Sustainable Agri-Food System and Resilience in Thailand

Exploring Technology-Driven Solutions for a Resilient Future

Emerging Trends *in* APO Members

Asian Productivity Organization

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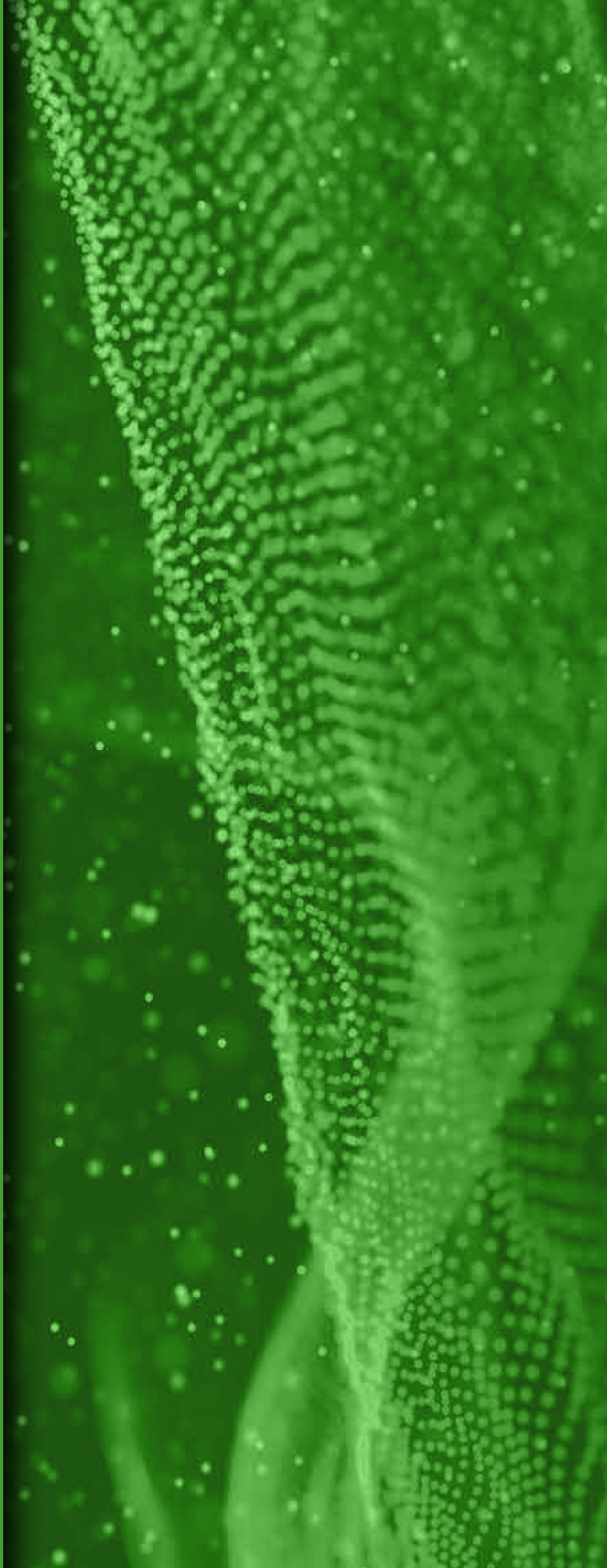

EMERGING TRENDS IN APO MEMBERS:

SUSTAINABLE AGRI-FOOD SYSTEM AND RESILIENCE IN THAILAND - EXPLORING TECHNOLOGY-DRIVEN SOLUTIONS FOR A RESILIENT FUTURE

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EMERGING TRENDS IN APO MEMBERS:
SUSTAINABLE AGRI-FOOD SYSTEM AND RESILIENCE IN THAILAND - EXPLORING TECHNOLOGY-DRIVEN SOLUTIONS FOR A RESILIENT FUTURE

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PREFACE

This publication on *Emerging Trends in APO Members* is aimed at enabling better navigation of the volatility, uncertainty, complexity, and ambiguity (VUCA) landscape. In today's turbulent, unpredictable world, the APO adopts a country-specific approach to understand and analyze emerging trends and driving forces that will have significant effects on member economies in terms of productivity and competitiveness. This series of reports introduces several emerging trends with the potential to disrupt and transform markets, governments, and society now and in the near future. It is hoped that through these publications analyzing those impactful trends, governments, policymakers, and ordinary citizens from all walks of life will be able to harness those driving forces while coping with critical uncertainties.

Recommended approaches and methods to address the challenges ahead include political, economic, social, technological, legal, and environmental perspectives. Being future-ready requires such a comprehensive approach to informed decision-making by governments, enterprises, and individuals in the fast-changing environment in the Asia-Pacific region. For the APO, it is all about early identification of issues and prospects, which requires strengthening its role as a think tank and regional adviser on productivity in the region.

The APO thanks all contributors to the report. We hope that it will benefit those seeking to improve productivity and quality of life brought about by emerging trends in a rapidly changing world.

SUSTAINABLE AGRI-FOOD SYSTEM AND RESILIENCE IN THAILAND: EXPLORING TECHNOLOGY-DRIVEN SOLUTIONS FOR A RESILIENT FUTURE

Abstract

Transforming the agri-food system involves various emerging trends to shape its future. These trends are influenced by technological advancements, economic shifts, environmental pressures, and changing consumer preferences. This report highlights emerging trends within social trends, technological, environmental, economic, and political spheres.

Sustainable, equitable, and healthy agri-food systems are vital for a well-functioning economy, society, and environment. The COVID-19 pandemic and climate fluctuations have exposed deep-rooted flaws in the global agri-food system. Imbalance food distribution, hunger, malnutrition, and diet-related health issues are closely tied to poverty and the sharp rise of food insecurity trends. These crises have demonstrated that our agri-food systems are fragile, often neglected, and at risk of disruption, leading to global recession, loss of income, and diminished livelihoods. As rapid urbanization, social marginalization, climate change, and biodiversity loss continue to disrupt, the transformation of the agri-food system to be sustainable and resilient becomes increasingly important.

