LEVERAGING TECHNOLOGY FOR SUSTAINABLE AGRICULTURE: A COMPARATIVE ANALYSIS OF LIVELIHOOD OUTCOMES BETWEEN TECHNOLOGY-ADOPTING AND TRADITIONAL SMALLHOLDER FARMERS

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APPROVAL

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ABSTRACT

This thesis is on "Leveraging technology for sustainable agriculture: A comparative analysis of livelihood outcomes between technology-adopting and traditional smallholder farmers."

Smallholder farmers face significant challenges living a good life, let alone maintaining a sustainable livelihood. They often lack the utilization of modern technology and proper education or training for sustainable agriculture. This study examines a comparative analysis to assess how technology adoption influences the sustainable agriculture and the sustainable livelihood outcome (economic, social, and environmental) of smallholder farmers.

A quantitative, comparative cross-sectional design was made, and data was collected from 128 smallholder farmers from two different communities in Bangladesh, where half of them are from a community (Noakhali) that utilizes the traditional farming techniques and is not familiarized with technology, and the other half of them are from a community (Cox's Bazar) that utilizes various technology-driven methods in their daily farming activities supported by various NGOs and INGOs. The research is guided through a hybrid theoretical framework merging the Technology Acceptance Model (TAM) and the Sustainable Livelihoods Framework (SLF). Various statistical tests, like chi-squared tests, were used to find the significant difference between the livelihood outcomes of the two communities.

The study shows that there is a statistically significant difference between the two groups of farmers who use technology for their farming and those who do not. It shows farmers adopting technology have higher rates of adopting sustainable practices, better yields and better prices, and less reliance on middlemen with more access to various market channels compared to the group who do not utilize the technology. It also shows that traditional farmers who do not use technology suffer various challenges with lack of enough knowledge, low trust, and not getting deserved prices for the products they produce. These challenges were linked to a much lower

perceived ease of use for technology. The study reveals that although technology adopters are benefiting from superior market access, they still believe that they are not getting a fair price because their heightened awareness resulted in an increased perception of price inequity.

The study provides empirical evidence that implementation of technology in farming is significantly correlated with enhanced livelihood outcomes for smallholder farmers. A comprehensive approach is required to implement successful technology-driven models in the farming sector, having digital tools and a strong investment in training farmers to use them, while investing to improve the rural infrastructure, and finally building trust to close the digital divide. Strong support from the government is required, as they are the most trustworthy that the smallholder farmers believe.

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LIST OF ABBREVIATIONS

AI: Artificial Intelligence

eNAM: National Agriculture Market

FAO: Food and Agriculture Organization of the United Nations

GPS: Global Positioning System

GSMA: GSM Association

HDI: Human Development Index

IFS: Integrated Farming System

IoT: Internet of Things

IPM: Integrated Pest Management

LDC: Least Developed Countries

NGOs: Non-Governmental Organizations

PA: Precision Agriculture

PPPs: Public-Private Partnerships

SDG: Sustainable Development Goals

SLF: Sustainable Livelihoods Framework

SMS: Short Message Service

SPSS: Statistical Package for Social Sciences

TAM: Technology Acceptance Model

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CHAPTER 1: INTRODUCTION

1.1. Background

Food is considered the crucial element for human survival, and agriculture is the key source of food, which provides food, fiber, and energy. Agriculture is the first phase of human civilization, and it enabled humans to shift from nomadic hunting and gathering to a stable and established society (Arora, 2018; Malik, 2020). Global population depends on agriculture for the basic requirement for food security and sustenance in both rural and urban areas (Arora, 2018; Barnett & Whiteside, 2002). Agriculture does not only provide the source of food, but it also provides primary employment opportunities for rural areas around the world. It also provides key raw materials for various industries, including food and garments. Developing countries' economies heavily depend on agriculture, with a significant portion of GDP attributed to this sector, typically more than a quarter, engaging the majority of the labor force in these activities (Saidulu, 2021; Adusumilli et al., 2014).

Sustainable agriculture is farming practices that ensure the requirements of current needs of food, fibers, animal products, and other raw materials without compromising the ability of future generations to meet their own requirements. This also includes the reduction of degradation of the environment while improving the quality of life. This includes utilization of renewable energy, conservation of soil and water, minimizing adverse environmental impacts, and maintaining ecological sustainability. It is important that global issues such as food security, environmental degradation, and climate change are properly addressed (Bonny, 2018; Velten et al., 2015; Dönmez et al., 2024). Sustainable agriculture works to achieve food security through its alignment with Sustainable Development Goal 2 (Zero Hunger) by eliminating hunger by 2030. Again, sustainable agriculture involves sustainable crop production that depends heavily on soil health improvement and biodiversity growth, which both provide essential ecosystem services, including nutrient cycling and greenhouse gas removal. This also focuses on reducing utilization and dependencies on nonrenewable resources. Sustainable agriculture also aims to improve the livelihood of farmers of rural communities. Finally, it also ensures the requirement for future generations to fulfill their needs.

Technology brought significant advancements in all aspects of life, and agriculture is not excluded. Various technology utilization in agriculture benefits the efficiency and quality of the food produce and boosts the productivity (Rehman et al., 2016). It provided benefits starting from the planning of the plantation until the consumption of the food by the consumers by utilization of various technology tools like robotics, artificial intelligence (AI), machine learning technologies, etc. It helps better crop and livestock monitoring, which leads to higher production levels and better-quality outcomes (Karthikeyan & Pandian, 2021; Shanmugasundaram et al., 2023; Wrzecińska et al., 2023). This helps farmers adapt to environmental changes and transforms traditional farming into agribusiness and drives economic development (Shanmugasundaram et al., 2023; Wrzecińska et al., 2023). Having the immense benefit of technology, the utilization of technology in agriculture, especially in developing countries, is still not as it should be due to various challenges. This study will investigate various challenges by the rural people for adapting the technology in the agricultural system and evaluate if that helps improve the livelihood.

1.2. Statement of the Problem

Bangladesh is a developing country having recently graduated from the list of least developed countries (LDCs) in late 2021. Technology usage in agriculture is still at an early stage, and there is no single or standard solution on how to use technology in agriculture in Bangladesh. While some countries are already getting benefits from using technology in agriculture, Bangladesh, along with its farmers, is still far behind in getting the most benefit. In Bangladesh, using technology in farming is still limited to watching online streaming platforms like YouTube or Facebook, etc., to get some knowledge from the farmers. Some projects or initiatives from various organizations in Bangladesh are already trying to integrate digital farming tools utilizing technology, but the utilization of technology at every level of farming as well as the coverage of the service are still very limited to a few districts only. Although the coverage of these projects is still very low, if we compare the farmers who are utilizing those digital tools using technology in farming and those who do not, then we observe a large gap between them. Also, the progress and expansion of technology utilization in agriculture seem slower, and that indicates a research problem: it is unclear what the relationship is between the utilization of technology in agricultural systems and the improvement of livelihood outcomes for technology-adapting farmers in Bangladesh compared to the traditional farmers who do not use any technology in their farming activities.

Farmers in developing countries like Bangladesh suffer from various challenges that make their livelihood difficult to maintain, having an adverse impact on overall productivity and considering it as the obstacle towards sustainable agriculture. In countries like Bangladesh, farmers are heavily impacted by the climate-related challenges, e.g., cyclones in the southern region of Bangladesh, floods in the northern region of Bangladesh, heavy or less rainfall, and salinity (Rahman et al., 2014; Aryal et al., 2020). On top of that, the economic situation and the rural infrastructure are not adequately in favor of the smallholder farmers. They often face challenges in adequate access to credit (Khatun, 2019), inefficient access to technologies and digital marketplaces (Misra, 2016), unaffordable labor, and the extensive cost of modern machinery (Gregg et al., 2019). Additionally, due to lack of direct access to the major marketplaces, they often become the victim of middlemen and do not get an equitable price for their products (Sultana, 2019). These all-external factors, added to their major internal factors, like their self-awareness (e.g., lack of proper education and technical expertise), create an overall livelihood and productivity in great danger to their survival and sustainability. These challenges often failed them to adopt new technologies (Dhillon & Moncur, 2023). Technology is intended to provide solutions, and it really benefits improvement in every aspect of life; however, adoption of technology and its real impact on the livelihood of the farmers remains insufficiently quantified. A comprehensive analysis is required to develop an impactful technology solution for smallholder farmers that can improve their livelihood and ensure sustainable agriculture. Policy makers and development organizations need this as evidence for their effective project development and interventions. This study aims to address the gap between technology-adopting smallholder farmers and those who are still utilizing the traditional farming techniques by directly comparing the livelihood outcomes.

1.3. Research Objectives

The primary objective of this research is to have a comparative analysis of livelihood outcomes between the two groups of smallholder farmers in rural Bangladesh—one who adopted a technology-driven model for their farming and another who still follows the traditional farming without using any technology-driven model.

The specific objectives of this research are to identify, assess, analyze, evaluate, and compare:

1. The primary challenges faced by the farmers and compare them between the technology-driven farmers versus traditional farmers.
2. Market engagement practices and perceived economic outcomes between the two groups.
3. The technology usage patterns and social outcomes between the two groups.

4. The adoption rates of specific sustainable farming practices by the two groups as an indicator of environmental outcomes.
5. The role of perceived usefulness and perceived ease of use in influencing the willingness of the smallholder farmers to adopt a proposed technology-driven model.

1.4. Research Hypothesis

The research will test the following hypothesis:

- **Null Hypothesis (H_0):** There is no statistically significant difference in sustainable livelihood outcomes (economic, social, and environmental) between smallholder farmers who adopt a technology-driven model and those who do not.
- **Alternative Hypothesis (H_1):** The adoption of a technology-driven agricultural model by smallholder farmers leads to statistically significant improvements in sustainable livelihood outcomes (economic, social, and environmental) compared to farmers who do not adopt the technology.

1.5. Research Questions

Primary Research Questions:

To what extent do the sustainable livelihood outcomes (economic, social, and environmental) of smallholder farmers who adopt technology-driven agricultural models differ from those who rely on traditional farming practices in Bangladesh?

Secondary Research Questions:

1. What are the significant differences in market sales channels, access to price information, and perceived economic challenges (e.g., fair pricing, middlemen exploitation) between technology-adopting and traditional farmers?
2. How do technology adoption, digital literacy, and access to information differ between technology-adopting and traditional farmers, and how do these factors relate to their sense of empowerment and control over their farming business?
3. Is there a significant difference between technology-adopting and traditional farmers in how they say they use important sustainable farming methods?
4. What are the key challenges towards technology adoption as reported by traditional farmers, and how do their overall farming challenges compare to those of farmers who adopt technology?
5. How do farmers' perceptions of the usefulness and ease of use of a hypothetical digital platform influence their willingness to adopt it?

1.6. Significance of the Research

Developing a technology-driven agricultural model or utilizing technology in farming does not necessarily indicate improvement of livelihood outcomes or promotion of sustainable agriculture. Technology adoption depends on various factors, and without taking them into account while developing technology solutions, the project may fail. This study compares the effects of technology on two groups of farmers: those who use it and those who don't. The result will offer important insights for the policymakers, development actors, and private companies to design the technology solutions for the farmers to achieve sustainable agriculture with the most impactful benefits along with improving the quality of life of farmers. This will help determine the return on investment for organizations that are working on developing technology-based solutions for farmers. This will help effective and targeted programs for farmers in developing countries like Bangladesh.

1.7. Scope and limitations

This study performs a comparison between two groups of smallholder farmers in Bangladesh. The definition of smallholder farmers varies based on localization, and hence this study focuses on smallholder farmers having farm sizes between a few decimals and a few hundred decimals of land intended for selling their produce along with self-consumption. The study takes samples from two different locations for their two different groups: one group from the Ukhiya sub-district of Cox's Bazar and the other group from the Companigonj sub-district of Noakhali. The farmers in Ukhiya utilize technology tools for their farming activities and use digital tools for selling their products, while the farmers from the Companigonj area only depend on traditional farming techniques with very little involvement of technology but do not use any digital tools for selling their products. A survey questionnaire is defined to identify the demographics, farming practices used, perceived challenges, technology usage patterns, and perceptions toward a hypothetical digital model.

