRD and MRD are with 82% and 85%) and harvesting increased from 15% in 2008 to 70% in 2018 respectively at 25% in RRD and 85% in MRD) [13]

However, in general, the mechanization level of agricultural production is still low. It is applied only in a few regions [11] and focused on some production stages. Typically, in some specialized vegetable production areas, mechanization in soil preparation and irrigation reached nearly 90%. The harvesting stage, meanwhile, is mostly done manually. In maize production, the level of mechanization has reached about 70% for some stages like soil preparation, sowing seed, and tending, but is only at a 5% level for harvesting. In sugarcane production, mechanization is applied mainly in land preparation, with a rate of more than 85%. The mechanization at the planting and harvesting stages, however, is only 30% and 25%, respectively [11]. The mechanization of crop production in mountainous and remote areas is very limited.

TABLE 3

MACHINERY USED IN AGRICULTURE SECTOR (2014-2016).

No	Machinery Type (unit)	2014	2016	Change Compared to 2011 (%)
1	Overall tractors	600,718	774,900	45.5
	a. Big tractor (>35 HP)	27,182	32,200	92.4
	b. Medium size tractor (18-35 hp)	252,300	290,600	31.3
	c. Small tractor(<15 hp)	321,236	452,100	53.5
2	Sowing machines	49,836	N/A	9.0
3	Combine harvester	22,423	25,700	77.1
4	Agricultural dryer/kiln	68,841	80,100	25.8
5	Feed processing machinery	58,405	137,200	90.6
6	Aquatic feed processing machine	N/A	14,200	220.0
7	Pumps	2,169,800	3,300,000	52.2
8	Insecticide sprayer	713,927	1,800,000	310.0

Source: IPSARD, 2017 [14].

Animal Husbandry

Most of the mechanization is focused on feeding, providing drinking water, primary processing, and waste treatment activities. In large-scale and close chicken-raising farms, mechanization is about 90%, including drinking water supply, feeding, microclimate creation, and egg collection. About 55% of the environmental treatment process is mechanized. With commercial and in-house pig farming, cooling, and heating systems for piglets, and feeder and drinker systems, the level of mechanization can reach around 72%. For buffalo and cow raising, about 60% of big farms are equipped with forage and straw-cutting machines while nearly 75% of big dairy farms use milking machines. The level of mechanization and automation in production, processing, storing, packaging, etc. is highly concentrated in big dairy companies such as TH True Milk, Vinamilk, and Moc Chau Milk [12].

Applying machinery and mechanization in livestock farming can limit epidemics and reduce environmental pollution while ensuring food safety and hygiene and increasing the competitiveness of the livestock industry.

Fishery
The fishery sub-sector uses several modern equipment and machines to improve productivity, offer better quality assurance, and meet food hygiene and safety requirements. These include systems for making flake ice, dry ice, processing lines, etc., especially in MRD. Some high-tech models of shrimp and fish cultivation have been developed in Quang Ninh, Nghe An, Bac Lieu, and Binh Thuan. Machines used in the fishery sector are quite diverse, from aeration machines to water temperature monitors and aquaculture harvesters, etc. Besides, the number of ships with a capacity of 90 horsepower in 2018 was 34,563 with a total designed capacity of more than 13,480,000 horsepower [12].

Forestry
Mechanization in forestry production has barely kept pace to meet the demands of the country with 70% of the workload in the sector still being done manually; only 30% of the workload is mechanized. Overall, mechanization in forestry production has mainly happened in two functions: felling and transporting the forest products. Other critical production stages, such as planting, tending, forest firefighting, and log handling have a low mechanization rate of 2-5%. While planting, tending, and developing forests are labor-intensive stages, the mechanization rate is only 3%, especially in forest fire fighting, where the use of machines accounts for only 2%. Also, no machinery is used in forest pest and disease control at all [12].

In short, the transformation in Vietnam's agriculture production[5] is mainly limited to mechanization. The country's overall readiness for SAT stands at the lower-medium level. Vietnam's level of mechanization in agricultural production varies across different processes, commodities, and regions and the country stands quite low as compared to the other countries in Asia on this front.

Vietnam's agricultural sector has achieved important successes over the last period (from 2010-2019). However, a large proportion of the agricultural growth has stemmed from the expanded or highly intensive use of resources like land, water, labor, and other inputs, especially the heavy use of fertilizer and other agrochemicals. The inefficient use of inputs entails higher environmental problems and therefore, environmental costs and externalities. In addition, there has been limited scope for further expansion of productivity which is forcing the young population to exit the sector.

The assessments of the agriculture sector of Vietnam indicate that the country needs an accelerated SAT process. Since the agricultural sector can no longer rely solely on the extensive growth model with intensive use of inputs, the adoption of modern, high-value-added, and sustainable agriculture is a must.

The Prime Minister Decision No. 899/QD-TTg, issued on 10 October 2013, approving the ARP towards high value-added and sustainable development, aims to maintain the growth rate, and drive production efficiency and competitive capacity by improving productivity, quality, and value addition. It also focuses on satisfying the needs of domestic consumers and boosting export by applying smart and advanced technologies in agriculture.

Although smart agriculture is still a relatively new concept in rural areas of Vietnam, it is still seen as one of the most lucrative sectors in terms of opportunities to achieve intended targets. Big Data, Artificial Intelligence (AI), Machine Learning (ML), and deep learning are admired as breakthrough

[5] Vietnam's agricultural sector includes the following production sub-sectors: crop, livestock, forestry, aquaculture, and water resource management.

applications of science and technology in agriculture. These technologies enable farmers to have better insights and help them make informed decisions on farming practices. Big Data can further provide a wealth of information about soil, seeds, livestock, crops, costs, farm equipment, and the use of water and fertilizer. Using Big Data, AI models can analyze and provide insight into how to optimize the yield, improve planning, and make smart decisions to minimize waste and increase yields. Precision agriculture involves the use of the most modern means of technology to optimize the yield per unit of farming land, thus achieving the best quality, quantity, and financial return. The Internet of Things (IoT)-based systems are backed up by real-time data from sensors and Big Data analytics, to provide farmers with additional information concerning all aspects of farming that may not be visible. This helps the farmers make better decisions, reduce waste, and maximize efficiency.

In recent years, there has been an increase in the level of awareness about the need for SAT in Vietnam. Authorities in the country, from central to local levels, have made a lot of efforts to implement and promote high-tech agriculture, including smart agriculture in Vietnam. By the end of 2018, three high-tech agricultural regions of Hau Giang, Phu Yen, and Bac Lieu were set up. These regions saw some enterprises, cooperatives, and farms apply high-tech and advanced technologies at different stages of the production chain to achieve some good results.

Apart from the high-tech agricultural zones established by the Prime Minister, there have been other agricultural production models applying some forms of SAT. These kinds of high-tech zones have mostly been developed and invested in by enterprises and received support and preferences (e.g. being allocated or leased land, etc.) from the public sector (national and local authorities). Their activities follow a closed system from production to preliminary processing, processing, and consumption of the products. Agricultural products mainly focus on vegetables, fruit, dairy, pig, poultry, and aquaculture. By 2018, there were 124 established, high-tech production zones, nationwide. Although they are being evaluated as highly effective operations, the scale of these models is generally quite small and is mainly focused on the production processes [12].

Even though SAT has been under observation for some time, it has recently brought an encouraging highlight. Based on the linkage between scientists and farmers, the needs of society and requirements from production have been grasped as bases for R&D, to boost technological applications in general and SAT in particular. For example, crop production technology in greenhouses uses automatic and semi-automatic control systems for lighting, temperature, watering, fertilizing, and pesticide protection programming. Hydroponic, aeroponic, and substrate planting technology are becoming more popular with crop growers. The application of the pressurized drip irrigation system makes watering simpler and uses water resources more efficiently. In animal husbandry, there are software applications for health, diet, and nutrition management, and for controlling individual heard by applying Best Linear Unbiased Prediction (BLUP) method to assess the genetic coefficient, selecting breeds and sex-predetermining animals, etc. In aquacultural, there are applications of the Biofloc method for production in indoor automation film houses.

Smart agriculture promises to optimize crop inputs, based on actual crop needs with the aid of technologies such as GPS, remote sensing networks, and the Internet, to create cyber-physical systems. These systems can provide real-time intelligence on soil conditions, plant and animal needs, weather conditions, crop yield, and market demand. This information can dramatically improve yields, nutritional value, animal welfare, and systems waste. 4IR in agriculture can harness blockchain distribution networks. Blockchain can provide paddock-to-plate visibility of food available in shops. This can increase consumer trust in Vietnamese produce, and improve value-added components of food – such as nutritional value, geographic sourcing, animal welfare, and organic attributes. Realizing the prospects of smart agriculture, big Vietnamese business groups, and companies have started to invest in the sector recently, a key indication of readiness for SAT in Vietnam.

Smart Farm in Hoi An

In 2015, the eco-farm of 20 hectares was established by Vineco, a member of Vingroup in Quang Nam province. This is the first eco-farm using modern and intelligent farming technologies like climate control greenhouses, multi-storey cultivation, and irrigation intelligence technologies. The multi-storey vegetable growing system consists of 60 planting towers with different heights of 3 meters, 6 meters, and 9 meters, appropriately allocated within the farm. The stratification helps increase planting density and productivity by three to four times compared to traditional farming methods. In addition, the climate control system and light distribution mechanism provide a superior environment for the growth of crops.

In this farming practice, the vegetable production system is designed with two protective layers of net and nylon to prevent the penetration of harmful insects and minimize the use of pesticides in the production process. In addition, thanks to the microclimate control systems, such as the cooling pad, sun-shading net, reversing fan, and indoor ventilation fan, the system ensures the necessary conditions for vegetable production. There are also automatic irrigation systems installed with clean water sources, misting to retain moisture and climate control. The entire process of supplying nutrients for plants is managed through an automatic computer-controlled system, fully meeting the nutritional needs of plants at each stage of growth and development (through fertigation). This eco-farm can be seen as an example of effective SAT application throughout Vietnam.

The Limitations and Challenges of SAT in Vietnam

Agricultural production in Vietnam is small and fragmented in scale at 88.3% of the 8.5 million farmer households have farm sizes of less than one hectare [12] . The lack of linkage, between farmers and businesses horizontally and vertically hinders the SAT process in general and mechanization in particular.

The overall infrastructure for agricultural production in the country is quite poor; the inter-regional and inter-communal road networks are exacerbated by the small scale of scattered farming fields. Hence a significant shift to smart agriculture, mechanization, and modernization is difficult. Besides, the quality of farming labor is low as many farmers operate and use agricultural machines without any training.

Readiness Assessment and Gap Analysis

While reviewing the data and literature to understand Vietnam's readiness for SAT, the study carried out assessments at three levels, including Upstream, Production, and Downstream. The assessment criteria were meant to understand the fundamental conditions like infrastructure, human resources, technological level, as well as the institutional and policy environment. The analytical methods used included both qualitative and scoring[6] approaches. Note that the ratings based on the expert's judgment have been used wherever the data is missing.

[6] The Likert's scoring scale of five was applied as described in Appendix 1 of this chapter.

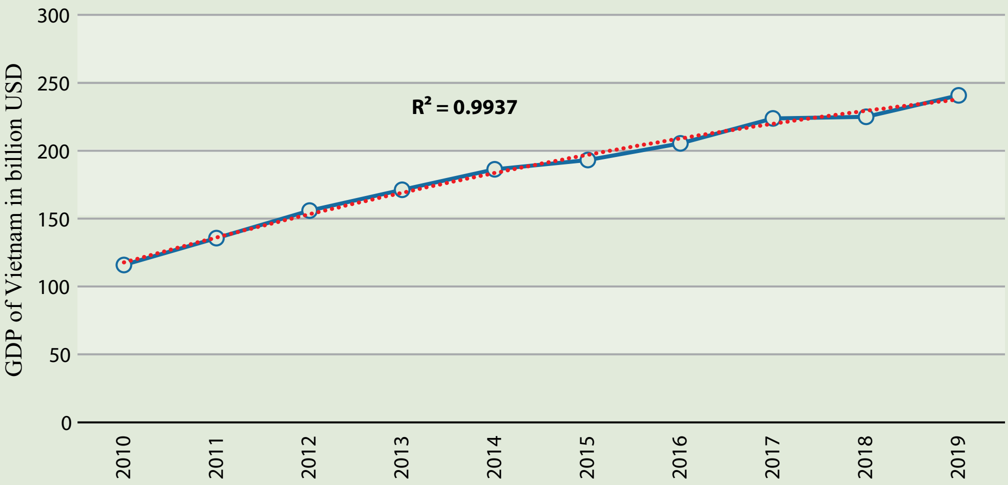
Upstream Level

Development Indicators

Although the agricultural sector's contribution to the country's GDP in absolute terms has continuously increased, the share in total GDP has been decreasing (Figure 3), reflecting the modernization of Vietnam's economy and the fact that it has been progressing towards industrialization and expansion of the service sector. However, agriculture still plays a big role in ensuring sustainable growth, food security, social stability, and balance of trade.

FIGURE 2

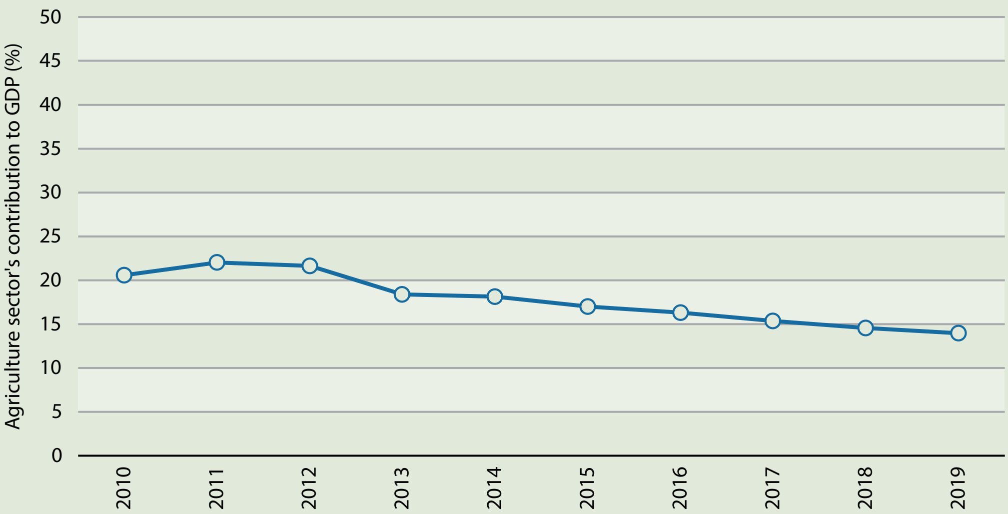
GDP OF VIETNAM (2010-2019).



Source: WB, 2020 [15].

FIGURE 3

CONTRIBUTION OF THE AGRICULTURE SECTOR TO THE GDP OF VIETNAM.



Source: GSO [2].

The assessment results represented in Table 4 indicate a significant improvement in Vietnam's SAT readiness as compared to 2010, especially for certain indicators like the existence of laws and policies on agricultural finance, technician-to-farmer ratio, and the share of extension personnel who are computer-literate. Overall, Vietnam's readiness for SAT at the upstream level can be rated as medium.

In the agricultural sector, the government has established a favorable institutional and policy environment, to take full advantage of the last achievements and existing foundation, and make full use of these opportunities that the 4IR brings. In recent years, the Government has made great efforts in promoting the development of high-tech agriculture, including smart agriculture, considering this as an effective solution to overcome the weaknesses and limitations of the old growth model.

At the upstream level, these policies also have layout mechanisms and institutional arrangements in support of agricultural finance, insurance, preference credit schemes, and extension, to encourage farmers and businesses to invest in the application of new technologies in agricultural production, in a more cost-effective, high value-added, and sustainable manner. Some main policies related to smart agricultural transformation are as stated.

- The Law of High Technology (No. 21/2008/QH12), issued by the XIIth Vietnam National Assembly[7], directed the development of high-tech in the agriculture sector, focusing on the following main tasks: developing and propagating high productivity and quality plant varieties and animal breedings, preventing and eliminating epidemics, planting and raising animals with high efficiency, and creating materials, machinery, and equipment used in agriculture.

- The Government's Resolution No. 30/NQ-CP (2017), on the key policy, measures to promote the development of high-tech agriculture that promulgated the orientation of solutions and development of high-tech agriculture, including the development of criteria for identifying high-tech agricultural research programs and projects.

- Credit support: Developing loan programs to encourage the development of high-tech and clean agriculture. Under this program, commercial banks lend for short-term, medium-term, and long-term capital needs in Vietnam, with lower interest rates from 0.5% to 1.5% per year compared to the normal lending interest rate for the same term of a commercial bank[8].

TABLE 4

SAT READINESS ASSESSMENT FOR UPSTREAM LEVEL.

	Indicator	2010	Currently
Upstream	**Development**		
	Existence of law/policy on agricultural finance	M	H
	Agricultural insurance penetration ratio	L	L

(Continued on next page)

[7] The Law of High Technology was later merged in Document 13/VBHN-VPQH, dated 11 December 2014.
[8] The credit policies to promote the development of high-tech agriculture are Decision 2457/QD-TTg; Decision 1895/QD-TTg; Decision No. 1050/QD-NHNN; Decree 55/2015/ND-CP (amended and supplemented by Decree 116/2018/ND-CP); Decision 813/QD-NHNN; and Decree No. 57/2018/ND-CP.

(Continued from the previous page)

	Indicator	2010	Currently
Upstream	Share of borrowing smallholders and fishers who borrow from formal sources (%)	L	M
	Technician-to-farmer ratio: public; private	L	M
	The proportion of agricultural land that is irrigated (%)	H	H
	Digitization		
	Share of extension personnel who are computer-literate (%): public; private	M	H
	Existence of IT-based agricultural insurance products (e.g. remote sensing)	L	L
	Overall assessment of the upstream indicator	L=4; M=2; H=1	L=2; M=2; H=3

Source: Synthesized by the author from [2, 16, 17, 18, 19].

Despite the remarkable improvement in the policy and regulations for creating a foundation for SAT, some shortcomings like low agricultural insurance penetration ratio still exist. The technician-to-farmer ratio (of both public and private) is also quite low since a majority of farmers in Vietnam are still smallholders and the land is very fragmented [12]. Extension services face several challenges, including limited human resources; there is one public extension worker, including full-time and part-time, for 330 farming households. Besides, the expenditure on extension services is at a dismal USD3.30 per farming household.

The extension system is considered weak and lacks experience. This limits the services for the development of small and medium enterprises (SMEs) that are dominated by the top-down approach. It also lacks services that are tailored to different types of farms, participation of the private sector is also weak, and the monitoring systems are poor [3]. Other public services (quality control, plant protection, veterinary, irrigation, trade promotion, etc.,) are still operating mainly under the top-down imposed mechanism and do not focus on innovation, technology acquisition, quality management, market and product distribution channel development, and branding.

Strong human capital and dynamic agricultural innovation systems are critical to increasing investment in agriculture and developing smart agriculture. It is, therefore, important to support high-quality education and well-functioning extension and advisory services to enhance human capital. Partnerships between national and international research should be promoted, and the research should be connected with the demand to build effective innovation systems.

Digitization Indicators

To catch up with the new development of 4IR, the Vietnam Digital Agriculture Association (VIDA) was officially established in September 2019, opening new investment opportunities for digitization in agriculture. However, there is a lack of IT-based agricultural insurance products. Another clear signal, in support of SAT in agriculture, is the Ministry of Information and Communication's announcement of an ambitious plan of popularizing smartphones in the country with the introduction of a USD25 handset, made locally, to cover 100% of the population [20].

TABLE 5

SAT READINESS ASSESSMENT FOR UPSTREAM LEVEL USING SCORING METHOD.

	Indicator	2010	Currently
Upstream	**Development**		
	Existence of laws and policies on agricultural finance	3	4
	Agricultural insurance penetration ratio	1	2
	Share of borrowing smallholders and fishers who borrow from formal sources (%)	2	3
	Technician-to-farmer ratio: public; private	2	3
	The proportion of agricultural land that is irrigated (%)	4	4
	Average score for the development group	**2.4**	**3.2**
	Digitization		
	Share of extension personnel who are computer-literate (%): public; private	3	5
	Existence of IT-based agricultural insurance products (e.g. remote sensing)	1	1
	Average score digitization group	2.0	3.0
	Overall average of the upstream indicators	**2.0**	**2.5**

Source: Synthesized by the author from [2, 16, 17, 18, 19].

The results of using the quantitative method (scoring) for evaluating the SAT readiness at the upstream level are shown in Table 5, providing a clear picture of the SAT readiness at the upstream level, and reaffirming the improvement in SAT readiness over the years, which increased from 2.4 to 3.0 for the development indicator group and from 2 to 2.5 for the digitization indicator group at the upstream level. These results suggest that although there has been a clear improvement in SAT readiness in Vietnam at the upstream level, the readiness status is still at the medium level and there are areas that need more attention to move SAT forward, e.g., agricultural insurance, especially development of IT-based agricultural insurance product.

Production Level

Development Indicators

Although Vietnam has some necessary conditions for boosting SAT forward, it is still facing a lot of challenges, especially at the production level. The SAT readiness assessment results presented in Table 6 provide more detailed information about these.

TABLE 6

SAT READINESS ASSESSMENT AT THE PRODUCTION LEVEL.

	Indicator	2010	Currently
Production	**Development**		
	Existence of a regulatory framework for seed	M	H
	Existence of a regulatory framework for agrochemicals (fertilizer and pesticide)	M	H

(Continued on next page)

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	Indicator	2010	Currently
Production	Existence of a regulatory framework for agrimachinery	M	M
	Tractors per 100 sq km of arable land	M	H
	Average monthly earnings in agriculture (USD per month)	L	M
	Rural employment in youth (from 15 -29) employment (%)	M	M
	The average age of a farmer	M	M
	Average farm size (ha)	L	L
	Share of smallholder (2 ha and below) who is owner-cultivator (mainly for rice)	M	H
	Share of agricultural workers who are women (%)	M	M
	Fertilizer utilization per ha	M	L
	Pesticide application per ha	M	M
	Utilization of certified seeds, share of total (%)	L	M
	Agricultural GVA per worker (=USD in 2010)	L	L
	Agricultural Total factor productivity (TFP) growth (2005 = 100)	L	L
	Overall assessment of the development indicator of the production	L=5; M=10;H=0	L=4; M=7; H=4
	Digitization		
	Share of youth in agricultural employment (%)	M	M
	Electricity infiltration rate (%)	H	H
	Telephone infiltration rate (%)	M	H
	Internet infiltration rate (%)	L	M
	Computer literate rate of agricultural employment	L	M
	Percentage of labor force trained in agriculture	L	L
	Average years of schooling of the agricultural labor force (year)	M	H
	Overall assessment of the digitization of production	L=3; M=3; H=1	L=1; M=3; H=3

Source: Synthesized by the author from [16, 21, 22, 23, 24, 25, 26].

