The Role of Industry 4.0 Technologies in Promoting Agrifood Supply Chain Sustainability in Africa: using Nigeria as a Case Study

A thesis submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy

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Dedication

I dedicate this thesis to God Almighty for the grace, courage, and provision to complete this study. I also dedicate it to the loving memory of my mother, Late Elder Mrs Felicia Taiwo Olafare, whose significant sacrifices ensured I had a higher education. I also dedicate it to my beloved Wife, Dr Mrs Oreoluwa Olafare, for her unwavering support and belief in me and her companionship as my PhD buddy. Lastly, to all my siblings, thank you for your love and encouragement.

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ABSTRACT

The purpose of this study is to explore the impact of Industry 4.0 technologies on the sustainability of the agrifood supply chain (AFSC) in the present state of the agrifood industry in Nigeria. The challenges facing the Nigerian and African agrifood industry are parallel to those facing the global agrifood industry. The agrifood industry in Africa has faced several challenges over the past few decades, hampering its productivity, hindering its ability to provide food and nutrition for human needs, and limiting its ability to provide sufficient raw materials for manufacturing processes. The agri-food industry faces several significant challenges, including the burgeoning population, change in dietary demands, degradation of natural resources, flood supply chain disruption, food wastage, climate change, and the absence of capital infrastructure, which have hindered the potential of the global agri-food system. In light of these challenges, there is a rising discourse among AFSC stakeholders to improve the conventional AFSC practices in an attempt to manage or mitigate the negative impacts of this pressing challenge, thus providing better ways to increase the efficiency and production of the region's AFSC productivity. The concept and practices of sustainability have emerged among the AFSC stakeholders in Africa and Nigeria over the years, where sustainable agrifood solutions and practices were implemented and adopted across several levels in the agrifood system. The underlying concept for this sustainable approach is; Economic—how can actors increase productivity and profit? Environmental—how can AFSC actors reduce the negative impacts of the food industry on the environment? Social—How can the livelihood of actors be improved?

The use of technology to achieve sustainability was foremost in most developed countries, where data-driven processes were promised to AFSC stakeholders to help them make better decisions. Several academic and business industry leaders have presented paradigm shifts in AFSC sustainability, which is based on the use of Industry 4.0 technologies with huge potential to tackle the challenges of the Agrifood system. Moreover, this reimaging is possible due to the current progress presented by Industry 4.0 technologies such as "Internet-of-Things (IoT), Blockchain, Big Data (BD), Drones, Precision Agriculture, Smart Agriculture, Smart Logistics, Smart Food Manufacturing processes, Cloud Computing (CC), and Cyber-Physical System (CPS)". These arrays of technologies bring distinct capabilities and functions to transition the AFSC supply chain towards sustainability. Technology enables an efficient e-commerce system necessary for a seamless cross-border agrifood trade, offering traceability options for monitoring the origin of products, and supports efforts for a circular economy.

This study employed a mixed-method approach to examine the role of Industry 4.0 technologies on the AFSC actors in Nigeria who are already deploying this technology in their

operations. The research is focused on examining the Economic, Social and Environmental impacts of industry 4,0 technologies on the agrifood industry in Nigeria. Data from interviews with AFSC actors were analysed using NVivo 12 software through a thematic approach. The findings reveal inspiring insights into the impact of Industry 4.0 technologies in the Nigerian context and provide a novel perspective on agribusiness transformation.

The finds of this study

The findings from this study creates an avenue for contextual study, which draws academic contribution from examining the impact of Industry 4.0 technology in the sustainable AFSC in the context of Nigeria's agrifood industry, enables in-depth analysis of AFSC actors' experience in the use and adoption of Industry 4.0 technology without generalising concepts and ideas captured in other studies conducted in different country or agrifood contexts. The findings gathered in this study have significant policy implications. They can serve as guidelines and frameworks in the development and application of policy within the AFSC industry in Nigeria, fostering the transition into a digital-driven and sustainable agrifood system, resulting in more resilient and competitive agricultural systems. The study's main theoretical contribution is expanding UTAUT and providing practical insights for professionals in the field. Including Technology Adoption Readiness (TAR), Price Value, and enabling conditions in the context of Nigeria AFSC sustainability using Industry 4.0 technology offers actionable strategies for technology adoption and use. The findings in this study have demonstrated that Industry 4.0 technologies are essential to creating new employment prospects in the AFSC industries. Consequent to these technologies, more professions requiring new skill sets are being created, which increases the workforce's need for ongoing learning and adaptation. The ability of Industry 4.0 technology to improve sustainability and operational sufficiency will encourage actors and agribusinesses to adopt and use technology within their operations successfully

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THE KEY CONCEPTS AND THEIR DEFINITIONS

AGRA- Alliance for Green Revolution in Africa

CSA- Climate Smart Agriculture

FAO- Food and agriculture Organization of United Nations

IFPRI- International Food Policy Research Institute

IoTs- Internet of things

NAERLS - National Agricultural Extension and Research Liaison Services

OECD- Organisation for Economic Co-operation and Development

PA- Precision agriculture

SCM – Supply Chain Management

SFT - Smart Farming Technologies

SSCM- Sustainable supply chain management

TAM – Theory of Acceptance Model

TAR- Technology Adoption Readiness

TBL- Triple Bottom Line

UAVs- Unmanned Aerial Vehicle systems (UAVs) such as drones

UNIDO- United Nations Industrial Development Organization

UTUAT -Unified Theory of used and Acceptance of Technology

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CHAPTER ONE (1)

1.0 INTRODUCTION, BACKGROUND, RESEARCH OBJECTIVES AND STRUCTURE

1.1 Introduction

This chapter covers the overview of the African agrifood industry, a topic of immense importance. It will discuss the history of development, challenges, and the role of sustainable practices in transforming operations across the supply chain. Several sustainable practices will be discussed, focusing on the potential of technology in the agrifood supply chain (AFSC) sustainability in Africa, using Nigeria as the study location, thus establishing the research problem and providing a justification for conducting the survey. The chapter further describes the study's objectives, research questions, and research methods and approaches employed to evaluate and support the arguments made in this research study. The chapter draws to a close by stating the content of each branch of the thesis, underscoring the significance of the African agrifood industry.