The research is subject to the following limitations:

- **Dependence on self-reported data**: The results are obtained from survey responses, and it depends on the subjective perception of farmers' self-evaluations. This information is subjective and lacks objectivity and does not include any externally validated metrics like actual income or crop yield data that can prove the information they have provided and may be influenced by recall or social desirability bias.

- **Generalizability:** The findings are not statistically generalizable to all smallholder farmers in Bangladesh because the study used a non-probability sampling method and focused on only two regions; however, they will only accurately represent the sampled locations.
- **Causation and choice Bias:** This is a cross-sectional study, so it can identify correlations and differences between the two groups, but it cannot definitively establish that one group caused changes in the other. There may be pre-existing differences between the groups, such as motivation, education, and initial resources, that could influence their livelihoods and technology usage.
- **Context specificity**: The specific technology platform (Farm2Go) and the unique socio-economic conditions in the chosen areas may influence the results. The results may not be directly applicable to contexts with varying technologies or market attributes.

1.8. Motivation

Due to the significant increase of inflation as well as the global economic instability due to recent conflicts and war in Europe and the Middle East, the prices of the essential goods and services have increased significantly, leading to increased hardship on the livelihoods of significant numbers of low-income populations in Bangladesh. Smallholder farmers are one of them. Additionally, the lower cost of imported food products from foreign countries like India, China, etc. significantly impacts the productivity of the smallholder farmers and forces them to migrate to urban areas to find alternative jobs, leaving the agriculture in a dark stage. The sustainability of agriculture is a key to food security, and failing to maintain it can lead to a country being food insecure and will force the country to depend on imported food to meet the domestic needs.

These adverse difficulties need urgent attention in various innovative solutions. In the current arena of artificial intelligence (AI) and technology innovation, agriculture needs to revamp to take advantage of technology to streamline the roadmap of sustainable development in agriculture. However, while the technology is advancing even in agriculture, the adoption is still not at the pace of it. Identifying the root cause of hindering technology adoption by the farmers, especially the smallholder farmers, has become the center of research nowadays, and that provokes enough motivation to work on this research as a technology lead professional working in a development sector like me. Identifying the gaps while finding out the challenges of the smallholder farmers in improving their productivity and obstacles to adopting technology: these queries always inspire me to work on it. I want to build a technological framework that will try to ensure a fair price for farmers, improve their productivity, and change their livelihood towards sustainable agriculture. My knowledge in information technology and working experience in the developing sector, especially in the food security and nutrition program, motivates me to implement various technological frameworks and solutions for the betterment of agriculture. Though my single effort may not be enough, the contribution from all the sectors, like NGOs, government, and private sectors, needs urgent attention to build a collaborative framework for sustainable agriculture for the improved livelihood of smallholder farmers, which will benefit every sector, as food security is the core of human existence. No innovation, solutions, etc., can be sustained if people go hungry.

1.9. Conclusion

In summary, food is the basic need for human existence, and agriculture is the major source of food; innovation in agriculture is mandatory for human development. Agriculture does not only provide food but also provides raw materials for many key industries and hence is a key direct and/or indirect source of significant employment. Global issues like food security, environmental sustainability, and climate change are closely related to agriculture, and hence its importance must not be overstated. Bangladesh, being a country of various natural calamities, at the edge of climate risk, economic and political instability, lack of proper infrastructure, and inadequate access to market and finance by the root farmers, hinders the productivity of the farmers and heavily impacts their livelihood.

This study will try to investigate various underlying perceived root causes of various challenges faced by the smallholder farmers, their challenges towards adopting technology for the improvement of livelihood, and what the perceived advantages of technology are, who adopts the technology, and how technology may benefit the smallholder farmers by empowering them with the advantage of a technology-driven model for accessibility to markets, easy access to credits, and necessary information required to improve their productivity. The result will offer important perspective towards the decision-makers, non-governmental organizations, and private sectors to develop a cooperative structure for sustainable agriculture and a fairer and more resilient future.

CHAPTER 2: LITERATURE REVIEW

2.1. Sustainable Agriculture and Smallholder Farmers

2.1.1. Sustainable Agriculture and Its Importance

Food production is the primary objective of agriculture, and it involves various activities, e.g., field cultivation for various staple foods like paddy, wheat, lentils, etc.; animal husbandry like cows, goats, chickens, etc.; fishing mostly in ponds and lakes, etc. Sustainability refers to fulfilling the current demands while preserving enough resources for the future generation without degradation of natural resources. Sustainable agriculture hence indicates agricultural activities that ensure the current food security of the populations in a way that does not degrade the environment and leaves enough for the future generations to sustain. This is the process of fulfilling human needs without causing irreparable harm to the environment, does not impact habitat loss, and does not compromise the social gains (Dunlap et al., 1993; Pretty, 2007). According to FAO (2017), sustainable agriculture has three fundamental aspects: environmental well-being, economic profitability, and social equity.

Cultivating in the same field again and again leads to degradation of soil quality, so environmental health also includes maintaining soil quality, improving plant productivity, and creating nutrient cycling (Tahat et al., 2020). One of the processes to maintain soil quality from degradation is the Integrated Farming System (IFS); it does not only maintain the soil quality but also creates an opportunity to increase productivity and maintain the natural ecosystem. This process includes the coexistence of field cultivation, livestock rearing, fishing, etc., on the same farm and the rotation of waste or residue from one activity to be utilized in other activities, creating a perfect ecosystem that improves the soil fertility, cycles the nutrients, reduces the carbon emission, reduces the utilization of artificial or harmful fertilizer, etc. Biodiversity and soil organic carbon content enhancement and increasing the farm's resilience to climate change are the primary goals of this system (Bieluczyk et al., 2020; Bhagat et al., 2024; Manivannan & Thilagam, 2022; Bhati et al., 2024). In addition to IFS, various other methods also promote sustainable agriculture, e.g., crop rotation, intercropping, organic farming, etc., and they help preserve the natural resources, maintain biodiversity, and eliminate the dependency on non-renewable synthetic fertilizers and pesticides (Altieri et al., 2018, Gliessman, 2014).

The main players who play the key role in the environmental well-being are the farmers, and without their capabilities to do so, they do not contribute at all to the sustainable agriculture. So, the enhancement in economic viability for farmers is as essential as protecting the environment's well-being. There are various techniques worldwide that provide evidence on the economic profitability of farmers. Precision Agriculture (PA) technology shows a moderate increase in economic profit and a moderate rise in social profit by potato production in the Netherlands (Van Evert et al., 2017). Boosting the production while reducing the spending creates an optimizing efficiency, and Chinese productive services proves it (Han et al., 2024). Particularly in South Asia, conservation agriculture provided evidence on feasibility in economy, while yield and water use efficiency have improved; practices such as zero-tillage with residue retention have optimized net economic returns (Jat et al., 2020).

Finally, the economic viability will not be achieved if the social equity is not ensured, as it links to the importance of fair distribution of resources and benefits among the parties involved in the agriculture, including the producers (farmers), buyers, and finally the consumers of the agricultural products. Ensuring the social equity improves the agriculture productivity, hence improving the economic viability and finally greatly contributing to the environmental degradation and creating a path to sustainable agriculture (Solomon et al., 2024). Social equity does not just provide importance on fair distribution of resources but also talks about gender dynamics. Almost half of the population related to and dependent on agriculture are women, and without involving them, without empowering them, and without reducing the inequalities between men and women, social equity cannot be imagined. So, sustainable practices can enhance women's productivity and reduce hunger in the society (Solomon et al., 2024; De Marco Larrauri et al., 2016).

The impact of sustainable agriculture is not limited to the local or social level, but it has a significant impact on global issues like global food security, climate change, and poverty reduction. The global population is increasing, and it is assumed that it will surpass 9 billion by 2050, while to accommodate the increased population, a large number of fertile areas are destroyed. This put the need for more food for an increased population while reducing the area for producing it and causing a serious risk in global food security. On top of that, urbanization, industrialization, and deforestation for natural resources are also creating a decline in cultivatable land. This creates a need for a sustainable solution and innovation in agriculture to redesign the agricultural system for yielding more in less land while maintaining the environmental integrity. Sustainable agriculture may provide a roadmap towards this, ensuring resource-conserving agricultural practices with reduced wastage with increased productivity (Godfray et al., 2010). Environmental integrity comes with handling global warming, which is one of the hot topics globally. Sustainable agriculture may slow down global warming. The traditional farming system is causing nearly one quarter of worldwide greenhouse gas emissions (Shukla et al., 2019), and this requires sustainable agricultural practices to help reduce producing greenhouse gas. Various methods like conservation tillage, agroforestry, integrated farming systems, and integrated pest management can be utilized as sustainable agricultural systems. These methods will help reduce the greenhouse gas emissions significantly while increasing the soil health (Lal, 2020). Sustainable agricultural systems will also reduce or maybe eliminate the use of monocropping and too-strong agrochemicals that cause the loss of pollinators, soil microbes, and other key species and help preserve biodiversity (Tscharntke et al., 2012).

Most of the developing countries are mostly dependent on agriculture, and three out of every four hectares of the world's agricultural lands are maintained by the smallholder farmers. The significant amount of population is impacting the poverty level of the countries' economies as well as reducing the human development index. Sustainable agriculture in this term is very crucial for the survival of the smallholder farmers. Smallholder farmers' production and income are hampered by limited access to markets, credit, and technology, among other obstacles. By giving smallholder farmers knowledge and tools to adopt environmentally friendly and economically viable practices (Pretty et al., 2011), like farmer field schools in participatory approaches, which have proven to enhance farmers' capacity to implement sustainable practices and improve their productivity, sustainable agriculture can empower them.

Finally, sustainable agriculture is a group strategy tackling the linked issues of food security, environmental sustainability, and social equality rather than only a collection of farming techniques. It also tackles the enhancement of rural living as well as, more generally, support of economic development. Sustainable agriculture is a hopeful answer to guarantee the long-term survival of agricultural systems and the welfare of farming communities by combining ecological ideas with creative technologies.

2.1.2. Role of Smallholder Farmers in Global Food Systems

Often defined as individuals running fewer than 2-hectare agricultural plots, smallholder farmers are vital players in world food systems. Smallholder farms constitute the vast majority of farms globally. Though their land occupation for farming is very small compared to the large agricultural farming company, the contribution of their produce still bears the largest amount of food supply globally. In critical regions such as Latin America, sub-Saharan Africa, and

South and East Asia, these farms provide the dominant proportion of food (Lowder et al., 2016; Samberg et al., 2016; Ricciardi et al., 2018).

As developing countries are mostly dependent on agriculture, they contribute significantly towards fulfilling food security, having visible improvements in both food production and agricultural productivity not only in their own countries but also in foreign developed countries (Azadi et al., 2022). They are particularly important in the production of staple crops like rice, maize, and wheat, which form the backbone of diets in many developing countries (FAO, 2017). Smallholder farmers account for the vast majority of the food produced in sub-Saharan Africa; hence, they are absolutely essential for local and regional food security (Jayne et al., 2010). The influence of smallholder farmers is not only limited to food production but also plays a key role in preserving agricultural biodiversity, as they grow a wide range of traditional and indigenous crops resistant to local environmental conditions (Altieri et al., 2018).

The smallholder farmers are not only contributing to food security through food production, but they also have a significant contribution to the economies. About 1.5 billion people are dependent on agriculture as their primary employment, and the maximum number of farmers are from developing countries where agriculture remains a primary source of livelihood and hence vital for achieving poverty reduction and inclusive growth (Baden & Harvey, 2011). They make the local markets alive by maintaining the supply chain and hence contributing to economic growth and reducing poverty (Reardon et al., 2018).