Besides the laws and policy frameworks articulated in support of the development of high-tech agriculture, the following are specifically targeted at the production level:

- Decision No.176/QD-TTg (2010), is for the approval of the proposal for applied high-tech agriculture towards 2020, dated 29 January 2010 for encouraging high-tech agricultural application in agriculture. The decision aims to put high-tech applications in agricultural regions/zones and enterprises. The decision was adjusted to fit with the development situation by Decision 1895/QD-TTg dated 17 December 2012, on the high-tech application agriculture program under the framework of a national program of high-tech development.

- Decision No. 575/QD-TTg of 4 May 2015, on "Master plan of high-tech agricultural zones and regions to 2020, orientations to 2030", and supplemented by Decision No. 694/QD-TTg, dated 24 May 2017. The decision aimed to create 11 high-tech agricultural zones[9] by 2020.

- Decision No. 66/2015/QD-TTg dated 25 December 2015 on "criteria, authority, recognition order and procedures for high-tech agricultural zones" defines a high-tech agricultural region.

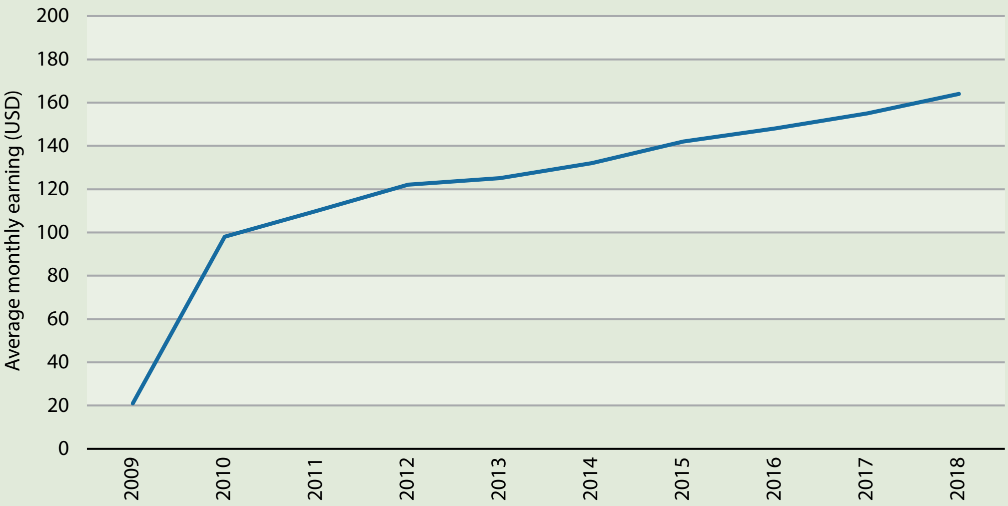
Although there have been sufficient enabling policy frameworks for moving SAT forward at the production level, there is still a lack of an evaluation of the actual achievements from the implementations of these policies, and to draw the lessons learned for enhancing the SAT process.

The Vietnam Human Resource Development Plan for the period of 2011-2020 shows that Vietnam's labor productivity is 2.5 times and 4.2 times lower than that of China and Thailand respectively [9]. The labor productivity in the agricultural sector is even lower, only 38.1% of the average labor productivity of the economy [3]. According to the Report on Human Capital of the World Economic Forum [27] in 2017, Vietnam's skilled labor was ranked only in the low average group, particularly, the intermediate skilled workers, who were ranked almost at the bottom (128/130) while the high-skilled workers ranked 99 out of 130 evaluated countries [27].

The reality shows that Vietnam has currently faced a shortage of skilled workers with professional qualifications, to meet the demand for human resources, for the application of 4IR in the agriculture sector.

FIGURE 4

AVERAGE MONTHLY EARNINGS.

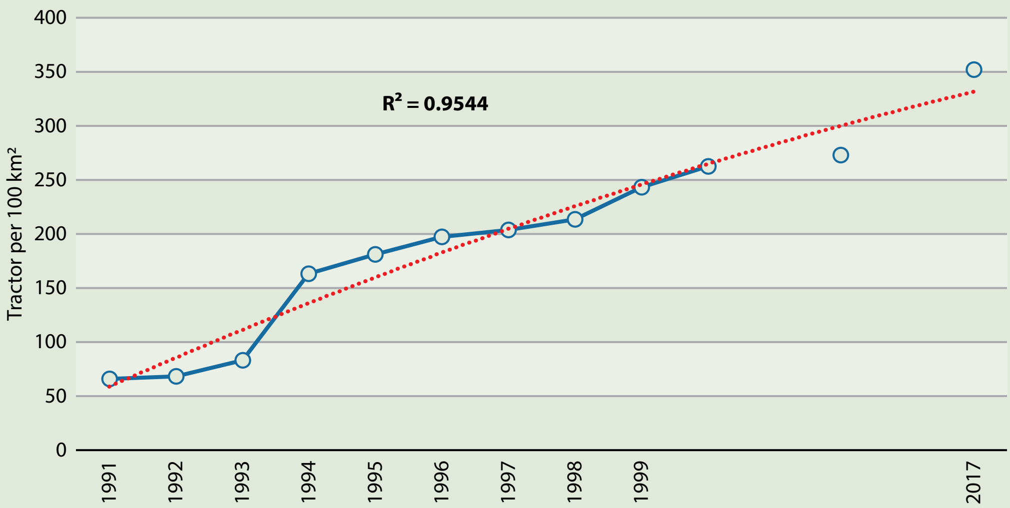


Source: ILO [22].

[9] Till December 2018, three zones Hau Giang, Phu Yen, and Bac Lieu were established by the Prime Minister. These are in the initial stages of building technical infrastructure and attracting investment. Of the remaining eight zones, Thai Nguyen, Thanh Hoa, Lam Dong, and Quang Ninh have prepared proposals to submit to the Ministry of Agriculture and Rural Development, but the appraisal process has not been completed. Ho Chi Minh City has not prepared a plan yet, Can Tho proposed other plans, while Khanh Hoa and Binh Duong have asked to drop it. [32].

FIGURE 5

TRACTOR PER 100 SQ KM.



Source: World Bank [21].

The low technical level of agricultural workers has greatly affected their ability to access science and technology, particularly in remote and difficult regions, e.g., mountainous and ethnic minority-populated areas. This becomes a major barrier for SAT. It is forecasted that by 2020, the agricultural workforce will lack about 3.2 million skilled workers. Figure 4 illustrates that although the average monthly earning of agriculture sectors has been improving over time it is still quite low, about USD162 in 2018 [22].

Again, in WEF's report [27], regarding the production potential, Vietnam's 4IR readiness is quite low, only in the nascent group. Production structure reached 4.96 out of 10 points (ranked 48/100) and production motivation reached 4.93 out of 10 points (ranked 53/100). Going into each component indicator, the complexity of the production structure ranked only 72, although the scale of manufacturing was quite large (ranked 17th). The component indicators of the production driving force were also not appreciated: technology and innovation ranked 90, human resources ranked 70, the institution was in class 53 (government effectiveness and efficiency, rule of law), sustainable resources were ranked 87, and the competitiveness score was 4.0. Vietnam just reached 51.2 points on a 100-point scale and was ranked 70 out of 120 countries.

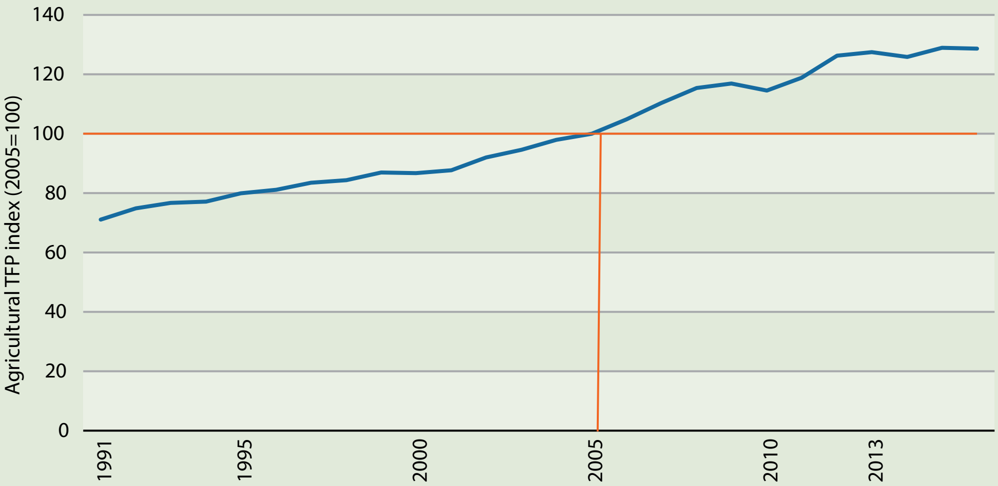
In terms of Total Factor Productivity (TFP), an increasing trend has been observed. In 2017, the TFP of the agriculture sector of Vietnam increased by about 30% compared to 2005 [26]. The value added per worker in the agricultural sector has also increased significantly (R2 of the trend is 0.98). These suggest favorable conditions for SAT process.

The high percentage of area equipped with irrigation (more than 70% of arable land), is also a good indicator of SAT readiness. Although the agricultural land of Vietnam is quite fragmented and small (80% of farmer households have an area of less than one hectare), the land is equipped for irrigation and it will be easy to establish and install automatic irrigation or drainage systems as a key component of the SAT.

Expenditure on R&D is also lower than that of the world average (about 0.37% of GDP[10]). The state budget also accounts for the largest proportion of Vietnam's total R&D expenditure (56.7%), while the share of the private sector is 41.8%. The rate of Vietnam's technological innovation is also very low (ranked 71 out of 137 economies assessed[11]). The management mechanism of science and technological activities in agriculture has been improved but it doesn't meet the development requirements yet. These limitations make SAT, in general, and the science and technological development in the agriculture sectors more challenging.

FIGURE 6

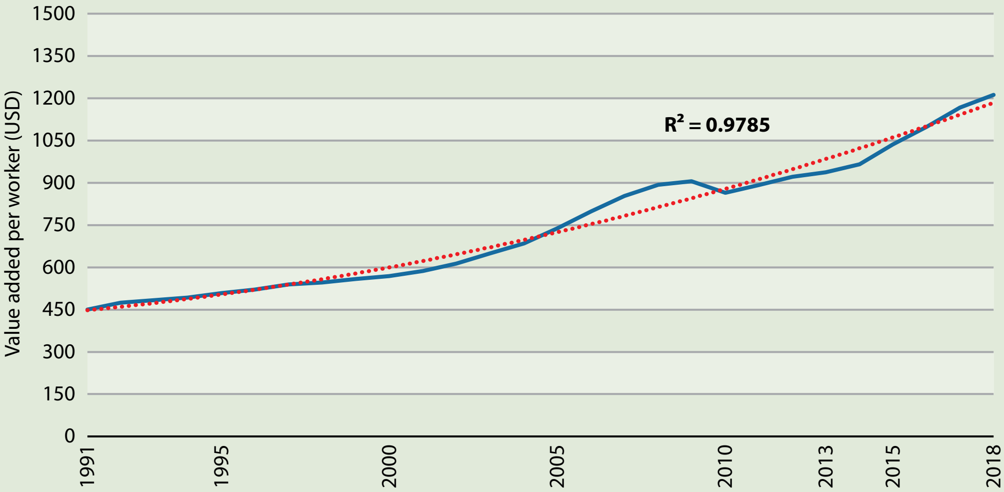
THE AGRICULTURAL TFP (1991-2013).



Source: USDA [26].

FIGURE 7

VALUE ADDED PER WORKER IN THE AGRICULTURAL SECTOR.



Source: The World Bank [15].

[10] Significantly lower than Thailand (0.63 %), Malaysia (1.13 %), and Singapore (2.20 %) (CIEM, 2018).

[11] Much lower than Singapore (14) and Thailand (60) (CIEM, 2018).

On the institutional aspect, although indicators of institutional quality have improved, they are still at low levels. Vietnam's agriculture is still based on household economies, which have small and fragmented production[12], which is not favorable for stimulating value chain linkages and applying SAT.

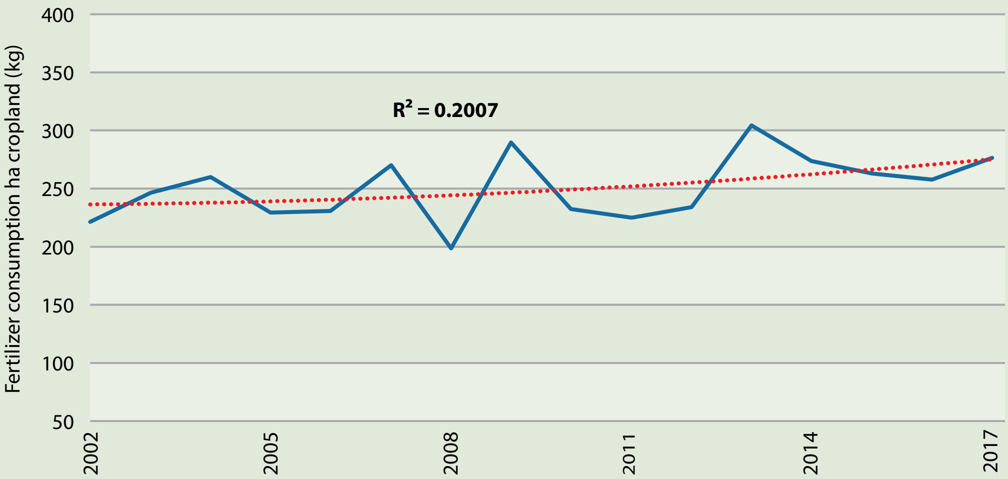
The SAT will help in using agricultural inputs more effectively, especially agricultural chemicals like fertilizers (N, P, K) and pesticides. The results shown in Figures 8 and 9 illustrate that while there is a clear trend of reducing pesticide use, fertilizer consumption for agriculture production is still high and the trend is still upward.

A very low score (1 out of 5) on the farm size indicator is noted, which suggests a big obstacle faced by the SAT process in Vietnam. To overcome this challenge, the land accumulation policy[13] for economies of scale has been a push factor mentioned in different sub-sectoral restructuring proposals, like crop production, livestock production, and forestry. The establishment of Agricultural High Tech Zones and Regions following the Prime Minister's Decision No 575/QD-TTg illustrates the move.

Also, the two indicators representing the "pull" factors for SAT at the production level are (i) Agricultural GVA per worker, and (ii) Agricultural total factor productivity, which does not have much progress and are currently still at a low level. According to the research done by the World Bank, the low value-added per agricultural worker is due to the dominance of rice, which uses Vietnam's best land and irrigation capacity, but very low productivity of labor for rice is evident in the Red River Delta and other areas, where production occurs on multiple small parcels of land held by households [10]. The research also shows that in high-performing middle-income countries, more than 80% of growth will be due to TFP growth. Agricultural labor productivity will increase substantially, and will also close the gap between Vietnam's agricultural sector and its labor-intensive manufacturing subsectors [10]. Therefore, creating economic incentives to enable the "pull" factors for SAT like TFP and GVA is essential.

FIGURE 8

FERTILIZER CONSUMPTION.



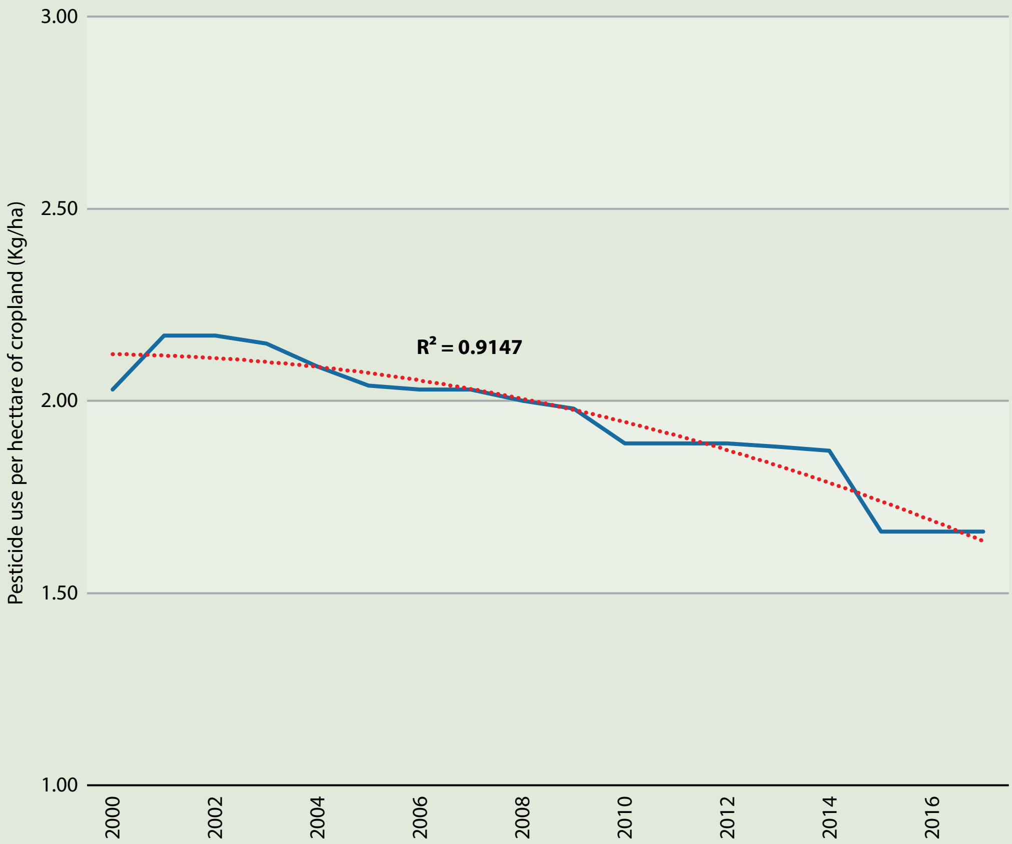
Source: WB [25].

[12] The average cultivated area per agricultural worker in Vietnam is only 0.34 hectares, about half (0.6 to 0.8 times) of Cambodia, Myanmar, or the Philippines.

[13] Land accumulation may include the following types: collectively in the business links between contract farming small farmers, cooperatives of small farmers, or farmers' land is considered as shares to join the farming business with enterprises, etc.

FIGURE 9

PESTICIDE USE IN VIETNAM (KG/HA).



Source: WB [25].

Overall, there have been some improvements in SAT readiness between 2010 and 2019, but the progress is still quite slow. To effectively apply high-tech achievements in agricultural development, the country needs to overcome certain difficulties, including human resource quality.

Digitization Indicators

Along with agricultural development, rural development programs have also helped rural infrastructure improve significantly, especially in transportation, electricity, water, and communication. Regarding rural transport, the percentage of commutes with motorable roads to the Commune People's Committee (CPC) increased from 94% in 2001 to 98.6% in 2011. Also, the number of asphalt and concrete roads to CPCs increased from 42.4% in 2006 to 87.4% in 2011 [12]. Regarding the electricity system, in 1997 the national electricity grid was only provided to 426 out of 470 districts, accounting for 90.6% of the country, 5,698 of 9,022 communes, accounting for 63.2%, and 6,031 out of 11,881,000 rural households. By 2010, all districts had electricity. Similarly, 100% of communes had electricity by 2018, while 99.47% of households across the country had electricity by 2019, of which 99.18% of rural households had access to electricity. Vietnam's electricity access index[14] in 2019 was assessed at 88.2/100 points, increasing by 0.26 points compared to 2018. The electricity access index of Vietnam at 88.2 points is ranked in the Top 4 in ASEAN.

[14] Electricity access index is evaluated according to four criteria: procedure, time and cost to connect to the grid, reliability of electricity supply, and transparency of electricity price [25].

TABLE 7

SAT READINESS ASSESSMENT AT PRODUCTION LEVEL USING SCORING METHOD.

	Indicator	2010	Currently
Production	**Development**		
	Existence of a regulatory framework for seed	3	4
	Existence of regulatory framework for agro-chemicals (fertilizer and pesticide)	2	4
	Existence of a regulatory framework on agri-machinery	2	3
	Tractors per 100 sq km of arable land	3	4
	Average monthly earnings in agriculture (dollars per month)	2	3
	Rural employment in youth (from 15 -29) employment (%)	3	3
	The average age of a farmer	3	2
	Average farm size (ha)	1	1
	Share of smallholder (2 ha and below) who is owner-cultivator (mainly for rice)	3	4
	Share of agricultural workers who are women (%)	1	2
	Fertilizer utilization per ha	3	2
	Pesticide application per ha	3	3
	Utilization of certified seeds, share of total (%)	2	3
	Agricultural GVA per worker (=USD in 2010)	1	2
	Agricultural Total factor productivity (TFP) growth (2005 = 100)	1	2
	Average score	2.2	2.8
	Digitalization		
	Share of youth in agricultural employment (%)	3	3
	Electricity infiltration rate (%)	5	5
	Telephone infiltration rate (%)	4	5
	Internet infiltration rate (%)	3	4
	Computer literate rate of agricultural employment	2	3
	Percentage of labor force trained in agriculture	1	2
	Average years of schooling of the agricultural labor force (year)	3	4
	Average	3.0	3.7
	Overall average score of the production indicator	2.6	3.3

Source: Calculated by the author [16, 21, 22, 23, 24, 25, 26].

The telecommunication and IT infrastructure of Vietnam has developed strongly and is standing among the top countries in ASEAN. In 2017, the number of people using fixed broadband Internet was 50.2 million, or 54.19% of the population. The total, international Internet bandwidth stood at 3,816 Gbps, equivalent to 79.66 bps/user. Regarding the progress of technology absorption, the

Global Adoption Index (DAI) ranked Vietnam 4.6 out of 10, higher than the world average. Vietnam is among the top 13 in the world in terms of Internet usage rate with an overall coverage of 54% with the social network usage rate reaching 40% of the country's population.