1.2 Background and Rationale

Agriculture remains one of Africa's most important economic sectors, contributing 15% of the region's GDP and creating employment for a large portion of the population(two-thirds). The Agrifood sector presents a prospect of transforming Africa's economy if it can overcome the pressing challenges faced by the industry. 90% of the total food production comes from small-scale farming, mainly family farms. Agriculture practices such as food cultivation and animal husbandry have played a vital role in feeding the world nutritious food, including raw materials for industrial purposes (FAO 2018).

The agrifood system plays a crucial role in attaining SDGS by serving as a significant source of nutrition, employment and economic prospects for many individuals and the global population. A daily average of 23.7 million tonnes of food is produced through agriculture. This includes 19.5 million tonnes of tubers, fruits, cereals, roots, and vegetables, a meat production value of 1.1 million tonnes, and milk production of 2.1 billion litres. Agriculture offers livelihood for over 2.5 billion people, with the majority living in low- and middle-income countries, and it continues to play a crucial role in promoting global development (FAO 2016).

The projected monetary worth of Nigeria's daily agricultural output amounts to approximately 7 billion US dollars. Beyond meeting basic human needs for food, animal feed, textiles, and energy, the agricultural sector employs over one-third of the global workforce, offering livelihood opportunities to about 2.5 billion individuals residing in rural areas. The AFSC system has various commercial businesses that provide potentially significant employment prospects across the continent (FAO 2018).

Presently, agriculture functions as the leading provider of decent livelihood for many across the continent. This significantly fosters social cohesiveness among rural regions while maintaining cultural traditions and history (Adenle et al. 2017). It's been projected that there is a need for a 60% increase in food production in Africa by the year 2050 to meet the potential demand posed by its growing population, but this cannot be achieved without overcoming the underlying challenges that cripple the industry's potential.

In recent years, the AFSC has experienced changes due to globalisation, extensive global sourcing, urbanisation, and changes in dietary intake, leading to the complexity of the food supply chain. The complexity of the food supply chain results in many challenges, such as food fraud, food safety, food contamination, food adulteration, malnutrition and food waste**.** These challenges have created an ongoing Increase in consumers' awareness of the source, quality and process involved with food from farm to fork, making sustainability and transparency a significant concern of government, FSC stakeholders and regulatory bodies.

Around 1962-1968, the national development plan was introduced to boost the export of crop production through increased cultivated land, improved seed distribution, and more modern farming practices. Further establishments like farmers' corporations and settlements were developed to help the farming communities access resources and commit to community agriculture breakthroughs (FAO 2007). During the colonial rule in Nigeria, high priority was placed on producing agricultural commodities like oil palm, cocoa, rubber, cotton, and groundnut for foreign exchange capacities. The Colonial masters prioritised production as these cash crops were used as raw materials for manufacturing and export into developed countries (Resnick . et al., 2020)

Africa was known as an agriculture-exporting continent until 2 decades ago; farmers grew and exported cash crops to European countries, which served as raw materials for their growing industries (FAO 2003). However, during the post-colonial period, most African countries experienced underinvestment and low trade in the global food market, as their government lost focus on the agriculture sector's potential. Several initiatives were created by the African Union (AU) to promote agricultural investment (Johnston and Mellor, 1960). However, over the years, most African countries, particularly the Sub-Saharan Africa region, changed from a minor exporter of food crops to a major importer (Johnston 1968). Exports of food crops, consisting mainly of groundnuts, decreased by 56%, while imports, mainly cereals, increased by 122% (FAO. 2014). The average yearly net imports of the region in 1973-1977 amounted to 3.5 million metric tons or about 5% of the average annual consumption. Only Ethiopia and

Kenya retained their trade positions among major food crop producers and exporters, including Nigeria and the Malagasy Republic. Nigeria underwent the most drastic change from a predominantly agricultural country to one that depends mainly on petroleum exports. Nigeria was the largest exporter of several food commodities (e.g., groundnuts, oil palm products, cocoa), but in 1973 and 1977, Nigeria became the most significant food importer (UNIDO 2013). Bad governance and underinvestment led to poor performance in the agriculture sector (Olomola and Nwafor 2018). In Africa, due to its inability to transform the economy, ensure food security, produce nutritious food and create jobs. IFPRI reported that during the colonial period (Resnick et al., 2020). Several such challenges hit the African continent, particularly Nigeria's agrifood industry.

1.3 Challenges of the Agrifood Industry

The global agrifood industry has faced several challenges over the past few decades, which have hampered its productivity, hindered its ability to meet the nutrition needs of the world population and limited its ability to provide sufficient raw materials for manufacturing processes. The food industry faces several significant challenges, including the growing population, change in dietary demand, degradation of natural resources, supply chain disruption, food waste, climate change, and capital infrastructure, which have hindered the potential of the global agri-food system (Annosi et al., 2020; Lee, Gereffi and Beauvais,2012).

1.3.1 Population Growth and Urbanisation

According to projections, the global population is anticipated to increase from around 7.2 billion to 9.3 billion by 2050. The United Nations foretold 0.96% annual growth in the world's population from now till 2030 and yearly growth of 0.63% between 2030 and 2050, making the estimated population growth 9 billion by 2050. This growth in the world's population will occur mainly in developing countries and low-income countries, which commonly face food insecurity and malnutrition (Verdouw et al., 2019). This increase in the population varies in different sub-regions, with a 2% increase in Europe and North America and a 99% increase in sub-Saharan Africa (Alonso, R.S. et al., 2020). Population growth and other socioeconomic concerns are putting demand on the agrifood sector to achieve a green supply of food locally and globally (Verdouw et al. 2019) and to increase its productivity to feed the growing world population. This implies that there is a need for an increase in food production to about 70% to meet the rising demand for food, prioritising resource efficiency and producing more food with fewer resources (Panetto et al. 2020). Godfray (2010) explained the growing concern of population growth, increased constraints on natural resources, and the impact of the agrifood industry on the environment (Godfray et al., 2010). Access to agrifood products is due to the rising population and increased food demand. Evans, B., 2010 stated that rising food prices are also a significant challenge of the 21st century.

The global population is experiencing significant expansion, primarily concentrated in metropolitan and urban regions of emerging nations. A corresponding increase in the demand and supply of food accompanies this demographic trend (Brown, 2015). This contrasts with rural agricultural regions that have historically catered to the local community's demands. In addition to a rising consumer need for year-round access to food locally and globally, various consumer requirements are placing further strain on the agrifood supply and the overall satisfaction of food provision. By 2050, 65% of people will live in urban areas; this significant movement to cities will occur in low-income countries (Vieira, 2021). The dispersion and massive migration of people across different geographical regions present a continual problem, majorly the declining populations in rural agricultural towns and similar places, driven by the pursuit of economic prosperity in urban centres and conurbations, has become a significant concern, where future rural workforce migrate to better geographical location, which is an increasing issue facing many regions, especially Africa. This vast urban migration is significant among young people, leaving the rural workforce to the ageing population.