Smallholder farmers are facing many challenges, like limited access to finance and credit like loans, limited access to markets, and lack of access to technology. These challenges are creating obstacles towards their productivity and sustainability. On top of that, climate changes and market fluctuations create additional burdens (Morton, 2007). E.g., in Sub-Saharan Africa, smallholder farmers often do not have access to better seeds, fertilizers, proper irrigation systems, etc. And that creates a blockade towards the optimum yields and revenue (Barrett et al., 2017).

Despite having extreme challenges in many areas, smallholder farmers showed their excellent durability and adapting capabilities to improve their output and sustainability; many have embraced creative ideas like integrated pest management, agroforestry, and conservation agriculture (Pretty et al., 2011), and some of the examples we can find are from Latin America, where they adopted agroecological techniques to improve the soil quality, water preservation, and biodiversity (Altieri & Nicholls, 2013).

In the end, we cannot separate sustainable agriculture and the role of smallholder farmers, as they are tightly intertwined. Without the contribution from smallholder farmers, we cannot achieve sustainability in agriculture. Again, if we are not able to provide a sustainable solution to smallholder farmers, then it is also very difficult to achieve sustainability in agriculture. So, they always complement each other in every way, and empowering smallholder farmers with sustainable technology and methods should be the focus of world leaders.

2.2. Perceived Challenges in Market Access

2.2.1. Middlemen and Syndicates: Exploitation and Inefficiencies

In the capitalist world, where market access is sometimes limited for the smallholder farmers, they often need to work with middlemen and syndicates to get to markets. Middlemen are working as intermediaries between the farmers and the buyers, ending up exploiting the smallholder farmers. They often offer very low prices, less than what the market rates are (Minten et al., 2015). Lack of enough open markets or lack of information among the farmers on the market price makes the middlemen exploit the farmers (Barrett, 2008). Smallholder farmers often lack bargaining power with the buyers and are sometimes systematically forced to sell the perishable products on time to avoid further losses (Jayne et al., 2010).

The middlemen are informal, disintegrated markets where transactions are not transparent and prices are not standard (Reardon et al., 2018), and they make the situation even worse. Farmers hardly get fair prices for their produce. The syndicate of middlemen defines the low rates everywhere in the locality, and farmers are forced to sell at the price that is defined by the middlemen. This makes the farmers find it difficult to verify the prices of their agricultural products (Sheahan & Barrett, 2016). Sometimes the middlemen delay the payment and deduct arbitrary amounts like transport costs, labor costs, etc., which reduces the farmers' overall revenues (Minten et al., 2015). Syndicates often control the supply chain of products, including transport, storage, etc., and create false demand to force unfavorable terms on farmers (Barrett et al., 2017). For example, syndicates of mandis in India are well known to collude in order to hold significant low prices and force farmers out of a reasonable return (Minten et al., 2015).

Both middlemen and syndicates significantly affect the farmers by lowering the revenue and gradually demotivating farmers from investing in agricultural production. Farmers have limited incentives to use better means of farming or invest in quality inputs because they are paid poorly for their produce (Reardon et al., 2018). This creates a vicious cycle of low productivity and poverty, which retards the process of development of attaining sustainable agriculture and rural development (Barrett, 2008).

2.2.2. Lack of Infrastructure and Technology in Rural Areas

Using technology is still a myth to smallholder farmers, and most of the developing countries are lacking the appropriate infrastructure and technology to support smallholder farmers in rural areas. They are also not, in most cases, able to afford the available infrastructure and/or technology they seem to have, and that limits their ability to increase their productivity as well as access to markets. The transportation networks in rural areas are one of the key challenges, and in addition to that, inadequate storage facilities like silos and limited access to electricity and communication technologies are common issues in rural areas, particularly in developing countries. These challenges impact productivity and increase the cost of the product. The logistics cost of the agricultural products becomes expensive, and sometimes the farmers do not get enough selling price to afford the transportation cost, or the cost of the product increases, and the smallholder farmers sometimes need to sell without profit (Minten et al., 2015) in comparison to the cost of other farmers who may get some benefit in terms of logistics cost, lower prices from big farmers' firms, and inaccessibility of real-time market information (Barrett et al., 2017). This also reduces the shelf life of perishable goods. In sub-Saharan Africa, the transport system is not that good and does not have paved roads in most of the locations, and it prevents the farmers from transporting their product to the urban markets where they may get better prices (Sheahan & Barrett, 2017). Again, the lack of suitable storage facilities increases the burdens on the farmers to sell their produce without any delay, even compromising the prices, and sometimes they have to accept post-harvest losses (FAO, 2017). These kinds of economic and in-kind losses reduce the overall income of farmers, causing food insecurity in rural areas.

Smallholder farmers often lack access to modern technology; either the technology is not affordable or doesn't exist in the locality. Hence, smallholder farmers are not getting any benefit of enhanced productivity as well as efficient market access. They had to follow the traditional way of farming and lacked improved seeds, fertilizers, and irrigation tools, which are essential for improving productivity and increasing the yields of crops and reducing production expenses (Jayne et al., 2010). Lack of a digital market means the farmers are very limited to the local markets only or, in most cases, depend on the local middlemen to sell their products without having enough information on the real-time market demands and prices. Utilizing digital tools like digital marketplaces, mobile banking systems, etc. could help them increase market reachability and benefit financially (Reardon et al., 2018). Southeast Asia is one of the examples where access to a smartphone with internet is considered a luxury; either they are not easily affordable or not available, but it is a crucial device that helps a farmer break the digital divide and gives them real-time market information with a connection to various buyers (Minten et al., 2015). The lack of financial technology access to mobile banking and digital payment systems makes it difficult for farmers to receive payments safely and easily, which limits their farm investment potential (Sheahan & Barrett, 2016).

In general, the issue of exploitation by middlemen, syndicate monopoly, and poor infrastructure and technology is the primary challenge for smallholder farmers to access markets and receive good returns for their produce. These need to be addressed through precise interventions such as establishing transparent and efficient market systems, rural infrastructure development, and digital technology adoption to empower smallholder farmers.

2.3. Digital marketplaces in agriculture

2.3.1. Overview of existing digital platforms for farmers

Digital transformation of the agricultural sector with digital marketplaces is one of the most important tools that help smallholder farmers to access markets that help to reduce transaction and logistics costs and increase their income. The platforms, like mobile apps, blockchain technology, and data analytics, link farmers directly with buyers through a direct channel and guarantee a fair price (Reardon et al., 2018). Digital markets, combined with real-time market prices, weather forecasts, and good agricultural practices, can help farmers make informed decisions (World Bank, 2020).

Among the most frequently used digital tools in agriculture, mobile-based apps are also widespread. Using the mobile-based application, farmers are able to sell their goods to the buyer directly, identify the market rates, and negotiate better prices, and they can get payment directly without any hassle. There are not many mobile apps available in various locations. Though they are intended for a specific location and do not cover wider area coverage. For example, the M-Farm app in Kenya provides farmers with updated market prices, buyer information, and other agricultural information. This helps the farmers greatly as it improves accessibility to the market and reduces time before selling, which positively affects perishable crops and hence increases income (Minten et al., 2015). India also has a similar app called eNAM (electronic National Agriculture Market) that helps farmers sell their products and get better prices (Gandhi et al., 2007).

Blockchain technology helps build trust and integrate blockchain technology into digital markets to boost the openness and confidence among farmers during agricultural transactions. Though the technology itself is a little complicated to understand for the farmers, having secured transaction records with smooth payment processes makes the farmers more engaged (Kamilaris et al., 2019). The Australian AgriDigital platform is one of the best examples of digital tools using blockchain technology that provides immediate cash settlement with minimal fraud risk (Kshetri, 2017).

Nowadays, the Artificial Intelligence (AI) revolution and Big Data analytics significantly contribute to the improvement of various digital tools to help make decisions promptly. These technologies enable large data analysis to forecast market movements, set the best prices, and link farmers with the right customers (Wolfert et al., 2017). The AgriPredict platform in Africa delivers information about crop diseases and market trends and prices to farmers, which boosts their earnings (FAO, 2019).

Although great potential is seen in digital markets, they have their set of challenges, which include low digital literacy among farmers, limited internet access, and high costs of implementation (Reardon et al., 2018). The World Bank (2020) proposes that these issues can be solved by enhancing rural internet infrastructure, teaching digital literacy, and providing technology adoption subsidies.

2.3.2. Case studies of successful digital marketplace models

There are several successful implementations of digital marketplace solutions. These solutions provided some potential that has significant influence on value creation in agriculture and have promised to create sustainable livelihoods for farmers.

Case study 1: M-Farm (Kenya)

M-Farm is a mobile platform that offers services that help farmers in Kenya get information on market prices, buyers, and even agricultural information. The platform helps the farmers to get information on crop prices through the SMS service, which helps in pricing their goods competitively when selling to buyers (Minten et al., 2015). M-Farm also offers a service where it collects farmers' crops and sells them to bulk buyers, thus helping in reducing costs and ensuring that the farmers get proper payment. M-Farm has launched its services to benefit thousands of farmers who have experienced better financial outcomes and market access (World Bank, 2020).

Case study 2: eNAM (India)

India is the second largest producer of agricultural products, with the largest in grain production. Having a huge internal consumption as well as exporting agricultural products, it has quite large markets. To maintain production efficiency while distributing them properly needs innovation, and hence the National Agriculture Market (eNAM) launched on 4th April 2016. It is an online platform where farmers from around the country can directly sell their produce to buyers around the country. This platform ensures price transparency so that farmers get a fair price. This helps reduce the role of intermediaries in the trading process. This also helps farmers get other benefits like quality testing, electronic payment, etc. The platform has connected more than a thousand markets since 2021 and has delivered benefits to over fifty million farmers (FAO, 2019).

Case study 3: AgriDigital (Australia)

AgriDigital is a digital platform that maintains the supply chain of grain management, and it connects the farmers, buyers, and financial services providers together to make the complex farming process simple. This platform has supply chain management that manages the flow of grain from production to delivery, facilitates the buying and selling of grain digitally, and links to actual financial services providers for real-time money transfer. Using the platform, the farmers can sell their products directly to buyers with real-time money transfer with proof of the transaction using blockchain technology (Kshetri, 2017). It also provides insurance services to farmers that boost the farmers' productivity and increase their financial strength. The platform has been able to uniformly decrease costs and increase the efficiency of the grain supply chain, addressing the inefficiencies in traditional grain supply chains, simplifying the complexity, and providing advantages both to the farmers and the buyers (Kamilaris et al., 2019).

Case study 4: Twiga Foods (Kenya)

Twiga Foods is a Kenyan tech-driven food delivery digital platform that connects the smallholder farmers directly to the retailers in the city market in Kenya. It aggregates the farmers' produce, and the retailers take the produce from the aggregation centers. That helps remove the intermediaries completely and helps minimize the post-harvest losses (Reardon et al., 2018). Farmers get reliable markets for their produce, technical advice, and mobile money payments that boost their productivity and income. Since its establishment, Twiga Foods has transformed the agricultural value chain in Kenya, benefiting thousands of farmers and retailers (World Bank, 2020).

The digital platforms for agriculture leverage technology to transform the agriculture sector by enabling and empowering farmers, enhancing the market's participation, and reducing food waste to improve the livelihood of farmers. The successful cases, such as M-Farm, eNAM, AgriDigital, and Twiga Foods, illustrate the great potential of digital platforms in the agricultural value chain. The models require additional work to overcome barriers such as restricted internet access, low digital literacy, and high implementation expenses.

2.4. Technology for agricultural power

New technologies are influencing agriculture and helping farmers in order to improve yields, reduce costs, and improve market access. The following are major innovations that are changing the agriculture sector globally: mobile technology, the Internet of Things (IoT), blockchain, and artificial intelligence (AI).

2.4.1. Mobile Technology

In the unserved and unpowered areas of the world, mobile technology has become an essential part of the lives of farmers. Through mobile phones, farmers can get information on weather forecasts, market information, and the best agricultural practices (Aker, 2011). In Kenya, the M-Pesa mobile money service has changed the way of financial service delivery to farmers by providing a simple, quick, and secure means of getting payment, thus eliminating the use of cash (Jack & Suri, 2013). Applications like M-Farm and iCow provide farmers with information, market access, and financial services that increase production and income (Minten et al., 2015).