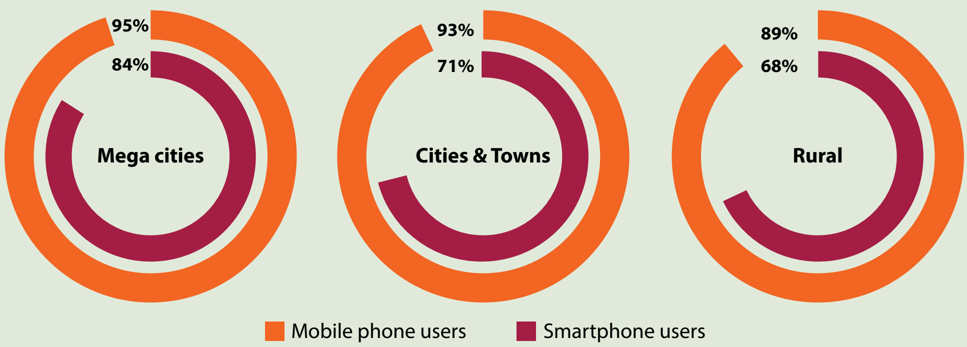
FIGURE 10

INTERNET USERS IN VIETNAM.

Indicator	Population Group	Accessibility
Electrification	Country	99.4%
Electrification	Urban	100%
Electrification	Rural	99%

Total Population	Internet Users	Active Social Media Users	Unique Mobile Users	Active Mobile Social Users
96.02 million	64.00 million	55.00 million	70.03 million	50.00 million
Urbanisation 35%	Penetration 67%	Penetration 57%	Penetration 73%	Penetration 52%

Telephone Penetration



Source: GSO [2], [16].

Well-developed rural infrastructure can be seen as an effective way to attract investments into the agricultural sector and increase competitiveness, as well as be a fundamental foundation for developing high-tech agriculture.

Figure 10 suggests a high level of readiness for the digitization process as required for SAT, with over 99% of the rural areas of Vietnam having electricity and a high telephone penetration rate, especially smartphones (68% in rural areas).

However, there is a lack of awareness and understanding of IoT solutions for agriculture and their benefits. Farming is still widely considered a manual job, and farmers want to stick to the traditional ways of farming.

Overall assessment of SAT readiness shows that there have been significant improvements in SAT readiness at the production level. The SAT readiness in production is above medium, especially for the digitization indicator group. This suggests that in terms of digitization for agricultural production (score of 3.7 out of 5), Vietnam is in a good position to push SAT forwards.

However, the assessment also shows areas that need to have more investment, for improvement of SAT readiness (low readiness score), e.g., land accumulation for bigger farm size, agricultural labor training, and agricultural TFP and GVA per worker.

Down Stream Level

Development Indicators

Agricultural value chains are still inefficient. In general, there are very limited forms of cooperation in purchasing agricultural products in Vietnam. The direct linkage between processing and exporting enterprises and farmers is small, except for aquaculture. In many value chains, there are still intermediaries with different technological, financial, and business ethics, which makes it difficult to trace the source of the supplier.

With one party in the series of Free Trade Agreements (FTAs), especially the EVFTA that the country signed with the European Union in June 2019, traceability of all products exported to the 28 European countries is a requirement. Therefore, a series of regulations and guidelines on product traceability have been issued and developed. These policies and regulations are also important bases for SAT moving forward.

TABLE 8

SAT READINESS ASSESSMENT FOR DOWNSTREAM LEVEL.

	Indicator	2010	Currently
Downstream	**Development**		
	Existence of laws and policies on food safety, traceability	M	H
	Infrastructure score in Global Competitiveness Index	M	M
	Logistics performance index	L	L
	Rural road density (km per sq. km)	L	M
	Stocks-to-production ratio, milled rice equivalent (%)	M	M
	Digitization		
	Existence of laws and policies on e-commerce	M	H
	Share of e-commerce in retail sales	L	L
	Existence of laws and policies on high-tech and digitalized agriculture	L	M
	Overall assessment for downstream indicator	L=3; M=4; H=0	L=2; M=3; H=2

Source: Calculated by the author from [16, 29, 30, 31].

The basic infrastructure supporting the technology application in agriculture and rural areas is still limited, even in large-scale agricultural production areas. Vietnam's recent rapid economic growth has resulted in serious infrastructure bottlenecks. New infrastructure is generally located in urban areas to connect major cities, airports, sea ports, industrial parks, tourist resorts, or areas related to security and defense, while the rural infrastructure is usually in a poor state and not maintained properly [3]. Rural transport infrastructure currently mainly meets the needs of people's welfare and doesn't meet the demand for trading goods. More importantly, several strategic inter-regional transportations, such as rail systems and highways have not been formed to connect difficult economic regions like the Northwest with markets, ports, and the main border gates, or to connect the two large-scale agricultural commodity production areas of Central Highlands and the Southwest. Inadequate transport infrastructure has led to several inefficiencies, including a high reliance on trucking as a mode of transport, compared to other cheaper options, such as rail for shipping products over long distances and congestion, because of inadequate highway infrastructure [3]. Therefore, the infrastructure score in Global Competitiveness Index and the Logistics performance index has not improved a lot from 60.2 to 65.4 points out of 100 and from 2.96 to 3.27 out of 10, respectively.

The rural road density has improved significantly over the years, from 0.89 km per sq km in 2005 to 1.75 km per sq km. The development of the rural road system will contribute to better market connections and agricultural production logistics arrangement, which helps SAT progress.

The stock-to-production ratio (milled rice equivalent) reflects the storage capacity of the country and the logistic facility, however, it does not mean that a higher ratio means better storage capacity. Since Vietnam is a rice-producing country, it maintains a stocks-to-production ratio, milled rice equivalent, of about 10-12% (medium level) [28].

Digitization Indicators

Although it has gained a lot of achievements, Vietnam has a lot to do in general, as it faces a challenging road ahead for smart agricultural transformation. Although there exists the law (Law No 51/2005/QH11 on e-commerce) and policies on e-commerce (Decree No 52/2013/ND-CP and Decree No 08/2018/ND-CP[15]) and high tech and digitalization, the share of e-commerce is still very small.

The official establishment of VIDA, with its members and network nationwide, led by the big digital cooperation, FPT Cooperation, lays out a foundation for SAT at the downstream level.

TABLE 9

SAT READINESS ASSESSMENT FOR DOWNSTREAM LEVEL USING SCORING METHOD.

	Indicator	2010	Currently
Downstream	**Development**		
	Existence of law/policy on food safety, traceability	3	4
	Infrastructure score in Global Competitiveness Index	3	4
	Logistics performance index	2	2
	Rural road density (km per sq. km)	1	3
	Stocks-to-production ratio, milled rice equivalent (%)	3	3
	Average score of the development indicator group	2.4	3.2
	Digitization		
	Existence of law/policy on e-Commerce	3	4

(Continued on next page)

[15] The government issued Decree No 52/2013/ND-CP on e-commerce on 16 May 2013 and Decree No 08/2018/ND-CP on amending several Decrees of the government on the conditions for trade and commerce later on 15 February 2018.

(Continued from the previous page)

	Indicator	2010	Currently
Downstream	Share of e-Commerce in retail sales	1	2
	Existence of law/policy on high-tech and digitalized agriculture	2	3
	Average score of the digitization indicator group	2.0	3.0
	Overall average score of downstream indicator	2.3	3.1

Source: Calculated by the author based on [16, 29, 30, 31].

Overall, the analytical results represented in Table 8 and the scoring results of the development indicators at the downstream level in Table 9, show that the SAT readiness of Vietnam has improved over time, but it is still at the medium status of readiness for the downstream level (comparing 2010 and the current year[16], the overall score increased from 2.3 to 3.1 in the Likert scale of 1 - 5)[33]. The analytical results also point out the areas for further improvement needed, like the share of e-commerce and logistics performance. There have been enabling factors like high Internet penetration rate, the rapid development of rural road systems, and government-supported policies and programs[17].

Lessons Learned and Insights from the Case Analysis: Policy Recommendations, Strategies, and the Way Forward

Based on the achievements and the gaps identified in the SAT readiness assessment, the study outlines how key outstanding issues can be addressed.

- The sector (MARD) should establish a clear mechanism to strengthen coordination and communication, vertically and horizontally, between related sectors at a national level, as also among the sector's planners and stakeholders for developing and implementing SAT. It should also integrate key targets into the planning and budgeting processes, both for short- and long-term planning.

- It should develop guidelines to elaborate on how to strengthen the coordination with the provincial and local government while planning for SAT and to strengthen the communication of risks and smart transformation strategies at sub-national levels.

- Develop guidelines for mainstreaming SAT strategies into planning and budgeting processes, for a comprehensive multi-level capacity assessment of MARD, and enhancement of the value chain stakeholders' participation in SAT capacity building programs and SAT planning processes.

- There should be a task force established within the Partnership for Sustainable Agriculture Development of Vietnam (PSAV) platform under MARD, that will work closely with the Department of Planning (DoP), to strengthen coherence among different SAT-related programs in the agriculture sector like organic agriculture, high-tech agriculture, biotechnology programs, digitalization of agriculture programs, 4IR in agriculture, New Rural Development (NRD), and Restructuring Agriculture Proposal (RAP).

[16] The current year is defined as the newest year of available data collected (mostly in 2018).
[17] On 2 March 2020, the Prime Minister of Vietnam signed Decision 324/QD-TTg giving approval to the Transition Strategies for Mekong Delta toward sustainable development to 2050.

- Ministry of Agriculture and Rural Development (MARD) should also work in collaboration with other line ministries, like the Ministry of Industry and Trade (MOIT), Ministry of Science and Technology (MOST), Ministry of Planning and Investment (MPI), and Ministry of Information and Communication (MIC) for establishing policies and legislations to incentivize both public and private investments for implementing SAT effectively and appropriately. The international cooperation for knowledge sharing, and technology and experience exchanges, especially among the APO economies, accurately prioritizing investments and resource allocations for implementing SAT, will play an important role in catching up with the fast-changing technical innovative, digital, and information age.

MARD should develop a clear roadmap that outlines key steps and processes being undertaken appropriately for particular subsectors, regions, and value chains from production, processing, storage, distribution, and marketing. The key value chain includes fruits, coffee, vegetable, shrimp, and pangasius, with priority placed in provinces whose Agriculture High Tech Zones (AHTZs) have been approved and established in Mekong Delta, Southeast, and Central Highlands.

Under the project supported by German Agency for International Cooperation (GIZ), there are plans to establish seven Green Innovative Centers (GICs) in the Mekong Delta provinces between 2020-2024. It is expected that the GICs will provide training and advisory services along rice and fruit value chains. These will be institutionalized to ensure business training and development advisory services for farmers and other value chain actors in the future.

The national database system on SAT is being developed to scientifically analyze and update the SAT readiness of the country. This will enable the agriculture sector to develop and adjust policies and strategies for enhancing SAT appropriately and efficiently. Investment in mechanization and digitization, and application of IoT and AI in planning and connecting products' supply, demand, and market information (automation, traceability, blockchains, the web portal of the system, etc.,) in both downstream and upstream levels are sufficient to take SAT forward.

The readiness assessment is an important and necessary step toward developing an appropriate roadmap for the SAT process. The readiness assessment provides a clear picture of the current SAT status, its progress and gaps, and areas that need higher attention and more investment priorities. For example, some subsectors in Vietnam like rice production, fruit, and vegetable production, and aquaculture are more advanced, compared to forestry. On the other hand, the readiness scores of different processes and levels are different. Some processes like land preparation and primary processing are more advanced in mechanization while processes such as crop and livestock management, product packaging and marketing, and product quality control are ahead in applying digitization.

In all three assessed levels of SAT readiness, i.e., downstream, production, and upstream, the existence of laws and policies related to agricultural finance for seed, agrochemicals, agriculture machinery, and food safety and traceability, that guide or are in support of the SAT process in Vietnam, are at a high level of readiness. This implies that the policy environment for SAT is ready.

The SAT readiness assessment results show the areas in need of improvement at all three levels of upstream, production, and downstream are land accumulation for larger scale production, agricultural insurance, e-commerce, and the share of e-commerce and logistics performance, etc.

There is still a gap between policy development and the actual implementation of the policies and regulations supporting the SAT process. There are high levels of SAT readiness at the upstream and production level, but not that high at the downstream level.

The assessment indicates that there has been an improvement at all levels of SAT readiness in Vietnam. The development of the Industry 4.0 revolution has also enhanced the digitalization process and the economic transformation in general, and SAT in particular.

Collaborations with business associations and big enterprises to build hi-tech incubators for agribusinesses for upscaling successful SAT models and champions are required. Creating a preferable policy environment for the application of AI, SMAC, and IoT, develops online commerce. It also helps connect consumers with manufacturers, which increases traceability and food safety control. At present, there are some typical Big Data and IoT application models in production such as vegetable control systems in greenhouses.

Establishing the agriculture information hub and connecting with SAT innovation centers and the VIDA, promotes the SAT processes along the key agriculture value chains in Vietnam.

Conclusion

Agriculture is still a key sector for the economy of Vietnam, contributing around 13%-15% to the GDP of Vietnam, as well as achieving the Sustainable Development Goals. However, the growth of agriculture during the last few decades has mainly been based on the intensive use of natural resources (scarce and degraded) and inputs (labor, materials) e.g., increasing agricultural production area (arable land), increasing crops, and focused investment on the irrigation system. A paradigm shift towards sustainable, high value-added, and effective use of resources in agriculture has been observed. This shift is presented clearly in the Agriculture Restructuring Proposal approved by the Prime Minister of Vietnam in 2013[18].

There is a need for the SAT program in the country to work towards sustainable, high value-added, and highly cost-effective uses of natural resources and inputs, in the context of increasing scarcity of the resources employed for agriculture production.

Although, there has been a significant increase in the legal bases for the development of SAT, e.g., the Law of High Technology, the Law on Transferring Technology, Decision No. 575/QDTTg/2015 on approval of the Master Plan of the hi-tech agriculture zones near 2020, orientation to 2030, etc., the smart agricultural transformation has still been quite slow.

The SAT readiness assessment results show Vietnam at a medium level, especially on the policy front. It also indicates that the country's readiness for SAT is higher at the production level, but lower at the downstream level.

To facilitate and speed up SAT process in Vietnam, the country needs to pay more attention to areas such as agricultural logistic arrangement, land accumulation for large-scale farming, risk mitigation (agricultural insurance), labor training, and agricultural TFP, and therefore GVA and the average income of agricultural workers. It also needs to increase investments in these areas.

[18] The Decision 899/QD-TTg of the Prime Minister dated 10 June 2013 on the approval of the Agricultural Restructuring Proposal towards high value added and sustainability.

A review of SAT status in Vietnam reveals the issues and challenges that need to be addressed.

- The mobilization of available resources has reached a limit. The main barriers preventing farmers and businesses from applying SAT to develop an agricultural value chain are a lack of technical and capacity-building technology transfer and accessibility to the sources that provide materials, information, and knowledge.

- Key factors affecting the application of SAT along the value chain are locations, logistics connection, technical costs, farm size, information/funding/access to land and infrastructure, and market information.

- Economic incentive is recognized as the main motivation to enable the "pull" factors such as TFP and GVA, for applying SAT in the development of holistic agricultural value chains.

- Risk bearing and sharing, among different stakeholders and value chain actors are also important when promoting new technology for SAT.

- Resource mobilization, land accumulation policy for taking advantage of the economies of scale, SAT investment stimulant packages, and a start-up innovation fund and start-up innovative incubator for up-scaling SAT models are probably key successful factors in developing effective SAT models in agricultural value chains.

- There should be a policy mechanism in place to mobilize or incentivize the private sector to invest in upscaling and outscaling the SAT, as a means to achieve LC/Green AV/ sustainable agriculture.

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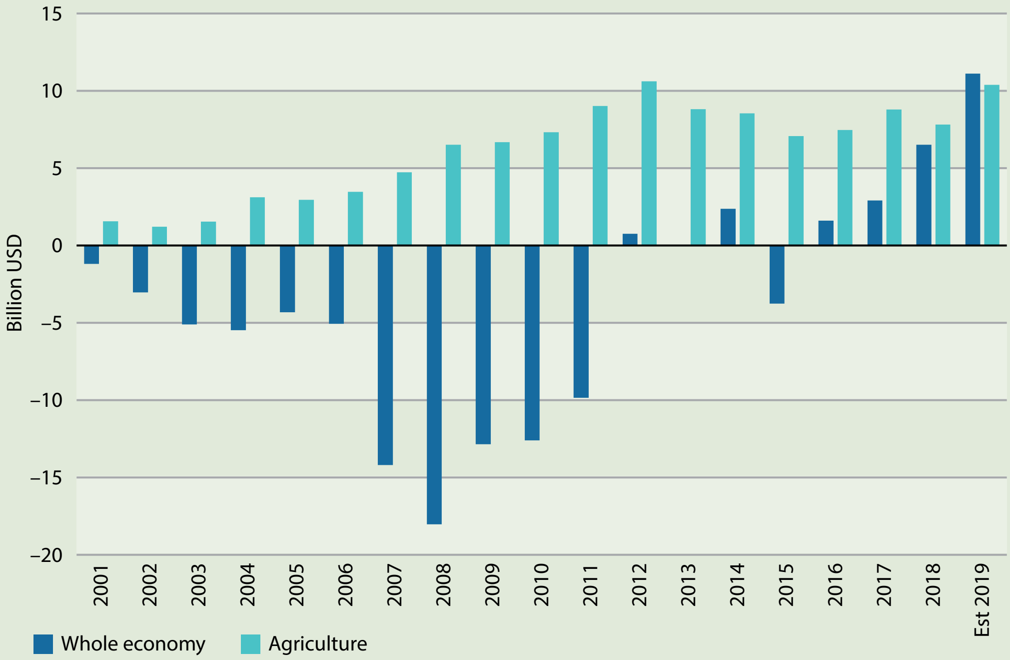
Appendix

APPENDIX 1

TRADE BALANCES OF THE WHOLE ECONOMY AND AGRICULTURE.



Source: GSO [2].

APPENDIX 2

DESCRIPTION OF SCORING METHOD OF LIKERT'S SCALE USED IN ASSESSING THE SAT READINESS INDICATORS OF VIETNAM.

	Indicator	Description of the Scoring Method for Each Indicator
	Development	
Upstream	Existence of laws and policies on agricultural finance	Very few mentioned =1; = 5 if full sets of policies and laws addressing the issue
	Agricultural insurance penetration ratio	=1 if 0-10; =2 from 11-20; = 3 from 21- 30; =4 from 31-40 and =5 if >40
	Share of borrowing smallholders and fishers who borrow from formal sources (%)	=1 if 0-20; =2 from 21-40; = 3 from 41- 60; =4 from 61-80 and =5 if from 81-100
	Technician-to-farmer ratio: public and private	=1 if one extensionist/more than 300 HHs (1 village); =2 if from 251-300 HHs; = 3 if from 201-250 HHs; =4 if from 151-200 HHs and =5 if from,<= 150 HHs
	The proportion of agricultural land that is irrigated (%)	=1 if 0-20; =2 from 21-40; = 3 from 41- 60; =4 from 61-80 and =5 if from 81-100

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	Indicator	Description of the Scoring Method for Each Indicator
Upstream		**Digitization**
	Share of extension personnel who are computer-literate (%): public and private	=1 if 0-20; =2 from 21-40; = 3 from 41- 60; =4 from 61-80 and =5 if from 81-100
	Existence of IT-based agricultural insurance products (e.g. remote sensing)	=1 if no or very few IT-based insurance products exists =1; = 5 if all insurance products are available on the IT form
Production		**Development**
	Existence of a regulatory framework for seed	Very few mentioned =1; = 5 if full sets of policies and laws addressing the issue
	Existence of regulatory framework for agro-chemicals (fertilizer and pesticide)	Very few mentioned =1; = 5 if full sets of policies and laws addressing the issue
	Existence of a regulatory framework on agri-machinery	Very few mentioned =1; = 5 if full sets of policies and laws addressing the issue
	Tractors per 100 sq km of arable land	=1 if less than 100; =2 from 101-200; = 3 from 201- 300; =4 from 301-400 and =5 if more than 400
	Average monthly earnings in agriculture (dollars per month)	= less than 100; =2 from 101-200; = 3 from 201- 300; =4 from 301-400 and =5 if more than 400 (based on the average income/month of the MICs by WB (1026-12475)
	Rural employment in youth (from 15 -29) employment (%)	=1 if 0-20; =2 from 21-30; = 3 from 31- 40; =4 from 41-50 and =5 if >50
	Average age of a farmer	=5 if <35; =4 from 35 to <40; = 3 from 40 to less than 45; =2 from 45-50 and =1 if from >50
	Average farm size (ha)	=1 if <1; =2 from 1- <10; = 3 from 10- <50; =4 from 50- <100 and =5 if >100
	Share of smallholder (2 ha and below) who is owner-cultivator (mainly for rice)	=1 if 0-20; =2 from F9021-40; = 3 from 41- 60; =4 from 61-80 and =5 if from 81-100
	Share of agricultural workers who are women (%)	=5 if <35; =4 from 35 to <40; = 3 from 40 to less than 45; =2 from 45-50 and =1 if from >50
	Fertilizer utilization per ha	=5 if <100; =4 from 100 to <150; = 3 from 150 to less than 250; =2 from 250 to <350 and =1 if from >350
	Pesticide application per ha	=5 if <1; =4 from 1 to <1.5; = 3 from 1.5 to less than 2; =2 from 2-2.5 and =1 if from >2.5
	Utilization of certified seeds, share of total (%)	=1 if 0-20; =2 from 21-40; = 3 from 41- 60; =4 from 61-80 and =5 if from 81-100

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	Indicator	Description of the Scoring Method for Each Indicator
Production	Agricultural GVA per worker (=USD in 2010)	=1if less than 1000; =2 from 1001-2000; = 3 from 2001- 3000; =4 from 3001-4000 and =5 if more than 4000
	Agricultural Total factor productivity (TFP) growth (2005 = 100)	=1 if 0-20; =2 from 21-40; = 3 from 41- 60; =4 from 61-80 and =5 if from 81-100
	Digitalization	
	Share of youth in agricultural employment (%)	=1 if 0-20; =2 from 21-30; = 3 from 31- 40; =4 from 41-50 and =5 if >50
	Electricity infiltration rate (%)	=1 if 0-20; =2 from 21-40; = 3 from 41- 60; =4 from 61-80 and =5 if from 81-100
	Telephone infiltration rate (%)	=1 if 0-20; =2 from 21-40; = 3 from 41- 60; =4 from 61-80 and =5 if from 81-100
	Internet infiltration rate (%)	=1 if 0-20; =2 from 21-40; = 3 from 41- 60; =4 from 61-80 and =5 if from 81-100
	Computer literate rate of agricultural employment	=1 if 0-20; =2 from 21-40; = 3 from 41- 60; =4 from 61-80 and =5 if from 81-100
	%age of agriculture-trained labor force	=1 if 0-20; =2 from 21-40; = 3 from 41- 60; =4 from 61-80 and =5 if from 81-100
	Average years of schooling of the agricultural labor force (year)	=1 if 0-2; =2 if from 2< to 4; = 3 if from 4<-to 6; =4 if from 6< to8 and =5 if from > 8
Downstream	**Development**	
	Existence of laws and policies on food safety, traceability	Very few mentioned =1; = 5 if full sets of policies and laws addressing the issue
	Infrastructure score in Global Competitiveness Index	=1 if 0-20; =2 from 21-40; = 3 from 41- 60; =4 from 61-80 and =5 if from 81-100
	Logistics performance index	=1 if 0-2; =2 from 2.1-4; = 3 from 4.1- 6; =4 from 6.1-8 and =5 if from 8.1-10
	Rural road density (km per sq. km)	=1 if less than 1; =2 from 1-less than 1.5; = 3 from 1.5 to < 2; =4 from 2 to <2.5 and =5 if >2.5
	Stocks-to-production ratio, milled rice equivalent (%)	=1 if 0-4; =2 from 4.1-8.0; = 3 from 8.1- 12.0; =4 from 12.1-16.0 and =5 if from 16.1-20 (20% is a maximum)
	Digitization	
	Existence of law/policy on e-commerce	Very few mentioned =1; = 5 if full sets of policies and laws addressing the issue
	Share of e-commerce in retail sales	=1 if 0-10; =2 from 11-20; = 3 from 21- 30; =4 from 31-40 and =5 if from 41-50
	Existence of laws and policies on high-tech and digitalized agriculture	Very few mentioned =1; = 5 if full sets of policies and laws addressing the issue

Appendix 3. Some examples of applying SAT by the businesses and agricultural companies in Vietnam

High-tech in a Closed Supply Chain in Nghe An

In 2009, TH True Milk set up its first cow farm and dairy process factory in Nghia Dan district, Nghe An province. This is a closed production chain system of fresh milk from the farm to the consumer (farm-to-fork or F2F model). The group has invested across 37,000 hectares, ensuring feed and forage supply for cows. All the process from caring, health checking, and milking cows to widespread distributing to the chain stores of TH True Marts is set up.