Integrating digital technologies into agriculture is a key driver to the shift toward sustainable and regenerative agricultural practices and building resilient food systems, including urban agriculture, vertical farming, and controlled environment farming. The adoption of circular loop design is also gaining momentum to reduce waste, reuse materials, and recycle by-products or postconsumer products. Consumers are increasingly demanding transparency in the food system and its environmental and social impacts, and implementing a more equitable and transparent system is becoming a source of competitive advantage. As global climate policies become more stringent, actions, like carbon credit and emissions trading systems, are expected to speed up greenhouse gas (GHG) reduction and reach sustainable goals.

Looking forward, these emerging trends in the agri-food system will continue to evolve. Stakeholders across the agri-food system can address the challenges by collectively pushing toward a more sustainable, resilient, and equitable future.

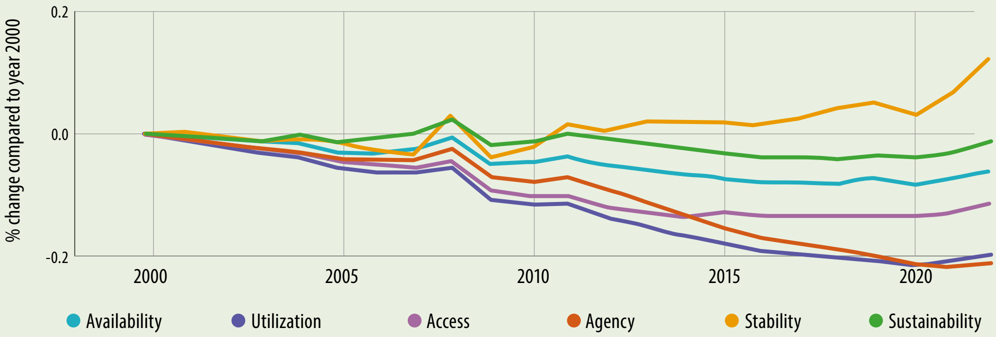
Introduction

The UN has stated that the food system contributes one-third of global GHG emissions from human activities [1], thus making the sustainability and resilience of the agri-food system an urgent mission for all. Agri-food system activities exert pressure on planetary boundaries and on the natural resources that are essential for sustaining global food security. The triple planetary crisis - climate change, pollution and waste, and biodiversity loss as well as other recent short-term shocks to the agri-food system, including the COVID-19 pandemic, geopolitical situations, and global recession, have disrupted the balance of production and consumption in the food supply chain and intensified stress on food system resilience. The impact of unstable climate events on agriculture is more severe in developing countries, where smallholder farmers rely on consistent weather patterns. Unpredictable climate conditions result in lower crop and livestock productivity, and increase pest and disease outbreaks, worsening food insecurity and poverty. Recent evidence shows several shocks to the food supply chain, including food shortage due to the COVID-19 pandemic, dramatic drops in crop yields from extreme weather, and the trade conflicts driving up food prices.

In Asia-Pacific region, for instance, climate change has adversely affected pest outbreaks, floods [2], water shortages, and soil degradation [3], causing significant crop yield losses, reduced product quality, and challenges to food security. Furthermore, multiple crises coupled with the COVID-19 pandemic forced 58 million people in the Asia-Pacific region into hunger and accelerated the poor to become poorer [4]. In 2023, about 9.8% or 467.3 million people faced severe food insecurity, mainly in Southern Asia [5]. Poor and vulnerable groups who contribute little to global carbon emissions are the most affected by climate change and the least prepared to cope and adapt to these crises. A report by the Economic and Social Commission for Asia and the Pacific (ESCAP) stated that 24% of GHG emissions in Asia are generated from the agri-food sector and 75% of forest loss is due to cropland expansion. Inequality also remains a serious issue, particularly for women farmers in East and Southeast Asia (almost 50% of total farmers) and South Asia (30% of total farmers) [6]. Figure 1 illustrates food system risk trends in 2022 in Asia and the Pacific by six food security dimensions: availability, access, utilization, stability, agency, and sustainability. After the COVID-19 pandemic, risks related to financial and market stability have increased dramatically while other dimensions showed limited improvement, especially the sustainability dimension of food security.

FIGURE 1

OVERALL FOOD SYSTEM RISK TRENDS BY FOOD SECURITY DIMENSION



Source: ESCAP.

The risk to food systems is further shaped by their capacity to adapt to various environmental, technological, infrastructural, political, economic, sociocultural, and demographic factors [7]. Environmental drivers primarily influence food systems on the production side, as food production heavily depends on the availability of natural resources, such as water, land, and biodiversity, leading to food insecurity [2–3]. While sociocultural and demographic factors play a critical role in shaping food demand, type of food consumed and consumption patterns, such as preferences for animal welfare, alternative proteins (plant-based and cultivated meat, and insect protein), and organic foods. Technological, infrastructural, and economic drivers influence both supply and demand by improving efficiency, enabling traceable food system, and enabling supply to meet demand.

The population in the Asia-Pacific region faces more severe challenges compared to other regions, as various threats accumulate with limited options for adaptation or mitigation [4, 6]. This situation calls for urgent action for all stakeholders - producers, businesses, consumers, policymakers, and financial institutions - involved in transforming food systems. It is crucial to consider the holistic or interconnected nature of these challenges and their multiple outcomes and risks to build more sustainable and equitable food systems. Anticipating and understanding the state of the agri-food system and its consequences to future trends is essential for effective policy-making decisions and ensuring food system transformation.

Data and Methodology

The methodology for reviewing literature involves four steps: defining the research scope on sustainable agri-food system, gathering data through reliable databases and sources, synthesizing the literature to identify common trends across the reviewed studies, and summarizing the key points.