2.4.2. Internet of Things (IoT)

The Internet of Things (IoT) is changing precision farming through the use of sensors and drones, which allows the farmer to check the status of the crop, the soil, and water use (Wolfert et al., 2017). IoT-based irrigation systems improve water use by providing feedback on soil moisture, thus leading to optimal water application and increased production (Kamilaris et al., 2017). In India, the smart farming technologies enabled by the IoT have helped the farmers in decreasing the cost of production and increasing the yield by giving them tips on the management of crops (Gubbi et al., 2013).

2.4.3. Blockchain

Blockchain technology is enhancing the integrity and efficiency of agricultural supply chains through the use of a digital ledger that cannot be tampered with. The blockchain technology can easily eliminate the risk of middlemen and financial fraud cases, as it provides a transparent transaction (Kshetri, 2017). The AgriDigital platform in Australia uses blockchain technology, and it has improved the trading that allows the farmers to receive money immediately and benefit from other financial services (Kamilaris et al., 2019). Tools like Bext360, built on the blockchain, are used to trace coffee supplies and ensure that smallholder farmers receive fair prices (FAO, 2019).

2.4.4. Artificial Intelligence (AI)

With the help of large amounts of data, AI is conducting a thorough examination of the crops, pests, and markets. Tools of artificial intelligence such as predictive analysis and image recognition help the farmers in the decision-making process and hence increase production and decrease losses (Wolfert et al., 2017). The African platform AgriPredict uses AI to determine the likelihood of disease outbreak in crops and recommends prevention treatments that can be used by farmers to protect their plants (FAO, 2019). The application of artificial intelligence is used to organize suppliers and customers and to move agricultural products effectively to the market (Reardon et al., 2018).

2.5. Role of technology in reducing intermediaries and improving transparency

An advantage of technology in agriculture is that it can limit the number of intermediaries and increase the visibility of value chains. Intermediaries usually take advantage of the smallholder farmers by giving low prices and late payment, but digital platforms can help in direct marketing of farmers to consumers, thus ensuring that they get fair prices and receive payment quickly (Reardon et al., 2018).

2.5.1. Reducing Intermediaries

It is examples such as digital markets like eNAM in India and Twiga Foods in Kenya that do away with the middlemen and women by directly linking producers with buyers. These platforms provide the farmers with market information in real time, which helps in arriving at better prices and reducing the costs of doing business (Gandhi et al., 2007). The eNAM aggregates agricultural markets in India, allowing farmers to trade online and get the best prices without the influence of intermediaries (Minten et al., 2015). Twiga Foods collects products from smallholder farmers and supplies supermarkets in urban areas, thereby reducing post-harvest losses and providing reasonable returns to the farmers (World Bank, 2020).

2.5.2. Enhancing Transparency

Blockchain technology improves transparency by providing a clear and clear record of transactions. This makes it so that all participants in the value chain know where their money is going and how much is being charged (Kshetri, 2017). Other examples of blockchain applications, such as AgriDigital and Bext360, help farmers trace what happens to their produce from the time it is planted up to the time it is sold, thus reducing fraud (Kamilaris et al., 2019). This transparency increases the confidence between farmers and buyers and also helps in the traceability of agricultural products, which are becoming important to consumers (FAO, 2019).

In general, new technologies are critical in enhancing the position of smallholder farmers by eliminating intermediaries, increasing transparency, and increasing yield. Mobile technology, IoT, blockchain, and AI provide farmers with timely information, optimal utilization of resources, and direct market access, which guarantees appropriate remuneration for production. The application of these technologies requires overcoming some limitations, such as lack of internet access, low levels of digital literacy, and high costs of implementation.

2.6. Perceived challenges by smallholder farmers adopting technology

Despite the progress made in using technology to support small-scale farmers and improve supply chains in recent years, there are still noticeable gaps in existing research and approaches. These gaps highlight the need for exploration and creativity to address the challenges faced by small-scale farmers.

2.6.1. Infrastructure and Connectivity

One major challenge to introducing technology in farming is the lack of infrastructure and internet access in rural areas where many small-scale farmers reside in developing countries like sub-Saharan Africa (Aker, 2011). In this region specifically, only about a quarter of residents have access to the internet compared to half of urban areas (GSMA, 2020). The technology disparity hinders farmers from obtaining up-to-date market details and financial assistance as agricultural advice. This barrier restricts their productivity and income, according to the World Bank report in 2020.

2.6.2. Financial Accessibility and Economic Obstacles

The high cost of devices, like smartphones and computers, poses a challenge to smallholder farmers looking to adopt digital technology into their practices. Farmers, in most cases, are facing difficulties affording these technology products, as the prices are often going beyond their budget (FAO, 2019). On top of that, expensive mobile data plans create an additional burden for low-income farmers and limit their ability to utilize digital tools and platforms (Minten et al., 2015). Finally, maintaining solutions, like setting them up and keeping them up, can be quite a burden for farmers (Reardon et al., 2018). Again, the farmers often do not have any access to credit, and hence it is becoming a challenge for them to invest in tools to improve their productivity (Quisumbing et al., 2014). Though microfinance organizations come up with a solution for smallholder farmers, the support is often hindered due to high interest rates, low credit amounts, and strict repayment terms (World Bank, 2020).

2.6.3. Absence of Holistic Digital Solutions

Most of the digital platforms available today are not covering all aspects of the agricultural industry; rather, they focus on specific parts of it. E.g., they mostly focused on digital marketplaces for selling and buying the produce, where other aspects like tracking and monitoring quality from plantation to harvesting and selling are not available (Reardon et al., 2019). Even if available, they have different solutions. Maintaining various solutions for farming by a farmer is way too complicated for farmers. To fully support small-scale farmers effectively and comprehensively from production to market stages requires integrated models that cover the value chain.

2.6.4. Insufficient Logistics Support or High Logistics Costs

Having organized logistics plays a role in the smooth functioning of online markets by ensuring timely and cost-effective delivery of farm produce items, like fruits and vegetables, to customers' doorsteps. Small-scale farmers often face challenges with logistics support, such as transportation networks and the lack of storage facilities and high transportation expenses (as noted by Minten et al., 2017). These difficulties are particularly heightened when dealing with goods that require care during handling and storage (FAO, 2019). To meet the needs of small-scale farmers, it is essential to conduct research in order to develop affordable and effective logistics solutions.

2.6.5. Commercial Strategy of Digital Marketplaces

Many online marketplaces prioritize making profits over supporting small-scale farmers, which can lead to transaction costs and neglect of low-income farmers who grow food instead of high-value crops (Reardon et al., 2019). Most of the platforms are maintained by commercial organizations and charge fees for establishing communication between farmers and buyers and for every transaction (World Bank, 2020). This becomes an additional burden on top of other critical burdens the smallholder farmers face, and strategies for more inclusive and smallholder farmer interest-based solutions need to be developed by the government, NGOs, and private companies.

2.6.6. Insufficient Financial Resources for Nonprofit Organizations

Non-governmental organizations (NGOs) and cooperative partners are the key players supporting poor and smallholder farmers in various ways, including the usage of various tools and techniques in farming. However, these organizations are fully relying on the external funding of the donors, and the funding situation is not always good. NGOs need to design their program based on the donor's recommendation and have less control, and hence their ability to implement expanded solutions is limited (Quisumbing et al., 2014). Additionally, some NGOs lack technical knowledge on how to effectively leverage technologies, impeding their effectiveness (FAO, 2019). It is important to conduct research aimed at identifying funding options and enhancing the NGOs' capabilities.

2.6.7. Absence of Public-Private Collaborations

Public-private partnerships (PPPs) have great potential to encourage various innovations and implement technology services for the smallholder farmers to make a balance between commercial and humanitarian perspectives (Reardon et al., 2019), e.g., blending the policy and infrastructure support from the government while the solution offered by the private organizations makes the solution efficient (World Bank, 2020). Studying is necessary to figure out the methods for developing partnerships between the private sectors and making sure that digital solutions align with the objectives and preferences of everyone involved.

2.6.8. Continuation of Intermediaries or Technological Facilitators

Despite having digital tools in farming, the smallholder farmers are still relying on the intermediaries or middlemen. Due to the lack of knowledge on how to use it or the lack of self-confidence, smallholder farmers are still using a third party for assisting them in the technological services available for them (Minten et al., 2017). While these intermediaries called "technology mediators" play a role in bridging the divide for illiterate farmers, their involvement may introduce inefficiencies and additional expenses that offset the benefits for farmers (Reardon et al., 2019). More exploration is needed to develop solutions that are inclusive and easy for users to use, reducing the reliance on middlemen in the process.

2.6.9. Insufficient Electricity or Limited Access to Economical Electricity

Even though the technology solution is there, farming areas are lacking proper electrical infrastructure, and electricity is a crucial requirement for technology usage. Even if there is electricity, the farmers do not have consistent access to the electricity, or having frequent blackouts makes the technology usage very inefficient (FAO 2019). There is a significant difference in electricity access between urban and rural areas. The majority of urban areas have easy access to electricity compared to rural areas, and farmers face difficulties utilizing technology, having limited access to electricity, impacting their productivity and earnings.

2.6.10. Elevated Expenses of Technological Products

Technology products like smartphones, IoT devices, and internet data plans are not cheap. In some countries, due to extended import taxes, the cost of the technology products is not affordable for many smallholder farmers. They often limit the usage with a regular keypad or bar phone, which is not suitable for utilizing the digital tools available for farming (Minten et al., 2017). It is also difficult for the smallholder farmers to maintain their smartphone in very good condition for long, as they have to work in dusty and harsh weather, and the cost of upkeeping and repairing the smartphone becomes an additional burden to the farmers and negatively impacts their revenue (Reardon et al., 2019).

2.6.11. Linguistic Obstacles in Digital Marketplaces

Language is one of the key barriers in the digital tools' implementation process. Even though some digital marketplaces have the national language available, the local language varies a lot, and it is not possible to have the local language available for all digital tools. E.g., the Bengali language can be available in a digital application, but people living in Chattogram or Cox's Bazar may not be comfortable with the Bengali language. Also, the local languages available in the applications are derived using translation, which lacks actual word selection and creates confusion and makes the app usage very difficult for smallholder farmers. The language gap can stop farmers from using digital tools completely and stop them from getting important information (World Bank, 2020).

2.6.12. Insufficient Emphasis on Scalability and Sustainability

Many of the digital tools and technology-driven solutions are in the pilot phase or limited to small-scale trials and are not widely adopted everywhere (Reardon et al., 2018). For example, platforms like M-Farm and e-NAM have shown significant success; however, it is still uncertain that they provide the same benefit to all other regions and can be expanded in different locations due to differences in infrastructure, legal structures, and the readiness of the farmers (Minten et al., 2015). The prolonged trial or the pilot phase is often questioned by the donor or investors and creates a funding shortfall and unexpected closure of the digital tools (World Bank, 2020).

2.6.13. Insufficient Focus on Digital Literacy and Adoption Obstacles

Digital tools and technology-driven solutions are often designed considering generalizing the demand from broader areas and often lack the focus on addressing the challenges faced by smallholder farmers in terms of literacy and adoption issues. Without focusing on increasing literacy and adoption by smallholder farmers, digital tools lose efficiency and productivity (Aker, 2011). Also, many digital tools require heavy engagement on smartphones and other expensive technology products that often create a burden, and adopting this costly solution is not welcomed by smallholder farmers (FAO, 2019).

2.6.14. Inadequate Incorporation of Gender Perspectives

Women involved in agriculture often lack the necessary resources and knowledge on utilizing digital tools and lack decision-making power, which hinders them from adopting any digital tools, while many existing solutions often overlook these challenges (Quisumbing et al., 2014; World Bank, 2020).

2.6.15. Insufficient Emphasis on Climate Resilience

Climate change is a hot topic, and it is considered a threat to smallholder farmers. Existing digital tools and technology-driven solutions often fail to prioritize the enhancement of climate resilience (Morton, 2007). Most digital tools are related to the marketplaces and focus on buying and selling, while they lack necessary intervention on farming techniques to reduce environmental degradation. IoT and AI offer potential for adapting to climate change, but their integration into farming remains very limited (Wolfert et al., 2017).