In 2013, the group developed a model of organic vegetable production on a 300-hectare farm in Nghe An province and 200 hectares in Da Lat city, Lam Dong province. In these farms, the closed systems have also been set up in a close circle from seeding, planting, crop management, harvesting, and primary processing to distribution to its market system. Vegetable production is strictly followed organic production requirements, e.g., no chemical fertilizers, no growth stimulants, no pesticides, no herbicides, no genetic modification, etc. The crop residues and animal manure were composted to produce organic fertilizers. Most of the production activities were mechanized to increase production efficiency and control weeds and pests.

Based on the success gained from these models, TH Group has been expanding its high-tech transforming model at different locations in the country like the one in Thai Binh province where the group established a 3,000-hectare farm in 2017.

Five-star Technology Cow Raising in Thanh Hoa

Vinamilk is running a high-tech dairy farm in Yen Dinh, Thanh Hoa province, following the four philosophies of the dairy industry: well-slept cows, good milk production, better reproductive cows, and environmental protection with community development around the farm.

With the CowScout system, each cow has a tracking ring with its code to assess its health status over the last 10 days. Similarly, calves use an automatic milk supply machine, each calf has a tag or necklace with an ID code that records eating habits, stores data, and immediately reports if anything is wrong.

There is a system of robots to push and feed automatically so that the cow always eats fresh, new, and nutritious food at any time of the day. The milking at the farm is done using a fully-closed automated system. Fresh milk is collected and transported through specialized pipes with temperatures cooled to 2-4 degrees C. The total time from milking and preserving to processing factory production is not more than 24 hours and without preservatives.

All waste is collected and processed at different stages, transported to safe areas, and does not affect the environment. Most of the treated waste meets the standard of reuse for farm operations, reducing the consumption of energy, water, and other resources.

Modern Chicken Farm in Binh Phuoc

Hung Nhon Group has invested millions of dollars in a high-tech farming system in Binh Phuoc province that meets the Global Gap standards. Accordingly, the Group has links with several big companies in the world for the whole production process, such as De Heus Co. Ltd. (the Netherlands) providing feed; Bel Joint Stock Company (Belgium) selling breeds; and Koyu & Unitek Co. Ltd. (in Dong Nai) for purchasing, slaughtering and exporting chicken to Japan. This chain creates a closed production line of clean chicken products that meet the strict quality standards of the Japanese market.

The Group has invested in a system of modern machinery and equipment of Big Dutchman Group (Germany) for 28 chicken farms, creating a closed, cool chain system for chickens. Thanks to the application technique of farm management and traceability, the whole production process and traceability are digitalized. Enterprises are implementing the production process of livestock under the model of linking chains from breeds, feed, and breeding models to slaughter processing, to supply the market with clean, safe, and stable products.

Smart Farm in Hoa Lac Hi-Tech Park Applied Domestic High-tech Solution

A membrane house technology on Smart Connected Platform (SCP), has just been built by VNPT Technology, a unit of VNPT, at Hoa Lac Industrial Technology Complex for research and development of domestic smart agriculture solutions that can be applied across the country. The solution serves the needs of both cultivation and animal husbandry. It helps measure all parameters of soil and environment, propose irrigation time, and lighting time suitable for each stage of farming farms. It also helps in the management of livestock farms across stages including feeding, lighting, egg harvesting, dung collection, and heating systems.

Thanks to the Big Data integration, VNPT smart agriculture solution allows farm owners to analyze and forecast. It also helps in proactive planning, production, transportation, and storage and brings in a high level of economic efficiency. Users can control the system using an application on the phone developed by the company.

Currently, smart agricultural solutions of VNPT Technology have been applied in many places. The company has also built a membrane production area in Hoa Lac Hi-tech Park, applying the smart agricultural solution to real farming for different types of crops, such as melon, vegetables, spinach, and lettuce.

Currently, the membrane area and the support systems have been completed and put into operation, and crops have completed the initial development stage. VNPT Technology has fully adopted smart agriculture solutions such as irrigation systems, automatic lighting, humidity, and PH control for cultivation.

MAINSTREAMING SAT: EXPERIENCE OF ROC

The agricultural sector in the Republic of China (ROC) faces challenges of labor shortage, aging farmers, climate change, and food safety. To tackle these problems, the government has initiated a series of new agricultural policies aimed at helping the agricultural sector move into an era of smart agriculture. The case analysis presents these policies and describes how ROC implements them, using some cases that have adopted smart technologies and services. Moreover, the lessons learned from the policy-making and implementation are presented to shed some light on how member countries of APO can speed up their smart agricultural transformation. Policy recommendations are also provided based on Taiwan's experience in promoting industry innovation and smart agriculture transformation.

Introduction and Background

The agricultural sector in the ROC has been developed since the early seventeenth century. Since then, agricultural products produced in Taiwan have been not only the source of food for local consumption but also the basis that supports the development of the whole economy. After the Second World War, when reconstruction began, the agricultural policies mainly focused on the self-sufficiency of food. When the goal was met in the 1960s, Taiwan started to export its agricultural products to other areas, and the agricultural sector became the pillar for the development of the industrial sectors. Meanwhile, Taiwan lent a helping hand to Asian and African countries by sending 'farming teams' to help farmers in the region grow a variety of crops. The seemingly successful agricultural sector, however, has been facing many challenges since the 1980s as the farming population began to age.

Early Agricultural Development

Taiwan has exported its agricultural products to other areas for over 600 years. During the Dutch rule from 1624 to 1662, for example, sugar, fish, and deerskins were exported to Japan, China, and the Dutch East Indies [1]. Later, during the Ching period, sugar, rice, and tea became the most important export commodities [1, 2]. Under Japanese rule between 1895 and 1945, sugar and rice remained the two most important exports, but they were exclusively exported to Japan.

After the Republic of China relocated to Taiwan in 1949, reconstruction began. Due to shortages in the food supply, the main goal of the agricultural sector was to improve productivity. To achieve this goal, the government launched a series of land reform policies, while helping farmers learn efficient farming skills [3]. The goal of self-sufficiency in food was then met in the 1960s, and thus, the government started to encourage farmers to grow crops with higher economic values and assisted them in finding foreign markets to sell agricultural products. For example, Taiwan was the third-largest granulated sugar exporter worldwide in the 1950s and 1960s. Canned mushrooms, pineapples, and asparagus were exported to European and North American countries in the 1970s [4]. Taiwan also exported bananas to other countries, mainly Japan.

In the 1980s and 1990s, the food consumption pattern of the Taiwanese people began to change, largely due to the increase in income and the rapid development of the industrial sectors. Rice consumption sharply decreased, while consumption of meat, milk, eggs, fruit, and vegetables increased. Meanwhile, Taiwan had to open its markets and import agricultural products from the United States at the request of the country. In 1994, for example, Taiwan agreed to open its markets and reduced agricultural subsidies at the Uruguay Round, conducted within the framework of the General Agreement on Tariffs and Trade (later, World Trade Organization) [5]. Due to these challenges, Taiwan's agricultural sector started to diversify its products by encouraging farmers to continue growing rice, which was still the main food on the table, and other crops with high economic values, such as tea, fruit, vegetables, and flowers. The cultivation of sugar cane and tobacco declined on the other hand, because of the cheap imports. In this period, in addition to fresh fruit, vegetables, and flowers, Taiwan exported farmed tiger prawns and eels to Japan. This counted for 50% of the eels sold in the Japanese market [6].

In addition to exporting agricultural products, Taiwan also supported countries that needed agricultural assistance. In 1959, Taiwan sent its first farming team to Vietnam and helped the Vietnamese government in conducting land reforms and taught the farmers new farming techniques. Since then, Taiwan's farming teams have assisted many African countries, including Burkina Faso, Chad, The Gambia, Liberia, Malawi, São Tomé and Príncipe, Eswatini, and Senegal, as well as Solomon Islands and Indonesia, to grow rice, corn, sweet potatoes, and other vegetables [7].

The successful agricultural development in Taiwan before the 2000s has been attributed to mechanization [8]. Since the 1950s, the government has promoted mechanization in agriculture by importing small power tillers to assist rice farming, which was welcomed by the rice farmers. Special loans were also granted, enabling farmers to purchase the machines. Later, Taiwanese companies began to manufacture power tillers by themselves, catalyzing the widespread use of power tillers in rice cultivation in Taiwan. Starting from the 1960s, as industrialization intensified, many farming laborers were drawn to work for factories. This led to a shortage in the farming sector. The ratio of employment in agriculture to total employment fell from 35.14% in 1971 to 12.95% in 1991 [9-11]. To alleviate the problem of labor shortage, large, advanced machines were introduced for rice cultivation, such as rice transplanters, agricultural tractors, ditch sweepers, and grain drying machines. These machines enabled farmers to increase productivity while reducing the use of labor. The mechanization was then expanded to other crop cultivation in the 1980s, such as corn, sorghum, peanuts, and soybeans [12].

New Challenges Since 2000

The successful agricultural development in Taiwan has run into new challenges since 2000. This time, the challenges are related to both global, as well as domestic trends. The Organization for Economic Co-operation and Development (OECD) has suggested that the three intertwined agricultural challenges that the world faces today should be tackled together. These challenges include feeding a growing population, providing a livelihood for farmers, and protecting the environment [13]. Based on the estimation made by the OECD, the world population is likely to grow from 7.5 billion today to 10 billion by 2050. Providing safe and sufficient food to the population, while sustaining agricultural developments will become a difficult task for every country. Thus, the organization has urged all countries to address these issues.

Meanwhile, Taiwan's agriculture sector shares similar, but much more profound challenges. Firstly, not only is the arable land limited, but the areas used for agricultural cultivation are also shrinking.

Based on the agricultural statistics in 2018, agricultural land accounted for 22% of the total land in Taiwan [14]. However, the land used for growing crops, decreased from 789,592 hectares in 2005 to 743,879 hectares in 2018 [15], approximately a 10% drop over 13 years. Secondly, the farming population is aging and decreasing. In 2018, there were 561,000 people employed by the agricultural sector, whereas the number was double in 1996 [16]. On top of the declining population, the average age of farmers is also rising. In 2018, only about 10% of the farmers were from the younger generations (younger than 35 years old), while the majority of them (around 70%) were between 35 and 64 years old. Much older farmers, older than 65 years, counted for 19% of the agricultural workforce. The average age of the farmers was 62 years old [17]. In the next 10 years, it is expected that more than one hundred thousand agricultural workers will retire, causing more serious labor shortages in the agriculture sector.

The third challenge that the agricultural sector faces is climate change. Global warming is a source of worldwide climate change. Many cities in Taiwan have witnessed an increase in average temperatures over the years. More importantly, the number of cold days during the winter has declined, and the weather in winter is getting warmer [18]. The hot weather may cause drought, increase the possibility of insect and pest outbreaks, and affect the growth of crops, bringing huge damage or loss to agricultural production.

Last, but not least, the agriculture sector in Taiwan has been affected by market liberalization. Taiwan became a member of the World Trade Organization (WTO) in 2002. Under the rule of trade liberalization, Taiwan had to make a significant tariff reduction on agriculture, livestock, and fishery. To reduce the negative impacts on the agricultural sector, the tariff was gradually decreased. In the first year of entering WTO, the average nominal tariff rate for agricultural products was reduced from 19.33% to 13.98%. The tariff rate continued decreasing and reached 12.86% as promised in 2011. A total of 1,021 products were brought under tariff reduction [19]. Meanwhile, for protection purposes, it was decided that the import of rice and other 21 sensitive products will continue to follow the rules of the tariff quotas [20]. With the substantial tariff reduction, agriculture imports considerably increased. The agricultural products produced at small family farms in Taiwan might not be able to compete with the products produced by large-scale farms overseas, due to the economy of scale. This would lead to the decreased value of domestic agricultural production as a whole, as well as an increase in unemployment in the agricultural sector [21].

To overcome these challenges, the government in Taiwan launched a series of policies aimed at improving Taiwan’s productivity. In 2015, borrowed from the ideas of technological upgradation introduced by various advanced countries, such as Germany, Japan, and the United States, a technology development strategy, titled Taiwan Productivity 4.0, was initiated by the government to promote technology upgrades in Taiwan’s industries [22]. In this strategy, enhancing agricultural productivity was also listed as one of the three priorities, and four areas were selected as the targets: agricultural equipment, poultry, fish farming, and agricultural product traceability. These areas were assisted by the government to increase their productivity and then they became the exemplars to other industries. Taiwan Productivity 4.0 can be viewed as the starting point for Taiwan’s development of smart agriculture.

In 2016, a new agricultural policy, the New Agricultural Innovation Promotion Scheme, was introduced [23]. This scheme aimed to integrate industrial and agricultural technologies, develop innovative technologies, and their applications, to help the agricultural sector move to a new and smart era. Three pillars were included in this plan. First, a new agricultural paradigm was established focusing on protecting the livelihood of farmers and enhancing agricultural development, while promoting sustainable agriculture. Various schemes, including price support and buyouts, subsidies for fallow land, agricultural insurance, farmland rental, farmer loans, fresh meat transporting regulations, disease control for livestock and poultry, subsidies for organic and sustainable environmental practices, inspections of land and agricultural resources, and incentives to develop automatic and smart equipment, were announced.

The second pillar emphasized the safety of agriculture and established a trustworthy food traceability system to meet international standards. Policies that promoted corn and soybean production, raised the self-sufficiency rate of the food, increased food safety practices, and created reliable food labeling and traceability systems were launched. Finally, the third pillar aimed to increase the competitiveness of Taiwan's agricultural products by enhancing its marketing ability. For example, a semi-public company, Taiwan International Agricultural Development Corporation, was established in 2016 to export Taiwan's agricultural products to the south and southeastern Asian countries, Australia, and New Zealand. In addition, agricultural product processing centers and regional distribution centers were set up to coordinate the production and sales systems, and to find new markets, so that agricultural production could be more stable. To achieve these goals, approximately USD4 billion was allocated during the four years between 2017 and 2020. By the end of 2020, it is expected that the self-sufficiency rate of food will reach 40%, the value of agricultural production would show an increase of 1.45 billion USD, 370,000 new jobs would be created, and agricultural exports for new foreign markets would account for 57% of the total agricultural exports [24].

Moreover, in 2017, the Smart Agriculture 4.0 policy aimed at agricultural transformation was launched by the Council of Agriculture [25]. The term smart agriculture has been used in all agriculture-related policies since then. As mentioned earlier, the main goals of Taiwan's agricultural policies have shifted over time. The policies related to Agriculture 1.0 concentrated on securing basic production, by using simple machines to assist in cultivation activities, as Taiwan began to recover from the Second World War and tried to feed a large number of immigrants from mainland China. Farming at the stage of Agriculture 1.0 was a labor-intensive and experience-based activity. By comparison, the goals of the policies for Agriculture 2.0 were to maximize agricultural productivity by improving cultivation techniques and introducing mechanization, as the agricultural sector faced the challenge of labor shortage due to the rapid industrial development in the 1960s and 1970s [9]. At that time, farming was a skill-intensive and machine-intensive activity. Later, Agriculture 3.0 policies tried to promote the idea of precision agriculture and emphasized utilizing biological technologies, automation, and information and communication technologies (ICT) in agriculture. For these policies, the quality and safety of agricultural products were very important, and farming was a knowledge-intensive and automation-intensive activity.

Currently, agricultural policies have aimed at increasing efficiency and effectiveness while considering risks. Thanks to the advancement and development of new information and communication technologies, such as various sensing technologies, the Internet of Things (IoT), artificial intelligence (AI), and intelligent robotics, agricultural productions are expected to become smarter, and services for the production and marketing will become digitalized [26]. Agriculture 4.0 can be viewed as an upgraded version of Agriculture 3.0. The former focuses more on automation and integration, while the latter aims at digitization and fully exploiting the potential of AI technologies.

In the following sections, policies for Smart Agriculture 4.0 will be introduced. In addition to introducing relevant policies, successful cases will also be presented to show how these policies are being implemented. Special attention will be paid to new production technologies and techniques applied to agricultural production. Through these real cases, it is expected that Taiwan's experience in smart agriculture transformation may be able to help other member countries of the APO shed some light on smart agriculture promotion.

Focus and Scope of Case Analysis

The agricultural policy implemented by Taiwan generally follows a top-down process. In other words, government agencies are the leaders in the policy-making and implementation process. Thus, in this chapter, special attention is paid to the roles that the government has played, as well as the policy tools that have been used, in facilitating smart agriculture transformation. These tools behind the smart agriculture transformation are introduced and the policy implementation is analyzed. The smart policies reviewed in this chapter can be divided into two categories. One is innovation-related policies, Productivity 4.0 [27], Five plus Two Industry Innovation Plan [28], Digital Nation (DIGI+) [29], Forward-Looking Infrastructure Program [30], and Taiwan AI Action Plan [31]. These five policies lay the foundation for the overall smart transformation. The other is the smart agriculture policies, which provide specific guidelines for smart agricultural transformation. These policies include Agriculture Productivity 4.0 [32], New Agricultural Innovation Promotion Scheme [23], and Smart Agriculture 4.0 [33]. Table 1 lists all policies reviewed in this report.

TABLE 1

SMART POLICIES REVIEWED IN THIS CHAPTER.

	Type	Launch Year	Duration	Budget (in USD)
Productivity 4.0 [27]	Industry innovation	2015	2016-2024	1.2 billion
Five Plus Two Industry Innovation Plan [28][1]	Industry innovation	2016	2016-2020	310.3 million
Digital Nation & Innovative Economic Development Program (DIGI+) [29]	Economic innovation	2016	2017-2025	1.53 billion
Forward-Looking Infrastructure Program: Digital Infrastructure [30]	Smart infrastructure	2017	2017-2020	2.44 billion
Taiwan AI Action Plan [31]	Smart services	2018	2018-2021	1.22 billion
Agriculture Productivity 4.0 [32]	Smart agriculture	2015	2016-2024	n.a.
New Agricultural Innovation Promotion Scheme [23]	Smart agriculture	2016	2017-2020	4 billion
Smart Agriculture 4.0 [33]	Smart agriculture	2017	2017-2020 (Phase One)	59.2 million

Note: [1]Renamed as Industry Innovation Flagship Scheme in 2017 [34].

In addition, 10 cases from the steering agricultural industries selected by Agriculture Productivity 4.0 are introduced as examples of the best practices in Taiwan. In each case, the innovative processes and technologies used in improving production and productivity are described. These cases show the current development of Taiwan's smart agriculture promotion and lay the foundation for future innovation movements.

Current Development

Policies Related to Smart Agricultural Transformation

Taiwan began to promote smart agricultural practices in 2015 [32]. Since then, several policies have been introduced, which have facilitated smart agricultural transformation by encouraging the agricultural sector in Taiwan to utilize these cutting-edge technologies to improve production efficiency and increase the quality of agricultural products. These policies can be divided into two categories: innovation-related policies and smart agriculture policies. The former aims to promote an overall upgradation for all industries in Taiwan by encouraging innovation and providing incentives to the industries for investing in smart technologies and services. These policies generally lay the groundwork for Taiwan's smart agriculture transformation. The latter, on the other hand, targets the agricultural sector in particular and helps the sector upgrade itself by promoting smart technologies and services.