Africa is experiencing a major demographic transformation, partly driven by rapid urbanization and population growth. Currently, cities around the world are home to 3.5 billion people, and by 2030, it's projected that 60% of the global population will live in urban areas. Notably, 95% of this urban growth is expected to occur in developing countries, with Africa witnessing massive urban migration (Leyerer et al., 2020). The continent boasts numerous cities and megacities characterised by diverse cultures and vibrant, dynamic economies (AGRA, 2020). Africa's urbanisation rate is projected to grow at an annual rate of 3.5% from 2015 to 2025. The African cities' population is expected to surpass 1.3 billion by 2050, with youth being the primary drivers of this urban shift (UN-DESA, 2018). This trend is primarily attributed to the perception that urban areas offer better opportunities (Dolislager et al., 2021), such as economic empowerment, quality education, higher social status, and improved food security, compared to rural regions on the continent (Cheng et al., 2022).

The surge in global population has intensified food demand, despite challenges like resource depletion and climate change impacting food production. Even with recent innovations, current agricultural methods may fall short of meeting projected food needs by 2050. In Africa, urban food markets - valued at $200-$250 billion annually - represent a significant opportunity for the agri-food sector. These markets drive economic growth and contribute to sustainable development and social empowerment.

As of 2021, urban areas in Africa and West Africa housed 43.9% of the population, with the remaining 56.1% in rural settings. Despite urbanization, African cities face persistent issues including malnutrition, poverty, food insecurity, and insufficient infrastructure for sustainable food production ((Newell et al., 2019). Meeting the food needs of Africa's expanding urban centres requires efficient production methods and access to key resources such as land, water, and energy (Barthel et al., 2019). Developing urban food production systems is vital to satisfy growing demand while minimizing environmental impact and fostering sustainability (Brown, 2015). The agri-food sector is crucial for sustaining and nourishing Africa's population. Urban areas and the broader African agri-food industry must prioritize quality nutrition, food security, and sustainable production methods. Achieving food sufficiency in African cities requires an integrated and collaborative approach among all actors in the agri-food supply chain(Armanda et al., 2019).

Rural-to-urban migration is reducing the rural workforce, limiting its ability to meet growing urban food demands (Dolislager et al., 2021). This necessitates integrating food production within urban landscapes, allowing living spaces and food systems to coexist. Reliance on food imports, which total $72 billion annually in Africa (with North and Southern Africa importing the most), has created significant competition for local agri-food suppliers in terms of price, quality, and market share. This situation underscores the need for innovative urban food production solutions (AGRA, 2020). As shown in Table 1.1, between 2010 and 2019, Africa's average food imports consisted predominantly of cereals, vegetable oil, sugar, and dairy products. The growing dependence on imported food underscores the local agri-food industry's struggle to meet domestic demand. To achieve food sustainability and self-sufficiency in African cities, stakeholders must investigate alternative strategies and innovative approaches to boost local food production (Houessou et al., 2020).

Table 1.1: Africa's Average Food Import

Food Category	US$BILLION	PERCENTAGE
Cereal	22.798	30.7
Vegetable oil	8.517	11.5
Sugar	6.434	8.7
Dairy products	5.034	6.8
Meat and edible meat offal	4.580	6.2
Fish and crustaceans	4.275	5.8
Preparations of cereal and flour	3.368	4.5
Other food items	19.080	25.8
Total foods import	74.068	100

Source: ITC Trade Map and AGRA, 2020.

Urban lifestyles in Africa, characterised by their fast pace, have led city dwellers to prioritise convenience in food consumption. This has resulted in a significant increase in the purchase of processed and prepared foods, which make up 62% of food purchases in African cities compared to 49% in rural areas. Additionally, rising incomes in many African urban centres have driven increased consumption of processed and perishable foods, including dairy, meat, poultry, and fish(Dube et al., 2017).

The changing food consumption patterns and dietary preferences in Africa's urban areas reflect Bennett's law: as incomes increase, there's a trend towards consuming more perishable foods (Eigenbrod and Gruda, 2015; AGRA, 2020). The need to feed African cities amidst these consumption trends has become a focal point of concern among stakeholders (Armanda et al., 2019). Consequently, there is a pressing need to develop more sustainable food production methods within urban areas to meet the growing demand. The anticipated population growth, coupled with the ongoing dietary changes and urbanization, has further intensified global food demand.

1.3.2 Dietary demand

Pursuing a gainful job and a stable, reliable source of income has led to the emergence of a class of individuals who have achieved financial sufficiency. These individuals seek to showcase and find satisfaction in their accomplishments by enhancing their quality of life (IFAD 2022). Their pursuit of a higher quality of life is reflected in their consumption patterns, purchases, shopping habits, and dietary choices (Minten et al. 2020). Numerous studies have shown that increased household income leads to shifts in food consumption towards more protein-rich and processed foods. (Van Berkum *et al*., 2017). The dietary consumption patterns in West Africa are transforming due to increased income levels and the evolution of consumer behaviours in response to urban lifestyles. A substantial body of evidence documenting the correlation between alterations in food habits and shifts in living situations has been found in various contexts (Eigenbrod and Gruda 2015). The growing trend of urbanisation and the adoption of urban lifestyles are often accompanied by changes in food habits, extending beyond metropolitan areas' boundaries. There has been an increase in the intake of fruits, vegetables, and processed foods, whilst the consumption of cereals and pulses is experiencing a decline (Gupta, 2022). Processed foods comprise 39% of the total amount spent on food by households and constitute a significant component of food consumption across various income levels, including those with low incomes. (Guzmán-Pérez et al 2021). The growth and change in dietary patterns are due to increased revenue and economic sufficiency; this is supported by the correlation between the rise in meat consumption and a predicted growth rate of 1.5% per annum in chicken consumption through 2020. Additionally, other types of meat are expected to have a growth rate of 0.5%. Several studies have emphasised the public health concerns linked to increased meat intake (Schmidt and Fang, 2021). A significant connection exists between rising income, food choice, food category consumption, and their influence on health and well-being, especially dietetics and obesity (Van Berkum et al., 2017). By the year 2030, a 50% increase in food and agricultural products is needed to meet the demand for food, and a 110% increase in food production is required to meet the food demand by 2050 due to the growing population and increase in income (Lezoche et al. 2020).