Digital tools and technology-driven solutions offer opportunities to support smallholder farmers, but this solution requires a more holistic approach prioritizing local demands and focusing on affordability, adaptability, and cost efficiency, while support from government, private organizations, and non-governmental organizations is required to work together to enhance the infrastructure, create easy access to credit, provide logistics support, and promote environmentally sustainable solutions. A thorough assessment is required at every locality to identify location-dependent variables to design location-specific solutions. Considering the above challenges and identifying appropriate solutions and combining them together can make an appropriate digital tool for smallholder farmers, and scholars and researchers have a vital role in that.

2.7. Conclusion

The literature review presents the great potential of technology in agriculture in solving various problems of smallholder farmers. They can resolve the market access limitation, create the opportunity of broadening the reachability to many buyers, and remove the middlemen, and hence increase their income. This will have a direct impact on their livelihood. Digital marketplaces, smartphones, IoT, blockchain technology, and AI have been shown to have a positive impact on the farmers' empowerment, real-time information gathering like real-time market prices, self-awareness of markets, reduced dependencies on middlemen, transparency in transactions, immediate payouts, etc. However, technology implementation is not as easy as it seems while the infrastructure and connectivity, affordability, lack of access to credit, linguistic barriers, lack of education and knowledge on digital literacy and tools, high cost of products and services, logistics cost, etc., are still blocking the implementation of technology-driven solutions for smallholder farmers in agriculture. Moreover, the commercial ideology, lack of government and other stakeholders' involvement, consistent dependencies on middlemen, and funding for NGOs are the obstacles for digital tools even in locations where digital tools are available. These gaps can only be closed by a holistic approach to scalable, inclusive, and sustainable solutions, farmer-centered models, and stakeholder collaboration. Thus, technology can be said to have the potential to revolutionize agricultural value chains and achieve fair returns as well as improved livelihoods and enhanced resilience of smallholder farmers in the face of global challenges.

CHAPTER 3: THEORETICAL FRAMEWORK

3.1. Introduction to the Framework

To analyze the factors influencing technology adoption and to comprehensively compare its impact on the livelihoods of the farmers, a theoretical framework is necessary. Related to technology acceptance and sustainability in agriculture, I have found five different frameworks widely used and closely related to this study, and they are:

a. Technology Acceptance Model (TAM)
b. The Theory of Planned Behavior (TPB)
c. Sustainable Livelihoods Framework (SLF)
d. The Unified Theory of Acceptance and Use of Technology (UTAUT)
e. The Diffusion of Innovations (DOI) theory

Here are some brief descriptions of the models:

a. **Technology Acceptance Model (TAM):** When we need to explain the determinants of the users about their acceptance of new technology, then using the TAM model is very influential (Davis, 1989). A person's behavior to adopt the use of technology is primarily determined by two beliefs:
    - Perceived Usefulness: Technology will enhance the person's performance.
    - Perceived Ease of Use: Technology use will be free of any effort.
b. **The Theory of Planned Behavior (TPB):** TPB is an extensive theory of human behavior that suggests three key factors influence the behavioral intention of humans (Ajzen, 1991). They are:

- Attitude toward the behavior (how the person evaluates it positively or negatively)
- Subjective norms are like the perceived social pressure to either perform the behavior or not.
- Perceived behavioral control that suggests perceived ease or difficulty of performing the behavior.

c. **Sustainable Livelihoods Framework (SLF):** When it is required to understand the complexities of poverty and the factors affecting people's well-being, the SLF model is used as a holistic analytical tool. It evaluates how individuals and groups perform within a vulnerability context like shocks, trends, etc.; their access to different livelihood assets like human, social, natural, physical, and financial, etc.; and how all of these impact their livelihood practice and results (DFID, 1999).

d. **The Unified Theory of Acceptance and Use of Technology (UTAUT):** UTAUT is an extensive version of the TAM model where it added two additional perceived beliefs in addition to the TAM model. Venkatesh et al. (2003) propose the intention of use of technology is influenced by the four key constructs, and they are:

   - Performance Expectancy (similar to perceived usefulness of the TAM model)
   - Effort Expectancy (similar to perceived ease of use of the TAM model)
   - Social influence suggests the influence of others' beliefs on the use of a new system.
   - Facilitating a condition that suggests people's belief in the existence of support regarding organizational and technical infrastructure for the use of the system.

e. **The Diffusion of Innovations (DOI) theory*:*** The DOI theory describes how and why any new ideas and technology spread through the cultures and focuses on the characteristics of the innovation itself, what communications channel was used, the adoption time, and the nature of the social system (Rogers, 2003).

There are some other established models that I have found that relate to technology adoption with agriculture and sustainable development, which are also notably required to be described here:

f. **The Value-Belief-Norm (VBN) Theory:** This theory is mostly useful to understand the pro-environmental and pro-social behaviors and particularly relevant for the adoption of sustainable agricultural practices by creating a causal chain: people's core values impact their beliefs about impacts of environmental issues and activate a personal norm to act in a pro-environmental way (Stern et al., 1999).

g. **The Socio-Ecological Model (SEM):** When it is required to map out the multi-level barriers and enablers of technology adoption, the Socio-Ecological Model, or SEM, is one of the models to choose, as it does not only focus on individual psychology but also focuses on understanding the behavior of a complex interplay between individual (knowledge, attitudes), interpersonal (family, social networks), organizational (farmer cooperatives, NGOs), community (local norms, infrastructure), and public policy (Bronfenbrenner, 1979).

h. **The Livelihood Vulnerability Index (LVI):** While the Sustainable Livelihood Framework (SLF) is a great tool to conceptualize the livelihoods, the Livelihood Vulnerability Index (LVI) is a quantitative tool used to determine and measure a household's or community's vulnerability to various strains or tensions, especially climate change. By analyzing data using various components like socio-demographic profile, livelihood strategies, social networks, health, food, water, natural disasters, etc., the index particularly helps assess how technology can reduce the overall vulnerability of a farmer (Hahn et al., 2009).

3.2. Hybrid Theoretical Framework

While the above models are all powerful enough to study the research, this research problem requires a hybrid theoretical framework, as it combines both technology adoption with agricultural economics and sustainable development elements by the targeted population, e.g., smallholder farmers. Based on that, the Technology Acceptance Model (TAM) with the Sustainable Livelihoods Framework (SLF) will be combined to make a theoretical framework for the research paper. The reason for choosing these two among the other models is because of the two distinct but interconnected goals that no single model addresses completely:

1. To understand the individual cognitive factors influencing a farmer's decision-making to adopt a specific technology.
2. To evaluate the holistic socio-economic impact of that technology on their sustainable livelihood.

The TAM is powerful yet simple, as it is directly relevant to the technology adoption in the context, as it discusses two core constructs: perceived usefulness (achieving fairer prices, circumventing exploitative syndicates, improving access to key inputs like seeds, fertilizers, etc., increasing overall productivity and income) and perceived ease of use (farmer's digital literacy and technical expertise, access to digital platforms, the cost associated with the technology like smartphones, internet data plans, etc.). UTAUT is more comprehensive, and social influence and facilitating conditions are captured in the framework as moderating variables. Using TAM over the UTAUT keeps the core adoption model clean and focused on the farmers' personal cognitive evaluation. DOI theory would be the best for studying how innovation gradually spreads through a society over time; however, my study is a cross-sectional snapshot focusing on understanding the initial perceptions and preconditions for adoption.

The various technology adoption models like TAM, UTAUT, DOI, etc. are suitable to explain why someone might use a technology, but they are not designed to measure the developmental outcomes of the use of technology. My research is not just about adoption but also about leveraging technology for sustainable agriculture and improved livelihoods. As my research is directly concerning farmer empowerment, income improvement, and resilience, the Sustainable Livelihoods Framework (SLF) is suitable to describe the different livelihood capitals and outcomes to analyze the impact of the technology.

In conclusion, neither the technology model alone nor a development framework alone could capture the full scope of my research, and hence a hybrid framework combining TAM to provide the precise mechanism to explain why a farmer would choose to use the technology and SLF to provide the holistic lens to evaluate what happens to the farmer's life after using the technology. Integrating them together creates a two-stage framework that first explains the decision-making process and then measures the resulting impact on sustainable development, aligning with my research questions and objectives.

3.3. The Integrated Framework for Technology-Enhanced Sustainable Livelihoods

By synthesizing TAM and SLF, this study proposes an integrated framework to guide its comparative inquiry. This model posits that the intervention (the technology-driven model) influences the livelihood outcomes through the adoption process. The entire process is then moderated by the contextual factors within the operations of the farmers. The components are defined as follows:

1. The intervention (independent variable) is where the technology-driven model using smartphones and digital marketplaces for agricultural inputs and sales is introduced.

2. The adoption process (mediating variables) is considered the cognitive evaluation of farmers on how they perceived the usefulness and the ease of use of technology and determines their intention to adopt it into their life.
3. Contextual factors (moderating variables) consist of various external and internal conditions that influence the adoption process, e.g., infrastructural challenges, socio-economic status, institutional factors, etc.
4. Livelihood outcomes (dependent variables) are the tangible and intangible impacts on farmers' economic, social, and environmental improvements and contribute to a sustainable livelihood.

If we visualize the theoretical framework, then it will be explained like the following diagram:

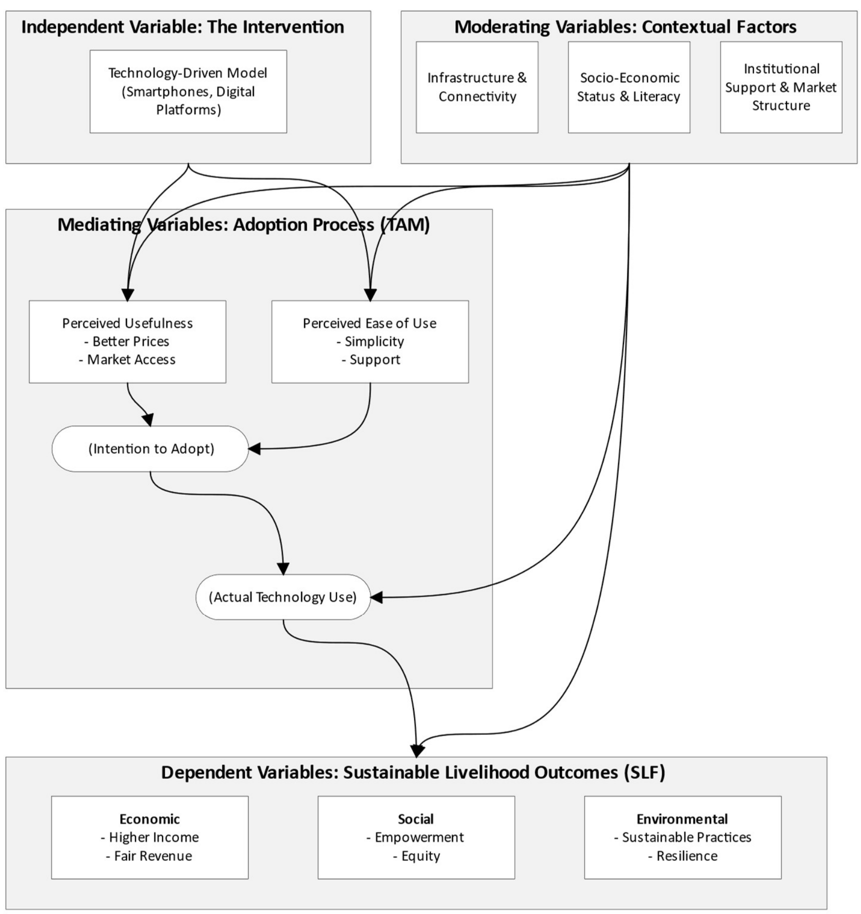

Figure 1: An Integrated Framework for Technology-Enhanced Sustainable Livelihoods

This framework helps the research by structuring the comparison: it establishes the two groups (independent variable), identifies the outcomes to be measured and compared (dependent variables), and accounts for the cognitive reasons for the group differences (mediating variables).

