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INSIGHT PUSTAKA

INNOVATIONS FOR SUSTAINABLE FOOD SYSTEMS

Salwa Maulia, dkk.

INNOVATIONS FOR SUSTAINABLE FOOD SYSTEMS

INSIGHT
PUSTAKA

INNOVATIONS FOR SUSTAINABLE FOOD SYSTEMS

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FOREWORD

Food security and the sustainability of food systems represent one of the most critical challenges facing the world today. Global population growth, climate change, environmental degradation, unequal food distribution, and continuously evolving socio-economic dynamics demand new approaches that are more adaptive, inclusive, and oriented toward long-term sustainability. Food systems can no longer be understood merely as processes of production and consumption, but rather as complex ecosystems involving technology, policy, culture, the environment, and social justice.

Innovations for Sustainable Food Systems is presented as an effort to bridge conceptual thinking with practical applications in the development of sustainable food systems. Innovation is positioned not only as technological advancement, but also as a transformation in ways of thinking, managing resources, and building cross-sector collaboration. This approach places sustainability as a core principle that balances the needs of the present generation with responsibilities toward future generations.

This book explores various forms of innovation relevant to sustainable food systems, ranging from environmentally friendly agriculture and food technologies to supply chain management, as well as the roles of public policy and community participation. Each topic is designed to provide a multidisciplinary perspective, enabling readers to understand the interconnections among ecological, economic, and social dimensions within food systems in a comprehensive manner. In this way, the book aims to enrich understanding and encourage critical thinking in addressing both global and local food challenges.

In addition to serving as an academic reference, this book is intended for practitioners, policymakers, educators, and observers of food-related issues who are concerned with the future of sustainability. The ideas presented are expected to serve as a foundation for reflection, inspiration, and guidance in designing food strategies and policies that are more resilient and equitable.

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CHAPTER I

TECHNOLOGY FOR HOUSEHOLD FOOD WASTE MANAGEMENT

Contributor: Salwa Maulia, Danish Irfan Bin Kamarudin, Aung Thu Zin, Mawya Mohamed

Household Food Waste and Sustainability

Household food waste (HFW) represents the "downstream" segment of inefficiency in the food system that is often overlooked, despite its substantial implications for sustainability. Within the supply chain framework, it is important to distinguish between *food loss*—which occurs at the stages of production, post-harvest handling, processing, and distribution—and *food waste*, which refers to food discarded at the retail, food service, and consumption/household levels (FAO, 2011). This distinction is crucial because the strategies for intervention differ accordingly: food loss is largely associated with infrastructure, logistics, and post-harvest handling, whereas HFW is strongly influenced by consumption behavior, shopping practices, storage, food preparation, and social norms within households.

At the global level, the scale of HFW has been mapped with increasing precision. The *Food Waste Index Report 2024* estimates that in 2022 total food waste (retail + food service + households) reached approximately 1.05 billion tonnes, equivalent to 132 kg per capita per year, with around 60% of this occurring at the household level (UNEP, 2024). The same report estimates average global household food waste at about 79 kg per capita per year (UNEP, 2024). These figures underscore that households are not merely the "end point" of consumption, but a strategic arena for reducing resource waste, lowering emissions, and strengthening food security.

Household food waste (HFW) has therefore become a central concern in the sustainability agenda, as food discarded at the household level reflects not only inefficiencies in consumption but also generates multidimensional impacts that are closely interconnected—ranging from environmental degradation due to unnecessary emissions and wasted natural resources, to economic losses for households and the wider food system, and ethical as well as social justice issues that directly intersect with food security.

1. Environmental dimension (planet)
   Every item of food that is wasted carries a "double" environmental footprint: (1) the footprint from production, processing, transportation, and storage that has already occurred, and (2) the footprint from disposal processes (for example, methane emissions if waste ends up in landfills). Consequently, reducing HFW is often described as a cost-effective or *low-regret* mitigation option within climate and sustainable food system strategies (IPCC, 2019). The IPCC emphasizes that the mitigation potential of reducing food loss and waste becomes even greater when assessed through a life-cycle approach, as it captures emissions across all stages of food system activities (IPCC, 2019). In other words, preventing food from becoming waste generally delivers greater benefits than merely managing waste at the downstream stage.
2. Economic dimension (prosperity)
   For households, HFW represents a leakage of food expenditure. At the macro level, food waste reduces market efficiency, increases environmental external costs, and drives higher demand for land, water, and energy that could otherwise be saved through more effective consumption (FAO, 2011). In the context of sustainable food systems, improving consumption efficiency—including reducing HFW—helps stabilize demand pressures, particularly for commodities with high environmental footprints.
3. Social dimension (people)
   HFW is directly linked to issues of food security and equity of access. While some segments of society discard food that is still edible,

CHAPTER II

THE ROLE OF SOCIAL MEDIA IN FOOD WASTE REDUCTION

Contributor: Md Baha Uddin, Nicolas Soubeiga, Gwen Muninggar Maharani

In an era defined by digital connectivity, social media has fundamentally transformed the way individuals communicate, exchange ideas, and engage with global challenges. Among the most urgent issues facing contemporary society is food waste-aparadoxical crisis in a world where millions still suffer from hunger. According to the Food and Agriculture Organization (FAO) of the United Nations, approximately one-third of all food produced globally-equivalent to 1.3 billion tons-is lost or wasted each year (FAO, 2011). Even in the recent report, the amount stayed unchanged (FAO, 2024). This not only represents a massive misuse of resources but also contributes significantly to environmental degradation, including greenhouse gas emissions and loss of biodiversity. As societies strive to implement innovative and sustainable solutions, a critical question emerges: Can social media play a constructive role in reducing food waste? The answer is a resounding yes. By fostering education, promoting behavioral change, encouraging digital activism, enabling community collaboration, and supporting technological innovation, social media holds significant potential to address food waste at both local and global levels.

Figure 2.1 Icons of Diferent Social Media Platforms

Behavior Change Through Digital Content

One of the most significant strengths of social media lies in its ability to disseminate information rapidly and extensively (Cai et al., 2022; Chan et al., 2020). Platforms such as Instagram, TikTok, X (formerly Twitter), and Facebook have become powerful tools for educating the public on the causes, consequences, and potential solutions to food waste. Digital awareness campaigns-such as #StopFoodWaste,#LoveFoodHateWaste,and# Zero Food Waste-have reached millions of users worldwide, promoting practical guidance on meal planning, proper food storage, portion control, and correcting common misconceptions about expiration dates (Green Horizon, 2024; Joanne Gauci, 2024).

Unlike traditional media, social platforms engage audiences through visually compelling and emotionally resonant content. A brief video demonstrating how to repurpose leftovers, or a viral infographic illustrating food waste statistics, can effectively inspire individuals to reassess their consumption habits. In this way, social media does more than inform-it actively shapes perceptions and helps normalize sustainable practices.