1.3.3 Natural resources degradation

Several factors, such as loss of biodiversity, deficiency of soil nutrients, water contamination, loss of beneficial microorganisms in the soil, erosion, flooding, and poor water management, are elements crippling the effectiveness of AFSC. Similarly, the source of energy and fuel used has a literal effect on the performance of AFSC if not correctly managed and monitored. The use of renewable energy has the potential to reduce the carbon footprint in agriculture and AFSC's operations. Soil degradation is another primary concern resulting in the depletion of soil nutrients and the extinction of beneficial microorganisms in the soil (Emam et al., 2015). An estimated 10 million hectares of land are lost to erosion each year, reducing arable land available for farming (Ji and Tan 2017). An increase in food production can be achieved through resource efficiency, producing more food with fewer resources, and tackling the challenges of climate change, food waste, land degradation, water contamination, animal well-being(health), repealing bad government policies and promoting healthy consumption (Ji and Tan 2017). Since soil is the foundation of agricultural production, there is an inherent connection between soil quality, preservation, and the food supply capacity to meet consumers' needs. However, this is not solely true in the period of soilless food production, which has enormous potential but has not been fully maximised due to several constraints. Hence, soil erosion is regarded as a primary contributing cause to the decline in soil productivity, which may substantially affect crop output (Emam et al., 2015). The agri-food business, which comprises agriculture and food production, is significantly affected by soil erosion. Approximately one-third of the global farmland is experiencing a depletion of topsoil at a rate that surpasses the formation of new soil, diminishing the intrinsic fertility of the land. The depletion of topsoil can reduce agricultural output, as crops have challenges in accessing the essential nutrients and water required for optimal development (Tvaronavičienė, 2021). The process of soil erosion can result in the deposition of eroded soil particles into adjacent water bodies, leading to sedimentation and subsequent degradation of water quality, which has the potential to cause detrimental effects on aquatic life. The long-term cultivation of crops might become increasingly complex due to the more significant land degradation resulting from persistent soil erosion.

1.3.4 Food waste

Approximately one-third of global food production intended for human consumption is lost or wasted, leading to significant resource depletion and the emission of greenhouse gases (Ishangulyyev, Kim, and Lee, 2019). The agrifood supply chain experiences food losses and waste across all stages. An estimated 2 billion tons of garbage are generated annually across the globe (Dou and Toth 2021). In medium/high-income nations, most food waste occurs during consumption. In contrast, low-income countries tend to have losses during production and post-harvest (Kumar and Lin 2015). Ishangulyyev, Kim and Lee (2019) describe several factors contributing to food loss and waste in different parts of the globe. The food loss and waste can be attributed to inappropriate production practices, inefficient use of resources and labour, and lack of infrastructure and technological solutions. Food waste in medium/high-income countries is predominantly influenced by consumer eating and purchasing habits, leading to food loss (Aschemann-Witzel et al. 2015).

Various factors can influence food waste, including agricultural production techniques, seed quality, internal infrastructure and capacity, quality distribution channels, infrastructure like roads, and consumers' shopping behaviour. Most food waste experienced in low-income countries is due to inadequate farming and postharvest technologies to preserve farm produce(Girotto, Alibardi and Cossu 2015). The issue presents a considerable challenge in achieving food sufficiency and attaining the Sustainable Development Goals (SDGs) (Barthel et al., 2019). Food losses and waste have significantly impacted various aspects of reality, like nutrition, food quality and safety, economic progress, and environmental sustainability. The precise factors contributing to food losses exhibit variability throughout different regions worldwide, contingent upon the unique circumstances and local context within each respective country. Several studies have highlighted the importance of enhancing the resilience of food supply chains, fostering knowledge and consciousness among actors across the AFSC and consumers, and identifying potential waste to minimise food waste at both the household and industry levels. Additionally, it underscores the necessity for further research and solutions in this area. Mitigating food losses and waste is paramount in enhancing food security and optimising the overall efficacy of the food supply chain. Several methods have been proposed to curb food waste at the household and industry level. Many solutions are being developed to explore the variation of food waste.

Food losses and waste hold significant importance steps in the means to address hunger, improve the economic capacity of farmers, and enhance food security across the globe, especially in the most impoverished nations (Alexander, Gregson and Gille 2013). Farm produce, which will be an economic advantage to actors, has now ended up as waste, which has adversely influenced the financial well-being of agricultural producers and consumers. Therefore, leaving a substantial number of small-scale farmers residing in precarious conditions regarding food security, a decrease in food losses could have a prompt and noteworthy effect on their livelihood (Schanes, Dobernig and Gözet 2018).

Several studies have demonstrated that Africa has significant economic losses due to agrifood loss and waste, crippling the continent's food industry. The extent to which agrifood commodities end up as waste cannot be quantified due to a lack of substantial data regarding this issue. Therefore, it is imperative to conduct periodic examinations of the extent of Agri-Food waste nationally, and the same initiatives should be encouraged in low-income countries in Africa, even though these countries have more pressing challenges, ranging from economic instability to political incompetence. Although agrifood waste examination is been observed in developed economies, it is uncommon in the developing world, particularly in countries within Africa, which constitute a significant portion of the food insufficiency region. Despite the vast potential of Nigeria's agrifood industry, FAO has listed the nation as experiencing food insecurity (FAO 2011). The Nigerian agrifood industry has several established agrifood supplies, with diverse operations and different actors. The extent of agrifood waste and loss generated in Nigeria cannot be measured, as there is no appropriate data or information. The perishable food supply chain faces this challenge due to an inadequate logistics network and cold chain. Many farmers in this region dispose of their food waste haphazardly, often through drainage systems or rivers, which contributes to long-term aquatic pollution. Waste from animal abattoirs is also disposed of in rivers and water bodies. Although numerous recommendations exist to reduce food waste across the supply chain, their effectiveness varies by country due to differing national contexts and political and economic landscapes. Adopting these recommendations can be challenging if they are not tailored to address the specific food waste challenges of each country (Dou and Toth 2021).

1.3.5 Climate change

1.3.5.1 Impact of agrifood industry on the environment- Climate Change

Climate change, through rising temperatures, significantly threatens food production, livelihoods, and nutrition, coupled with unpredictable precipitation patterns, prolonged droughts, excessive flooding, and rising sea levels, threatens the food industry(Malhi, Kaur and Kaushik 2021). Conversely, it is worth noting that the agricultural sector and food systems generate around one-third of the total greenhouse gas emissions worldwide (FAO 2022).