CHAPTER 4: METHODOLOGY

4.1. Introduction

This chapter discusses the methodology used for data collection, including research design, sampling strategy, data collection methods, data analysis plans, ethical considerations, etc.

4.2. Research Design and Approach

This study is designed to collect quantitative, cross-sectional research design methods. This design is chosen as it is highly effective to compare two or more groups at a single point in time. A questionnaire is used to collect data and compare the livelihood outcomes of two distinct groups of smallholder farmers. One group of farmers uses a technology-driven agricultural model, and the other uses traditional methods without utilizing any digital tools for farming. A survey with the questionnaire is conducted within the defined case study area in Bangladesh. While some open-ended questions are included to capture supplementary qualitative insights, the core analysis is quantitative, focusing on frequencies, percentages, and measures of central tendency to create a statistical snapshot to compare the difference between the two groups.

4.3. Sampling Strategy

- ***Target Population:*** The target population for this study comprises smallholder farmers in rural Bangladesh. These are individuals for whom farming is a primary activity and who operate on a relatively small scale. I have selected two different areas as target populations group
    - Group 1 (Technology adopting): Smallholder farmers from the Ukhiya sub-district of Cox’s Bazar district who utilize Farm2Go digital platforms in agriculture. There are some commercial digital platforms available, like Deshi-

Farm, iFarma, etc. Farm2Go is designed for sustainable agriculture without any commercial benefits and is solely intended for sustainable livelihoods; hence, the Farm2Go digital tools are selected as my research's primary source of data for this group.

    - Group 2 (Traditional): Smallholder farmers from Companigonj sub-district of Noakhali district, where every household of the population depends on agriculture, but they use traditional farming methods and do not have access to any digital platforms or tools. This is selected as one of the best candidates for serving the purpose.

- ***Sample Size*:** A total sample size of 128 smallholder farmers will be targeted, as calculated using G*Power (Faul et al., 2007) for detecting a medium effect size with 80% power at a 0.05 significance level for comparing two independent means. The sample will be evenly split between the two groups:
    - n1 = 64 from the technology-adopting group (Ukhiya).
    - n2 = 64 from the traditional group (Companigonj).
- ***Sampling Technique:*** A non-probability sampling method will be employed, specifically combining purposive (to ensure that participants meet specific criteria relevant to the study) and convenience sampling (based on the accessibility and willingness of the farmers to participate within the selected case study area).

4.4. Data Collection

- ***Data Collection Instrument:*** The primary data collection instrument is a structured survey questionnaire, designed to capture data on all variables within the theoretical framework designed for this research that includes sections on:

  - Section A: Demographics and farming profiles to capture baseline data on age, education, farm size, primary crops, sustainable practice adoption, and market engagement patterns. This section provides data for economic and environmental outcome variables.
  - Section B: Challenges faced by the farmers with detailed follow-up questions on market access, fair pricing, inputs, climate, finance, training, infrastructure, and exploitation by middlemen. This data maps to the vulnerability context within the SLF.
  - Section C: Technology usage patterns that measure the level of technology adoption, smartphone ownership, digital literacy, confidence levels, and specific uses of technology for farming activities. This section provides the key data for the independent variable and social outcome variables.
  - Section: D: Digital marketplaces awareness, usage and challenges related to it.
  - Section E: Perception of a proposed technology-driven model to measure the core constructs of the TAM model.
- ***Data Collection Process:*** The survey will be administered as face-to-face questionnaires by an interviewer in Bengali, and the respondent's chosen answer will be recorded directly onto the questionnaire. This method is chosen over self-administration to overcome potential literacy barriers and ensure all questions are understood and completed accurately.

4.5. Data Analysis Plan

The collected data has been coded and analyzed using statistical software packages and conducted into two primary stages:

- Descriptive Statistics: Frequencies and percentages were calculated for all categorical responses like education level, sales channels, technology use, etc. Means and standard deviations were calculated for Likert scale responses. This will provide a comprehensive profile of each group with summarized overall distribution of responses.
- Inferential Statistics: To test the hypothesis and identify statistically significant differences between the two groups of smallholder farmers who utilize technology-driven digital tools and who do not use it in Cox's Bazar and Noakhali respectively with a significance level (alpha) of $p < 0.05$.
  - Chi-squared test for independence will be used to compare the frequencies of categorical variables between the two groups of farmers. For example, to determine if there is a significant association between a farmer's location (and thus technology use status) and their:
    - Adoption of Integrated Pest Management
    - Primary sales channel
    - Use of specific technologies like mobile apps for farming
    - Feeling that they receive a fair price for their produce
  - Independent samples t-test will be used to compare the mean value of the ordinal data from Likert scales between the two groups. Some key comparisons are:
    - The level of agreement with statements about exploitation by middlemen
    - The perceived usefulness of the proposed digital app
    - The level of agreement on the potential benefits of the app

4.6. Ethical Considerations

Strict ethical standards will be maintained throughout the research process:

- *Informed Consent*: Prior to each interview, the purpose of the research, the voluntary nature of participation, and the use of the data will be clearly explained to each farmer. Verbal consent will be obtained before proceeding.
- *Anonymity and Confidentiality*: The confidentiality of the participant is protected, and the questionnaire clearly indicates the name as an optional field, and the file data, which is processed in a computer program like Excel/SPSS, removes the name to protect the privacy even when shared for study purposes with the supervisor. *Voluntary Participation*: Participants were asked before starting the survey to confirm the voluntary participation in the survey. They were also provided an option to omit any questions if they feel not comfortable answering.
- *Data Security*: All the collected data is stored securely and is used for academic research purposes only.

4.7. Limitations of Methodology

The study acknowledges the following limitations:

- *Lack of Statistical Generalizability*: As the sample size is small to compare two groups with utilization of non-probability sampling, the finding cannot be statistically generalized for the entire population of smallholder farmers in Bangladesh. The results are only limited and represent the sampled location only.
- *Limited Depth*: A quantitative survey is conducted to identify the "What?" instead of identifying the underlying root cause, "Why?" As a result, the responses were not verified with actual impacts or measurements. Though there was an option to identify some other reason with an open-ended question.

- *Sampling Bias*: The purposive sampling techniques are used, and they may introduce bias and may not be a perfect representation of the group's diversity of opinions.

CHAPTER 5: RESULTS AND FINDINGS

5.1. Introduction

This chapter provides the results and findings from the survey of 128 smallholder farmers, of which 64 of them are from the traditional farming group in Noakhali who do not use any technology-driven solution in their agricultural system. The other 64 participants are from Cox's Bazar districts who utilize digital tools called Farm2Go for their farming activities. The outcome of the results is organized with the alignment of the research objectives and research questions to enable distinct comparative analysis and verify the significance of difference among the groups.

5.2. Demographic and Farming Profile

Demographically very different farming profiles are observed, where gender distribution in Cox's Bazar was balanced (28 female, 36 male), but the Noakhali sample was made up entirely of male respondents. It is also observed in education level, where 55% (35 out of 64) of farmers do not have any formal education, while in Cox's Bazar 81% (52 out of 64) of farmers have at least primary education, with 41% (26 out of 64) of farmers having completed secondary education or higher. If the chi-squared test is applied, then the difference in education levels between the two groups is statistically significant ($p < 0.001$). Paddy is produced as a crop in both areas, but a diversified variety is observed in Cox's Bazar, having different vegetables (45 respondents) and chili (12 respondents) compared to Noakhali, where they focused on lentils (36 respondents) and mustard (11 respondents) other than paddy, and both groups use crop rotation for better soil nutrient preservation.

5.3. Comparative Analysis of Farming Practices and Market Engagement

5.3.1. Sustainable Farming Practices

The farming techniques that both groups use have significant differences. The farmers from both areas are using crop rotation and organic fertilizers, but only farmers in Cox's Bazar seem familiar with Integrated Pest Management (IPM), and 83% (53 out of 64) of farmers are utilizing this technique in Cox's Bazar, while no farmers in Noakhali utilize this method. The difference is statistically significant (χ^2 (1, N=128) = 96.4, $p < .001$). Similarly, integrated farming systems are used by 45% (29 out of 64) of farmers in Cox's Bazar, which is significantly higher than the farmers in Noakhali with only 9% (6 out of 64), and the difference is also statistically significant (χ^2 (1, N=128) = 18.5, $p < .001$).

5.3.2. Market Sales Channels and Price Information

The farmers in Noakhali are mostly dependent on the middlemen, with 89% (57 out of 65) of farmers solely relying on middlemen, while very few farmers have some alternative access to other sales channels. Only 22% of farmers have access to local markets, and 31% of farmers have access to direct consumers. On the other hand, the farmers in Cox's Bazar have various channels for selling their products. For example, 92% of farmers have access to local markets, 52% of farmers can sell the produce directly to the consumers, and 41% of farmers use various cooperative farming groups. This data shows a very strong difference between the two groups of farmers ($p < .001$). This information gives a clear understanding of how much farmers are aware of the different channels and how capable they are of using various channels. In Noakhali, 31% of farmers said that they do not have any reliable price information before selling their produce and they fully rely on the price information they get from the middlemen and from other farmers, while only 3% of farmers said the similar information in Cox's Bazar. This comparison explains the statistically significant difference in the market access by the two groups of farmers (χ^2 (1, N=128) = 18.4, $p < .001$).

5.4. Comparative Analysis of Farming Challenges

Farmers from both areas reported similar types of challenges they face in their farming activities. However, some challenges are quite similar in type, but the underlying root cause seems quite different. For example, 92% of the farmers in Cox's Bazar reported that they believe that they are not getting fair prices, while only 55% of the farmers from Noakhali reported similar unfair prices (χ^2 (1, N=128) = 22.0, $p < .001$). Though the farmers in Cox's Bazar have more access to markets and buyers due to their use of digital tools, the underlying root cause can be interpreted as due to increased awareness of price inequality, which makes the farmers in Cox's Bazar believe that they are not getting fair prices. Farmers in Cox's Bazar were much more likely to blame middlemen/syndicates for unfair pricing than farmers in Noakhali (97% vs 68%). The difference was statistically significant ($p < .001$).

While both groups indicated that inputs like seeds, fertilizers, etc. are expensive, farmers in Cox's Bazar reported the poor quality of inputs (37 vs. 4 respondents), and it is also a result of high awareness of the quality of inputs. When asked to the farmers in Noakhali, they always believe the verbal confirmation from the seller about the quality without verification of the quality of inputs, as they do not know how to verify it. Lack of education may cause incompetence in identifying the quality of inputs.

Poor roads were a major issue for both groups of farmers, but the farmers from Noakhali shared a much greater concern about the lack of storage facilities (54 vs 32 respondents). Lack of internet facilities was mentioned by more respondents in Cox's Bazar (19 vs. 4 respondents), likely because of their heavy reliance on it.

5.5. Comparative Analysis of Technology Adoption and Usage

The digital gap between the two groups was wide and statistically significant on almost all measures.

Technology Use: In Noakhali, 89% (57 out of 64) of farmers said they didn't use any digital technologies for farming. In Cox's Bazar, only 11% (7 out of 64) said they did. On the other hand, more than 87% (56 out of 64) of farmers in Cox's Bazar used mobile apps for farming, while only 8% (5 out of 64) of farmers in Noakhali did. A chi-squared test shows that these differences are highly significant ($p < .001$).

Smartphone Ownership and Confidence: both groups showed almost everyone owns a smartphone, but their levels of confidence were very different. In Cox's Bazar, 62% (39 out of 63) felt "Very Confident" using a smartphone, compared to only 8% (4 out of 52) in Noakhali, and a chi-squared test shows that these differences are highly significant ($\chi^2(3, N=115) = 39.29$, $p < .001$).