In addition, social media platforms increasingly serve as cultural trendsetters (Abidin, 2020; Appel et al., 2020). Influencers, chefs, and sustainability advocates leverage their digital presence to promote zero-waste lifestyles and innovative culinary practices. For instance, food bloggers

CHAPTER III

PUSH–PULL TECHNOLOGY FOR MAIZE RESILIENCE IN INDONESIA

Contributor: Xavier Uwiringiyimana, Nur Isabella Ramadhania Binti Pardjo

Maize is a commodity in the local market of Indonesia that is more than just a commodity. It is considered one of the staple foods in most locations and a primary feed for animals, with millions of smallholder farmers finding it a source of livelihood. Raging attacks by pests, particularly the invasive fall armyworm, have swept the provinces of Gorontalo, Lampung, and East Nusa Tenggara, resulting in farmers losing a quarter to a half of their production (Prasanna et al., 2021). Over the decades, the heavy use of chemical fertilisers has led to a deterioration in soil fertility. Due to rainfall becoming unpredictable and prolonged droughts, a characteristic feature of climate change, yields are further threatened. This is the day-to-day reality for these smallholder farmers, who operate on thin profit margins and depend on whether they can feed their families or provide an education for their children.

During our visits to maize-growing communities, we have seen farmers struggling with these exact challenges. One farmer in Lampung told me he lost nearly half of his harvest to fall armyworm despite spending money on pesticides he could barely afford. Stories like his remind us that farming is not just about yields; it is about survival, dignity, and hope for the next generation.

The current outbreak of the fall armyworm, *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae), which has brought particularly devastating losses to maize production, has intensified food and environmental security concerns in Africa, especially in Sub-Saharan Africa and some Asian nations, as said by Mendesil et al. (2023). This undermines local food production, places more emphasis on costly maize imports, depletes foreign reserves, and exposes farmers and consumers to market vagaries and shortages in uncertain global situations. The use of chemical pesticides and synthetic fertilizers is a short-term solution that comes with significant costs and environmental side effects, offering no long-term benefits.

As an agronomist, we believe Indonesia cannot keep relying on chemicals alone. Instead, we need solutions that align nature with production and improve resilience for the long term. This is because this agroecological approach uses intercropping of desmodium and Push-Pull cropping in which fall armyworms in maize are repelledand stray into trap crops such as napier grass (Kansman et al.,2023; Khan et al., 2018; Mumo et al., 2024).

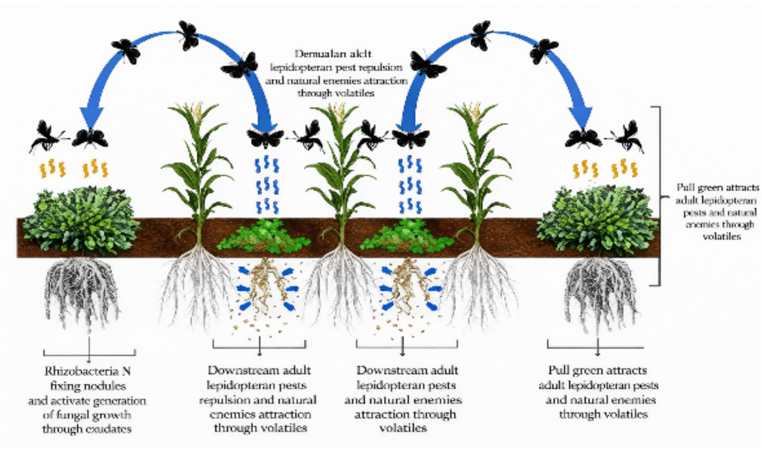


Figure 2.3 Mechanism of Push-Pull Technology in Maize Farming

The Desmodium, besides enriching the soil, also fixes nitrogen, and at the same time, the Napier grass gives livestock feed, and therefore, the income is diversified. This system can grow indigenous legumes that are used in Indonesia,such as mung beans or peanuts, and allows reducing pollution by pesticides, increasing biodiversity, and harmonizing with the current farming systems.

CHAPTER IV

RESILIENT FOOD SYSTEM MANAGEMENT AMID GLOBAL UNCERTAINTY

Contributor: Rayvaldo Prabu Arya Aviantara, Nwe Aye, Lister Matikiti
Hussein Fahmi Al Smadi.

The major hurdle is the weakness of the worldwide food distribution and its primary effect on security of food. The sequence that move the food from the production to the consumption is very complex and it involves the processors, regulators, farmers, retailers and transporters. A stage breakdown leads to spiking of prices,produce that is wasted and scarcity of products and that can be because of policy shifts,bad weather conditions or market shock. The shortage of food nationally can be escalated by the disruptions that are short term even, for those countries that are heavily relying on the import. According Ssennoga et al., (2019), the infrastructure limitations, market disorganization and inefficiencies can increase shortage of the supply of agri food even though there is a sufficient production.

When addressing the problem, the role of the Group B members is to try to bridge the gap that is between the application practical and the academic research by coming up with solutions that can combine the supply chain management resilience with the farming methods that are sustainable. By enhancing the team work and building the relationship across the sectors, we hope it will be possible creating the system that adapts and thrives when facing uncertainties and survive the crises.

The Five Key Stakeholders Categories

1. Small Scale Farmers

   The small scale farmers are the most important and also the most vulnerable stakeholders in the system. In most of the developing countries,the small-scale farmers yield a large proportion of the food supplied nationally so the situation impact them directly and also the sustainability and availability of food. According to Yang & Liu (2018), the small scale farmers usually face the seasonal production risk, unstable market access and the cold chain infrastructure that is limited of which that increases the supply chain risks. If the diverse cropping patterns and the climate resilient practices are adopted, the productivity will be improved and that will ensure the sustainability and the security of the food chain.

2. National Authority or Government

   The intervention of the government is very important in agri-food chain. The domestic needs are balanced with the global trade requirements by the government or national authority. When funds are provided for sustainable agriculture inputs, drought-and flood-resistant crops researches and effective implementation of agricultural policies by the government, that will enhance farming that is sustainable. When investments are made to the rural facilities and the market interventions,this will allow the low-income citizens to have access to daily nutrition (Ssennoga et al., 2019).

3. Global Trade Bodies

   International bodies or organisations such as WTO (World Trade Organization) are required for open and successful trades among countries. Such organizations help prevent export restrictions or barriers that threaten the supply chain of food globally. When there are crises like extreme weather conditions, conflicts or pandemic, the global bodies can organize support logistic routes and emergency trade measures (O'Reilly et al., 2018).