Numerous activities within the food system have been major contributors to the emission of greenhouse gases, which hurts the climate; the agrifood industry has also experienced the impact of climate change on the industry's efficiency. Agrifood production heavily depends on quality inputs such as seeds, fertilisers, irrigation and pesticides (Powell, J.P., and Reinhard, S., 2016). Among these elements, the primary contributor to greenhouse gas (GHG) emissions is the production of fertilisers. Research findings indicate that around 25% of worldwide greenhouse gas emissions may be ascribed directly to food and animal production and forestry activities, with a particular emphasis on deforestation. This is primarily due to the high energy requirements involved in the process. Manufacturing nitrate fertilisers also releases nitrous oxide (N2O), contributing to GHG emissions. Agrifood activities contribute 13.5% of GHG emissions (FAO. 2022). The food industry is responsible for 19% to 29% of anthropogenic greenhouse gas emissions globally. of this emission value, primary production, like farming, accounts for a significant proportion, ranging from 80% to 86% (FAO. 2022). It is crucial to note that this contribution has substantial variations among different countries. The remaining portion of the environmental impact arises from preliminary production activities, primarily related to fertiliser manufacturing and off-farm activities like processing and distribution.

However, it is essential to recognise their potential to function as a global carbon sink. It is necessary to assist vulnerable small-scale farmers in facilitating their adaptation to climate change. Additionally, lowering greenhouse gas emissions within the agrifood supply chain is crucial for the long-term sustainability of food systems and for maintaining food and nutrition.

The primary GHG emissions produced as a result of FSC chain activity are carbon dioxide (CO2), methane (CH4) and nitrous oxide(NO2). Methane is produced primarily by the anaerobic decomposition of organic matter, nitrous oxide is produced by the microbial action on nitrogen(N) content in soil and manure and carbon dioxide is produced by energy usage in different FSC operations (pre-farm, during farming, post-farming). The FSC generates 25% carbon dioxide, 50% methane, and 70% nitrous oxide, making an overall 13.5% contribution to GHG emissions (FAO 2022). The current increase in greenhouse gas emissions has the potential to result in a temperature rise of 5ºC, hence leading to significant implications for our ecosystem. Given the temperature variance between this modern era and the one before the ice age, it is evident that the significance of this issue is readily understandable and can be traced to the root cause (Diogo et al. 2017). The food industry contributes to greenhouse gas (GHG) emissions through CO2 from production, and CH4 and N2O from wastewater systems. Food transportation is a major source of emissions, with "food miles" becoming a key concern for supply chain stakeholders (FA0 2022).

The agricultural sector is the primary catalyst for the depletion of forests and biodiversity, which encompasses the loss of important diversity necessary for promoting good diets and nutrition. Approximately one-third of the Earth's soil is experiencing degradation, with agriculture being responsible for about 70% of the total global freshwater withdrawals (Porter et al. 2019). Preserving a robust and diverse natural environment is of utmost importance to ensure the enduring viability of food systems and the well-being of human populations.

The agricultural sector substantially contributes to climate change, which stands as the foremost critical environmental issue confronting the global population in modern times. Several interrelated trends and risks threaten agriculture and food systems, with climate change being one of them. Additional factors contributing to the future of food security encompass the rapid loss of biodiversity, agricultural land use, and access to fresh water, which are also pressing concerns within the sector (Chersich and Wright 2019). However, climate change, specifically increased climate variability, is one of the greatest threats to food security. Achieving a sustainable food system across the globe ultimately relies on effectively managing the interconnected environmental changes and adopting more climate-adaptive processes.

An extensive body of knowledge and literature exists about the consequences of climate change, encompassing viewpoints from both proponents and sceptics regarding the influence of modern societies and industrialisation on the environment. This body of argument includes those who believe that the recent increase in climate change is attributable to periodic shifts in climate and is not causally linked to pollution and other detrimental emissions associated with human activities. Nevertheless, no matter the broad and varying perspective, it is indisputable that the global climate is changing, resulting in severe weather occurrences (Diogo et al. 2017). These occurrences may subsequently exert a significant influence on our agri-food industry. The primary sources of scientific knowledge about food systems in the context of climate change are studies of how weather changes and climate trends have affected food systems in the past and the direct effects of climate change on plant growth and yields, malnutrition, price and quality of goods available (Ceglar et al. 2017). Numerous studies have examined the impact of climate change on food security, focusing on aspects such as food availability, access, and utilization. Supporting this view, Ceglar et al. (2016) investigated the negative effects of climate on agricultural yields in France

1.3.5.2 Impact of Climate change on the Agrifood industry

The agricultural sector is also adversely affected by climate change, which manifests in various ways, such as increased temperatures, heightened pressures from pests and diseases, water scarcity, extreme weather events, diminished biodiversity, and other related impacts (FAO 2013). Crop production is anticipated to decrease in tropical regions, home to a significant proportion of the global population suffering from food insecurity and malnutrition. It is projected that yields in Asia and Africa would see an 8% loss. It is commonly known that the variations in climate situations of a local area are expected to drive the cultivation of some specific food. However, climate change and drifts in weather conditions in a geographical location significantly affect that region's productivity and economic prosperity, which may lead to population extinction and ineffective adaptation of AFSC operations to suit the conditions, harming the food system. Moreover, it is worth noting that climate change has resulted in the depletion of around 33% of the Earth's cultivable land during the last four decades (Malhi, Kaur and Kaushik 2021). Additionally, it is estimated that roughly one-third of the world's food production intended for human consumption is squandered, leading to substantial environmental, economic, and societal consequences. The effects of global climate change on food systems are likely to be wide-ranging, complicated, and vary across different geographical locations. Current and future social and economic conditions will also heavily affect them. Converting natural ecosystems into agricultural land leads to significant depletion of soil organic carbon, with potential losses of up to 80 tonnes per hectare. Most of this carbon is released into the atmosphere (Bamwesigye et al. 2019). The climate change phenomenon is anticipated to contribute to an escalation in market volatility, exerting a disproportionate impact on individuals and communities already susceptible to adverse effects.