Use for Farming Activities: The use of smartphones for farming activities is higher in Cox's Bazar compared to the farmers in Noakhali, and the most notable usages are communicating with buyers (56 vs. 8 respondents), accessing market prices (18 vs. 8), and ordering inputs (17 vs. 0).

Perceived Benefits of Technology: The farmers from both areas reported using their smartphones and internet connections for farming activities, but the perceived benefits have significant differences. In Cox's Bazar, 86% of farmers reported that the technology helped them get increased yields, and 84% of farmers reported that they are getting better prices than before when they did not have the digital tools for farming. In Noakhali, these numbers were only 16% and 2%, respectively, and indicate a significant difference (χ^2 (4, N = 186) = 25.80, $p < .001$ for both comparisons).

5.6. Perceptions towards a Proposed Technology-Driven Model

Both groups were interested in a hypothetical digital marketplace app, but they had very different ideas about what it would be like.

***Perceived Usefulness*:** Both groups reported that the proposed app would be highly useful. However, the degree of enthusiasm was higher in Cox's Bazar, where 78% (50 out of 64) rated it "Extremely Useful," compared to 14% (9 out of 64) in Noakhali, where the majority (70%) rated it "Very Useful." A chi-squared test showed that the farmers in Cox's Bazar perceived the application to be significantly more useful than the farmers in Noakhali ($\chi^2(2, N = 128) = 54.78$, $p < .001$, considering the categories "Not useful at all", "Not very useful", and "Moderately useful" were combined as their counts were too low).

In Cox's Bazar, 75% (48 out of 64) of farmers strongly agreed that the app would lead to a fairer price, compared to Noakhali, where only 44% (28 out of 64) of farmers agreed so. The gap was even bigger when it came to income: 78% (50 out of 64) in Cox's Bazar strongly agreed that it would increase their income, while only 30% (19 out of 64) in Noakhali did. Compared to only 14% (9 out of 64) of farmers in Noakhali, 50% (32 out of 64) of farmers in Cox's Bazar strongly agreed that the app would give them more control.

An independent samples t-test, utilizing a scoring system from 5 (Strongly Agree) to 1 (Strongly Disagree), would validate that the mean score for perceived usefulness across all benefit statements is statistically significantly elevated for the Cox's Bazar group in comparison to the Noakhali group.

Perceived Ease of Use: There was a much difference in how people thought they could do things on their own. In Cox's Bazar, 97% (61 out of 64) agreed or strongly agreed that the app would be easy to learn. In Noakhali, only 70% (45 out of 64) agreed or strongly agreed. This difference in proportions is statistically significant (χ^2 (1, N=128) = 17.5, $p < .001$).

Concerns: A significant difference was observed in self-assessed capability. The main worries for Noakhali farmers were practical problems like "Not understanding how to use it correctly" (83%) and "Fear of being cheated online" (78%). The fact that 23% of respondents in Cox's

Bazar reported "no concerns"—a sentiment not shared by any farmer in Noakhali—is a statistically significant finding ($p < .001$).

CHAPTER 6: DISCUSSION

6.1. Introduction

The findings that have been presented in the previous chapter from the primary data will be interpreted here in this chapter. The discussion will explore the implications of the significant differences observed between the two different farmer groups from Noakhali and Cox's Bazar.

6.2. Technology's Impact on Economic Livelihood Outcomes

The results and findings in the previous chapter strongly support the alternative hypothesis that adopting technology significantly dominates the improvement of economic outcomes. It showed that farmers from Cox's Bazar who utilize the digital platforms have diverse access to the market, and they have their freedom of choice on how they sell their products and are not only limited to the middlemen, who were, in many cases, only media for the farmers from Noakhali district (Research Question 1). The freedom of choice confirms a perceived benefit of technology helping farmers get better prices, and that benefit is completely unrecognized in the Noakhali area.

The results align with the literature (Reardon et al., 2018; Minten et al., 2015) that suggests technology-driven solutions can reduce intermediaries and can improve the price transparency; however, there is a paradox that even the digital tool-adopting farmers significantly feel that they are not getting the price they deserve. This is a crucial insight and suggests the empowerment and self-awareness of the market demands and the awareness of the true value of their produce make them believe that they are not getting fair prices, and this insight is proved as they also reported that they are getting better prices than before but still not the price they deserve. It is a clear indication of economic empowerment of the farmers in Cox's Bazar due to their perceived usage of technology-driven solutions.

6.3. Technology's Impact on Social and Environmental Outcomes

The data provides a link between the use of technology and the improvements achieved in social and environmental outcomes that support the alternative hypothesis. Though it was not measured how much technology usage impacts social and environmental outcomes, it is observed that the education level and the use of sustainable agricultural techniques within technology adopters significantly support the alternative hypothesis.

Social Outcomes: The difference in digital literacy and confidence between the two groups is a key finding of the study. In Cox's Bazar, the farmers are more confident in using the smartphone, e.g., they are more engaged with the buyer and show having more bargaining power as they are aware of the price information and have more available channels to sell their products, and it represents a significant shift towards social capital (Research Question 2) and is considered a core component of the Sustainable Livelihoods Framework (SLF). This empowerment made them an active participant in the market rather than a passive recipient like the farmers in Noakhali. This sharply contrasts with the farmers from Noakhali, where the primary source of information remains other farmers or the middlemen, whom they mostly distrust.

Environmental Outcomes: One of the key observations from the study is about the practices the two different groups of farmers are using in farming. The farmers from Cox's Bazar who adopted technology seem to be utilizing sustainable methods like Integrated Pest Management (IPM), though in a limited range, but that clearly indicates a positive impact on environmental capital. This provides evidence that access to information and adopting technology in farming can promote sustainable practices (Research Question 3). Though this study did not measure the actual environmental impact of technology adoption by the farmers in Cox's Bazar district.

6.4. Barriers to Adoption and the Digital Divide

The study identifies some of the key reasons that stop the farmers from the Noakhali district from getting the benefits that technology provides (Research Question 4). Multiple reasons were highlighted, and the significantly focused reasons for not using technology are the cost of technology products and services, lack of knowledge, and poor connectivity, and they are also what other studies have found (Aker, 2011; FAO, 2019). The comparative data in this study reveals an important layer: that these obstacles create a cycle of disadvantage. Farmers who do not have access to technology are less informed, more dependent on the intermediaries, and much less likely to use sustainable practices.

The results also show that trust is a crucial psychological barrier. Farmers from Noakhali districts are much more worried about being cheated online, and they are not sure how to use the app correctly. It shows that adopting technology is not just about giving the farmers a tool to use but about building an ecosystem of support and digital literacy.

6.5. Implications for the Theoretical Framework (TAM + SLF)

The results and findings validated the chosen hybrid theoretical framework which is integrated TAM and SLF framework.

Technology Acceptance Model (TAM): The data is highly similar to TAM (Research Question 5). Both groups of farmers perceived the product to be very useful (perceived usefulness), but the main difference was how easy it was to use, which was statistically significant ($p < .001$). The high confidence level of the farmers from Cox's Bazar, which comes from their existing digital literacy, is very different from the fear of the farmers of Noakhali, which shows that both constructs are very important.

Sustainable Livelihoods Framework (SLF): The comparative data from the study demonstrates that technology adoption has a statistically significant impact on multiple livelihood capitals. Better access to markets increases financial stability and capital, while learning about sustainable agricultural methods like Integrated Pest Management (IPM) and directly communicating with buyers helps build both human and social capital, as well as directly impacts natural capital.

6.6. Implications for Policy and Practice

The results from the study can be used as useful information for the government, NGOs, and private organizations to identify appropriate policies and design suitable digital tools for farmers in need.

6.6.1. ***Digital Literacy is Paramount*****:** Implementing technology without providing robust training on accessibility will be insufficient. The interventions should include "in-person group training" in local languages and easy to understand techniques to have the interventions effective.

6.6.2. ***Infrastructure is a Non-Negotiable Prerequisite*****:** Without a proper infrastructure like available, affordable and reliable electricity and internet connectivity cannot ensure the implementation and adoption of technology-driven solutions. Government and private organizations must work together and invest more in infrastructure improvements to make the technology available for everyone.

6.6.3. ***Build Trust and Localized Support*****:** The policymaker and authorities of the technology division should be careful on permitting applications targeted for digitally illiterate populations to avoid the fear of being cheated online. Cybersecurity policy and law should be improved and provide assurance on trustworthy platforms. The digital platforms should be supported by the local support system to ensure more accessibility.

6.6.4. ***Content is King*****:** The technology adoption can benefit the adoption of sustainable agricultural methods, and the study showed a clear linkage between them. The linkage between the adoption of technology and utilization of IPM confirms the integration of various sustainable agricultural solutions into the digital platforms and makes it accessible to the farmers, which can ensure an improved livelihood.

CHAPTER 7: CONCLUSION

7.1. Summary of the Study

This research aimed to perform a comparative analysis of the livelihood outcomes between the two different groups of smallholder farmers- one adopted technologies as their farming tools, and the other still follows the traditional farming techniques in rural Bangladesh. A quantitative and cross-sectional design was developed and surveyed 128 farmers from the above-mentioned two groups, where the technology adopters are from Ukhiya in Cox's Bazar and the traditional farmers group from Companigonj in Noakhali district. The study is then guided by an integrated theoretical framework combining the Technology Acceptance Model (TAM) and Sustainable Livelihood Framework (SLF). The findings of the research show the statistically significant differences between the two groups in every aspect of economics and social and environmental dimensions.

7.2. Answering the Research Questions

The study answered the primary research questions along with the secondary research questions. The primary research question is—to what extent do the sustainable livelihood outcomes (economic, social, and environmental) of smallholder farmers who adopt technology-driven agricultural models differ from those who rely on traditional farming practices in Bangladesh? The answer is derived from the study with the high association of improved sustainable livelihood outcomes with the adoption of technology-driven agricultural models. To be specific, the results prove that the farmers who use the technology solution and digital tools in farming are provided enough information and easy access to markets with better awareness of the price information and are empowered to get higher yields and better prices and increase income compared to the farmers in Noakhali who do not use digital tools. Though the challenges are still there, they have better tools to handle the challenges to minimize the impact.

7.3. Contribution to Knowledge

The study contributes to the academic literature, providing substantial evidence from Bangladesh, and provides a picture of how technology can directly impact livelihood outcomes and where the challenges are in implementing the digital tools, and the technology developer can design appropriate tools considering the obstacles. The study will also help integrate the technology adoption model (TAM) with the sustainable livelihood framework (SLF) to design a comprehensive model for assessing the real-world effects of digital tools in Bangladesh.

7.4. Limitations and Recommendations for Future Research

The study has a limitation on the data collected from the farmers, as it is not objective; rather, the data is self-reported data from the farmers' voluntary responses, and the sampling was done using the non-probability methods and hence is not generalized for the whole community. The result indicates a significant correlation but may fail to establish the definitive causation.

Considering the limitations and the results obtained from this study, the following future study is suggested:

- Incorporating the measurement of actual increased yield as a benefit of the usage of digital tools in farming.
- Measuring the actual income benefit and changes in the livelihood, e.g., changes in the human development index (HDI), to verify the livelihood outcomes.
- Designing a qualitative study to identify the underlying root causes and identifying the actual empowerment impact.

Finally, the study confirms that technology is not the final solution, but it is a catalyst to improve the livelihood outcomes. However, the prerequisite of implementation of digital tools is directly linked with the education of the farmers, and thus technology usage and the increase in education can complement each other and can improve the farmers' livelihood outcomes. Implementing the right digital tools and support from all sectors and stakeholders can make the digital tools the key for sustainable agriculture towards sustainable livelihood outcomes for farmers and make a prosperous and resilient agricultural future.

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APPENDIX

(QUESTIONNAIRE)

Dear respondent,

I am a student at Daffodil International University, Dhaka, Bangladesh pursuing master's degree in development studies. I am conducting research with the title: "Leveraging Technology for Sustainable Agriculture: A Comparative Analysis of Livelihood Outcomes Between Technology-Adopting and Traditional Smallholder Farmers".