The research scope on sustainable agri-food systems and resilience is developed according to the drivers affecting the future of food systems, which respond to environmental, demographic, technological, political, economic, sociocultural, and other factors [6–7]. In addition, the risk to food systems is further shaped by adaptation capacity, which is taken into account when building resilient, healthy, fair, and sustainable food systems.

Foresight analysis is a strategic planning approach used to anticipate and prepare for potential future challenges, emerging trends, and opportunities [8]. It involves exploring various possible futures based on current data, trends, and expert insights to better inform decision-making. A common method within foresight analysis is the PESTEL framework, which categorizes external forces affecting a sector into six key areas: political and regulatory, economic, social and cultural, technological, environmental, and legal factors. Based on these issues, applying PESTEL in foresight analysis helps to identify five emerging trends for sustainable agri-food system: social trends, technological trends, environmental trends, economic trends, and political trends.

Data were collected from previous studies and various sources, including ESCAP, ADB, FAO, UNDP, the United Nations Convention to Combat Desertification (UNCCD), the World Bank, the World Economic Forum, McKinsey, WTO, the International Finance Corporation (IFC), and Krungsri Research.

Social Emerging Trends

Mental Health and Well-being

Well-being frameworks emphasize the importance of factors, such as social connections, purposes, and physical health as integral to mental well-being. After COVID-19, the trend toward prioritizing mental health within the agri-food system has become significant for the sustainability and resilience of agricultural communities [9]. Several factors, including social isolation, financial stress, unpredictable weather, and long working hours, contribute to elevated levels of stress, anxiety, and depression among agri-food workers. Many farmers and agricultural workers operate in rural and remote areas, leading to social isolation, loneliness, and depression [10]. The economic volatility of farming - driven by fluctuating commodity prices, increasing costs of production inputs, and debt - places significant financial stress on farmers [11]. Addressing mental health challenges in this sector not only supports individual well-being but also enhances the overall productivity and sustainability of the agri-food system.

Climate change and unpredictable weather patterns introduce additional stress for those in the agri-food system. The reliance on favorable weather conditions for crop production means that adverse events, such as droughts, floods, and extreme temperatures, can have devastating effects on livelihoods. The uncertainty surrounding these events adds to the mental burden experienced by farmers [12].

In response to these challenges, there has been a growing focus on providing mental health support and resources tailored to the unique needs of the agricultural sector. Some initiatives include the development of farmer-specific mental health programs, the expansion of telehealth services to reach remote areas, and community-based support networks aimed at reducing isolation and promoting mental well-being [13]. Additionally, the concept of work-life balance and wellness programs on stress management are designed to create supportive work environments and reduce the economic burden. Furthermore, the rise of digital health technologies has led to the proliferation of online mental health resources, including apps, teletherapy, and digital counseling platforms [14].

Equitable Food Systems and Ethical Sourcing

As the demand for equity and transparency increases, businesses are discovering that embracing equitable food systems and ethical sourcing practices is both a moral obligation and a strategic advantage. Inequitable practices in agri-food systems lead to unfair distribution of benefits, poor availability, and unaffordability of food [15]. The issues of inequity come from income disparities, imbalances in political and economic power, and gender and social inequalities. These unequal outcomes continuously leave many people behind, causing more hunger, malnutrition, and diet-associated health effects. Transforming agri-food systems requires addressing inequalities and ensuring equitable access to resources as well as integrating information, technology, and human rights principles [16]. To cope with inequitable food systems, sustainable practices, such as community-supported agriculture, urban farming, and food justice movements are gaining attention for their role in improving food access, advocating for local food systems, empowering communities, and reducing dependence on global supply chains [17].

Ethical sourcing involves the practice of ensuring that products are obtained responsibly and sustainably, respecting the environment, workers' rights, and local communities [18]. The Fairtrade movement is a key initiative in this area, offering certification that guarantees producers receive a fair price for their goods, often alongside social and environmental standards [19]. Consumers are increasingly looking for labels like Fairtrade, Rainforest Alliance, and organic, signaling that products are sourced with care for the environment and the well-being of workers [20]. This shift in consumer behavior is influencing businesses to improve their sourcing practices and offer more ethically produced products. Today, consumers are more informed and are using their purchasing power to support brands that demonstrate a commitment to social and environmental responsibility [21].

Case Study: India's Tea Industry

India is the world's second-largest tea producer, employing millions in tea plantations. However, the tea industry has been criticized for low wages, poor working conditions, and exploitation of workers, particularly in states like Assam and West Bengal [22]. Ethical sourcing in the tea industry has gained momentum as consumers and advocacy groups demand greater transparency and better conditions for workers. To promote a sustainable tea industry, the Fairtrade Foundation has partnered with companies like Unilever and Tata Global Beverages, which have committed to sourcing tea from Fairtrade-certified plantations. This certification ensures fair wages for workers and environmentally sustainable production practices. Additionally, Fairtrade certification provides social premiums that can be used to improve living conditions for workers and their families.

The move toward more equitable food systems and ethical sourcing in agri-food sectors shows promise, but challenges remain [23]. Ensuring that these practices are adopted widely, and not just by niche markets or local advocacy, requires continued consumer education, strong regulatory frameworks, addressing power imbalances, and commitment from all stakeholders in the food supply chain. Moreover, there is a need to balance ethical sourcing with affordability, ensuring that ethically sourced products are accessible to all consumers, not just those who can afford to pay a premium.

Cultural Food Diversity and Gastronomy

Globalization, increased migration, and rising interest in a rich variety of food traditions and culinary practices have facilitated the exchange of food cultures worldwide, leading to increased access to diverse ingredients, cultural food diversity, and gastronomic exploration. The growing movement to preserve and celebrate culinary heritage plays a vital role in cultural identity and unique culinary technique [24]. Efforts to promote local or regional dishes as well as to document indigenous culinary practices passed down through generations reflect a broader interest in preserving the cultural diversity of the country [25]. For instance, Lanna crispy *khao soi*, a traditional Thai noodle dish, was featured at the APEC 2022 gala dinner, showcasing Thailand's culinary heritage and significantly enhancing the appeal of Thai soft power, which has since experienced growing demand among both locals and international tourists.