The potential consequences of climate change extend beyond crop yields, encompassing food quality. These repercussions are of utmost importance in ensuring food security in the future. Studies have shown that the increased levels of carbon dioxide (CO2) ranging from 540 to 958 ppm resulted in a notable decrease in protein content in several crops, such as wheat, barley, and rice(FAO 2022); the agri-food sector needs to step up in its action to improve production and lower the impact of AFSC operations on the environment (emission of GHG). The vulnerability of Sub-Saharan Africa to climate change is heightened due to the interaction of many biophysical, political, and socioeconomic pressures, which also limit the region's ability to adapt. In addition to the observed rise in temperature, climate change is anticipated to induce uncertain variations in the intensity of rainfall patterns across sub-Saharan Africa. The increase in severe events, such as droughts and floods, has seen an upward trend. Africa's agrifood system has witnessed losses due to the flooding of farmland, an increase in the price of food, and an increase in the price of agrifood commodities for regional agrifood processing firms. The conventional agricultural practices regions increase their vulnerability to the uncertainty of weather outcomes.

Stakeholders and government organisations are finding ways of promoting the sustainability of the region's agrifood system. Several organisations, like the United Nations (UN), have collaboratively implemented a global call for nations to reduce GHG emissions. Initiatives like the Kyoto Protocol and the Paris Agreement played a significant role. The climate ambition set by different countries in the Paris Agreement highlighted the importance of national commitment in setting global GHG emissions reduction targets. This seeks to work to achieve the reduction of the worldwide rise in temperature to the pre-industrial temperature range, which is set to be less than 2^0C. The Paris Agreement is an international agreement which was a mutual pledge by 196 parties at the UN Climate Change Conference (COP21) in Paris, France, on December 12, 2015(COP 21 Report, 2015), and was set in motion on November 4th 2016. One of the most significant actions of the National Determined Contributions (NDC) entails several actions to reduce GHG emissions and enhance (COP 21 Report, 2015) adaptability to climate change to improve ambition progressively. The Paris Agreement establishes a comprehensive structure for providing financial, technological, and capacity-building assistance to countries, emphasising the responsibility of wealthier nations to aid those economically disadvantaged and more susceptible to the impacts of climate change. In contrast to the Kyoto Protocol, the Climate Action Tracker asserts that the Paris Accord of 2015 will provide favourable outcomes in enhancing global capacity to mitigate the worst consequences of climate change. Different countries are taking bold steps in reducing agriculture GHG emissions; for instance, the EU roadmap, whose objective is to achieve a low carbon economy, has set a target of agriculture GHG emission reduction to 36-37% by 2030 and 49% by the year 2050.

1.3.6 Capital Infrastructure

The growth and expansion of the agrifood supply chain business necessitates the presence of economic infrastructure, which encompasses several components such as transportation, energy, irrigation, and information and communication technology. This capital infrastructure is the bedrock of successful expansion and effective agribusiness in Africa. Unfortunately, most African countries have been battling bad road networks, leading to massive market irregularities and uncertainties, invariably contributing to weak market access to farmers' output. According to Mhlanga (2010), limited access to markets and inadequate infrastructure are common barriers that impede growth in Africa. This limitation can be vividly seen during the physical transportation of agrifood raw materials and completed goods, from one point to another, to undergo several activities such as processing and other crucial operations on the supply chain till it gets to the end users. Most primary food production ends as waste because it takes longer to link raw food materials to processors. Several African agribusinesses face challenges due to inconsistent energy supply (electricity), leading to them opting for alternative energy supplies, which are always very expensive. This infrastructure inadequacy has a massive impact on investment opportunities for both local and international investors due to the unproductivity perceived by the agrifood industry. In the same vein, Adenle A.A. et al., 2017 describe several challenges agribusiness in Africa faces, highlight several factors hindering agribusiness innovation in Africa, and describe agribusiness transformation as a prerequisite for economic growth of this sector in Africa.

Parallel to these, Ongayo (2008) African agrifood challenges are mismanagement and inadequate regulation and policy, traced to political instability, which hampered the AFSC actors and has led to significant challenges for impoverished individuals and communities. However, private sector investments play a crucial role in addressing the existing gap by offering valuable resources, including technology and finance, while facilitating the wholesome linkage between producers and the market. Hence, it is crucial to note the significance of the role of international organisations and the private sector in developing the agrifood industry in Africa and its impact on the socio-economic advancement of rural areas. Such crucial roles encompass investment opportunities, Seed funds, Research and Development (R&D), and support for several sectors' initiatives.

1.4 Research Aims, Objectives, and Questions

1.4.1 Research Aims

Considering the challenges facing the global agrifood system and the huge vulnerability of Africa’s agrifood system to pressing issues. The research seeks to contribute to knowledge and practices by examining the role and impact of industry 4.0 technologies in Africa's Agrifood supply chain system to achieve sustainability, in the context of Nigeria; using several research studies within Nigeria AFSC industry and considering the sustainability impacts (Economic, Social, and Environmental) and implications of Industry 4.0 technologies for actors within the Nigeria context.

1.4.2 Research Objectives

- To explore the level of knowledge and awareness of sustainability among agrifood actors in Nigeria.
- To identify the sustainability impacts of employing Industry 4.0 technologies by agrifood stakeholders in Nigeria.
- To understand the underlying enablers and challenges responsible for using and accepting Industry 4.0 technologies.

1.4.3 Research Questions

This study aims to address the following three research questions to meaningfully contribute to the literature and practices on agrifood supply chain sustainability in Africa (Nigeria).

I. How does using industry 4.0 technologies contribute to the Agrifood Supply Chain (AFSC) sustainability of AFRICA(Nigeria)?

This research question will examine the role of technology in building the socioeconomic status of the local communities in Nigeria and the level of adaptation this technology provides AFSC actors to face pressing challenges facing the continent's agrifood supply chain sector. Several studies (Wolfert, S. et al., 2017; El Bilali, H., and Allahyari, M.S., 2018; Klerkx, L., Jakku, E. and Labarthe, P., 2019) have highlighted the socioeconomic impacts of technological adoption in the AFSC. According to the research carried out by Schimmelpfennig and Lowenberg-DeBoer 2021) on precision agriculture, the authors highlighted the positive socio-economic impact of technology usage among farmers. This RQ will explore the effects of adopting and using Industry 4.0 technologies on Africa's social, economic and environmental context, using Nigeria as the country of consideration. This will provide a holistic view of the potential that these technological solutions can offer the agrifood practice, structure, and actors of the AFSC.