You have been selected as respondent in the study based on the criteria I have defined for the study area. Your response will be treated with high confidentiality, and the collected data will be used for this research purpose only. Any questions that you are not feeling comfortable answering will be skipped.

Thank you.

SECTION A: DEMOGRAPHICS

1. Respondent's Name (Optional):
2. Age: ___ years
3. Gender: ☐ Male ☐ Female ☐ Other
4. Highest Education Level: ☐ No formal education ☐ Primary ☐ Secondary ☐ Higher
5. Farm Size: ___ acres/hectares/bigha/Gonda
6. How many years have you been farming? ______ years
7. Is farming your primary source of household income? ☐ Yes ☐ No. If No, then what is? ___________________________
8. Main crops grown: ____________________

9. Which of the following farming practices do you currently use? (Select all that apply)

আপনি ☐ Crop rotation

☐ Using organic fertilizers (cow dung, compost)

☐ Integrated Pest Management (IPM)

☐ Integrated Farming (e.g., crops + livestock/fisheries)

☐ I am not familiar with these practices

☐ Other (Please specify):____

10. How do you usually sell your crops?

☐ To middlemen (foria/bepari)

☐ At the local market (haat)

☐ At a larger wholesale market (arat)

☐ Directly to consumers

☐ Through a farmer cooperative/association

☐ Other (Please specify):____

11. Are you aware of the current market price of your produce before selling?

☐ Yes (হ্যাঁ) ☐ No (না)

12. How do you get information about the current market price for your crops before selling?

☐ From the middlemen/buyers who come to me

☐ By asking other farmers

☐ By visiting the market myself

☐ From TV/Radio/Internet

☐ I don't get reliable price information before

☐ Other (Please specify): ____

SECTION B: CHALLENGES

13. What are your current challenges in farming? (Select all that apply)

☐ Access to market

☐ Fair pricing

☐ Access to quality inputs

☐ Climate-related issues

☐ Lack of finance

☐ Lack of training

☐ Poor infrastructure

☐ Exploitation by middlemen/syndicates

☐ High cost of labor and machinery

☐ Others (please specify): ____

13.1. If "**Access to market**" is selected: What limits your access to markets?

☐ Long distance to market

☐ High transportation costs

☐ Lack of buyers

☐ Lack of information about market demand

☐ No digital platforms available

☐ Other: ____

13.2. If "Fair pricing" is selected: What do you think causes unfair pricing?

☐ Middlemen/syndicates

☐ No access to price information

☐ Poor quality grading

☐ Lack of bargaining power

☐ Delayed payments

☐ Other: ____

13.3. If "Access to quality inputs" is selected: What inputs are difficult to access? (Select all that apply)

☐ Seeds

☐ Fertilizers

☐ Pesticides

☐ Tools/machinery

☐ Irrigation equipment

☐ Other: ____

13.3.1. Why are these inputs hard to access?

☐ Too expensive

☐ Not available locally

☐ Poor quality

☐ Lack of knowledge on usage

☐ Other: ____

13.4. If “Climate-related issues” is selected: What climate-related problems affect your farming?

☐ Flooding

☐ Drought

☐ Salinity

☐ Cyclones

☐ Unpredictable weather

☐ Other: ___________

13.5. If “Lack of finance” is selected: What prevents you from accessing finance?

☐ No collateral

☐ High interest rates

☐ Complicated application process

☐ Lack of awareness about loan options

☐ Previous loan rejection

☐ Other: ___________

13.6. If “Lack of training” is selected: What kind of training do you feel you need?

☐ Modern farming techniques

☐ Use of digital tools

☐ Pest and disease management

☐ Post-harvest handling

☐ Marketing and sales

☐ Other: ___________

13.7. If "Poor infrastructure" is selected: What infrastructure issues affect your farming?

☐ Poor roads

☐ Lack of storage facilities

☐ No electricity

☐ No irrigation system

☐ No internet access

☐ Other: ___________

13.8. If "Exploitation by middlemen/syndicates" is selected: Please state your level of agreement with the following statements:

Statement	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Middlemen exploit us by offering very low prices.	☐	☐	☐	☐	☐
It is very difficult to sell our produce without middlemen.	☐	☐	☐	☐	☐
Middlemen provide useful services like quick cash and transport.	☐	☐	☐	☐	☐
Organized syndicates control market prices.	☐	☐	☐	☐	☐

13.8.1. How often do you feel exploited by middlemen or syndicates?

☐ Always

☐ Often

☐ Sometimes

☐ Rarely

☐ Never

13.8.2. How often do you face issues with middlemen or syndicates?

☐ Always

☐ Often

☐ Sometimes

☐ Rarely

☐ Never

13.8.3. Do you feel you receive a fair price for your produce? Yes ☐ No

13.8.3.1. If “No”, ask the following: What do you think is the main reason for not receiving a fair price? (Select all that apply)

☐ Middlemen take a large share

☐ Lack of access to market price information

☐ No access to direct buyers

☐ Poor quality assessment or grading practices

☐ Delayed payments

☐ Lack of bargaining power

☐ High transportation costs

☐ Other (please specify): ____________

14. Do you have access to any platform or service that provides real-time market prices?

☐ Yes ☐ No

If “Yes” then what platform ____

15. Have you ever tried to sell your produce directly to consumers or retailers?

☐ Yes ☐ No

15.1. If yes, how successful was it in terms of getting a better price?

☐ Very successful

☐ Somewhat successful

☐ Neutral

☐ Not successful

☐ Not applicable

16. Would you be willing to use a digital platform to sell your produce if it ensured better pricing?

☐ Yes ☐ No ☐ Maybe

SECTION C: TECHNOLOGY USAGE

17. Do you own a smartphone? ☐ Yes ☐ No

17.1. If “Yes”: What type of smartphone do you use?

☐ Basic Android

☐ Advanced Android/iPhone

☐ Other: ___________

17.1.1. (If you own a smartphone) What do you use it for? (Select all that apply)

☐ Making calls/sending SMS

☐ Using apps like Facebook, WhatsApp, YouTube

☐ Getting news or weather information

☐ Mobile banking (e.g., bKash, Nagad)

☐ Seeking information about agriculture (prices, techniques)

☐ Other (Please specify): _______________

17.1.2. How often do you use your smartphone for farming-related activities?

☐ Daily

☐ Weekly

☐ Occasionally

☐ Rarely

☐ Never

17.1.3. How confident are you in using a smartphone and the internet?

☐ Very Confident

☐ Somewhat Confident

☐ Not very confident

☐ Not at all confident / I don't know how to use them

17.1.4. What farming-related activities do you use your smartphone for? (Select all that apply)

☐ Checking weather forecasts

☐ Watching agricultural tutorials

☐ Accessing market prices

☐ Communicating with buyers/sellers

☐ Using mobile banking or payment apps

☐ Ordering seeds/fertilizers

☐ None of the above

17.1.5. Do you face any challenges using your smartphone for farming purposes?

☐ Yes ☐ No

17.1.5.1. If yes, what are the challenges? (Select all that apply)

☐ Poor internet connection

☐ High data costs

☐ Apps are difficult to use

☐ Language barriers

☐ Lack of training

☐ Other: ___________

17.2. If you do not own a smartphone: What is the main reason you do not own a smartphone?

☐ Too expensive

☐ Don’t know how to use it

☐ No electricity to charge

☐ Prefer basic phone

☐ Not useful for farming

☐ Other: ___________

17.2.1. What are the main difficulties that stop you or other farmers you know from using technology (like smartphones) for farming?

☐ Smartphones are too expensive to buy.

☐ The cost of internet data is too high.

☐ I don't know how to use these technologies.

☐ Poor internet connection in my village.

☐ Lack of reliable electricity to charge phones.

☐ Most apps are in English, which is hard to understand.

☐ I don't trust online transactions.

☐ I don't see the benefit for farming.

18. Do you use the internet for farming-related activities? ☐ Yes ☐ No

18.1.1. If "Yes": What type of internet connection do you use?

☐ Mobile data

☐ Wi-Fi

☐ Public internet center

☐ Other: ____________

18.1.2. How frequently do you access the internet for farming purposes?

☐ Daily

☐ Weekly

☐ Occasionally

☐ Rarely

☐ Never

18.1.3. What farming-related information do you search for online? (Select all that apply)

☐ Crop cultivation techniques

☐ Pest and disease control

☐ Weather updates

☐ Market prices

☐ Government schemes or subsidies

☐ Online marketplaces

☐ Other: ___________

18.1.4. Have you ever used an online platform to sell or promote your produce?

☐ Yes ☐ No

18.1.4.1. If yes, how satisfied were you with the experience?

☐ Very satisfied

☐ Satisfied

☐ Neutral

☐ Dissatisfied

☐ Very dissatisfied

18.2. If “No” to question 18, what prevents you from using the internet for farming? (Select all that apply)

☐ No internet access in my area

☐ Cannot afford data

☐ Don’t know how to use it

☐ No relevant content in my language

☐ Other: ___________

19. Which of the following technologies do you use for farming? (Select all that apply)

☐ Mobile apps

☐ SMS alerts

☐ Online marketplaces

☐ IoT devices (e.g., sensors)

☐ None

20. How frequently do you use digital tools for farming?

☐ Daily

☐ Weekly

☐ Monthly

☐ Rarely

☐ Never

21. What benefits have you experienced from using technology? (Select all that apply)

☐ Increased yield

☐ Better market prices

☐ Reduced costs

☐ Easier access to inputs

☐ No noticeable benefit

SECTION D: DIGITAL MARKETPLACES

22. Are you aware of any digital marketplaces for selling your produce?

☐ Yes ☐ No

23. Have you ever used a digital marketplace to sell your produce?

☐ Yes ☐ No

23.1. If yes, how satisfied were you with the experience?

☐ Very satisfied

☐ Satisfied

☐ Neutral

☐ Dissatisfied

☐ Very dissatisfied

24. What challenges did you face while using digital marketplaces? (Select all that apply)

☐ Poor internet access

☐ Difficult to use

☐ Language issues

☐ High transaction fees

☐ Lack of trust

☐ Other: ___________

SECTION E: PERCEPTIONS OF A PROPOSED TECHNOLOGY-DRIVEN MODEL

"Now, I want you to imagine a mobile application designed for farmers like you. This app would allow you to:"

- See real-time prices of your crops in different markets
- Sell your produce directly to buyers, reducing the need for middlemen.
- Buy good quality seeds and fertilizers directly from companies.
- Receive payments securely through mobile banking (like bKash/Nagad).

25. How useful would such an application be for you?

☐ Extremely Useful

☐ Very Useful

☐ Moderately Useful

☐ Not very useful

☐ Not useful at all

26. To what extent do you agree with these potential benefits of using such an app?

Potential Benefit	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
I would get a fairer price for my crops.	☐	☐	☐	☐	☐
It would increase my income.	☐	☐	☐	☐	☐
It would save me time and transport costs.	☐	☐	☐	☐	☐
I would have more power to negotiate prices.	☐	☐	☐	☐	☐
I believe an app like this would be easy for me to learn how to use.	☐	☐	☐	☐	☐
This app would give me more control over my farming business.	☐	☐	☐	☐	☐

27. If this app also provided information and tutorials on modern farming (like Integrated Pest Management or soil health), would it help you adopt these practices?

☐ Yes ☐ No ☐ Maybe

28. What would be your biggest concerns about using such an app?

☐ Fear of being cheated online

☐ Not understanding how to use it correctly

☐ Who would help me if I have a problem with the app?

☐ The buyer might reject my produce after I send it

☐ I don't have any concerns

29. If training was provided on how to use this technology, what method would you prefer?

☐ In-person group training in my village

☐ One-on-one help from a trained person

☐ Video tutorials I can watch on my phone

☐ A simple printed guide with pictures

30. Who do you think should provide this technology and support to farmers?

☐ The Government

☐ Private Companies

☐ NGOs (Non-Governmental Organizations)

☐ A partnership between Government, NGOs, and private companies

31. (For female respondents) Do you face any special difficulties in accessing or using mobile phones and technology compared to men? If yes, please explain briefly.

☐ Yes: ____
____
____
____

☐ No