Innovation-related Policies

Productivity 4.0

In 2015, inspired by Germany's Industry 4.0, Taiwan launched its version titled Productivity 4.0 [27]. The policy attempted to address two important issues. One, it aimed to meet the challenges of growing global competition on smart technologies and services, particularly with advanced countries actively promoting smart production and sales systems to respond quickly, or predict, market demands. Taiwan also needed to set its goals on increasing the ability to develop smart technologies and provide smart services, so that it can play a crucial role in the global smart supply chain. Besides, there was a concern that the aging population will lead to a decline in the labor force and result in a drop in productivity. The development of smart technologies and services, therefore, was the best way to mitigate the problem caused by the reduction of the labor force.

Productivity 4.0 attempts to address the following six issues before 2025, as shown in Figure 1. The first issue is to strengthen the smart supply chains for the selected steering industries in Taiwan by enhancing the vertical value chains inside the businesses, establishing horizontal value chains in the industries, creating mechanisms to provide guidance and services to the industries, promoting and setting standards for information and communication interfaces, establishing certification systems for industrial products, technologies, and production processes accepted by international communities, and assisting Taiwanese corporations to join international supply chains. Overall, eight industries, including electronics and information, metal vehicles, machinery and equipment, food, textile, retail, logistics, and agriculture have been selected as the steering industries and to serve as the exemplars, as well as the seeds, to transform and lead all industries into a smart era [22].

In addition to steering the industries, the government encourages new and innovative start-ups. Four industries or businesses are promoted, including corporations that manufacture key components like sensors and actuators for cyber-physical systems (CPSs) and smart equipment manufacturers. These also include businesses that provide CPS solutions, additive industries that produce core equipment, systems, key components, and materials, and innovative additive manufacturing and application industries. Under the program, the government is assisting start-ups in developing innovative business strategies and introducing international businesses, products, and services.

FIGURE 1

THE NEED FOR PRODUCTIVITY 4.0.

Improving Economic Growth and Competitiveness in International Markets

Building a Basic Environment for Productivity 4.0

1. Creating a better ecosystem for the smart supply chain of the steering industries
   - Enhancing intelligent ability of the vertical value chain for the industries
   - Building intelligent ability of the horizontal value chain for the industries
2. Facilitating startups*
3. Improving localization of productions
4. Controlling core technologies and autonomous ability
5. Fostering practical talents
6. Investing in policy tools for the industries

Agriculture 4.0 Strategic Choices
Accounting for 50% of the total production value of agriculture

- Agricultural biotechnology (orchids, seedlings, mushrooms)
- Quality agriculture (rice, agriculture facilities, aquaculture, poultry, waterfowl)
- Precision agriculture (traceable agricultural products - TAP, milk, marine fishery)

Manufacturing 4.0 Strategic Choices
Accounting for 62% of the total production value of manufacturing

- Electronic information industry
- Metal vehicle industry
- Machinery equipment industry
- Food industry
- Textile machinery industry

Business 4.0 Strategic Choices
Accounting for 18% of the total production value of service industry

- Retail
- Logistics

Source: Board of Science and Technology, Executive Yuan.
*(1) CPS components (sensors, controllers, etc.) and smart equipment industry.
(2) CPS solution service industry.
(3) Additive manufacturing and key equipment, system, components, and material industry.
(4) Additive manufacturing startups.

The third issue focuses on promoting products manufactured and services provided by domestic corporations. To achieve this, products and services offered by international companies are first introduced in the domestic market so that local companies can gain access to critical skills and technologies. In addition, incentives are provided to domestic companies that manufacture key systems and components.

To promote smart industrial transformation, the government has set the priority on acquiring critical skills and techniques in CPSs and additive manufacturing. Corporations are encouraged to utilize various smart technologies, such as IoT, smart machines, Big Data analytics, and AI, to provide customized products and services, while improving production efficiency and product quality.

The workforce is also key to a successful smart transformation. Therefore, the government helps corporations gain access to high-tech workforces, by introducing a variety of schemes, including continuing education and training for high-tech workers, multidisciplinary high-tech training for workers in industry-university cooperation, training for international talent in the cooperation among industries, universities, and research institutes, and recruiting international talent for industry, universities, and research institutes.

The last issue is to use various policy tools, to encourage and support the steering industries and start-ups to acquire critical skills and techniques that they need. These tools include providing investment and incentives, loans for start-ups, tax deductions for research and development, legal and consultant services for small and medium-sized companies, and the scheme for credit enhancement guarantee. The end goal of these policies is to promote industry upgradation and transformation while increasing industries' capability in utilizing smart technologies, research and development, and business management.

To achieve the goals mentioned above, various government agencies have consulted with representatives from the targeted industries and experts to discuss the implementation of the policies and schemes. Among the government agencies that have participated in the policy implementation, three agencies play a leading role in pushing forward the smart technological transformation. These are the Industrial Development Bureau (IDB) and the Department of Commerce (DOC) under the Ministry of Economic Affairs, and the Council of Agriculture (COA). They all set up some priorities to achieve the goals for upgrading the industry.

For the manufacturing industries, the IDB has selected five industries and supported their smart technological transformation. These industries generally face fierce international competition, seek higher values through manufacturing, and aim to attract a large number of people to work for them, so they can benefit greatly from the use of smart technologies. Based on the criteria, industries, including electronics and information, metal vehicles, machinery and equipment, food, and textile, are targeted. The transformation proceeds with the priority on the optimal use of energy, friendly environments for human and machine collaboration, flexible and agile manufacturing, predictive production management, mass production with customized high-quality, value products, and innovative production and service networks, as shown in Figure 2.

Meanwhile, for the business sector, DOC has created a blueprint for retail and logistics. For example, DOC encourages the two industries to develop various smart and integrated services for their customers, such as helping retailers establish smart retail business models, create excellent shopping environments, and improve retail and logistics service efficiency and competitiveness, by utilizing various smart technologies, including Big Data analytics, Internet of Things, mobile pay, and automation. As shown in Figure 3, the goals of the transformation are to change consumer behavior and upgrade retail and logistics services by providing customers with better, smarter services.

In addition to the upgrading of the industrial and business sectors, COA has also been making efforts to promote smart agriculture transformation by developing critical technologies for precision agriculture, establishing service and supportive systems for productivity enhancement, and creating an innovative, user-friendly communication model for producers and consumers based on interaction technologies, as shown in Figure 4. COA also encourages the use of smart technologies such as wireless sensor networks (WSN), GIS, and Big Data analytics for agricultural production to improve the quality of production and achieve the goals of saving time and labor [32]. Moreover, several smart agriculture alliances have been formed to increase the cooperation between farmers, businesses, and agriculture-related organizations. To facilitate smart transformation, teams are also organized to provide customized training programs to farmers. Most training programs are hosted either by Agricultural Research and Extension Stations in different districts or by the Farmers' Academy [35]. In addition, smart outsourcing farming centers have been established to increase productivity while reducing farming costs. For example, different task forces for agricultural

FIGURE 2

GOALS FOR SELECTED MANUFACTURING INDUSTRIES UNDER PRODUCTIVITY 4.0.

Manufacturing

- Electronic information industry
- Metal vehicle industry
- Machinery equipment industry
- Food industry
- Textile industry

Industrial Structure Optimization

Optimization of resource uses

- Production upgrading. Land and energy use improvement.
- Waste reduction and regeneration. Resource utilization Improvement.

Friendly human-hobot collaboration

- On-the-Job Training for employees. Helping them become managers and decision makers.
- Working with robots to achieve collaborative production.

Flexible manufacturing

- Flexible production lines. Real-time management. Fast response to market demands.

Manufacturing prediction and management

- Using big data analysis to improve production and predict maintenance and market needs.

Mass customization for high value products

- Promoting CPS-based high value products.
- Ensuring product quality by monitoring productions/using real-time feedback methods.

Networks for innovative production and services

- Integrating production and sales systems. Creating innovative production and business operation models and innovative industries.

Source: Industrial Development Bureau, Ministry of Economic Affairs.

FIGURE 3

GOALS FOR SELECTED SERVICE INDUSTRIES UNDER PRODUCTIVITY 4.0.

Using Smart Technologies and Mobile Devices to Transform Retail/Logistics Industries into Smart Retail/Logistics Industries

Industry Improvement

Retail

Changes in consumer behavior

- Almost everyone owns intelligent devices.
- Purchasing habits change from going to real stores to on-line shopping.
- Economic development facilitates the changes.
- Social media and reputation affect shopping decision.
- Consumers pay attention to the potential for the use of mobile payment.

Industry Trends

Industry trends

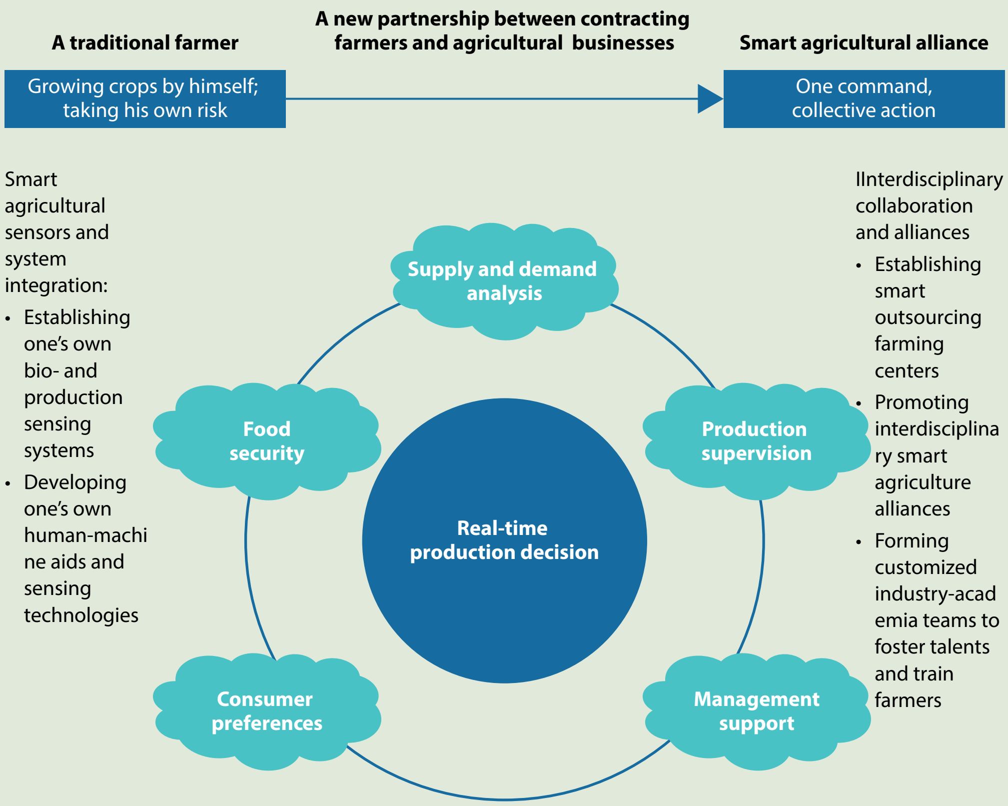
- Globalization
- Technology
- Scales
- Chain-oriented
- Multiple ways of payment
- Multiple ways of connection (e.g. take-over and strategic alliance)

Source: Department of Commerce, Ministry of Economic Affairs.

machine outsourcing are organized, to help farmers grow tea, lettuce, cabbage, corn, grapefruit, and pineapples. The associations of local farmers also provide monetary incentives to youngsters who are willing to participate in these task forces [36].

FIGURE 4

GOALS FOR AGRICULTURAL INDUSTRIES UNDER PRODUCTIVITY 4.0.



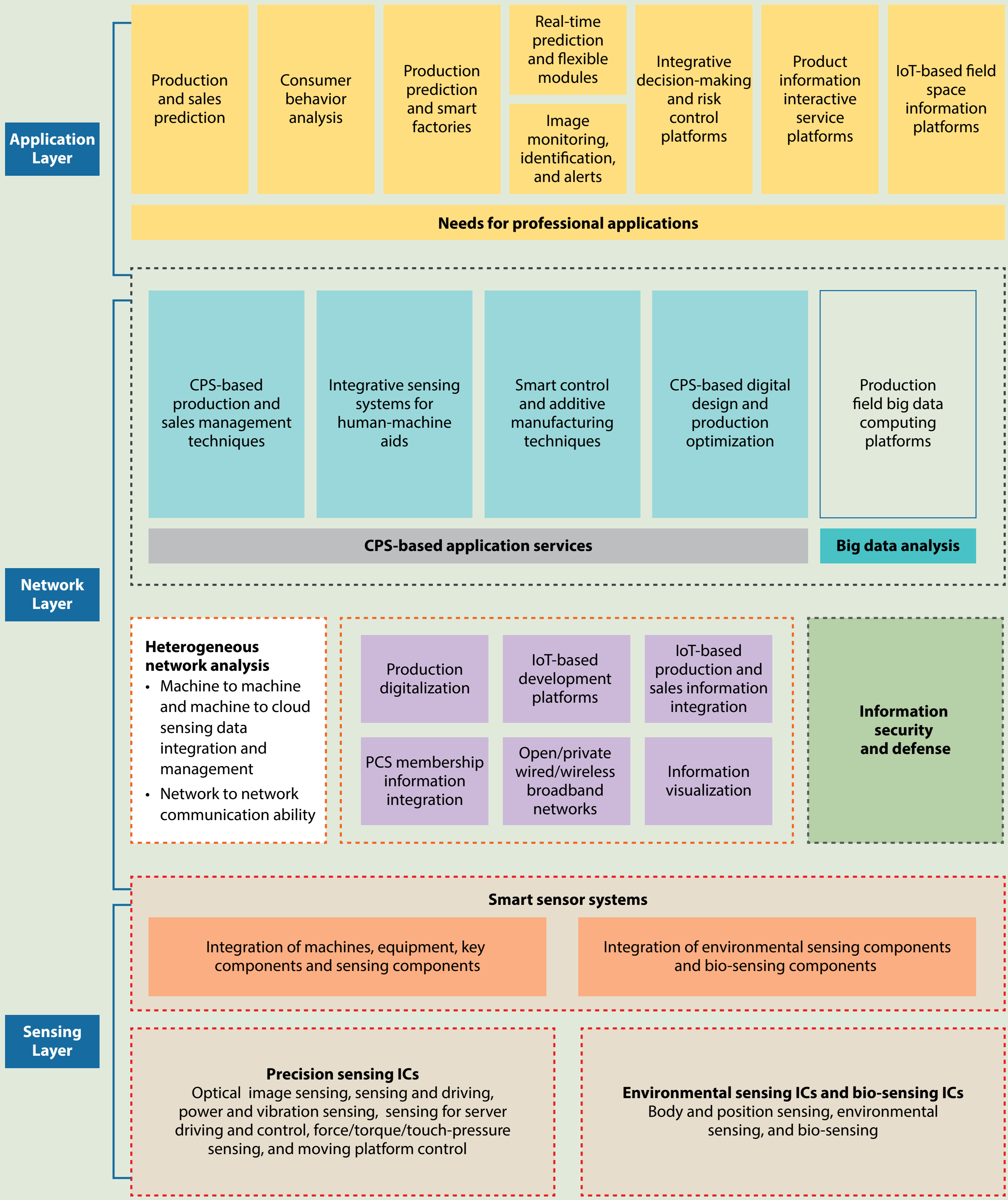
Source: Council of Agriculture.

Productivity 4.0 proposes a framework of core technology development for the industrial, business, and agricultural sectors, as shown in Figure 5 [27]. There are three layers in this framework and each layer has its core techniques. The sensing layer, for instance, includes knowledge and skills to develop smart sensing systems, their key components, and the integration of these components. In the networking layer, the core techniques are linked to heterogeneous network integration, IoT-based development platforms, wired and wireless broadband networks, and cyber security. Similarly, the core techniques in the application layer refer to technologies associated with CPS-based services, Big Data analytics, and professional applications. All targeted industries can use this framework to develop core techniques that can increase their production and improve the quality of services and products.

To evaluate the effect of the industry upgradation, Productivity 4.0 provides some estimates for the targeted sectors, as listed in Table 2 [27]. By 2024, it is expected that the industry upgradation would lead to an increase of 150% in GDP per capita. The investment in the industry upgradation is also expected to grow rapidly, from USD0.33 billion in 2014 to USD4 billion in 2024, using the manufacturing sector as an example.

FIGURE 5

A FRAMEWORK OF CORE TECHNIQUE DEVELOPMENT FOR THE INDUSTRIAL, BUSINESS, AND AGRICULTURAL SECTORS UNDER PRODUCTIVITY 4.0.



Source: Council of Agriculture.

TABLE 2

ECONOMIC PERFORMANCE INDICATORS FOR THE MANUFACTURING, BUSINESS, AND AGRICULTURAL SECTOR UNDER PRODUCTIVITY 4.0 (IN USD).

Indicators	2014	2020 (Estimated)	2024 (Estimated)
GDP per capita for the manufacturing sector[1]	2.04 million[2]	2.67 million	3.33 million
GDP per capita for the business sector (retail and logistics only)[3]	0.53 million	0.64 million	0.77 million
GDP per capita for the agricultural sector (three steering industries included)[4]	0.48 million	0.67 million	0.83 million
Industry upgrading investment for the manufacturing sector	0.33 billion	2 billion	4 billion
Industry upgrading investment for the business sector (retail and logistics only)	0.55 billion	0.97 billion	1.43 billion

Note: [1] It is calculated by the total production value generated by the manufacturing sector divided by the number of workers employed by the sector.
[2] All dollars presented in the table are US dollars.
[3] It is calculated by the total production value generated by the retail and logistics industries divided by the number of workers employed by the industries.
[4] The three steering agricultural industries are biotechnology (orchids, seedlings, and mushrooms), quality agriculture (rice, agricultural facilities, fish farming, and poultry), and precision agriculture (agricultural product traceability, dairy, and fishery). The value is calculated by the total production value generated by the steering industries divided by the number of farmers and workers employed by these industries.

Source: Taiwan productivity 4.0 initiative 2016-2024; p. 141. [27]

Five Plus Two Industry Innovation Plan

President Tsai emphasized the importance of speeding up the industry's upgradation and transformation since her presidential campaign in 2015. The first industry upgrading policy initiated by the Tsai government was the Five plus Two Industry Innovation Plan [28]. As part of the plan, five high-tech areas were first picked up as the seeds of industry upgradation and transformation. These were IoT, which was later titled the Asia Silicon Valley Development Project, bio-medical industries, green energy technology, smart machinery, and national defense industries. Later, new agriculture and circular economy were added to the list [37]. Table 3 lists the seven areas and the government agency responsible for the promotion of the development projects. Unlike Productivity 4.0, which attempts to trigger an overall industrial transformation, the Five Plus Two Industry Innovation Plan pays more attention to individual industries, especially those in high-tech areas, and hopes that these industries will support Taiwan's overall economic development.

In the selected areas, the development and application of smart technologies are at the center of attention. For example, in the smart machinery industry promotion project [38], smart technologies, such as cloud computing, Big Data analytics, IoT, AI, and robotics are viewed as tools to upgrade Taiwan's precision machinery industry and help them transform into a smart machinery industry. The transformation would further lead to the creation of more jobs and help Taiwan become a global smart machinery research and development (R&D) center, that manufactures advanced equipment and key components. The upgrading of the machinery industries also has a spill-over effect on other high-tech industries in Taiwan, such as the national defense and aerospace industries.

In 2017, in addition to the annual budget approved by Legislature Yuan, over USD310 million from the National Science and Technology Development Fund was used to promote the policies as discussed earlier [34]. Overall, 15 government agencies proposed 74 development projects. The Five plus Two Industry Innovation Plan was re-named as Industry Innovation Flagship Scheme, and more innovation-related policies such as the digital economy and culture industry innovation were included [39].

TABLE 3

TARGETED AREAS AND DEVELOPMENT PROJECTS UNDER FIVE PLUS TWO INDUSTRY INNOVATION PLAN.

Areas/Projects	Project Approved	Supervised by	Goals
IoT: Asian Silicon Valley Development Project [40]	September 2016	National Development Council	• Create a better ecosystem for innovative start-ups and entrepreneurship • Enhance links between local and international R&D clusters • Establishing a complete IoT supply chain • Construct demonstration sites for smart productions and services
Bio-medical industries: Bio-Medical Industry Innovation Promotion Project [41]	November 2016	Ministry of Science and Technology	• Help Taiwan become the center of bio-medial research and development among Asian countries
Green energy: Green Energy Industry Innovation Promotion Project [42]	October 2016	Ministry of Science and Technology	• Encourage investments in green energy industries to reduce the use of fossil fuels and the effect of greenhouse gas emissions
Smart machinery: Smart Machinery Industry Promotion Project [38]	July 2016	Ministry of Economic Affairs	• Use smart technologies to develop smart production • Provide innovative products and services • Upgrade and transform Taiwan's industries
National defense and aerospace: National Defense Industry Promotion Project [43]	May 20191	Ministry of National Defense	• Develop satellite technology-related industries
Circular economy: Circular Economy Promotion Project [44]	December 2018	Ministry of Economic Affairs	• Improve the efficiency of resource use, find better ways for the disposal of wastes, and avoid environmental pollution by redesigning products and business models
New agriculture: New agriculture Innovation Promotion Scheme [23]	December 2016	Council of Agriculture	• Establish a new agricultural paradigm to create an agricultural safety system and enhance the marketing ability for agricultural products, based on the principles of innovation, employment, allocation, and sustainability

Note: The Act for Enhancing National Defense Industries was passed in May 2019 [45].