II. How will industry 4.0 technologies in the AFSC promote agribusiness transformation into more sustainable practice in Africa (Nigeria)?

This Research Question seeks to explore the possible transformation that Industry 4,0 technologies bring into the AFSC in Africa. It duly sits on scholarly work on academic literature, which explores the impact of Industry 4.0 technologies on the transformation of the agrifood system.

Lezoche provided scholarly evidence of the agrifood transformation using industry 4.0 technologies, Panetta, et al. 2020 of literature explain the new frontiers and possibilities industry 4.0 offers across the supply chain in terms of a data-driven process that comprises monitoring and a new decision-making model.

The studies further explored the impact and application of IoTs, Big Data and Precision agriculture on economic, social and environmental. Alonso et al., 2020 further explore the use of the Internet of Things in the livestock industry and highlight huge possibilities for promoting health with this technology.

Most research conducted in the line of study is in the context of developed countries. Therefore, this research will add to knowledge by exploring the questions in the context of Nigeria.

III. What underlying factors can promote the use and acceptance of technology in Africa (Nigeria)?

This research question will examine factors that promote the adoption of Industry 4.0 technologies in the AFSC in Nigeria. Several studies used Roger 2003, diffusion of innovation theory, across many disciplines. Feder and Zilberman 1985 employed the diffusion theory of innovations to examine the underlying factors that promote agricultural innovations in developing countries; Pannell, et al. 2006 in his study also argued the importance of this theory of diffusion in promoting innovative practices among rural farmers. Venkatesh et al. 2003 and Venkatesh . et al. 2012 researched factors influencing users' behaviour to accept and use technology and proposed a theory of unified use and acceptance of technology (UTAUT), with later research presenting the upgraded theory model. Many researchers have used this theory in different fields; Ronaghi, M.H., and

Forouharfar., 2020 applied the theory to using IoT technologies in smart farming. Ronaghi, et al. 2020 conducted research in the Middle East to identify factors that influence the adoption of intelligent farming among farmers in that region.

This research question will explore factors influencing the use and acceptance of industry 4.0 technology among agrifood supply stakeholders in Africa (Nigeria|) in their journey towards a sustainable AFSC system.

1.5 Research Methods

This research employs a mixed-method approach, described by Creswell & Plano 2017, as an approach that combines the use of qualitative and quantitative methods in one study, Hall, 2013 supported by the point that these two methods are employed to address the research questions. Saunders, Lewis, and Thornhill (2009) highlighted several principles that show the right choice of appropriate research strategy: research questions, research objectives and body of literature, which this study has duly followed in its selection of research strategy.

The research process approach started with qualitative data collection, which was done by interviewing farmers, food manufacturers and logistics actors who work and used industry 4.0 technologies in their operations across the AFSC to answer the RQ1 RQ2: How does using industry 4.0 technologies contribute to the Agrifood Supply Chain (AFSC) sustainability of AFRICA(Nigeria)? How will using industry 4.0 technologies in the AFSC promote agribusiness transformation into more sustainable practice in Africa (Nigeria)?

The interview process was conducted appropriately, encompassing recording, transcription, and analysis. The thematic analysis was conducted using the laid down procedure presented by Braun and Clarke (2006) using NVivo 12 software. The quantitative approach delved into the use of surveys. The framework proposed by Venkatesh, developed by V. et al. 2003, investigates certain factors that promote the use and acceptance of industry 4.0 technologies among AFSC actors in Nigeria. This investigates how factors like social influences, ease of expectancy, and facilitating conditions influence AFSC actors to use industry 4.0 technologies. The structural equation modelling was conducted using SmartPLS, a research method supported by Ringle et al 2022.

1.6 Research Gaps: Industry 4.0 in African Agrifood Supply Chains

An extensive literature review conducted in chapter 2 (literature review) showed that there are limited industry 4.0 technology applications within the agrifood industry in Africa and Nigeria. Most published papers and research are conducted in Asia and most developed countries; the application and research on Industry 4.0 within Africa and Nigeria's agrifood industry present critical research gaps worth investigating.

Firstly, it is worth noting that there exists a substantial knowledge and application gap between the application of Industry 4.0 technologies in Africa and developed economies. Despite the voluminous body of knowledge and literature that exist in this field, the application of industry 4.0 in Africa’s agrifood supply chain is underrepresented within the body of literature; because the continent has its uniqueness (60% of world’s arable land and young population), and its story of adoption and use of industry 4.0 technology needs to be study

Secondly, the current body of literature and studies on Agrifood 4.0 does not sufficiently address Africa's agrifood system's unique socioeconomic, infrastructure and readiness limitations. Having the majority of farm workers being smallholders, with digital literacy gaps, poor rural infrastructure and an ageing population of farm workers, this all contributed to unique acceptance and use of industry 4.0 technology across the agrifood supply chain, which has not been thoroughly studied in the current body of literature.

Thirdly, the African agrifood industry needs a contextual technology adoption framework that is specific to the African agricultural systems. The current research only presented a general adoption model that overlooks the characteristics of African agrifood practices, which requires a region-specific context adoption framework and research, the methodological gaps of which are addressed in this study.

Finally, there is limited or no empirical data to support the huge potential on the use and acceptance of industry 4.0 technology in tackling Africa agrifood challenges such as climate change, food waste and loss, youth employment and profitability to the actors.

1.7 AFSC Challenges Addressed in this Study

There are numerous challenges facing the global agrifood supply chain, which is common to most countries. The African (Nigeria) AFSC industry faces the challenges of post-harvest loss, food waste, climate change, lack of capital infrastructure, increasing food demand, natural resources degradation and lack of workforce. This study has examined the AFSC context of Nigeria. It will address how adopting industry 4.0 technology has helped address post-harvest loss, food waste, climate change, lack of capital infrastructure, increasing food demand, natural resources degradation, and lack of workforce.