4. Supply Chain Actors

   Retailers, distributors and processing companies are needed and important to ensure that there is efficient movement of food from

CHAPTER V

LUXURY FOOD CONSUMPTION AND ITS IMPACT ON GLOBAL FOOD SECURITY

Contributor: Walid Qarar, Afiq Muhaimin, Rijki Abi Nugraha, Abdelhafez Ramadan

The food system is very deeply interconnected globally, as food consumption in developed countries, such as meat and ice cream, could significantly impact global food security, hunger, and supply resilience. While production of meat is a major driver of grain use, crops such as soy and maize are used as animal feed rather than being directly consumed by humans.This increases the global grain price, reduces the poor's affordability, and as a result, accelerates food insecurity and hunger in developing countries (Rosegrant, 1999). The environmental negative impact of meat production, including emission of greenhouse gases, inefficient use and overuse of water and land resources, strains the agricultural system, and at the same time contributes significantly to climate change (Steinfeld, 2006). Seemingly, ice cream consumption also has significant consequences, as it relies on intensive resource use of the dairy and sugar supply chain, and the sources are mostly coming from those nations that face food security issues. The energy use for cold chain,storage, and transport is also.

the main contributor to greenhouse gas emissions, boosting climate risk (Golub, 2012). Thus, the pattern of luxury consumption of foods especially meat and ice cream consumption could simply impact significantly low-income countries negatively. Meat production and consumption, in general livestock account for 14.5 of GHGs emissions according to FAO (AP News, 2023). But over all food system is responsible of one -third GHGs *emission (UNFCCC,* 2023). Per kg meat production CO2 emission is 20-60 kg (Compartir, *2023). A* kg meat use 15415 liter of water (Earth.org, 2022). *Cattle* ranching caused 80% deforestation in the Amazon (WEF 2019). Stock operation is inefficient as only 18%global calories are from livestock, but use 83% farmland and produce 60% agriculture GHGs emissions (UNFCCC, 2023). 31% methane emissions are from ruminant animals' digestion and 10% manure decomposition, so overall 45% livestock related GHGs are emitted because of feed production (UNFCCC, 2023).

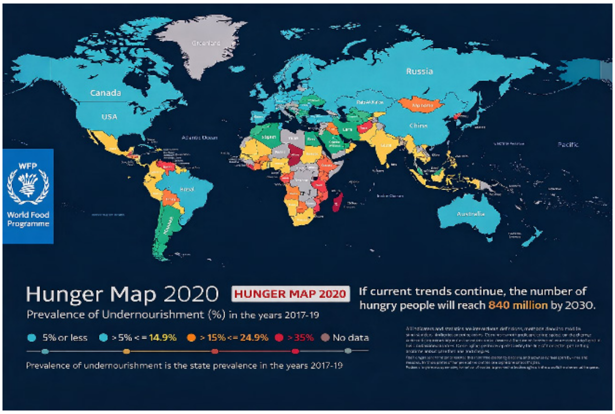


Figure 5.1 2020 World Hunger Statistic and Map

Resources: Food Aid Foundation, 2020

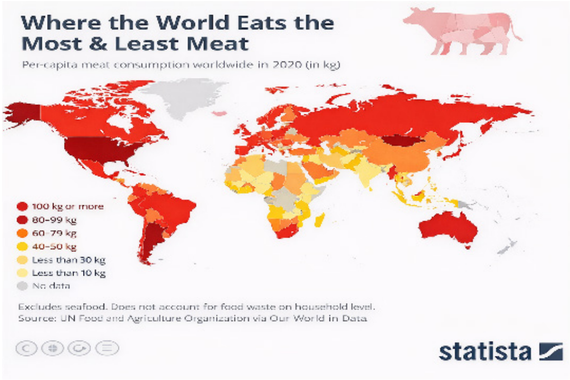


Figure 5.2 2020 World Eat Consumption Map

Resource: Statista, 2023

CHAPTER VI

INFANT NUTRITION SECURITY AND FOOD SECURITY

Contributor: Aye Thi Khaing, Sutham Nanthamongkolchai, Muhammad Ali, Sri Riva Virgianti, Komang Monica Ary Octaviana

Building Resilience Through Innovation

The increasing prevalence of unsafe milk substitutes in Myanmar represents a significant obstacle to achieving optimal infant nutrition and ensuring national food security. Since 2021, the compounded effects of political instability and the COVID-19 pandemic have disrupted health services, regulatory functions, and supply chains, making safe infant feeding practices more difficult to uphold (United Nations International Children's Emergency Fund &Save the Children, 2022). Although implementing the 2014 Order on Marketing of Formulated Food for Infants and Young Children (OMFFIYC) (Myanmar National Trade Portal, 2014), weak enforcement mechanisms and disrupted monitoring systems threaten both immediate infant health outcomes and long-term food security foundations.

The surge in marketing and use of breastmilk substitutes, such as infant formula, sweetened condensed milk, and diluted cow's milk, has posed further challenges with ongoing political crisis. This reliance on milk substitutes is not without consequences. Infants fed on unsafe alternatives face increased risks of diarrheal diseases, respiratory infections,and poor developmental outcomes. Media audits from Southeast Asia consistently indicate that Myanmar experiences frequent violations of the International Code of Marketing of Breast-Milk Substitutes, with advertising campaigns that compromise caregiver confidence in exclusive breastfeeding (Vinje et al, 2017). Consequently, when commercial formula is unavaiable or unaffordable, families, especially those in peri-urban and rural areas,may resort to unsafe alternatives (Nutridev, 2016). Simultaneously, families dealing with food insecurity must allocate scarce resources to milk products, often at the expense of acquiring diverse and nutritious foods (Hashmi et al., 2019; LEARN, 2016; World Food Programme, 2018).

Nevertheless, there have been encouraging developments. Between 2010 and 2016, the rate of exclusive breastfeeding in Myanmar rose from 23.6% to 51.2% (Ministry of Health and Sports, The DHS Program, & ICF, 2017)(see in *Figure* I). Early initiation of breastfeeding reached 67.9% as documented by the 2015-2016 Myanmar Demographic and Health Survey, and most recently, research conducted in peri-urban areas reveals an early initiation rate of 77.42%. This achievement surpasses the SDG global target of 70%, demonstrating the impact of focused interventions and improved health service delivery. However, such progress remains uneven, and challenges persist across rural and marginalized communities, where food insecurity and supply chain fragility inhibit consistent improvements in infant feeding practices (LEARN, 2016).

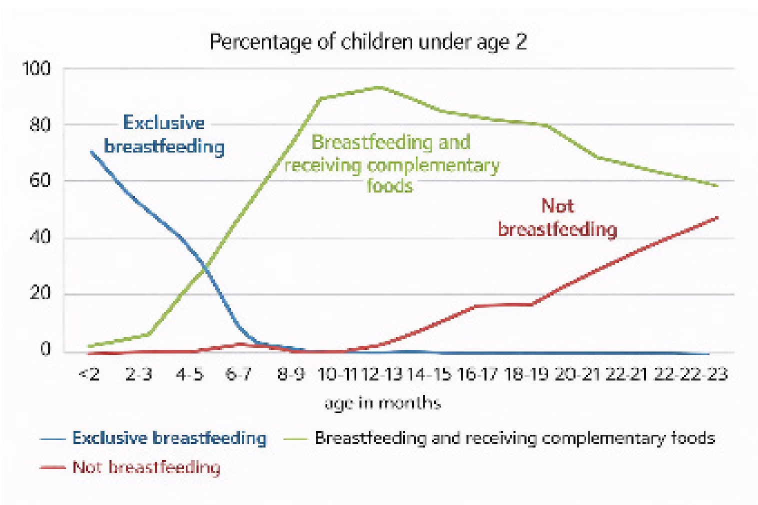


Figure 6.1 Breastfeeding Practices by Age

CHAPTER VII

GLOBAL SUSTAINABILITY RISK MANAGEMENT

Contributor: Muhammad Syakir Irfan

Global Sustainability Risks in Food Systems

In general terms, sustainability risk corresponds to an environmental, social, or governance (ESG) state that might negatively affect the organization's value and cause investments in it to decline in value. In leading this fact, the sustainability issues we are experiencing can lead to a number of problems. Human activity, technological advancement, physical infrastructure, economic growth, political governance, and natural disasters are the primary risk factors (Khan, 2023).