The blending of different culinary traditions has given rise to fusion cuisine, where chefs combine ingredients and techniques from various cultures to create innovative dishes and gastronomic experience. The dynamic nature of food highlights the creativity and the interconnections among global food cultures. Gastronomic tourism is an example of this trend, which is becoming increasingly popular as travelers seek authentic food experiences on their journey [26]. The promotion of food festivals, cooking classes, and farm-to-table experiences allows tourists and locals to engage with local food cultures. Gastronomic tourism not only supports local economies but also fosters a deeper understanding of cultural diversity through food [18, 24].

Technological Emerging Trends

Data and Platform Transparency in Food Production

In the digital era, consumers and stakeholders are increasingly interested in knowing where their food comes from, how it is produced, and whether it meets ethical and environmental standards. Data transparency enables food producers to demonstrate their commitment to sustainability and ethical practices as well as supply chain accountability [27–28]. It involves making data available on food safety, sustainability practices, and supply chain management, and using technology platforms to share this information. Thus the openness and accessibility of information related to the processes, practices, and outcomes associated with food production can boost business reputation, traceability, and customer loyalty. Moreover, transparency helps ensure that all stakeholders, from farmers to retailers, adhere to agreed-upon standards and practices, reducing the risk of fraud, contamination, and unethical practices [28].

Digital platforms play a crucial role in enhancing transparency by providing tools for data collection, analysis, and dissemination. For example, blockchain technology is used to create immutable records of transactions and processes throughout the food supply chain, enhancing traceability and accountability [29]. Artificial intelligence (AI) technology is used to analyze big data or social data to provide new values and predict consumer demand, enabling better inventory management and reducing food waste. Other platforms might offer real-time data on farming practices, resource use, and environmental impact, which can be shared with consumers and stakeholders. QR codes on product packaging, for instance, can link consumers to detailed information about the product's journey from farm to market.

While transparency is crucial, it must be balanced with the need to protect sensitive information. Ensuring data security and privacy while maintaining transparency can be challenging, particularly when dealing with proprietary data or information that could expose vulnerabilities in the supply chain [28]. Implementing transparent data platforms can be costly, particularly for small-scale producers. Additionally, the complexity of some technologies may limit accessibility for certain users, requiring investment in education and training.

Agri-tech Innovations

With climate change, a growing population, and rising concerns over food security, global attention on food and agriculture has intensified. The adoption of sustainable and modern agricultural practices has become more critical. In the fast-paced world of agri-tech, the application of advanced technologies, especially AI, is transforming agriculture to improve efficiency, productivity, sustainability, and profitability, helping to address global challenges.

Precision agriculture involves using technology to monitor and manage variability in agricultural production. This includes the use of AI tools to analyze data from sensors, drones, and data analytics to optimize inputs, like water, fertilizers, and pesticides. Farmers can make data-driven decisions, resulting in more efficient resource use, higher crop yields, and reduced environmental impact [30].

Digital twins and generative AI are emerging as game-changing technologies, leveraging both real and synthetic data to decide on agronomical research and real-world situations. Digital twins are virtual models of physical systems [31] while generative AI is the brain that can generate new content, ideas, or solutions based on existing data [32]. The combination of digital twins and generative AI offers a powerful fusion for modern agriculture by providing predictive analytics and recognition. They transform agriculture into a dynamic field with predictive capabilities that help farmers to seek the best performance of sustainable farming operations.

Biotechnology and genetic engineering in agriculture include innovations like genetically modified organisms (GMOs), transgenics, microbiomes, and other biotechnological innovations that enhance crop resistance to pests, diseases, environmental stressors, and food security [33]. For example, drought-tolerant rice varieties developed in Thailand can improve the resistance to extreme weather conditions [34]. These technologies can significantly increase crop yields, develop resilient varieties suited for climate change, improve nutritional content, and reduce the need for chemical inputs.

Automation and robotics are revolutionizing agriculture by improving the efficiency of farming operations, reducing labor costs, and enabling precise and timely interventions. Leveraging these technologies in agriculture involves the use of machines and robots to perform agricultural tasks, such as planting, harvesting, weeding, and spraying. Automation helps in optimizing the use of resources, reducing waste, and improving crop yields by ensuring that each plant receives the right amount of water, nutrients, and care [35]. Moreover, robotics in agriculture can also improve the quality of the harvest, enhance labor ethics and safety, and reduce exposure to high-risk activities and health hazards [36]. These technologies are particularly important in countries facing a labor shortage and an aging workforce.

Case Study: China's Investment in Automation and Smart Agriculture

China, the world's largest agricultural producer, is investing heavily in automation and smart agriculture to ensure food security and reduce its reliance on manual labor. With the Chinese government actively promoting the use of technology in farming as part of its Made in China (MIC) 2025 strategy, automation and robotics are becoming integral to modern Chinese agriculture [37]. China has introduced a range of autonomous farm equipment, including driverless tractors and crop harvesters. For example, YTO Group manufactures driverless tractors (Figure 2) that use GPS and AI technology to operate

FIGURE 2

DRIVERLESS TRACTOR IN CHINA

Source: YTO Group (2021).

autonomously in large-scale farming [38]. These tractors can plow, seed, and harvest with high precision, making them particularly useful for China's massive grain production sector.

Digital agriculture and smart farming involve the use of digital tools and platforms to collect, analyze, and apply data in agricultural practices, including the Internet of Things (IoT), big data, greenhouse systems, and cloud computing [30]. To improve productivity and sustainability, these digital tools help farmers make informed decisions by providing real-time data on weather conditions, soil health, crop performance, and market trends [39]. Big data and machine learning algorithms analyze agricultural data to identify patterns, predict outcomes, and optimize practices, leading to better planning, reduced risks, and optimized production [40].