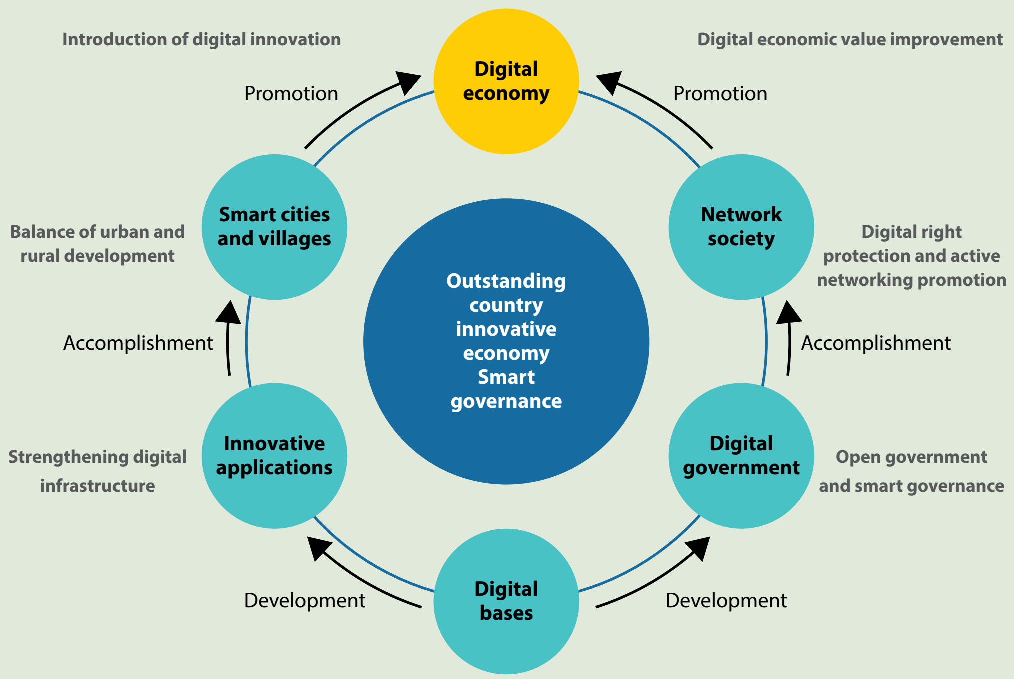
Digital Nation and Innovative Economic Development Program (DIGI+)

As mentioned earlier, digital economy policies have become a part of the Industry Innovation Flagship Scheme [34]. The goals of the digital economy are to use digital industries for boosting economic activities while encouraging non-digital industries to pursue innovation by utilizing digital technologies. In November 2016, the concept of digitalization was further extended to the national level, as the Executive Yuan launched a new national innovation program, Digital Nation and Innovative Economic Development Program or DIGI+ [29]. The four letters of the program title DIGI+ represent the areas covered under it, where "D" is the development and focuses on building a strong infrastructure. This is followed by "I" which stands for innovation to transform the national economy into a digital economy. Next, the "G" represents governance, to promote the concept of a digital nation. The second "I" is inclusion, to establish a civil society that emphasizes inclusivity. In addition, the symbol "+" means upgrade, which aims to improve Taiwan's infrastructure, to promote digitalization, industry, and economic innovation [46]. The general purposes of the program are to develop a nation with strong networking capacities and pursue a new economic paradigm (such as a high value-added and innovative economy), as shown in Figure 6. To achieve these goals, a variety of strategies have been proposed, as listed in Table 4.

This program also sets up several performance goals. It is expected that the rate of the GDP generated by the digital industries and services, and the electronic businesses to the total GDP would increase from 20.3% in 2015 to 29.9% by 2025. Also, the percentage of people utilizing digital services would rise from 25.8% in 2016 to 80% while the coverage rate of high-speed broadband services would reach 90% by 2025 [47].

FIGURE 6

ULTIMATE GOALS OF A DIGITAL ECONOMY UNDER DIGI+.



Source: Executive Yuan.

TABLE 4

STRATEGIES PROPOSED BY DIGI+.

Strategy	Descriptions	Objectives
Infrastructure	Creating a helpful environment for digital innovation.	• Speed up infrastructure construction for extra-broadband networks and clouds. • Create a safe and reliable environment for digital equipment and services • Improve network governance, regulations, and laws • Build a fair environment for the competition of digital convergence • Formulating a visionary spectrum of policies
Innovation	Deepening the technologies developed earlier while developing independent technical solutions.	• Emphasis on semiconductor chip and smart technology development, AR/VR, data technologies, IoT, 5G broadband, and information and communication safety
Talents	Creating a stage for interdisciplinary talents with expertise in digital areas.	• Create a smart learning environment for elementary, middle, and high school students • Cultivate talents through high-quality compulsory education • Provide more interdisciplinary and digital training programs • Offer digital training programs to employees and the employed • Recruit talents from international communities
Regulations	Formulating and amending laws and regulations that relate to a digital nation and innovative economy.	Two types of regulations should be paid attention to: • Basic: Information and commutation safety and personal protection; intellectual property protection; business set-up and operation; digital assets and venture capital; and digital governance • Application: sharing economy; open access data; digital financing; electronic business; Internet of Things; tele-health care
Industry	Promoting digitalization and innovation to support industrial updates and transformation.	• Facilitating the connections between universities, research institutes, industries, and businesses in different areas to form a digital innovative ecosystem • Promoting digitalization and innovation to achieve the goals of industrial update and transformation

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Strategy	Descriptions	Objectives
Globalization	Boosting economic development through improving hardware and software development.	• Construct an innovative environment to attract global talents with digital expertise • Strengthening the environment to support the development of the new, digital economy • Finding the best niche for Taiwan's industries through innovative software and hardware integration
Incubation	Encouraging youngsters to start their businesses, and medium and small-sized enterprises to branch out new businesses.	• Connecting to international innovation resources • Integrating innovation resources in Taiwan. • Enhancing the consulting mechanism after the incubation • Improving the flexibility of related regulations • Providing venture capital assistance schemes
Governance	Promoting the right to use broadband Internet services and the idea of an open government to facilitate interaction in a networked society.	• Laying the foundation for the legal issues associated with digital rights and improving the digital infrastructure for remote villages and islands • Ensuring that citizens can gain access to the Internet via broadband services, improving their ability to use information, and developing a fair digital development plan to provide equal opportunities for citizens to participate in social networks • Developing civic technologies and implementing participatory democracy • Granting access to government data and promoting a service-oriented government • Encouraging all citizens to engage in digital diplomacy and make a contribution to international communities
Cities	Building up smart cities and facilitating regional innovation through the cooperation between the local and central governments.	• Integrating the resources from society and the government to promote smart cities and villages and provide person-centered innovative applications and public services

Source: [47].

Forward-Looking Infrastructure Program

In 2017, the Tsai government launched Forward-Looking Infrastructure Program, as shown in Figure 7, and digital infrastructure is one of the five areas covered by the program [30]. In the digital infrastructure, five issues are addressed, including broadband infrastructure and Internet security; digital inclusion and the right to Internet access via broadband infrastructure; digital culture and creativity industry development and high-definition television promotion; open government, and smart cities and villages; science research for the next generation and smart learning environments. The four-year budget for the digital infrastructure program reaches USD2.44 billion.

FIGURE 7

AREAS ADDRESSED BY FORWARD-LOOKING INFRASTRUCTURE PROGRAM.

Climate change solutions

Creating a better environment for water resource protection

- Finding sustainable water resources
- Rich resources and homeland safety
- Ecosystem protection for shorelines and environment improvement

Fast and safe transportation

Railway Construction

- Inter-cities railways
- Improving the efficiency of railways and promoting railway tours
- Railways for urban areas

Sustainable environments

Constructions for green energy

- Establishing Shalun Smart Green Energy Science City
- Promoting solar energy generation
- Promoting wind power generation

Forward Looking and Innovation

Smart nation

Digital Infrastructure

- Constructing infrastructure for information security
- Completing social inclusion and promoting the right to access to broadband services
- Supporting digital cultural and creative industries and promoting high-definition television services
- Establishing a open government and providing smart city services
- Creating a scientific research and learning environment for next generations

Urban/Rural development

Balancing urban and rural development

- Solving the problem of car parking and bad roads, and establishing local industrial parks
- Promoting cultural activities nearby, and increasing the use of school campuses and the number of public service centers
- Creating better environments for leisure activities and sports, promoting romantic tours for Provincial Highway 3, and providing various services to indigenous tribes

Source: Executive Yuan.

Taiwan AI Action Plan

In 2017, a program to promote AI in all industries was initiated. Titled Taiwan AI Action Plan, the USD1.22-billion program was initiated to speed up the development of AI applications using five strategies [31]. The first strategy aims to enlarge the pool of AI talents. An AI innovative research center has been established in several universities in Taiwan to promote the research of AI techniques, health care, smart manufacturing, smart services, and smart biomedical industries. The government is also cooperating with private enterprises to provide AI training. The second strategy focuses on semiconductor manufacturing. Taiwan's chip manufacturing industries have played a leading role around the world. With this merit, a committee for AI on Chip was created by the government. It invited 15 chip manufacturers to form an alliance and promote the integration of heterogeneous AI chips, and the software and hardware integration for AI systems. It was also aimed toward facilitating the industry-university cooperation projects to help Taiwan's semiconductor industries stand firmly in the world market.

The third strategy is to attract more investments from foreign companies to set up AI research centers in Taiwan. Incentives are given to build connections between foreign and local AI companies. Moreover, various AI applications have entered practical testing. For example, a lab called Taiwan Smart Driving Lab was established in 2017, which ran tests on automatic driving vehicles [48].

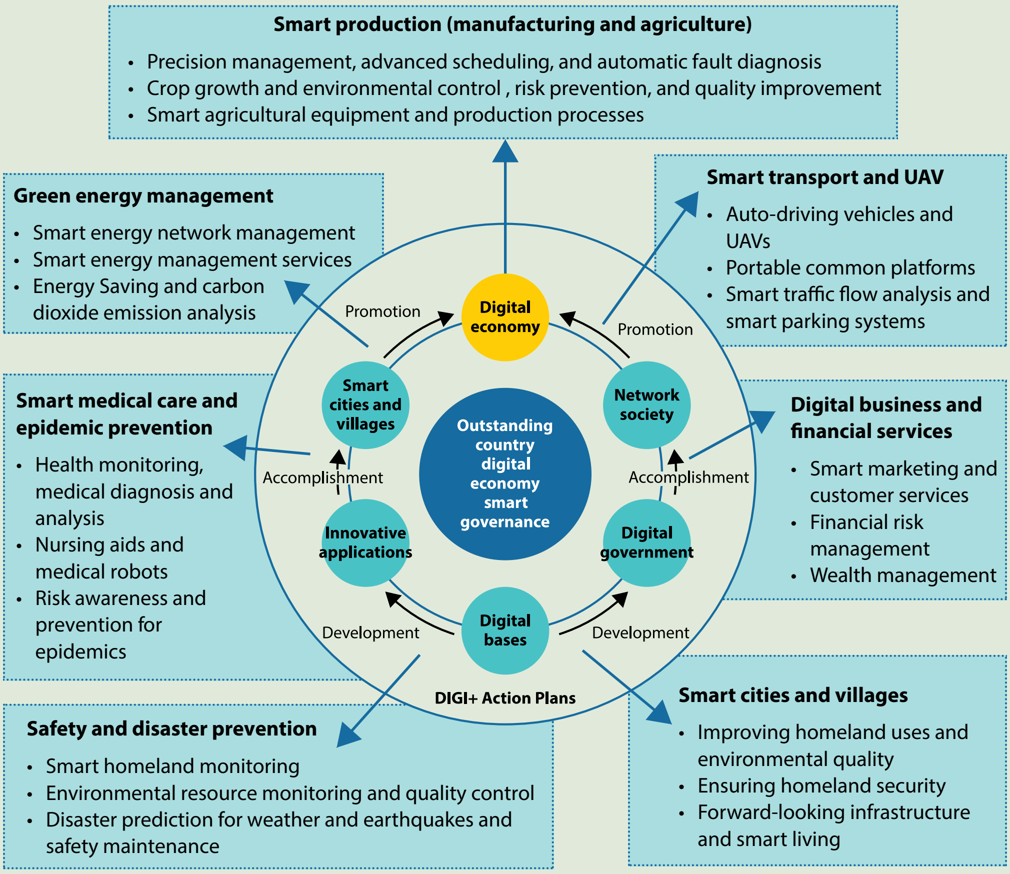
In the legislative area, the Unmanned Vehicle Technology Innovative Experimentation Act was passed in 2018 [49]. This act aims to create a safe and sound environment for conducting innovative experiments and speeding up the development of industry technology and innovative services.

The last strategy is to find AI solutions for the industries in Taiwan. The government began to investigate the transformation and upgradation demands from different industries and then invited AI experts to provide suggestions and solutions to assist the transformation. In 2018, for example, a total of 32 companies from six industries (biomedical, information services, e-commerce and advertising, manpower, security, and Internet of Things) participated in this program [50].

Currently, Taiwan AI Action Plan has been integrated with DIGI+ [29]. All of the action plans under DIGI+ are shown in Figure 8. DIGI+ has also become the most important project to promote digitalization in Taiwan.

FIGURE 8

ALL OF THE ACTION PLANS UNDER DIGI+.



Source: Executive Yuan.

Smart Agriculture Policies

Agriculture Productivity 4.0

As mentioned earlier, the agriculture sector was selected by Productivity 4.0 as the steering sector to lead to the overall smart transformation [27]. To achieve the goal of enhancing agricultural productivity, three strategies have been proposed. First of all, smart agriculture alliances would be organized, which will be responsible for developing core techniques for improving agricultural productivity and implementing these techniques, such as developing smart biological and agricultural sensing systems that can be integrated with GIS and decision-making systems, based on the analysis of weather and water resource data, to support the production models of precision agriculture. Meanwhile, cross-industry collaboration is encouraged, and innovative cultivation alliances are promoted. In these alliances, members generally come from different industries. In addition, smart cultivation outsourcing centers are established, and special training teams consisting of experts from the agricultural sector and universities are formed to provide customized training programs for the farmers.

Furthermore, smart service and support systems are developed to assist farmers in upgrading their production processes [32]. These services and supporting systems utilize a variety of information and communication technologies, and Big Data analytics techniques, to provide farmers with digitalized production and sales services, so farmers' risk management ability can be improved. Besides, IoT-based production and sales systems are created, to establish prediction models for production and sales to reduce the imbalance between production and sales. In addition, a supporting system that analyzes the development of the agricultural industries in Taiwan and worldwide is set up to investigate the technologies and techniques used in the local industries and develop cost-benefit evaluation models, to find high-potential areas in agriculture.

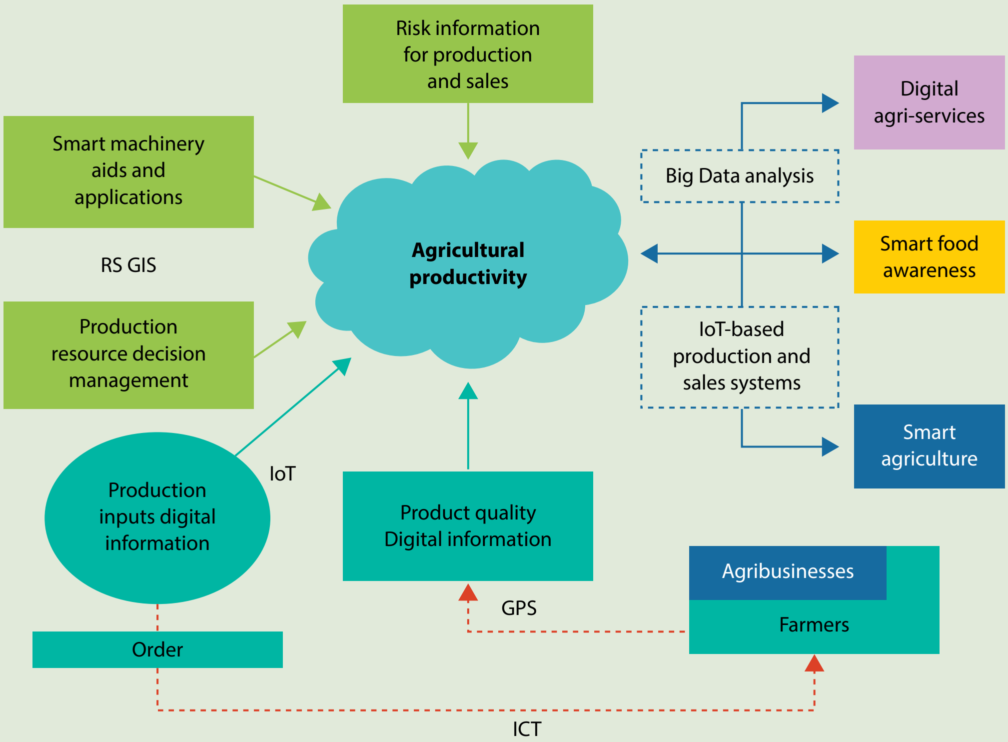
Apart from the development of smart supporting systems, new communication models between farmers and customers are promoted. Such models emphasize person-centered interactions. Smart traceability systems is one such example. By using these systems, customers can obtain accurate production and product information. With high information transparency, the goal of food safety can be achieved. In addition, a smart service platform that enables agricultural data and sales information inquiry is also encouraged. This platform is generally equipped with an interactive panel or a wearable device, so consumers can easily obtain the information that they need.

Figure 9 shows the promotion framework of Agricultural Productivity 4.0 [27]. Generally speaking, Agricultural Productivity 4.0 tries to use the strategies mentioned above to achieve the goals of applying smart technologies to promote alliance-based smart production, encourage agricultural digitalization to attract more agricultural industries to improve their production and sales, and establishing a relationship of trust between farmers and customers through information sharing.

To implement these strategies, COA selected biotech agriculture, quality agriculture, and precision agriculture, as the targeted areas. A total of 10 industries in these areas were picked, as listed in Table 5 [51]. A pilot project under Agriculture Productivity 4.0 was initiated in October 2015, which continued for eight months. Three special interest groups, supervised by COA, were formed to provide guidance to the selected industries and help them develop smart technologies and services. The developed technologies and services are listed in Table 6 [27].

FIGURE 9

PROMOTION FRAMEWORK OF AGRICULTURAL PRODUCTIVITY 4.0.



Source: Council of Agriculture.

TABLE 5

AGRICULTURAL INDUSTRIES SELECTED UNDER AGRICULTURE PRODUCTIVITY 4.0.

Area	Industries
Biotech agriculture	Orchids, seedlings, and mushrooms
Quality agriculture	Rice, agricultural facilities, fishing farming, and poultry
Precision agriculture	Agricultural product traceability, milk, and fishery

Source: [51].

TABLE 6

SMART TECHNOLOGIES AND SERVICES DEVELOPED UNDER THE AGRICULTURE PRODUCTIVITY 4.0 PILOT PROJECT.

Selected Industry	Development of Smart Production and Human Machine Aids	Establishment of Digital Services and Parameter Models	Traceability Data Exchange and Application Interface Development
Agriculture facilities	Highly efficient environmental control systems and labor-saving moving machines	Cloud-based decision-making systems for facility operation parameters	Establishment of mechanisms and standards for traceability data exchange

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Selected Industry	Development of Smart Production and Human Machine Aids	Establishment of Digital Services and Parameter Models	Traceability Data Exchange and Application Interface Development
Fish farming	Highly productive farming sites and energy- and labor-saving machines	Production capacity adjustment and energy-saving control parameter systems	Establishment of mechanisms and standards for traceability data exchange
Poultry	Smart automated systems for poultry breeds and incubation of hatching eggs	Big Data-based decision-making systems for poultry farming and environmental control	
Agricultural product traceability	Organizing smart agriculture alliances and cultivation/production groups	Digital login platforms for information on production and sales	

Source: [27].

New Agricultural Innovation Promotion Scheme

A new program was launched after Tsai Ing-Wen won the presidential election and aptly titled New Agricultural Innovation Promotion Scheme [23]. Fortunately, the agricultural policies proposed by the Tsai government largely followed the agricultural policies launched before the election. The new agricultural innovation scheme is a part of the Five plus Two Industry Innovation Plan [29], and it emphasizes innovation, employment, allocation, and sustainability. The main purpose of the scheme is to upgrade the agricultural sector by using innovative technologies and their applications.

The New Agricultural Innovation Promotion Scheme addressed three issues [24]. First, It aimed to establish a new agricultural paradigm with a focus on protecting farmers' livelihoods and enhancing agricultural development while promoting sustainable agriculture. Various methods, including price support and buyouts, subsidies for fallow land, agricultural insurance, farmland rental, farmer loans, fresh meat transporting regulations, disease control for livestock and poultry, subsidies for organic and sustainable environmental practices, land and agricultural resource inspections, and incentives to develop automatic and smart equipment, were introduced as part of the initiative.

The second issue that the scheme addressed was the safety of agricultural production and products. This included establishing a trustworthy food traceability system that could meet international standards. Other measures included promoting corn and soybean production, increasing the self-sufficiency rate of food, promoting food safety practices, and developing reliable food labeling and traceability systems. Moreover, to ensure food safety, the government decided to adopt five steps [52]. The first step focuses on the origin of food. Efforts are put into setting food safety standards, developing testing techniques to find substance in food that harms human health, and using Big Data analytics to analyze food safety-related data. The second step is to establish self-management systems to improve product monitoring and inspection, as well as traceability systems that can trace food through all stages of production, processing, and distribution, to enhance the ability of self-management of the agricultural industries. The rest of the steps try to improve food safety through the viewpoints of the government and the public. The government will increase the inspection of food and other agricultural products while encouraging the public to report unscrupulous farmers and businesses.

Finally, the scheme also tries to increase the competitiveness of Taiwan's agricultural products by enhancing its marketing ability [24]. For example, a semi-public-owned company Taiwan International Agricultural Development Corporation was established in 2016 to export Taiwan's agricultural products to the south and south-east Asian countries, Australia, and New Zealand. In addition, agricultural product processing centers and regional distribution centers were set up to coordinate production, the sales systems, and find new markets, so that agricultural production would be more stable.

To achieve these goals, approximately USD4 billion has been allocated over four years (2017-2020). It was expected that the income of farmers would increase by 10% each year for four years and approximately 15,000 new farmers would be trained and ready to engage in agricultural production [24].