In the agri-food industry, the circular economy places a strong emphasis on sustainable methods that reduce waste and improve resource efficiency. In recent years, the agro-food system has focused a lot of emphasis on multifaceted problems like nutrition safety, production traceability, product quality,and respect for the environment and human resources. As a result,production systems are starting to adopt more sustainable practices (Hegab et al., 2023). Businesses initially want to make choices that will guarantee the organization's long-term viability and value generation without endangering the environment or having a negative social or community impact.

Indeed, according to the Department of Economic and Social Affairs, all agreed-upon risk-taking in sustainable management aligns to the fundamental principles of the 17 Sustainable Development Goals. Absolutely no question that the corporate community can contribute significantly to overcoming the sustainability concerns facing worldwide. (Elkington, 1997). The business community can only provide a portion of the solution to address the environmental and social threats facing our world. Consequently, the more effective global governance that can direct the corrective actions of these complex sustainability issues at multiple levels (Martinelli et al., 2010). The entire global commercial community can use a sustainability viewpoint to deal with any issue including environmental and social hazards according to today's leading-edge methodology.

The Geothermal Power Plant in the Philippines is implementing Environmental,Social,and Governance (ESG) standards, according to The Star (2025). Due to Black Swan occurrences like the Covid-19 outbreak and the Ukrainian crisis, corporate managers worldwide are taking action to improve their chances of surviving the growing instability and unpredictability of the world's economic climate. There is widespread use of the ESG framework. This strategy focuses on the ESG factors that are essential to the business's long-term survival. ESG scores and the need for a new methodology that would accurately represent company sustainability. The primary goal of the ESG scores is to identify which companies are performing better than others. In terms of sustainability.

Next, the three measures of ESG sustainability. Initially, Environmental, the ecological standards for business performance as a natural resource steward. Next, Social, the guidelines a business uses to govern its interactions with clients, employees, suppliers, and the communities in which it works. Lastly, for the measures of ESG sustainability is Governance, elements pertaining to a business leadership style, pay structure, corporate responsibility, and shareholder rights. High standards of performance in these three ESG areas illustrate a company's concern for its stakeholders and ensure a consistent flow of financing. (The Star, 2025).

It is difficult to switch to long-term perspective management once an organization has adopted short-termism in its decision-making process. Businesses typically believe that contributing a specific amount of money

CHAPTER VIII

CONSTRUCTED WETLANDS FOR WATER SECURITY

Contributor: Aya Maher Fayiz Hamdan, Rosvita Nurlaeli, Reza Annas Tasya, Nur Ain Nabila, Refida Farrelia Abbas, Hwanhyihwa Khamphrakhun

Foundations of Constructed Wetlands for Water Security

The issues of climate change and forced displacement have posed unprecedented risks to sustainability that put the water security of the vulnerable people around the world at risk. In the current world, there are more than 100 million forcibly displaced persons, which makes refugee settlement acute water management challenges very severe and which spill down across environmental, social, and economic lines. With 1.4 million refugees living in the country on very limited water availability of just 61 cubic meters per capita annually, Jordan illustrates the problem of sustainability risks meeting at the point of fragility.

The main issue is that the traditional methods of wastewater management cannot deal with the interrelated sustainability risks in refugee settlements. Conventional treatment systems are more short-sighted, aiming at compliance instead of capturing resources and turning them into useful resources that contribute to food security and economic independence. In Zaatari refugee camp, poor treatment of waste water results in environmental pollution and health hazards besides wasting precious water which can be utilized in farmlands.

The constructed wetlands are solutions to nature-based risks since they propose integrated solutions to sustainability risks to be managed in a multi-risk approach. Contrary to the current treatment technologies, which demand a large amount of energy, and are complex to maintain, constructed wetlands employ natural processes which effectively remove pollutants and provide.

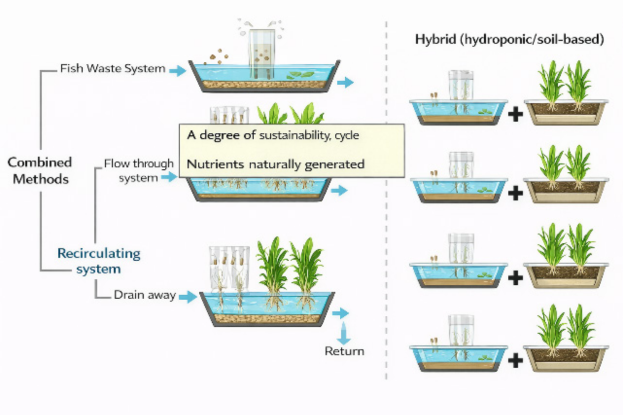


Figure 8.1 Constructed wetland

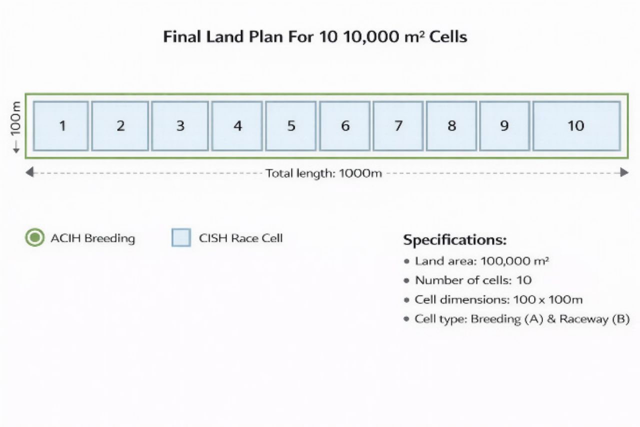


Figure 8.2 Final Land Plan for 10 VSSF

A study carried out in Zaatari camp shows that hybrid constructed wetland systems with a combination of vertical subsurface flow (VSSF) and

CHAPTER IX

INNOVATION IN AGRICULTURAL PROCESSING

Contributor: Justin, Tindano Hermann, Phonphat Thongboon, Arkar Zaw, Khalila Bandu

Plant-Based Meat as a Market Opportunity

The global plant-based meat industry has expanded rapidly. Valued at USD 7.17 billion in 2023, it is projected to reach USD 24.77 billion by 2030 with a CAGR of 19.4% (Grand View Research, 2024). While vegetarians and vegans remain core consumers, the largest growth comes from flexitarians who reduce but do not eliminate animal protein. Millennials and Gen Z are particularly attracted by sustainability and wellness narratives.

For agricultural processors, this demand presents an opportunity to move beyond low-margin raw commodities. Crops such as soy, peas, wheat, and potatoes can be processed into high-protein ingredients, creating higher value while positioning agriculture as central to sustainable diets.