Climate-smart agriculture (CSA) has emerged as a holistic approach aimed at ensuring food security, promoting sustainable development, and mitigating climate change [41]. CSA is a set of agricultural practices and technologies that are designed to simultaneously boost productivity, enhance resilience, reduce GHG emissions, and contribute to food security. For example, renewable energy sources, such as solar and wind power, are integrated into farm operations. Additionally, the application of sensors is used for monitoring soil moisture and drones are used for assessing crop health. The choices of agricultural practices and technologies should be tailored to specific ecological conditions and socioeconomic contexts, with options including agroforestry, precision farming, water management strategies, and climate-resilient crop varieties.

Controlled Environment Agriculture

Controlled Environment Agriculture (CEA) is an advanced and highly intensive farming method where crops are grown within a controlled environment to optimize growth conditions [31, 42–43]. This approach allows for the manipulation of various environmental factors, such as temperature, humidity, light, and carbon dioxide (CO_2) levels, creating ideal conditions for plant growth throughout the year, regardless of external weather conditions. CEA encompasses a variety of systems, such as greenhouses, vertical farms, and indoor farms. These systems use technologies, like hydroponics, aeroponics, and aquaponics, which allow plants to grow without soil and with minimal water usage.

Hydroponic systems grow plants in nutrient-rich water solutions while aeroponic systems deliver nutrients to plants through mist. These methods not only conserve water but also reduce the need for chemical fertilizers and pesticides [31].

Vertical farming systems use stacked layers to grow crops in a controlled indoor environment, maximizing space efficiency. In addition, CEA can produce crops year-round, offering a consistent supply of fresh produce even in regions with harsh climates. This continuous production capability is particularly valuable for reducing food miles and ensuring food security in urban areas [42]. One of the primary advantages of this system is its ability to produce high yields in a smaller space compared to traditional farming.

Indoor farming systems often replace natural sunlight with either limited or entirely replaced by artificial lighting. These systems integrated with light-emitting diode (LED) have become the preferred lighting technology due to its energy efficiency, long lifespan, and ability to emit light at specific wavelengths. LED technology helps manage plant-light interactions, which are crucial for optimizing photosynthesis and plant growth [43]. For instance, blue light promotes vegetative growth while red light encourages flowering and fruiting [44].

Case Study: Japan's Use of Robotics and Automation in Agriculture

Japan, a country with a rapidly aging population and declining agricultural workforce, has turned to robotics and automation to address its agricultural challenges [45]. The focus on precision agriculture has led to the adoption of robots and autonomous machines designed to reduce labor and improve productivity. Spread Co., a Japanese company from Kyoto, runs an automated leafy green facility where robots and advanced technology manage tasks for cost-effectiveness [46]. Temperature and humidity are optimized to accelerate the growth of the greens and improve nutritional quality, which

FIGURE 3

AUTOMATED LEAFY VEGETABLE FACTORY IN JAPAN

Source: Spread Co. (2022).

are harvested by robots (Figure 3). This approach reduces the need for human labor, bypasses weather impacts, ensures more accurate harvesting, and minimizes crop waste.

CEA also allows for the precise control of growing conditions, which results in produce of higher quality, with better flavor, nutritional content, and shelf life. By minimizing exposure to pests and diseases, CEA reduces the need for pesticides, contributing to more sustainable and environmentally friendly farming practices [31, 43]. However, CEA systems require significant initial investment and energy inputs, particularly for lighting and climate control. Despite these challenges, advancements in renewable energy and energy-efficient technologies are making CEA more viable and sustainable in the long term [43].

Environmental Emerging Trends

Zero-waste Movements and Upcycling

Growing environmental initiatives focus on reducing waste by minimizing consumption, maximizing reuse, and recycling materials to prevent them from ending up in landfills or incinerators. This movement advocates for reducing waste and food loss at every stage, from farm to fork, while efficiently using resources. Food waste and loss generate an estimated 8%–10% of global GHG emissions and account for nearly 30% of global agricultural land use [47]. The zero-waste movement is driven at different levels, such as community initiatives, government policies, and global environmental trends. Promoting the consumption of locally produced and seasonal foods reduces the need for long-distance transportation and the associated waste while giving support to local economies and reducing the carbon footprint of the food system [48].

Upcycling refers to old or discarded items that are creatively repurposed into new products of higher value. This emerging trend focuses on transforming food by-products, waste, and surplus materials into valuable products [49]. It not only reduces waste but also contributes to sustainability and economic efficiency within the food industry. For example, by-products from the brewing industry, such as spent grains, are used as nutritious feed for livestock, leading to reduced waste and providing a cost-effective feed source [50].

Case Study: Thailand's Bio-Circular-Green (BCG) Economy Model

Thailand has embraced the BCG Economy Model, which integrates biological resources, circular economy principles, and green technologies to promote sustainable agriculture and reduce environmental impacts. Thailand generates approximately 27 million tons of waste annually, with around 60% being organic waste, including significant portions of plastics [51]. With a high rate of plastic waste and limited landfill capacity, Thailand is making concerted efforts to promote a circular economy to reduce waste generation. Singha Corporation Co. Ltd, a Thai brewery, has implemented a Zero Waste Policy, ensuring that all waste and by-products are utilized effectively. After fermentation, the yeast from the bottom of the tanks is separated and thickened. The spent grains (e.g., malt waste) and yeast residue have been certified by the Central Laboratory as containing nutrients suitable for animal feed [52–53]. Farmers can lower feed costs while increasing milk production. Moreover, the spent grains are also developed into furniture materials, such as desks and chairs, which are donated to local schools (Figure 4).

FIGURE 4

WASTE MANAGEMENT IN THAILAND

Source: SD Thailand (2022).

Agricultural waste, such as cassava peels or sugarcane bagasse, can be processed into biodegradable packaging materials [54]. This upcycling process not only reduces food waste but also addresses the environmental issues associated with petroleum-based plastic packaging. Food waste and agricultural residues can be converted into bioenergy or high nutritional value animal feeds [55].