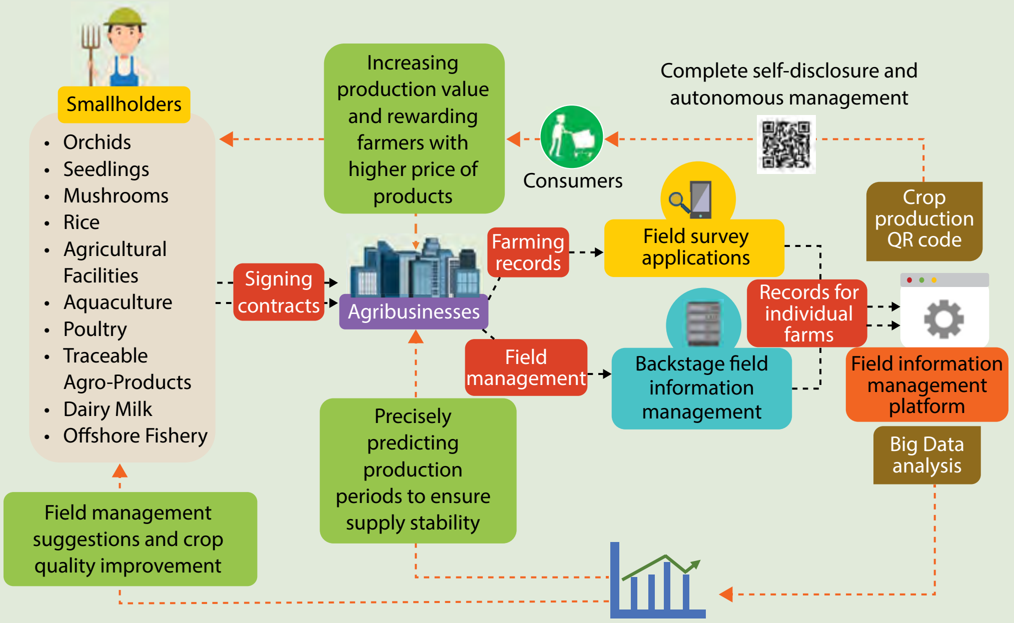
Smart Agriculture 4.0

As mentioned earlier, New Agricultural Innovation Promotion Scheme aims to establish a new paradigm for agricultural development [23]. In this new paradigm, smart technologies and services play a very important role, because they can improve the quantity and quality of agricultural products while supporting the suitability of agricultural development. Advanced technologies, such as remote sensing, GPS, GIS, expert systems, smart decision-making, and knowledge systems, and Big Data analytics, can be used to monitor the parameters associated with soil, weather, and crop growth-related variables while performing data analysis for farmers to make appropriate decisions and take proper measures. In other words, the key elements in Smart Agriculture 4.0 are smart production and digital services [53]. A schematic diagram of Smart Agriculture 4.0 is shown in Figure 10. In this figure, small family farms are collaborating with agribusinesses to sell their products. A variety of IoT- and AI-based technologies are used to improve crop growth, production management, and management of buying and selling agricultural products. The end goal of Smart Agriculture 4.0 is to increase production and product values and reward farmers with higher profits.

Smart Agriculture 4.0 targets ten agricultural industries selected by Agriculture Productivity 4.0 [33]. The main purposes of the policy are to develop core technologies for agricultural upgrading, integrate existing technologies to build up smart equipment and human-machine aids, establish bio-sensing monitoring models and IoT-based production and sales platforms, encourage agricultural as well as other industries to invest in the development of smart agriculture applications, provide marketing and sales guidance to the targeted industries, and set up demonstration sites to serve as exemplars. Currently, there are ten industries and four task force groups participating in the promotion of smart agricultural transformation [34]. The measures taken by these industries and task force groups are described as follows.

FIGURE 10

SCHEMATIC DIAGRAM OF SMART AGRICULTURE 4.0.



Source: Council of Agriculture.

A. Orchids

A variety of smart devices are introduced in orchid greenhouses, including direct variable-frequency drive-based fans and energy-saving heat pumps. The data on the performance of energy saving is collected and analyzed. To solve the problem of labor shortage and reduce the use of water, automatic sprinklers, tissue culture management systems, and automated pot-changing machines are developed.

B. Seedlings

Farms that grow seedings are visited to collect seedling growth-related data and environmental parameters. A database is set up, a network of production and sales for seedlings is established, and a management model for seedling production is developed to produce high-quality seedlings and reduce the time and labor required by the production process.

C. Mushrooms

A framework for smart mushroom production is developed. This framework integrates all the systems required to grow mushrooms, and the related data can be browsed through an information platform. A management and decision-making system for the smart production of mushrooms is established and tested to upgrade the mushroom industry and improve its competitiveness in the global market.

D. Rice

The main smart transformation tasks for the rice industry are to establish smart agricultural machines, monitoring systems for pests of field crops, and smart cultivation management systems. The data generated from these systems is collected for further analysis. Through the development and use of core technologies, the rice cultivation systems can be diversified more, the use of farmland and rice production can be more effective, and the risk associated with climate change can be reduced. The utilization of smart technologies and services can also reduce production costs and save labor while improving productivity and pursuing environment-friendly agricultural practices.

E. Agricultural Facilities

For the agricultural facility industry, it is necessary to develop IoT and AI-based smart cultivation management systems. It is also important to use image identification techniques and crop growth models to identify the growth stage of a crop so that various measures can be taken based on the growth stage, including adjusting temperature, lighting, and the schedules of irrigating and providing nutrient solutions. By doing so, a better cultivation environment can be developed, and the quality and quantity of the crops can be stabilized.

F. Aquaculture

In the aquaculture industry, the developed IoT-based water quality monitoring system, smart feeding system, and wireless gateways are used to continuously collect fish farming parameters, such as water quality, oxygen supply, water supply, fish growth (sizes and growth rates), food pellets, feeding, farming environments, and costs and benefits. This data would be stored in a database and used by bio-identification systems for fish size measurement, precision feeding system improvement, smart farming decision-making, and feedback system management.

G. Poultry

To achieve the goals of improving poultry rearing techniques and the environment for poultry farming, upgrading the production and packaging of processed meat and eggs, smart poultry farming and rearing systems, intelligent poultry processing systems, and digital services and management systems are established. In addition, through the integration of digital information services and technologies of IoT, data is collected and analyzed, so the product services become value-added services.

H. Traceable Agro-Products

The upgrade targets the industries that grow or produce major exporting crops, such as iceberg lettuce, edamame, pineapples, and tea. Labor-saving smart machines and IoT-based systems are developed for the process of production and sales. The existing automatic production method is transformed into a production model that follows the concept of precision agriculture. In addition, cultivation systems that produce safe and high-quality exports are established, the quality of traceable agricultural products is improved, supply chains for traceable agricultural products are set up, and traceability information exchange is enhanced. These measures aim to increase the competitiveness of Taiwan’s agricultural products in the world market.

I. Dairy Milk

To deal with the problem of labor shortage, upgrade and transform the industry of livestock husbandry farming, improve the work environment, maintain a stable milk supply, and increase the competitiveness of the industry of breeding stock, robots are used for completing the tasks of milking and feeding cows. It is expected that robotics can contribute greatly to the breeding stock industry.

J. Offshore Fishery

Different energy-saving and labor-saving automatic fishing techniques and smart management systems for the catch of fish are developed to facilitate the upgradation of the marine fishery industries. These smart systems include electronic monitoring systems with the capability of identification, traceability systems, smart fishing lights, automatic classification, arrangement, and packaging systems. In addition, smart marine fishery alliances are also organized to promote the ideas of industry upgrade and transformation.

K. Taskforce Group: Developing Common and Integrative Smart Technologies for the Steering Industries

Researchers and experts from many universities are invited to conduct studies on smart equipment and human-machine aids, bio-sensing monitoring systems, and IoT-based production and sales platforms. The research results, along with the outcomes of various agricultural upgradation projects conducted in many districts by the Taiwan Agricultural Research Institute and Agricultural Research and Extension Stations, would contribute greatly to core technology development, required for agricultural upgradation and complete the development of common technologies used by different industries. By doing so, the goals of interdisciplinary cooperation, technology integration, and diffusion can be achieved.

L. Taskforce Group: Fostering Agricultural Talents and Learning through Benchmarking

The strategy of fostering agricultural talents follows the framework of smart agricultural development so that the demand for agricultural workers would meet the supply of workers. In addition, special education and training programs are designed to meet the demand of different steering industries.

M. Taskforce Group: Improving Industry Participation

COA has initiated the Agri-Tech Program that encourages agricultural industries and other institutes and organizations to invest in innovative research and development for agricultural transformation [54]. In addition, it has launched, titled Smart Agriculture Participation Program [55]. In this program, the participation rules and regulations are specified. Agricultural industries are encouraged to use smart agriculture applications and key components developed by local and international companies. This would strengthen the links between smart technology suppliers and users.

N. Taskforce Group: Engaging in Operation and Management, Technology Improvement, and Industry Analysis

To assist the aforementioned projects, connect the research projects conducted in different steering industries, and implement the research results, a special team is formed to develop management mechanisms for these projects, present the progress made on smart agriculture promotion in the steering industries to stakeholders, and ensure that all of the goals are achieved.

Table 7 lists the expected results for each steering industry by 2022. It can be seen that with the developed smart technologies, the goals of labor-saving, cost-saving, energy-saving, decreasing water use, increasing production efficiency, and improving productivity and quality can all be achieved. In addition to applying smart technologies to agricultural production and services, the ultimate goal of Smart Agriculture 4.0 is to assist agricultural industries in Taiwan to become a part of the supply chain of smart agriculture applications and services in the global market.

From the strategies and practices mentioned above, it is clear that selecting steering industries is only the first step toward smart agricultural transformation. Creating and providing the public goods that are needed for the transformation is also important. As part of Smart Agriculture 4.0, different resources are pooled to form several task force groups that not only train farmers to use smart technologies but also provide critical technical know-how to farmers and help them solve production and management problems. These public goods might be the key point for the success of the smart agricultural transformation.

TABLE 7

EXPECTED RESULTS FOR STEERING INDUSTRIES BY 2022.

Agricultural Industry	Expected Results
Orchids	Saving energy by 25%; increasing successful breeding by 25%; reducing management costs by 30%; and saving labor reaching 750 hours for a greenhouse
Seedlings	Supply meets over 90% of the market demand; increasing transplanting speed by 40% with automatic transplanting machines
Mushrooms	Increasing production capacity by 30%; reducing costs by 30%, saving labor by 60%; increasing production values by 10% each year
Rice	The areas where the iron coating direct seeding technique is used reach 3% of the total cultivated areas; reducing costs by 10% with the use of robotic arms; cutting back the use of agricultural materials by 40%; reducing labor costs by 30%; reducing water use by 20%
Facilities	Increasing facility cultivation by 15%
Traceable agro-products	Reducing labor costs by 10%; decreasing internal browning of pineapples by 10%; increasing the efficiency of goods collection by 5%; increasing tea exporting by 2%
Offshore fishery	Saving labor by 50%
Aquaculture	Increasing production capacity by 50-100%; saving labor by 50%; saving water use by 30%; reducing feeding costs by 15%; saving energy by 20%; sending out alerts 3 days before water quality degradation for large-scale fish farms
Poultry	Increasing successful breeding by 10%; raising management efficiency by 40% and operation efficiency by 50%; increasing product sales by 30%; the estimated production value for farms participating in the project reaches USD6 million
Dairy milk	With robots, working time reduces from 6 to 2 hours per day; the rate of milk quality consistency increases from 60 to 90%; the death rate of newborn piglets reduces to 0% with the caring robots

Source: Council of Agriculture.

Smart Agriculture Practices

In 2015, COA invited a biotech industry research institute to conduct a three-year survey on the development of smart agriculture in Taiwan. This survey targeted the ten steering agricultural industries mentioned earlier. It was found that the gross production per capita for the steering industries increased from USD54,630 in 2016 to USD59,600 in 2018. The estimated gross production per capita in 2022 was expected to cross USD74,333 [56].

Moreover, for the surveyed agricultural businesses, the most widely used technology or service in 2018 is e-commerce (26.3%), followed by sensing and monitoring systems (21%), and knowledge management and business resource management (19.8%). In 2022, by contrast, the most widely used technology and service would be Big Data analytics (37%) and automated machines and aids (26.7%), as shown in Table 8 [57]. Thus, agricultural businesses in Taiwan tend to adopt more digital and automated techniques to improve their production and manage their businesses, which is compatible with the smart agricultural formation framework promoted by the government via a variety of industrial and agricultural innovative policies and programs.

TABLE 8

SMART TECHNOLOGIES AND SERVICES ADOPTED BY AGRICULTURAL BUSINESSES IN TAIWAN.

Smart Technologies and Services	2017	2018	2022
Sensing and monitoring systems	23.9%	21%	26.3%
Image identification systems	7.3%	6.6%	14%
GPS, GIS, and remote sensing	3.9%	4.1%	7.4%
Wireless radio frequency identification systems	5.4%	4.9%	8.2%
Big Data analytics	10.4%	13.6%	37%
Knowledge management and business resource management	22.4%	19.8%	24.3%
e-Commerce	27%	26.3%	27.6%
Real-time push notification	4.2%	3.7%	9.5%
Traceability systems	15.4%	15.6%	11.9%
Cyber-physical convergence and IoT	5.4%	4.9%	9.1%
Automated machines and aids	21.6%	17.3%	26.7%
High throughput screening and next-generation sequencing	4.2%	4.5%	6.6%
Unmanned aerial vehicles	–	1.2%	8.2%

Source: [57].

Best Practices

In this section, several cases from the steering industries are introduced. These cases serve as examples of the best practices that have successfully employed smart technologies and services in their productions.

Seedlings: A Smart Production System for Vegetable Seedlings

The vegetable seedling industry in Taiwan used to be a labor-intensive industry. Seedlings need to be moist but not wet and never allowed to dry out completely. Thus, it is necessary to precisely monitor the growth environment. Therefore, farmers have to put a lot of effort into maintaining a proper environment for seedlings. A seedling farm in Changhua has adopted a remote control system and a smart seedling production management system in its seedling production, as shown in Figure 11 [58].

FIGURE 11

THE SMART SEEDING PRODUCTION MANAGEMENT SYSTEM USED IN A SEEDLING FARM [58].

Source: [58].

This remote control system utilizes a sensor to detect growth-related environmental parameters of the seedlings and automatically records these parameters. The parameters are transmitted to a cloud-based server, and they can be checked via a smartphone. Famers can also remotely control shading nets and circulation fans to reduce the use of labor on the farm.

In addition to the remote-control system, this farm also adopts a smart production management system. This customized system is capable of placing orders, scheduling, and managing production, sales, inventory, and dispatch records. The data collected by the system can be further analyzed based on revenue and expenditure, or the rate of damaged seedlings. The analysis results can be used to adjust production schedules and improve production and management efficiency.

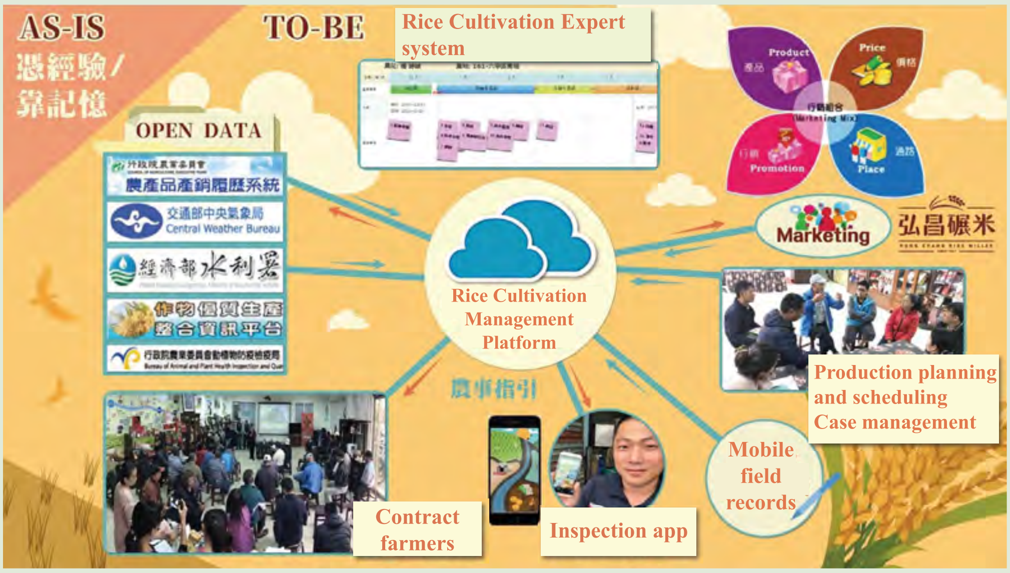
Rice: Smart Rice Production

A rice milling factory, located in Tainan, has produced rice since 1970 [59]. The rice milling factory has organized a rice contract farming group to bridge the gap between rice sales and production. A traceability system for rice products is also set up to guarantee the quality of rice products sold by the factory. Moreover, the factory has cooperated with various research institutions, such as Taiwan Agricultural Research Institute, Tainan District Agricultural Research and Extension Station, and Industrial Technology Research Institute, to develop a platform for rice quality management and storage information service. Platform users can monitor contract farmers in real-time and guide them to achieve the goals of properly applying fertilizers and pesticides, reducing costs, and promoting a friendly environment. An app called sûn tshân tsuí, meaning field inspection in Chinese, was developed, which allows contract farmers to record important information, so their experience can be passed to other farmers. In addition, the platform can track and record the process of rice drying and storing, so low-quality rice would not be mixed with high-quality rice.

Since 2018, paddy fields over 111 hectares have been managed by the platform, and the wet rice harvested from these areas has reached 840 metric tons [60]. A schematic diagram of the platform is shown in Figure 12.

FIGURE 12

SCHEMATIC DIAGRAM OF THE RICE CULTIVATION MANAGEMENT PLATFORM [60].



Traceable Agro-Products: Smart Edamame Production and Management

Edamame is called green gold in Taiwan. In 2018, for example, the export of edamame reached USD84.5 million [61]. Edamame is usually harvested at night before dawn to ensure its quality and sweetness. In Taiwan, agricultural machines, such as tractors, multi-functional tillers, and green bean harvesters, are used in edamame harvesting, to speed up green bean harvesting. In 2017, farmers began to work with Chinan Division, Kaohsiung District Agricultural Research. and Extension Station to employ a GPS vehicle tracker and an image monitoring system in their edamame fields. With the GPS, the location of the harvester and real-time images can be seen on a smartphone, so farmers can effectively monitor the process of harvesting. Pictures of the edamame harvester with the GPS tracker and image system, and the smartphone app for the GPS location and images, are shown in Figure 13 [62].

Offshore Fishery: Smart Fish Farm Management

To improve fish farming efficiency and reduce the damage caused by birds preying on fingerling, a fish farming company, located in Hengchun, has introduced several smart systems [63]. The first one is an IoT-based management platform for smart fish farming, which is capable of fish farm management, document management, backend control, and permission management. Different types of sensors are employed to measure the temperature, salinity, oxygen saturation, and pH values of water so that the farming environment and water quality can be monitored in a real-time manner. The environment and water quality data are further analyzed by artificial intelligence techniques. An automatic control mechanism for waterwheels is also developed to reduce the use of labor. These smart systems would lead to a 5% decrease in the number of sick fish and a 15% reduction in labor [64]. Figure 14 shows a schematic diagram of the IoT-based fish farming

FIGURE 13

AN EDAMAME HARVESTER WITH THE GPS TRACKER (LEFT); INTERFACE FOR GPS INFORMATION AND REAL-TIME IMAGES (RIGHT) [62].

management platform. Meanwhile, with the help of the National Pingtung University of Science and Technology, a smart bird deterrent unmanned aerial vehicle (UAV) system is developed, which effectively reduces bird damage and the inconvenience of manually controlling a UAV system. A schematic diagram of the smart bird deterrent UAV system is shown in Figure 15. It is expected that this system can reduce the damage caused by birds by 10% and the labor costs associated with setting up bird netting by 2% [64].

FIGURE 14

SCHEMATIC DIAGRAM OF SMART IOT-BASED FISH FARMING MANAGEMENT PLATFORM [64].

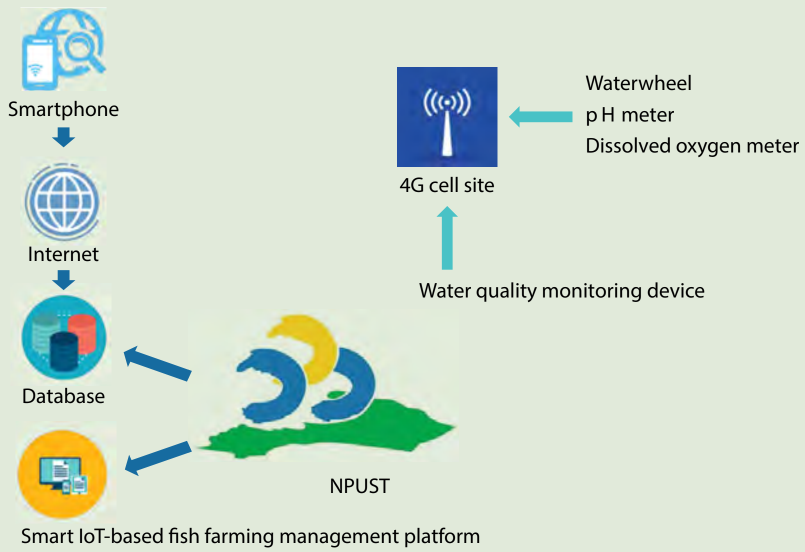
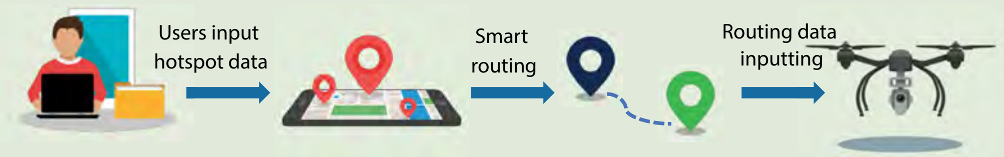


FIGURE 15

SCHEMATIC DIAGRAM OF SMART BIRD DETERRENT UAV SYSTEM [64].



Poultry: Digital Services for Agricultural Industry Transformation

A poultry meat processing company, founded in 1996, has established a business situation room to fast formulate sales, production, finance, and marketing strategies [65]. The situation room employs an enterprise resource planning system, a food traceability system, and a SKOV poultry farm management system to collect various farm management information. After participating in Smart Agriculture 4.0, the company extends its situation room by incorporating an international business information platform. This platform shows an integrative map for agricultural trades and provides marketing information regarding the top 10 countries that import and export various agricultural products. The data collected by these smart services are stored in a database and analyzed using data mining techniques to generate visualized sales targets and inventory analysis figures. This platform can combine internal business information and external market information, and the integrated information can be browsed by management personnel anytime anywhere via a smartphone.