Technological Foundations of Production

Plant-based meat depends heavily on advanced processing to mimic the fibrous structure of animal muscle. The most critical method is High-Moisture Extrusion Cooking (HMEC),which aligns plant proteins into fibrous strands through controlled heat, pressure, and shear, creating textures similar to animal meat (Zhang et al., 2022).

Other technologies, including spray drying, twin-screw extrusion, and flavor encapsulation, maintain protein stability and integrate oils such as coconut or sunflower to replicate juiciness. Color and flavor compounds, like beetroot extract or Maillard intermediates, complete the sensory profile. Without these innovations, plant-based meat would remain a novelty rather than a viable substitute.

Functional and Nutritional Value

The nutritional and sensory performance of plant-based meat depends on balancingproteins, fibers, lipids, and flavor compounds. Proteins provide structure, fibers improve texture and water retention, while lipids contribute richness.

Beyond conventional soy or wheat, diversification of protein sources is gaining importance. Barley, typically used for malting or feed, has shown potential as a functional ingredient. Singh et al. (2025) demonstrated that blends of pea protein and protein-enriched barley flour, extruded under.

high-moisture conditions, produced fibrous textures comparable to animal meat. At 15% inclusion of CDC Austenson barley and 57.5% feed moisture, the anisotropy index reached 1.57, indicating strong fiber alignment. Although higher barley levels increased hardness and chewiness, moisture adjustments reduced these effects, proving texture can be fine-tuned.

These findings highlight the promise of barley in diversifying plant-based formulations, reducing overreliance on soy, and creating resilient food systems. For agricultural processors, using underutilized crops such as barley opens new value chains while offering authentic sensory and nutritional benefits to consumers.

Consumer Segments and Social Drivers

Although early adoption was driven by vegetarians and vegans,current growth comes from flexitarians and health-conscious consumers. A global

CHAPTER X

DIGITAL ZAKAT FOR FARMER EMPOWERMENT

Contributor: Niko Faiz Fahrezi, Dr. S. Shanmugasundaram, Respati Mandalagiri

Digital Zakat Ecosystem

Indonesia is an agrarian country with abundant natural resources, yet food security remains fragile (Salasa, 2021). Food security depends on meeting individual needs, where larger households demand more (Pujiati et al., 2020). With a population of 284 million projected to reach 324 million by 2045 (Statistics Indonesia, 2023), agriculture remains underdeveloped. Farmers face poverty,low incomes, limited resources,technology gaps, and little social security (Fadhilah et al., 2024).

Zakat, an Islamic financial instrument,redistributes wealth to empower the poor (Pratama, 2023). Productive zakat provides capital for income-generating activities (Fatimah & Guslina, 2024). In Kwajon Village, East Java, LAZ Dompet Dhuafa gave seeds, fertilizers, or equipment plus technical support, boosting farmer productivity and income (Erlangga & Ryandono, 2024).

Challenges include limited financial literacy, insufficient capital, lack of technical assistance, and weak coordination between zakat bodies and farmers (Mu'is et al., 2025). Indonesia's zakat potential is IDR 230 trillion, yet less than 10% is collected (Hasan,2021). Online zakat offers accessibility,efficiency, and wider reach, encouraging participation (Arif, 2023).

In addition, TANIZAK is a digital platform to maximize productive zakat collection and distribution, aiming for full absorption. It integrates digital collection, accurate distribution, and reporting for farmers (mustahiq) and zakat payers (muzakki).

(a) (b) (c)

Figure 5.1 Mobile Illustration of TANIZAK

1. Sign-In Page
   The Sign-In Page serves as the entry point for TANIZAK users. Users can log in using their registered email and password or create a new account if they don't have one. There are two access options: Farmer (Mustahiq) or Zakat Payer (Muzakki), and users will be directed to the appropriate dashboard based on their role.
2. For Farmers (Mustahiq)
   Farmers are provided with a dedicated dashboard that allows them to:
   a. Consult directly with expert farm consultants for personalized advice.
   b. Submit regular digital reports on fund usage, farming progress, and challenges.
   c. Monitor farming performance and productivity through the evaluation feature.

CHAPTER XI

VERTICAL INTEGRATION AND SMALLHOLDER EMPOWERMENT

Contributor: Nasywan Yafi, Aleeya Nabihah Binti S. H., Azalia Syaza N.

The Triple Threat to Food Security

In an era of unprecedented global challenges, the interconnected threats of food, energy, and economic insecurity demand innovative solutions. A critical factor exacerbating this situation is the global transformation of land use, which is shrinking the agricultural base required to feed a growing population. Research by Kimisato Oda et al. (2018) in Kyoto, Japan, illustrates this problem, revealing a 10% decline in agricultural land over a decade, with a significant portion repurposed for residential (40%) and vacant (28%) use. This trend is particularly alarming in land-scarce regions and highlights a critical need to reimagine food production beyond traditional, horizontal models. Further compounding this issue are the challenges of water scarcity, climate change, and geopolitical instability, which, as noted by researchers like Professor Johan from NUS, threaten to destabilize global food systems. To secure a resilient future, nations must transition towards sustainable, high-yield food production systems that can operate independently of these external pressures.

Roadmap for a National Vertical Food Park Programme

To address these multifaceted challenges, a strategic, phased roadmap is proposed, culminating in a network of national vertical food parks. This approach is designed to be economically viable and scalable, starting at the grassroots level and building towards national self-sufficiency.

Phase 1: Fostering Smallholder Collaboration and Innovation. The initial phase focuses on leveraging the existing strength of smallholder farms. A study by Vincent Ricciardi et al. (2018) provides a compelling argument for this approach, revealing that farms under 2 hectares, despite occupying only 24% of the world's agricultural land, produce approximately 30—34% of the global food supply by calories. The DFlD's Conceptual Framework on Agriculture also underscores the importance of supporting this "missing middle" to help them transition into commercially viable enterprises. Therefore, the first step is to establish pilot "mini food parks" by partnering with these smallholder farms. This collaboration will provide them with low-cost, yet advanced, vertical gardening technology and training. This strategy Serves a dual purpose: it empowers local economies at the micro-level, creating a stable foundation for growth, and it allows for the testing and refinement of vertical farming technologies in real-world, diverse agricultural contexts.

The success of this initiative is contingent not only on technology adoption but also on human resource readiness. While smallholder farmers are rich in traditional agricultural knowledge, they require specific training to manage integrated vertical systems with IOT and Al. Therefore, Phase I must also include a comprehensive education and training program. This approach is supported by quantitative research demonstrating a strong correlation between a higher level of education and increased income. As highlighted by Wanru Mou in "A Quantitative Analysis of the Relationship between Education Level and Income" (2023), higher education has a significant positive correlation with salary. Specifically, the research found that "the higher the education level, the greater the income gap compared with the neighboring education level, demonstrating that improved knowledge and skills gained through education directly contribute to better financial capabilities, which in turn enables individuals to invest in and innovate

CHAPTER XII

SMALLHOLDER RESILIENCE

Contributor: Karyan Mon, Lulu Razita Griffin

Adaptive Resilience of Smallholders

Adaptive resilience of smallholders is a key concept in *Innovations for Sustainable Food Systems* because it directly relates to the capacity of small-scale farmers to withstand, adjust to, and thrive amid increasing environmental, economic, and social pressures. Adaptive resilience is not merely understood as the ability to recover after shocks occur, but also as the capacity to learn, innovate, and transform farming systems in order to remain sustainable over the long term (Folke, 2006; Tendall et al., 2015).