While the zero-waste movement and upcycling are gaining momentum in Asia, challenges remain, such as the need for better waste management infrastructure, greater public awareness, and stronger enforcement of environmental regulations. Future policies may include stricter enforcement of recycling practices, extended producer responsibility (EPR) schemes, and incentives for businesses adopting sustainable practices. Efficiently integrating upcycling and the zero-waste movement into existing food supply chains can be complex and requires collaboration across the supply chain [49, 56].

Sustainable and Regenerative Agriculture Practices

The rapid growth of intensive agriculture and monoculture cropping systems has had significant negative effects on natural resources, creating major challenges for the long-term sustainability of food security and production [57]. While sustainable agriculture has been a well-established concept in farming for decades, regenerative agriculture has recently gained prominence as an emerging term. The combination of sustainable and regenerative agriculture practices focuses on farming techniques that enhance soil health, biodiversity, and ecosystems while farming and producing agricultural products in a way that is environmentally sound, economically viable, and socially responsible. Unlike conventional agriculture, regenerative practices aim to improve the land and environmental conditions over time, making agriculture more resilient and sustainable.

The practice of regenerative agriculture consists of cover cropping, crop rotation, no-till farming, decomposition of organic waste, biochar, permaculture, and agroforestry [58–59]. Moreover, studies on Southeast Asia croplands indicated that regenerative agriculture practices are more likely to rise soil carbon sequestration [58]. Composting and the use of organic fertilizers are also common in Southeast Asia, enhancing soil fertility and reducing reliance on chemical inputs. These practices support regenerative agriculture by improving soil structure and microbial activity [58–60]. In Thailand, efforts are being made to address environmental challenges and promote sustainable farming. For example, restoring traditional rice paddy systems using regenerative practices, such as reintroducing traditional water management techniques and integrating cover crops to improve soil health [58]. In northern Thailand, regenerative practices are being applied to coffee farming, including shade-grown coffee, which integrates native trees to enhance biodiversity and soil health [59].

To implement regenerative agriculture, smart technologies and systems have evolved in response to the demand for sustainable agricultural production. In modern agriculture, precision agriculture uses GPS, drones, and sensors to monitor field variability, allowing farmers to manage inputs, such as water, fertilizers, and pesticides more efficiently, reducing waste and optimizing resource use [57–58]. However, small-scale farmers may struggle with the costs of these technologies as it requires significant upfront investment.

Closed-loop Systems and Green Design

The rapid pace of population growth and dynamic movement has accelerated resource consumption and waste production, leading to environmental impact and climate variability. The existing system is operated in a linear sequence, involving extraction, production, consumption, and disposal, a model that may not serve climate change and sustainability [61]. Closed-loop systems aim to create a circular flow of resources to waste by reducing, reusing, and recycling materials with a system design that considers the balance of economic, social, and environmental impacts. The goal of this system design is to increase resource efficiency, reduce waste generation, keep materials in use, and recycle to recover valuable materials. In agriculture and food systems, this approach involves recycling organic waste into compost, reusing water, and integrating waste products from one process into another [62]. For example, manure and crop residues can be composted and returned to the soil as fertilizers, reducing the need for synthetic inputs and minimizing waste.

Green design, or eco-design, focuses on creating products, processes, and services while minimizing the environmental impact. Green designs are applications of material closed-loops, such as designing for remanufacturing, disassembly, recycling, reducing surplus capacity, enhanced durability, selecting low-carbon materials, and promoting product–service combinations to ensure holistic integration across the supply chain. Increasing number of green businesses in the agri-food sectors adapt biodegradable, recyclable, or reusable packaging materials to reduce environmental impact. These businesses also design systems that minimize energy use, such as energy-efficient irrigation systems or solar-powered processing facilities [63]. In addition, green innovation is becoming a strategic development and managerial process, leading to enhanced productivity, applied technology development, and improved competitive advantage of the business.

However, the adoption of closed-loop systems and green design has moved at a slow pace due to insufficient connection of green or sustainable strategies across all stakeholders in the supply chain. This has resulted in an imbalanced cost-benefit ratio for the involved parties [64]. There is an urgent need to develop and implement effective policies that promote green design and green supply chains. Governments must establish sufficient regulations to effectively drive market transformation toward a green ecosystem while supporting green businesses and actions. Businesses can embark on an environmental responsibility by providing green products and services to potential customers and incorporating a green supply chain.

Economic Emerging Trends

Green Financing and Impact Investment

To achieve sustainable goals and tackle environmental challenges requires both ecosystem resilience and significant financial support during the transition. The allocation of financial flows and capital will shape the ecosystems and influence production and consumption patterns toward sustainability [65–66]. Major actors in the financial sector must work together in partnerships to develop the financing system and sustainable finance roadmaps. According to the 17 Sustainable Development Goals (SDGs), green financing mainly supports public and private sectors in creating positive environmental impacts, capacity building of community enterprises for microcredit, and promotes public-private partnerships (PPPs) through financing mechanisms, such as green bonds, blue bonds, and climate transition bonds [67–68]. Moreover, green financing refers to the process of raising capital or securing funds through various financial instruments to support projects or activities that deliver environmental benefits, such as renewable energy, energy efficiency, pollution prevention, and sustainable land use. As such, green financing has become a crucial tool helping to reconcile the conflicting goals of environmentalism and capitalism.

Impact investment involves investing in companies, organizations, or funds that aim to generate a measurable, positive social or environmental impacts alongside financial returns. Many financial institutions offer investment products targeting green opportunities, such as environmental, social, and governance (ESG) or impact investment products [66]. For example, investments in enterprises that develop innovative solutions to increase food production sustainably or improve food distribution to underserved communities. Impact investors may also fund tech start-ups that develop technologies to reduce food waste or increase crop yields sustainably and invest in fair trade cooperatives that ensure farmers receive fair compensation while adhering to environmentally sustainable practices.