For poultry farm monitoring, another example is to use an IoT-based monitoring system. The poultry industry in Taiwan faces the challenges of aging farmers, labor shortage, and a lack of farming data collection, so a smart monitoring system for poultry farming has been employed, as shown in Figure 16. This system can monitor environmental parameters in poultry farms, and farmers can obtain these parameters via a smartphone app. This app also allows users to control the parameter and adjust various devices in the farms. By doing so, a better environment for the growth of chickens is created, the goal of effective labor is achieved, and the success rate of chicken rearing is increased. After adopting the smart monitoring system, the success rate of chicken rearing is expected to increase by 5%, and the costs of rearing are expected to be significantly reduced [66].

FIGURE 16

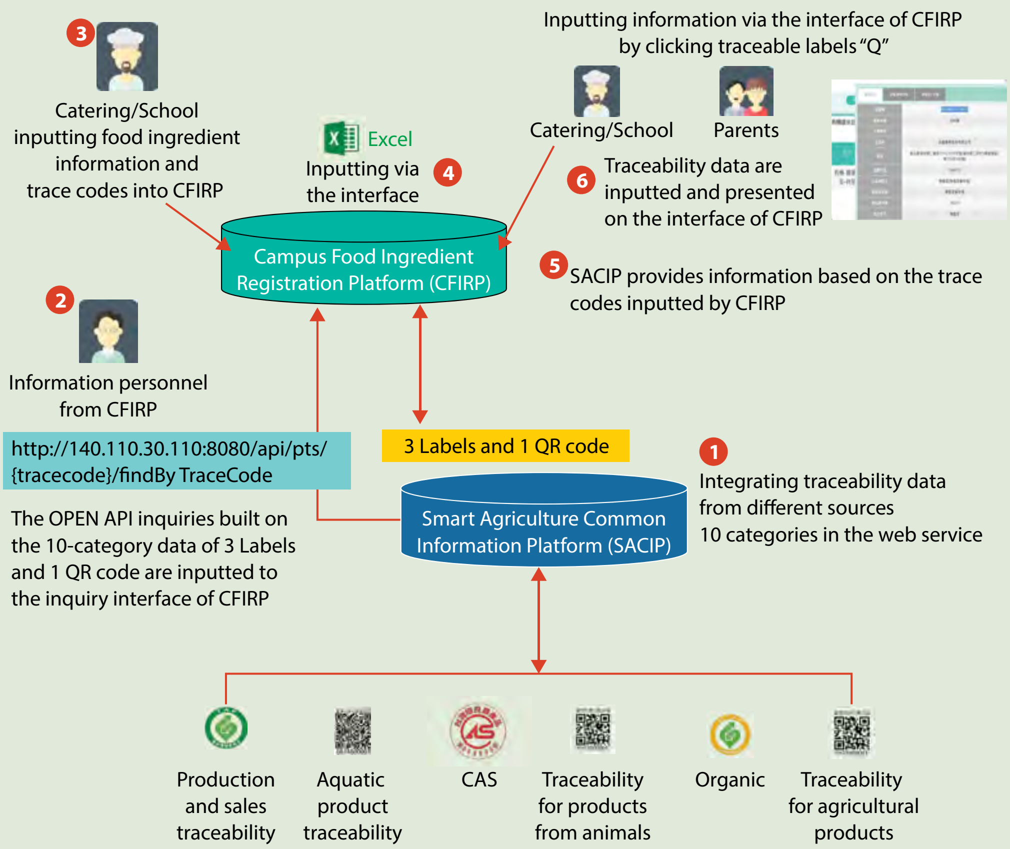
ENVIRONMENTAL DATA ON THE SMARTPHONE (LEFT); AN APP THAT CAN REMOTELY CONTROL THE TEMPERATURE IN THE CHICKEN FARM (RIGHT) [66].

Food Traceability: Integration of Records of Food Consumed by Students and Food Traceability Data

Currently, food traceability data is managed by different government agencies. The format of the data stored in databases is different, so it is difficult to integrate all the data. To solve such a problem, a common information platform (CIP) is established by an R&D team, responsible for developing common and integrative technologies for the steering industries. A publicly available application programming interface (API), is used to connect the traceability systems titled Three Labels and One QR Code with the Campus Food Ingredients Registration Platform [67]. The traceability data from the former can now be used by the latter, so schools can effectively track the sources of food used in the lunch. The interface of the common platform allows all data from the two sources to be browsed, to improve food safety. Inspectors can also use visualized figures to trace food flows and sources. A schematic diagram of the common platform is shown in Figure 17 [68].

FIGURE 17

SCHEMATIC DIAGRAM OF THE SMART AGRICULTURE COMMON INFORMATION PLATFORM [68].

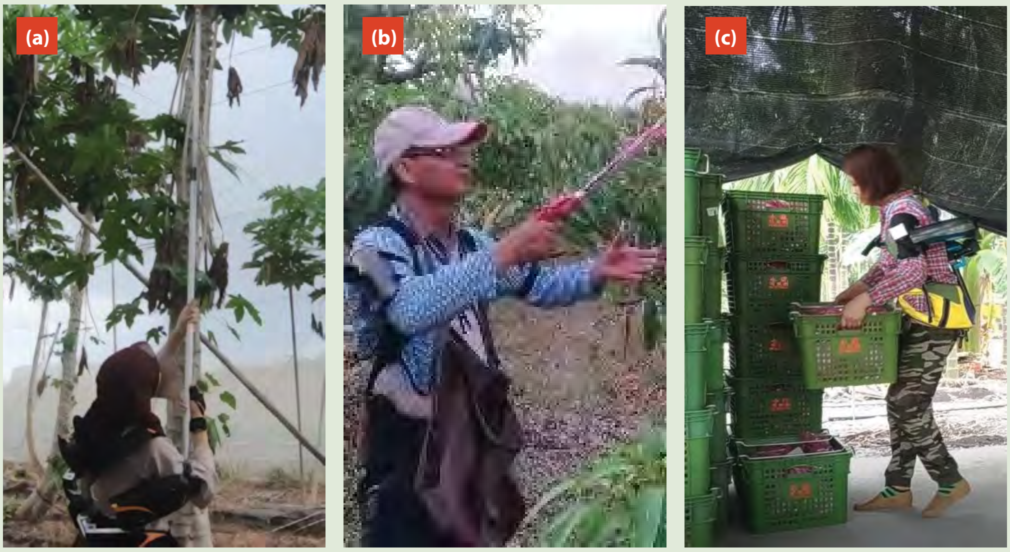


Wearable Aids: Wearable Time-Saving and Energy-Saving Moving Aids

Traditionally, farmers have to put a lot of effort into cultivating crops, so many youngsters do not want to join the agricultural sector. This leads to labor shortage, and the average age of farmers has been on the rise. To alleviate the problem, an R&D team responsible for developing common and integrative technologies for the steering industries has worked on developing several wearable energy-saving aids for plucking and moving fruit and vegetables, to improve operational efficiency and reduce labor costs. Currently, three aids have been developed to meet the demand of farmers that often grow different types of fruit on their farms [69]. The first one is a magnetically controlled energy-saving aid, as shown in Figure 18 (a), which is suitable for performing fruit picking and bagging tasks that require an arm to remain at a certain height, such as papaya picking and bagging. The second one is a machinery aid for fruit plucking and moving, as shown in Figure 18 (b), which can support one arm to lift objects of up to 5 kg to reduce the fatigue caused by arms moving forward and backward. This aid is particularly suitable for picking fruit scattered on shorter trees, such as mangoes and lemons. The third one is an electric moving aid for elbows and knees, as shown in Figure 18 (c). The elbow aid can provide a lifting force of 1.5 kg for one elbow, while the knee aid can support one knee with a force of 1.5 kg. The knee aid also has a mechanism to avoid falling over when the supportive force is suddenly too strong to bear. In addition, these three types of aid cost far less than similar products manufactured by foreign countries, so many farmers are willing to use them.

FIGURE 18

WEARABLE AIDS FOR (A) PAPAYA PICKING; (B) MANGO PICKING; AND (C) MOVING A CRATE OF BANANAS [69].



Pest Control: A Smart Management and Decision-Making System for Agricultural Pests

Pest outbreaks are the worst nightmare that farmers may have. A smart pest management and decision-making system were developed to help farmers effectively reduce the risks associated with pest outbreaks, as shown in Figure 19 [70]. Using this system, farmers can quickly gain knowledge about various pests and risks of pest outbreaks. Based on the research data provided by Taiwan Agricultural Research Institute, 20 pest-related issues are selected and each issue is provided with integrated pest control information. The information includes links to research reports, presentation slides, and videos that show key techniques for pest management and control, so farmers will have first-hand information about pest management measures. This system will become a great helper in improving farmers' ability in pest management, reducing the use of pesticides, and increasing the quantity and quality, as well as the safety of agricultural products produced in Taiwan.

FIGURE 19

HOMEPAGE OF THE SMART PEST MANAGEMENT AND DECISION-MAKING SYSTEM [71].

Unmanned Aerial Vehicle for Pesticides Spraying: Environment-friendly, Time-saving, and Labor-saving Drones

Currently, drones have been used by Taiwan's agricultural sector for two purposes: for inspection and spraying pesticides, as shown in Figure 20. Developed by Taiwan Agricultural Research Institute, drones have been employed to monitor rice fields for over six years. Combined with imaging technologies, the quantitative data collected by these drones can be used to effectively determine damaged and healthy rice fields, which could not be easily done using manual inspection. In addition, drones have sprayed pesticides on fruit farms. Using a pitaya farm as an example, the pesticides sprayed by a drone are less than 1/10 to 1/15 of the pesticides used by a portable sprayer, and the efficiency of the spraying increases by 300% [71]. Thus, the use of drones not only improves field inspection efficiency and accuracy but also solves the problem of the overuse of pesticides. In the future, other smart technologies, such as IoT, edge computing, and robotics, will be integrated with the development of drones enabling them to perform more tasks, making agricultural productions much more effective and environmentally friendly.

FIGURE 20

A DRONE SPRAYING PESTICIDES ON A PITAYA FARM [72].

Lessons Learned and Insights

There are many stories behind the smart agricultural transformation in Taiwan. In the following sections, the lessons learned in the case of the smart agricultural transformation in Taiwan will be presented.

High-Tech Industries Laying the Foundation for the Smart Agricultural Transformation

Taiwan's smart agricultural transformation seemed to start in 2015, as the government began to launch several industry innovations and smart agriculture policies. However, the true starting point might be far earlier than expected. For instance, Taiwan has been a world-leading semiconductor manufacturer since the 1990s, especially in wafer fabrication, IC design, and wafer probe and packaging [72] [73]. Semiconductors are widely used in laptop computers, cellphones, family appliances, and cars, which are very important tools to support today's smart transformation.

Apart from the semiconductor industries, Taiwan's machine tool industries also perform well in the world market. Based on the data of 2018, for example, Taiwan was the world's fifth-largest exporter of machine tools [74]. The machine tool industries are often viewed as a traditional industry, but with the advancement of technologies, the machine tool industries gradually evolve, from mid-tech industries, moving to high-tech industries. Some smart technologies have been applied to machine tool production, such as process automation, additive manufacturing, and electric vehicles [75]. With some help from the government, Taiwan's machine tool industry has been transforming itself, from delivering lower-end machine tools to supplying high-value-added equipment [76].

The successful experience of the semiconductor and machine tool industries has played a key role in supporting the overall industry transformation and upgrading, which in turn facilitates the transformation of the agricultural sector as well. For example, IoT-based agricultural monitoring systems generally include wireless communication modules, computers, and smartphones to remotely control various devices and equipment in a farm, and ICs are the core components of these devices. The mature, advanced semiconductor and machinery industries, therefore, lay the innovative foundation for Taiwan's agricultural transformation.

An Effective Top-Down Approach to Policy Implementation

In Taiwan, agricultural policies are often implemented by using a top-down approach. This means that the decision-making and process of policy implementation originate from higher levels and proceed downwards. Some of the advantages of employing a top-down approach are fast resource pooling and effective resource allocation, so the goals of the implementation can be quickly achieved.

Top-down policy implementation is particularly suitable for agricultural development in Taiwan. Smallholder farming is the main type of farming in Taiwan, so it is very likely that farmers cannot afford a large investment in innovative technologies and services. The government, therefore, has to step in and play a more active and central role in coordinating and investing in smart technology development to promote smart agricultural transformation. Currently, the government has encouraged public research institutes (such as Taiwan Agricultural Research Institute and various District Agricultural Research and Extension Stations) and research-based universities to develop smart technologies and services for agricultural uses. For example, National Taiwan University has cooperated with Tainan District Agricultural Research and Extension Station (which is a government-funded agricultural research center) to develop an IoT-based monitoring system for asparagus greenhouses. This monitoring system provides real-time greenhouse information to farmers, by using different kinds of sensors. Moisture sensors, for example, are placed in both the shallow and deep soil to measure the moisture of the soil, so the irrigation water can be used more efficiently [77]. The government also gives incentives to farmers who are willing to use new technologies and services to improve their production. These farmers then become the seeds of smart agricultural transformation. More farmers would be attracted by the benefits of using smart technologies and services, and start to participate in the transformation. Eventually, the role of the government as a direct investor and a commander will gradually fade out, but the role of a middleman that coordinates all resources will remain.

Keeping Innovation Policies and Smart Agricultural Policies in Sync

As mentioned earlier, Taiwan's smart agricultural transformation policies are always an important part of the overall industry innovation. Starting with Productivity 4.0, agricultural upgradation has been at the center of focus, along with industry and service upgradation. Including the agricultural sector in the programs of industry innovation, not only shows the importance of the agricultural sector to the whole economy in Taiwan but also brings out the possibility of reaping the benefits of economic and political complementarities.

Economic complementarities occur when the success of one policy relies on the effectiveness of other policies, while political complementarities exist when the ability of one policy to win political consent depends on the acceptance of other policies [78]. In other words, one policy may not be successful, if other related policies are not taken into consideration. Taiwan's smart agricultural policies and other innovative policies have been generally formulated at the same time, which greatly improves the complementarities between these policies and avoids excessive duplication of measures and counter-productive mixes.

Infrastructure: The Key to a Successful Transformation

In Taiwan, digital infrastructure has been heavily promoted. Based on a survey done in 2019, close to 90% of the people reported that they have been using Internet services via either smartphones or computers (laptop or desktop) [79]. Compared to the same survey done in 2018, Internet use for the older generation (aged 55 years and older) increased by 20.3%, while Internet use for other generations remains unchanged [79]. This means that the older generations are becoming more comfortable with getting Internet access. Given that the average age of farmers has increased over time, and that smart agricultural practices often involve the use of the Internet, it is a good sign that more elderly people have learned to use Internet services.

Moreover, as emphasized by the program DIGI+, the government aims to speed up the construction of digital infrastructure for extra broadband networking and cloud services to support smart agricultural practices. For example, USD1.67 billion has been used in the development of 5G networks over four years [80]. It is expected that the promotion of digital infrastructure will greatly enhance the development of information and communication technologies and digital services, which in turn, will enable a variety of smart agriculture practices.

Using Smart Agriculture Alliances to Create Public and Semi-Pubic Goods

Under Smart Agriculture 4.0, several smart agriculture alliances have been established. For example, the rice alliance has more than 700 members. The alliance is supervised by Taiwan Agricultural Research Institute, and the members receive training on the use of fertilizer and pest management, as well as consultation regarding rice demand and supply, so that the quality of rice is upgraded and stabilized, and the balance between production and sales is significantly improved, resulting in higher prices of rice. Thus, the forming of the alliance yields great outcomes for the farmers who join the alliance.

For the alliances responsible for developing smart technologies and services to support smart agriculture practices, their members come from government agencies, public and private research institutions, and universities. For example, the smart agriculture common information platform is developed by a team that consists of government officials from COA, researchers from the Taiwan Agricultural Research Institute, and engineers from the Institute for Information Industry. Such cooperation is an effective way to create public and semi-public goods required in smart agricultural transformation.

Policy Recommendations

Taiwan's experience in promoting smart agriculture practices might shed some light on the readiness for smart agricultural transformation. Various readiness indicators are mentioned in Chapter 1, including upstream, production, downstream, and enabling factors, that can be found in the case of Taiwan. To increase readiness for SAT, some policy recommendations are listed as follows.

1. The agricultural sector in each country may face a unique combination of challenges, so it is necessary to set up its own goals in smart agricultural transformation, after considering the assets of the country (e.g. industry structure, mature industries, legal framework, farming types, and talents).

2. Policy complementarities are important. The design and implementation of smart agricultural policies should consider all industry innovation policies.

3. Policy continuity matters. It may take a long time to achieve the goals of smart agricultural transformation, so it is important to have coherent, continuing agricultural policies.

4. To promote smart agriculture practices, it is necessary to select some steering industries that can serve as examples to demonstrate the benefits of employing smart technologies and services.

5. It is important to increase the cooperation between government agencies, public and private research institutions, and universities to create public and semi-public goods required in smart agricultural transformation.

6. Digital infrastructure, such as broadband networks and cloud services, is the key to the success of smart agriculture transformation.

7. It is necessary to improve farmers' digital competence. Digital competence refers to the confidence in employing digital technologies for information, communication, and problem-solving in all aspects of life. Farmers are more likely to adopt new technologies and services in their productions if they feel more comfortable using smart information and communication devices, such as smartphones and computers.

One may wonder if other APO member countries can successfully replicate Taiwan's smart agricultural policies. The answer is both yes and no. Most farmers in Taiwan are small-scale farmers. They generally lack the resources to upgrade their production. Thus, a top-down policy framework is suitable for Taiwan to pursue SAT. In other words, Taiwan's SAT is mainly led by the government. To many less developed countries, such an approach might become huge a financial burden to their governments, not to mention the concern of economies of scale. One possible solution is to find functional equivalent parties that can play a similar role in providing public goods needed for SAT. These parties can be local governments, businesses, associations, or NGOs. The e-choupal program launched in India might be a good example of functional equivalent approaches [81].

Taiwan's journey on SAT is far from complete. The government's promotion of smart agriculture practices did attract farmers' attention, but having them fully engage in the SAT is another story. For example, it may not be easy for older farmers to learn to use the new technologies, so the government targets youngsters and gives them more incentives (i.e., training and loans) to join the agricultural sector [82], but the outcomes have not yet met the expectation, and the average age of farmers remains high [17]. Thus, further studies are needed to reveal the true effect of the government heavily investing in SAT. The good news is that private IT companies have begun to extend their services to the agricultural sector. For example, Owlting, a Taiwan-based IT company, has developed IoT- and AI-based platforms for dairy farms and rice farms, to improve their production [83][84]. The company also provides services to logistics companies, using blockchain technologies to improve delivery efficiency and ensure the safety of the goods during cold chain delivery [85]. It is expected that such a trend will continue, but the effects brought by this trend remain an open question.

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LIST OF ABBREVIATIONS

API	Application Programming Interface
APJII	Indonesian Internet Service Users Association
APO	Asia Productivity Organization
ARP	Agriculture Restructuring Proposal
AT	Agricultural Transformation
AWR	Agriculture War Room
BLUP	Best Linear Unbiased Prediction
BNI	Bank Negara Indonesia
BNSP	National Professional Certification Agency
BPP	Agricultural Extension Center
BPS	Statistics Indonesia
BUMDes	Village-Owned Enterprise
CAS	Certified Agricultural Standards
CIAT	International Center for Tropical Agriculture
CIEM	Central Institute for Economic Management
CIP	Common Information Platform
COA	Council of Agriculture
CPC	Commune People's Committee
CPEC	China–Pakistan Economic Corridor
CPS	Cyber-Physical Systems
DBT	Integrated Broadband Village
DFI	Doubling Farmers' Income
DIGI+	Digital Nation
DOC	Department of Commerce
e-NAM	Electronic National Agricultural Market
GCF	Gross Capital Formation
GDP	Gross Domestic Product
GIC	Green Innovative Centers
GII	Global Innovation Index
GIZ	German Agency for International Cooperation
GNSS	Global Navigation Satellite System
GSO	General Statistics Office
GVA	Gross Value Added
IBV	Integrated Broadband Village
IDB	Industrial Development Bureau
IHDS	Indian Human Development Study

INSEAD	Institute of European Administration
IPSARD	Institute for Policy and Strategy on Rural Development
KKP-E	Food and Energy Security Credit
Kostratani	Strategic Command for Agricultural Development
KPEN-RP	Bio Energy Development Credit and Agricultural Revitalization
KPK	Khyber Pakhtunkhwa
KUPS	Cattle Breeding Business Credit
KUR	People's Business Credit
LAPAN	Institute of Aviation and Space
MCI	Ministry of Communications and Informatics (Indonesia)
ML	Machine Learning
MoA	Ministry of Agriculture (Indonesia)
MOAC	Ministry of Agriculture and Cooperatives
MoV	Ministry of Village (Indonesia)
MRL	Maximum Residue Limit
MSP	Minimum Support Price
NCAER	National Council of Applied Economic Research
NCF	National Commission on Farmers
ND	No data is available
NFSM	National Food Security Mission
NLM	National Livestock Mission
NSO	National Statistical Office
NSSO	National Sample Survey Organisation
PDP	Pulses Development Programme
PDT	Directorate General of Development of Disadvantaged Regions (Indonesia)
PEPI	Indonesian Agricultural Engineering Polytechnic
PMFBY	Pradhan Mantri Fasal Bima Yojana
PMKSY	Pradhan Mantri Krishi Sinchai Yojana
PPP	Public Private Partnership
PUAP	Rural Agribusiness Development
PUED	Directorate of Rural Economic Business Development (Indonesia)
R&D	Research and Development
RD&D	Research, Development, and Demonstration
RKVY	Rashtriya Krishi Vikas Yojana
ROC	Republic of China
Rotap	Rice Planting Robot
RTK	Real-Time Kinematic Positioning
S&T	Science and Technology
SAME	Sub-Mission on Agricultural Extension
SAT	Smart Agricultural Transformation
SME	Small and Medium Enterprises

SP-3	Agricultural Financing Services Scheme
STEM	Science, Technology, Engineering, and Mathematics
SUTAS	Inter-Census Agriculture Survey
TAP	Traceable Agriculture Product
TFP	Total Factor Productivity
UAV	Unmanned Aerial Vehicle
UPJA	Alsintan Service Rental Business
USO	Universal Service Obligation
VIDA	Vietnam Digital Agriculture Association
WIPO	World Intellectual Property Organization
WSN	Wireless Sensor Networks

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