Within global food systems, smallholders play a strategic role as primary food producers, particularly in developing countries. At the same time, they are among the most vulnerable groups to climate change, natural resource degradation, market price volatility, and limited access to technology, capital, and information. These conditions make adaptive resilience a fundamental prerequisite for the sustainability of smallholder-based food systems (FAO, 2016).

The vulnerabilities faced by smallholder farmers are multidimensional and interrelated. Climate change has increased uncertainty in planting seasons, intensified the frequency of droughts and floods, and reduced land productivity. Simultaneously, economic pressures such as rising input costs and unstable commodity prices further constrain farmers' livelihoods. Traditional coping strategies—such as reducing household consumption or selling productive assets—often exacerbate long-term vulnerability rather than resolving it. Consequently, adaptation strategies must move beyond reactive responses toward proactive and forward-looking approaches (Adger, 2003; IPCC, 2014).

Innovation represents a central pathway for strengthening adaptive resilience among smallholders. One widely promoted approach is agroecology. Agroecological practices, including crop diversification, intercropping, agroforestry, the use of organic soil amendments, and integrated crop–livestock systems, have been shown to improve soil health, enhance biodiversity, and increase water-use efficiency. By working with ecological processes rather than relying heavily on external inputs, smallholders can develop more stable and resilient production systems capable of withstanding environmental stressors (Altieri et al., 2015; Gliessman, 2018).

In addition to agroecology, climate-smart agriculture (CSA) contributes significantly to adaptive resilience. CSA integrates three core objectives: increasing agricultural productivity, enhancing adaptation to climate change, and reducing greenhouse gas emissions. The adoption of drought-tolerant crop varieties, rainwater harvesting technologies, and climate-informed cropping calendars enables smallholders to make more informed and adaptive production decisions under changing climatic conditions (Lipper et al., 2014).

Advances in digital technology have further expanded opportunities to strengthen adaptive resilience. Access to weather forecasts, market price information, and digital extension services helps reduce information asymmetries that traditionally disadvantage smallholders. Through mobile applications and digital platforms, farmers are better able to anticipate risks and respond more quickly and accurately. Nevertheless, the effectiveness of these technologies depends heavily on digital literacy, infrastructure availability, and institutional support (Aker, 2011; World Bank, 2019).

Adaptive resilience is also deeply embedded in social and institutional contexts. Social capital, collective action, and farmer organizations play a critical role in improving access to resources, strengthening bargaining power in markets, and accelerating the diffusion of innovations. Supportive public policies, secure land tenure, inclusive financial systems, and responsive

CHAPTER XIII

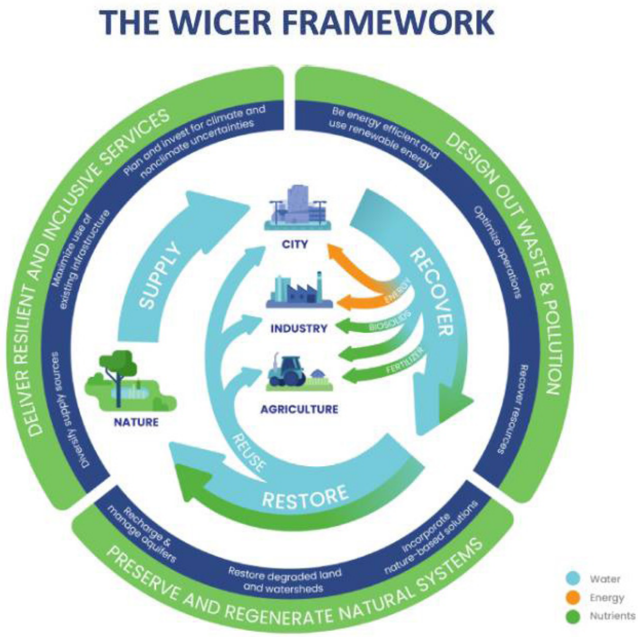
CIRCULAR WATER SOLUTIONS FOR FOOD SYSTEMS

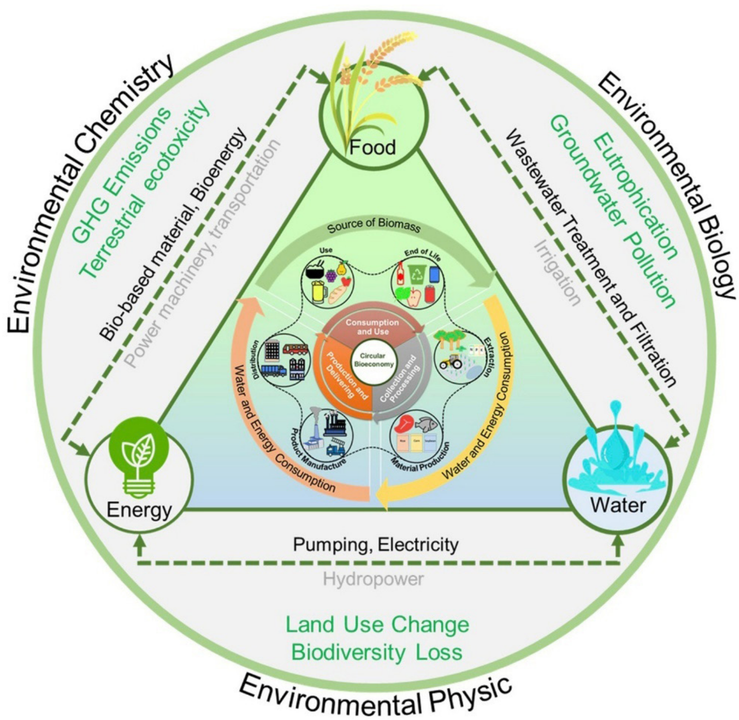
Contributor: Zain Abualhaj, Nurhafizah Ruslan, Muhammad Dzaky Andifitra

Water Circularity in Agri-Food Systems

Water is a fundamental resource underpinning the sustainability of global agri-food systems, as all stages of the food value chain—from primary production and processing to distribution and consumption—are highly dependent on the availability and quality of water resources. Over recent decades, however, agri-food systems have largely developed within a linear water-use paradigm, characterized by water abstraction, single-use consumption, and discharge as wastewater. This linear approach has intensified pressure on freshwater resources, accelerated aquatic ecosystem degradation, and increased the risk of water scarcity, particularly in water-stressed agricultural regions (FAO, 2021).

In response to these challenges, the concept of water circularity has emerged as an innovative and transformative approach to water management in agri-food systems. Water circularity seeks to redesign how water is used, reused, and restored by emphasizing reduced freshwater withdrawal, safe reuse of treated wastewater, and the regeneration of natural hydrological cycles. This approach aligns closely with the principles of the circular economy, which promote a shift away from the traditional "take–use–dispose" model toward closed-loop systems that maximize resource value and minimize environmental externalities (Geissdoerfer et al., 2017).