The transformation of agri-food systems remains an issue in the 2025 UN Climate Change Conference. Most farmers cannot implement sustainable practices or regenerative transition without external support. To address the initial cost of this transition, financial support, including upfront payments, guarantees, and insurance is required to shift the financial risks away from farmers. In addition, making collaboration models for green financing that benefit all stakeholders in the supply chain need to be developed [69].

Carbon Credits for Ecosystem Services

Climate change has advanced at a faster pace than the actions and policies needed to address it. Carbon pricing has been introduced to internalize the marginal external cost of GHG emissions [70]. Two main types of carbon pricing are emissions trading systems (ETS) and carbon taxes. ETS, referred to as a cap-and-trade system, limits the total level of GHG emissions and allows industries with low emissions to sell excess allowances. A carbon tax directly sets a tax rate on GHG emissions of each production and trade agreement between countries. The selection of the carbon pricing instrument will depend on the specific national, policy objectives, and economic situation.

Carbon credits are a key component of a market-based mechanism to address climate change, which represents the right to emit a measured amount of GHG [71]. The idea behind carbon credits is to create a financial incentive for reducing emissions by putting a price on carbon. Under an ETS, businesses are either issued or can purchase carbon credits, each representing the right to emit a certain amount of GHGs. Another way of generating carbon credits is through projects that reduce or sequester emissions outside the capped sectors, such as reforestation, renewable energy development, and sustainable land management. Examples of generating carbon credits in agri-food systems are soil carbon sequestration by cover cropping and agroforestry, methane reduction by improving feed quality or manure management, and renewable energy integration. Carbon credits are traded in both compliance and voluntary markets, where businesses can buy credits to offset their emissions as part of corporate social responsibility (CSR).

Farmers and agribusinesses can sell carbon credits on the carbon market, providing them with an additional income stream. However, small-scale farmers may face challenges in accessing carbon markets due to the high costs of certification and the complexity of market mechanisms. Accurately measuring and verifying carbon sequestration and emission reductions in agriculture can be complex and expensive, which may limit participation in carbon credit schemes.

Ecosystem services refer to the diverse benefits that are derived from the environmental project, which directly or indirectly contribute to human well-being, biodiversity, and economic benefits to stakeholders. Carbon credits for ecosystem services are a mechanism designed to incentivize the protection and enhancement of natural ecosystems by assigning a monetary value to the carbon sequestration and other environmental benefits they provide. This approach aligns economic interests with environmental conservation, in which payments for ecosystem services (PES) are made by the beneficiaries or users of an ecosystem service to the providers of that service [72]. PES programs generally focus on carbon sequestration, biodiversity protection, watershed protection, and landscape preservation. By creating a financial value for ecosystem services, carbon credits provide economic benefits to landowners and project developers, making conservation projects more attractive and feasible.

Skilled Workforce Development in Advanced Agricultural Technologies

Advanced agricultural technologies often aim to enhance sustainability by reducing waste, conserving resources, and minimizing environmental impact. As these agricultural technologies evolve and transition to less labor-intensive methods, there is a growing demand for a workforce that is knowledgeable, skilled, and adaptable to these shifts [73]. Advanced agricultural technologies, such as drones, sensors, precision agriculture, robotics, automation systems, and data analytics using AI tools, offer significant benefits, including increased productivity, efficiency, and sustainability [74]. For example, precision agriculture relies on data-driven decisions to improve crop yields and reduce resource use. Automation and robotics can further accelerate the shift toward less labor-intensive agriculture. However, these technologies require specialized skills for their operation, maintenance, and management. Therefore, investing in workforce development is crucial for enhancing the competitiveness of the agricultural sectors by fostering innovation, creating high-value jobs, and driving economic growth to improve the overall resilience of agricultural economies.

To address the need for a skilled workforce, it is important to develop specialized educational programs and training focused on advanced agricultural technologies as well as offer hands-on training through partnerships with technology providers [75]. Collaboration between educational institutions, technology companies, and agricultural organizations can ensure that training programs are aligned with industry needs. These partnerships can facilitate internships, apprenticeships, and on-the-job training opportunities. As technology continues to evolve, ongoing professional development and upskilling programs are necessary to keep the workforce updated with the latest advancements [74]. This includes workshops, online courses, and certification programs. Encouraging research in agricultural technology and its applications can help identify new skills and competencies required for the future workforce. Additionally, innovation in training methods and applying AI tools can also enhance the effectiveness of workforce development programs.

Political Emerging Trends

Climate Action and Trade Barrier

To mitigate global climate change and reduce GHG emissions, the emergence of trade barriers associated with climate action can take various forms, consisting of tariffs, regulations, or standards that are either directly or indirectly linked to environmental or climate policies [76]. As countries implement stricter climate policies, such as carbon pricing, emissions trading systems, and renewable energy mandates, each country may introduce trade measures to protect domestic industries from competition with countries that have less stringent climate regulations [77]. One example is the EU's Carbon Border Adjustment Mechanism (CBAM), which imposes tariffs on imports based on their carbon content. This measure is designed to ensure that imported goods are subject to the same carbon costs as domestically produced goods, thereby encouraging global emissions reductions while protecting European industries [78].

However, these climate-related trade barriers may exacerbate global inequalities and unfair trade in some countries potentially violating world trade agreements, especially involving developing countries. They may disproportionately affect their exports, especially in sectors, such as agriculture, manufacturing, and raw materials. Developing countries often lack the resources to implement stringent climate policies and trade barriers imposed by wealthier nations that could further hinder their economic development. This has led to calls for mechanisms that provide financial and technological support to help developing countries comply with global climate standards [79].

Addressing the intersection of climate action and trade barriers requires robust international cooperation [76]. Multilateral agreements and frameworks, such as those under the United Nations Framework Convention on Climate Change (UNFCCC) and WTO, play a crucial role in ensuring that climate policies are implemented in a way that is fair and equitable across all countries alongside economic growth. Collaborative efforts, such as the Paris Agreement, emphasize the need for collective action to reduce emissions, taking into account the different capacities and responsibilities of different nations [79–80].