THE WICER FRAMEWORK
DELIVER RESILIENT AND INCLUSIVE SERVICES
Plan and invest for climate and nonclimate uncertainties
Maximize use of existing infrastructure
Diversify supply sources
DESIGN OUT WASTE & POLLUTION
Be energy efficient and use renewable energy
Optimize operations
Recover resources
PRESERVE AND REGENERATE NATURAL SYSTEMS
Recharge & manage aquifers
Restore degraded land and watersheds
Incorporate nature-based solutions
SUPPLY
RECOVER
RESTORE
REUSE
CITY
INDUSTRY
AGRICULTURE
NATURE
Water
Energy
Nutrients


Environmental Chemistry
GHG Emissions
Terrestrial ecotoxicity
Bio-based material, Bioenergy
Power machinery, transportation
Environmental Biology
Eutrophication
Groundwater Pollution
Wastewater Treatment and Filtration
Irrigation
Food
Energy
Water
Source of Biomass
Use
End of Life
Consumption and Use
Circular Bioeconomy
Production and Delivering
Collection and Processing
Distribution
Extraction
Product Manufacture
Material Production
Water and Energy Consumption
Water and Energy Consumption
Pumping, Electricity
Hydropower
Land Use Change
Biodiversity Loss
Environmental Physic

CHAPTER XIV

AGRIFOOD RESILIENCE AND GENDER

Contributor: Rahimullah Barai, Faiz Arrazi Ridwansyah

Gender Dynamics in Agrifood Resilience

Gender dynamics represent a foundational dimension in understanding the resilience of agrifood systems, particularly in the context of increasing global challenges such as climate change, market instability, health crises, and socio-political disruptions. Agrifood system resilience refers to the ability of interconnected food-related activities—ranging from production and processing to distribution and consumption—to anticipate, absorb, adapt to, and transform in response to shocks and long-term stresses. Within this system, gender is not merely a social category but a structural factor that shapes access to resources, division of labor, decision-making authority, and adaptive capacity. Ignoring gender dynamics risks producing resilience strategies that are partial, inequitable, and ultimately unsustainable.

In many agrarian societies, women play a central yet often invisible role in sustaining agrifood systems. They are deeply involved in small-scale farming, seed selection, post-harvest handling, food processing, and household nutrition management. These roles place women at the heart of food security at both household and community levels. However, despite their significant contributions, women frequently face systemic barriers, including limited land tenure rights, restricted access to credit and agricultural inputs, unequal participation in extension services, and lower exposure to technological innovations. Such gender-based constraints reduce productivity and weaken the overall resilience of agrifood systems, as resilience depends on the optimal utilization of human, social, and natural capital (FAO, 2011).

Gendered inequalities also shape patterns of vulnerability and adaptive capacity within agrifood systems. Climate-related shocks—such as droughts, floods, and erratic rainfall—often disproportionately affect women, particularly in rural areas where livelihoods are closely tied to natural resources. Women's vulnerability is further intensified by time poverty, caregiving responsibilities, and limited mobility, which restrict their ability to diversify livelihoods or access markets during crises. Nevertheless, portraying women solely as vulnerable actors obscures their crucial role as agents of adaptation. Numerous studies demonstrate that women possess rich indigenous and experiential knowledge related to crop diversity, seed preservation, soil fertility management, and risk-spreading strategies. When women are empowered and actively involved in decision-making processes, agrifood systems tend to adopt more diversified and sustainable responses, thereby enhancing resilience at multiple scales (Doss et al., 2018).

Innovation plays a pivotal role in strengthening agrifood resilience, yet innovation processes are rarely gender-neutral. Agricultural technologies, financial mechanisms, and institutional arrangements are often designed based on male-dominated assumptions regarding labor availability, asset ownership, and decision-making authority. As a result, many innovations fail to address women's specific needs and constraints. Gender-responsive innovation seeks to correct this imbalance by ensuring that technological and institutional solutions are accessible, affordable, and relevant to women farmers. This includes the promotion of labor-saving technologies, climate-smart agricultural practices tailored to women's contexts, inclusive digital advisory platforms, and extension systems that actively reach and engage women. In addition to technological innovation, social innovations—such as women-led cooperatives, savings and credit groups, and collective marketing initiatives—have proven effective in strengthening social capital and enhancing adaptive capacity at the community level (Klerkx et al., 2019).

The role of governance and policy frameworks is equally critical in shaping gender-equitable agrifood resilience. Policies that secure women's

CHAPTER XV

AGRO-INDUSTRIAL INNOVATION AND VALUE CHAIN MANAGEMENT

Contributor: Pradap R

Agro-processing and value chain management are pivotal to improving farmer incomes, reducing post-harvest losses, and ensuring food quality and safety. This paper synthesizes global and Indian evidence on technological and organizational Innovations ranging from cold-chain modernization and digital marketplaces to blockchain enabled traceability and Al-driven process control. We present a practical framework for upgrading value chains across pre-processing, processing, logistics, and market access, and propose an integrated program (AGRO-NEXUS) to accelerate adoption for smallholders and SMEs. The approach emphasizes inclusivity, sustainability, and measurable outcomes, drawing on recent research and policy insights.

AGRO-NEXUS Conceptual Framework

AGRO-NEXUS is a programmatic platform that integrates process innovations and governance mechanisms to upgrade agro-processing value chains. It supports (a) process and product innovation at micro, small and medium enterprises (MSMEs), (b) farmer—processor linkages through digital contracting, and (c) end-to-end quality and traceability. The platform has dual interfaces for producers and processors, with shared services for finance, quality testing, and cold-chain logistics.

Key Value Chain Stakeholders

1. Smart Primary Processing: 10T/AI- enabled sorting, grading, and moisture control to reduce variability and improve yields in grains, fruits, and vegetables.
2. Energy-Efficient Cold Chains: Modular pre-coolers, solar-powered refrigeration, and route-optimized reefer logistics to minimize food loss and emissions.
3. Digital Market Linkages: e-contracts, e- auctions, and quality-based pricing connecting farmer groups/SHGs/FPOs to processors and retailers.
4. Traceability & Compliance: Blockchain-backed lot tracking integrated with QR codes and HACCP/ISO standards for export and domestic premium markets.
5. Financial Enablement: Invoice discounting, pay-as-you-process equipment leasing, and blended finance for MSME modernization.
6. Skills & Extension: On-site and virtual training for good manufacturing practices (GMP), sanitation (SSOP), and preventive controls.
7. Data & Analytics: Demand forecasting, inventory optimization, and performance dashboards for processors and farmer collectives.

Tabel 10.1 Pentahelix Model (Govemment—Academia—Business—Community—Media)

No.	Stakeholder Element	Roles and Contribution
1.	Government	Regulatory alignment; incentives for cold chain, quali infra; public data platforms.
2.	Academia	R&D on process optimization, food safety, packaging M&E and impact evaluation.
3.	Business	Technology providers, processors, retailers; logistics and financing partnerships.
4.	Community	Farmers/FPOs/SHGs as suppliers; MSMEs as processors• consumer feedback loops.

CHAPTER XVI

DIGITAL TRANSFORMATION OF AGRI-FOOD SYSTEMS

Contributor: Muhammad Irfan Arif bin Mohammed Ridzuan, Hsu Myat Noe, Aya Takrouni

Digital Technologies for Sustainable Agriculture

Digital technologies have emerged as a transformative force in contemporary agriculture, fundamentally reshaping how food is produced, managed, and distributed. In the context of sustainable food systems, the adoption of digital technologies is not merely a matter of increasing productivity, but rather a strategic approach to achieving environmental sustainability, economic efficiency, and social inclusion. As global agriculture faces mounting pressures from climate change, population growth, resource scarcity, and ecosystem degradation, digital innovation provides critical tools to enhance resilience and sustainability across agricultural systems (FAO, 2019).

Digital agriculture refers to the integration of information and communication technologies, data-driven tools, and automated systems into farming practices. This approach shifts agriculture from experience-based decision-making toward evidence-based management, where real-time data and predictive analytics inform key production decisions. Such a transition is particularly important for sustainable agriculture, as it enables more precise use of inputs, reduces environmental externalities, and supports long-term resource conservation (Wolfert et al., 2017).

One of the most prominent manifestations of digital agriculture is precision agriculture. Precision agriculture technologies utilize sensors, satellite imagery, drones, and global positioning systems to capture spatial and temporal variability within agricultural fields. Through detailed monitoring of soil conditions, crop health, moisture levels, and nutrient availability, farmers are able to tailor agricultural inputs to specific field conditions rather than applying them uniformly. This site-specific management approach significantly reduces excessive use of water, fertilizers, and pesticides, thereby lowering production costs and minimizing negative environmental impacts such as soil degradation, water pollution, and greenhouse gas emissions (Zhang et al., 2002; Gebbers & Adamchuk, 2010).

Beyond precision agriculture, the Internet of Things has become a cornerstone of smart farming systems. IoT-based agriculture involves interconnected devices that continuously collect and exchange data related to weather conditions, soil moisture, crop growth, and farm operations. These systems enable real-time monitoring and automated responses, such as smart irrigation systems that adjust water delivery based on actual crop needs and weather forecasts. By optimizing resource use and reducing human error, IoT technologies contribute directly to sustainable agricultural practices, particularly in water-scarce and climate-vulnerable regions (Rose et al., 2018).

The increasing availability of agricultural data has also driven the development of big data analytics in farming systems. Data generated from sensors, remote sensing platforms, farm machinery, and digital marketplaces can be aggregated and analyzed to support strategic decision-making at both farm and policy levels. In sustainable agriculture, data analytics is used to forecast crop yields, assess climate risks, optimize input use, and improve supply chain efficiency. These analytical capabilities enable farmers to anticipate challenges and adapt proactively, rather than reacting to crises after they occur (Kamilaris et al., 2017).

Artificial intelligence and machine learning further enhance the potential of digital technologies by enabling predictive and adaptive agricultural systems. AI-based models can analyze complex datasets to


CHAPTER XVII

COMMUNITY-BASED FOOD SECURITY IN SABAH

Contributor: Anisa binti Hj. Assan, Aldi Raenaldi

Agroecology and Local Farming Practices

Agroecology has emerged as a comprehensive framework for understanding and transforming agricultural systems toward sustainability by integrating ecological principles with social and economic considerations. Within the discourse of innovations for sustainable food systems, agroecology is not merely viewed as a set of farming techniques, but as a scientific discipline, a set of practices, and a social movement that collectively seek to redesign food systems in harmony with nature and society (Altieri, 2018). This approach conceptualizes farms as agroecosystems in which soil, plants, animals, humans, and the surrounding environment interact dynamically, requiring holistic management rather than fragmented, input-driven solutions.

In contrast to conventional industrial agriculture that prioritizes yield maximization through external inputs, agroecology emphasizes the optimization of natural processes such as nutrient cycling, biological pest regulation, and energy efficiency. By enhancing ecological functions within the farming system, agroecology aims to achieve sustainable productivity while maintaining environmental integrity and reducing dependence on synthetic fertilizers and pesticides (Gliessman, 2015). This ecological orientation positions agroecology as a foundational pillar in the development of resilient and sustainable food systems.

Local farming practices represent the concrete manifestation of agroecological principles within specific cultural, ecological, and socio-economic contexts. These practices are deeply rooted in farmers' accumulated knowledge, traditional wisdom, and long-term adaptation to local environments. In many regions, local farming systems have evolved through generations of experimentation, resulting in practices that are closely aligned with local climate conditions, soil characteristics, and biodiversity patterns (Wezel et al., 2020). As such, they embody context-specific innovations that are often overlooked in top-down agricultural development models.

The contribution of local farming practices to sustainable food systems lies in their emphasis on diversification, self-reliance, and ecological balance. Polyculture systems, crop rotation, mixed crop–livestock integration, and the use of local seed varieties are commonly found in agroecological farming landscapes. These practices enhance functional biodiversity, stabilize yields, and reduce vulnerability to pests, diseases, and climate variability (FAO, 2019). Moreover, the reliance on locally available resources strengthens farmers' autonomy and supports food sovereignty at the community level.

At the farm level, agroecology is operationalized through interconnected practices that reinforce each other. Soil health management is a central concern, as healthy soils form the foundation of productive and resilient agroecosystems. The application of organic matter through composting, green manure, mulching, and reduced tillage improves soil structure, increases microbial activity, and enhances water retention capacity (Lal, 2020). These practices not only sustain crop productivity but also contribute to long-term soil regeneration and carbon sequestration.

Crop diversification strategies such as intercropping, agroforestry, and rotational planting further enhance ecosystem services by improving nutrient use efficiency and supporting beneficial organisms. Livestock integration complements crop production by closing nutrient loops, where animal manure is recycled as organic fertilizer and crop residues are used as feed. This integrated approach reduces waste, minimizes environmental pollution, and increases overall system efficiency (Tittonell, 2014). Pest

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INNOVATIONS FOR SUSTAINABLE FOOD SYSTEMS

Food security and the sustainability of food systems represent one of the most critical challenges facing the world today. Global population growth, climate change, environmental degradation, unequal food distribution, and continuously evolving socio-economic dynamics demand new approaches that are more adaptive, inclusive, and oriented toward long-term sustainability. Food systems can no longer be understood merely as processes of production and consumption, but rather as complex ecosystems involving technology, policy, culture, the environment, and social justice.

Innovations for Sustainable Food Systems is presented as an effort to bridge conceptual thinking with practical applications in the development of sustainable food systems. Innovation is positioned not only as technological advancement, but also as a transformation in ways of thinking, managing resources, and building cross-sector collaboration. This approach places sustainability as a core principle that balances the needs of the present generation with responsibilities toward future generations. This book explores various forms of innovation relevant to sustainable food systems, ranging from environmentally friendly agriculture and food technologies to supply chain management, as well as the roles of public policy and community participation.

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