Food Security Policies

Food security is defined as the state in which people at all times have physical, social, and economic access to sufficient and nutritious food that meets their dietary needs for a healthy and active life [81]. Food security policies in each country address the various dimensions of food security, including availability, accessibility, utilization, and stability, with the ultimate goal of eradicating hunger and malnutrition. To explore challenges and policy implications for food security across countries, the Global Food Security Index (GFSI) was developed by Economist Impact. The GFSI captures four main dimensions: affordability, availability, quality and safety, and sustainability and adaptation [82]. For example, policies related to the availability of foods might focus on the promotion of sustainable farming practices, infrastructure development, and investments in agricultural research [83]. Food security policies also focus on the quality and safety of food, including the promotion of nutrition education, food fortification programs, and public health initiatives to address malnutrition and ensure that the food consumed contributes to a healthy diet [84].

At the global level, food security policies are often guided by international frameworks and agreements, such as the UN's SSDGs, particularly Goal 2: Zero Hunger. Organizations, like the FAO, the World Food Programme (WFP), and the International Fund for Agricultural Development (IFAD) play critical roles in coordinating and supporting global efforts to achieve food security [85].

As the global population continues to grow, and as climate change and other environmental challenges intensify, food security policies must integrate broader aspects into the agri-food system. Future policies will likely focus on promoting sustainable agricultural practices, enhancing food system resilience, and addressing the root causes of food insecurity, such as poverty and inequality. Investing in R&D and agricultural technology, such as precision agriculture and digital platforms, may also play a key role in improving food security outcomes and strengthen supply chain infrastructure.

Conclusion and Policy Recommendations

This report highlights five emerging trends that shape the transformation of agri-food systems toward sustainability and resilience. Agri-food systems remain highly vulnerable to shocks and the increasing rise of food insecurity caused by geopolitical conflicts, climate instability, extreme weather events, environmental degradation, and economic turndown. These challenges, compounded by increasing social inequalities and unfair trade practices, threaten the ability of agri-food systems to provide a balance between production and consumption while ensuring affordable, healthy diets for all. Due to population aging and high production costs in the Asia-Pacific region, technology and innovation are key to transforming the agri-food system. Green finance and impact investment are increasingly required to adapt to climate changes and decarbonization. To ensure sustainable development and food security in the region, key policy recommendations tailored to the Asia-Pacific region are as follows:

i) **Promote climate-resilient agriculture:** Climate change poses a significant threat to food production across Asia, particularly in countries highly dependent on agriculture [86]. Policies should focus on building resilience through climate-smart agricultural practices. The adoption of climate-smart agricultural technologies, such as drought-resistant crops, water-efficient irrigation systems, and sustainable land management practices, should be promoted. Financial and system support in climate adaptation, including access to real-time climate information, crop insurance, and early warning systems should be provided to smallholder farmers.

ii) **Foster inclusive and equitable food systems:** To ensure the benefits of agri-food system transformation are widely shared, policies must address issues of inequality and inclusivity, particularly for smallholder farmers, women, and marginalized groups. Moreover, mental health support and wellness programs should specifically provide to farmers, especially rural area. Credit and financial services must be affordable and accessible to inclusive groups, especially for women and youth. Empowering women and reducing inequalities in land ownership within the agri-food sector should be prioritized.

iii) **Encourage sustainable and circular practices:** Workforce upskilling and training should focus on developing digital applications, AI skills, and promoting sustainable and/or circular practices, such as recycling agricultural waste into biofertilizers and biogas, and reducing food waste throughout the supply chain. Policies should incentivize the reduction of carbon footprints in food production and processing through renewable energy use and carbon offset programs.

iv) **Support research and innovation in agri-food systems:** More funding for agricultural research institutes and fostering collaboration with universities and start-ups should be encouraged. The government should offer incentives for private investment in sustainable agricultural technologies and infrastructure as well as build resilient technology ecosystem and PPP.

v) **Enhance rural infrastructure and digitalization:** Improved infrastructure is crucial for increasing agricultural productivity and enabling smallholder farmers to access markets, inputs, and information. Strengthening digital infrastructure and e-commerce platforms will connect smallholder farmers to markets, provide access to market information and weather forecasts, and support the adoption of precision farming techniques. In addition, policies should also ensure fair pricing, especially for smallholder farmers, and reduce the role of intermediaries.

vi) **Promote climate finance and green investment to support trade transformation:** Trade-related climate action requires significant financial resources, particularly for infrastructure development, and technology transfer. Climate finance should be prioritized to support green investments that facilitate renewable energy and the trade of sustainable goods and services. Policies should aim to increase access to climate finance for developing countries in Asia to transition to low-carbon economies. As countries implement stricter climate policies (e.g., CBAM, carbon tax), policies should ensure to reduce the risk of trade distortions and provide transitional support, including green or clean technologies, and incentives for carbon-intensive industries.

To move forward the sustainable development goals, the next step for agri-food systems in the Asia-Pacific region is to adopt a holistic approach that addresses the interconnected challenges of climate change, inequality, infrastructure deficits, and food safety. Through coordinated policy efforts at national and regional levels, it is possible to create resilient, inclusive, and sustainable agri-food systems that ensure food security for all.

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ABBREVIATIONS AND ACRONYMS

AI	Artificial intelligence
ADB	Asian Development Bank
BCG	Bio-Circular-Green
CBAM	Carbon Border Adjustment Mechanism
CEA	Controlled Environment Agriculture
CSA	Climate-smart agriculture
EMS	Emissions trading systems
ESCAP	Economic and Social Commission for Asia and the Pacific
ETS	Emissions trading systems
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
GHG	Greenhouse gas
GFSI	Global Food Security Index
GPS	Global Positioning System
LED	Light-emitting diode
PES	Payments for ecosystem services
PESTEL	Political and regulatory, economic, social and cultural, technological, environmental, and legal
PPP	Public-private partnerships
SDGs	Sustainable Development Goals
UN	United Nations
UNDP	United Nations Development Programme
WTO	World Trade Organization


APO