1.8 Potential/Expected Contributions

The findings gathered in this study have significant policy implications. They can serve as guidelines and frameworks in the development and application of policy within the AFSC industry in Nigeria, fostering the transition into a digital-driven and sustainable agrifood system, resulting in more resilient and competitive agricultural systems. The study's main theoretical contribution is expanding UTAUT and providing practical insights for professionals in the field. Including Technology Adoption Readiness (TAR), Price Value, and enabling conditions in the context of Nigeria AFSC sustainability using industry 4.0 technology offers actionable strategies for technology adoption and use. The findings in this study have demonstrated that Industry 4.0 technologies are essential to creating new employment prospects in the AFSC industries. Consequent to these technologies, more professions requiring new skill sets are being created, which increases the workforce's need for ongoing learning and adaptation. The ability of Industry 4.0 technology to improve sustainability and operational sufficiency will encourage actors and agribusinesses to adopt and use technology within their operations successfully

1.9 Thesis Structure

Chapter One focuses on the global overview of the agrifood supply chain (AFSC) and is tailored to a specific region. It then further discusses the significant challenges facing the AFSC, which are drivers for sustainability. It describes global issues facing AFSC, like population growth, degradation of natural resources, climate change, lack of infrastructure (case of Nigeria), and food waste. These pressing challenges concern researchers and actors in the AFSC; nevertheless, they question how we can improve. How can AFSC be sustainable? Several methods have been employed to tackle these increasing questions; however, this research delves into the role of Industry 4.0 technologies to help AFSC achieve sustainability across social, economic, and environmental sectors. This chapter concluded by introducing the reason for a new way of doing things across the AFSC.

Chapter Two: This chapter aimed to do a robust critical review of the existing body of literature on agrifood sustainability (TBL perspective), agrifood 4.0, achieving AFSC sustainability in agrifood 4.0, integration of agrifood 4.0 and supply chain sustainability, technological scope (IoTs, Big Data, Precision agriculture, Drones, Blockchain), technological enablers, technology adoption and examining the readiness of technology adoption. The unified Theory of acceptance and use of technology (UTAUT) will be discussed and applied within the AFSC sustainability in light of Industry 4.0 technologies. A conceptual framework will be developed.

AFSC System Process Evaluation – an overview of the agrifood industry's challenges, including climate change, food waste, urbanisation, natural resource degradation, low yield and productivity, etc.

Chapter Three: This methodology explains the study's research philosophy, supported with appropriate justification. This study methodology research adopted Saunders et al., 2007 research onions, consisting of several essential parts of a research study. The researcher structures this section based on the several parts of the research onions: Research Philosophy, research approach, research strategy, research choices (or design), research techniques and procedures (Data collection), and justification, as well as the appropriateness of the method. Theories around food waste and other theories will be included here.

Chapter Four: Qualitative Data Analysis: Chapter four covers the qualitative data analysis, findings and presentation of results from AFSC actors in Nigeria who responded to the interview. NVivo 12 software was used to analyse the data in a thematic approach. The findings show inspiring ideas about the impact of Industry 4.0 technology in the context of Nigeria and the novelty of the overview of agribusiness transformation. Also, the findings in this chapter serve as a bedrock for developing an expanded UTUAT survey instrument for the quantitative method.

Chapter Five Quantitative Data Analysis: Chapter 5 presents the quantitative data analysis of this study. The survey instrument was developed using the Unified theory of use and acceptance of technology, with added variables such as Technology adoption readiness and enabling conditions. The survey questions were set up and distributed using the JISC survey, and the quantitative data were analysed using structural equation modelling (SEM) and analysed using SmartPls 4 software. The quantitative data analysis of the study helps investigate further factors that influence AFSC actors in Nigeria in the use and adoption of Industry 4.0 technology in their operations.

Chapter Six Discussion: This chapter comprehensively discusses the qualitative and quantitative findings presented in Chapters Four and Five and the research instrument (interviews and questionnaires) employed. Consequently, it further shows the correlations between the study findings and the reviewed literature, making logical conclusions about academic and AFSC practices in the Nigerian agrifood industry.

Chapter Seven: Contributions, Conclusion and Future Research

This section of the thesis covers how the research output meets the research objectives, the presentation of contributions to academics and practices and recommendations deduced from this study.

1.7 Summary

This chapter laid the foundation for the research background and rationale. It further explores the challenges the AFSC is facing and delves into the impacts of urbanisation and population growth, dietary demand, natural resources degradation, food waste climate change and lack of capital infrastructure. Stating the challenges the AFSC in Africa (considering Nigeria) face, the researcher presented the aims and objectives of the research studies, and research question which the study will be addressing.

CHAPTER TWO (2)

2.0 LITERATURE REVIEW

2.1 Introduction

This chapter provides a comprehensive literature review on the body of knowledge that exists within the agrifood 4.0 AFSC sustainability. The researcher begins by examining the brief overview of supply chain management, examines several SCM approaches establishes the TBL sustainability approaches within the several industries, and narrows it down to the agrifood supply chain context, considering the economic, social and environmental dimension of sustainability A further the application of TBL sustainability approach with the AFSC was discussed, and further discussion on the AFSC sustainability within the AFSC in Africa. The stakeholders within the system were discussed, as well as possible opportunities the AFSC industry has if the trajectory were towards sustainability across the supply chain. The chapter further discussed the application of Industry 4.0 technologies for sustainability within the

AFSC industry, which covers Big Data and the Internet of Things (Iot). The study recognises this technology's sustainability impact in farming, food processing, and manufacturing. This study further conducted a comprehensive application of these technologies to farming (Smart Framing, Precision Agriculture), food processing/manufacturing (Food processing industry 4.0), and Logistics (Smart Logistics) within the AFSC. The sustainable impact of this technology adoption was examined as stated in the literature and supported by leading authorities within the field. The theory of technology adoption was examined, which enables the researcher to understand factors that promote the use of this technology among AFSC actors in Nigeria and possibly presents a procedure or framework for AFSC 4.0 transition towards sustainability. The Unified Theory of Acceptance and Use of Technology was studied in the context of the agrifood supply chain.

2.1.1 Supply Chain Management.

Brandenburg et al. (2014) quoted Mentzer et al., 2001 definition of SCM Supply Chain Management (SCM) as managing the movement of physical, logical, and financial resources across network links between different organisations. The goal of SCM is to create value and ensure customer satisfaction**.** According to Mentzer's (2001) study of the definition of SCM, the author highlighted several SCM definitions from various authors and categorised them into management perspective, application of management perspective and management process. (Stock & Boyer's 2009) study explores different definitions of SCM and argues that the clarity of definition will propagate better implementation of the theory and practice of SCM. Mentzer et al. 2001, describe SCM as a management perspective that sees the supply chain as a whole entity, employing a systems approach.

However, there are a few significant issues with supply chain management (SCM), most of which come from the outdated systems' lack of transparency. A lack of transparency causes several misunderstandings and concerns by impeding stakeholders' capacity to comprehensively understand the supply chain process (Subramanian et al., 2023). Also, tracing products via these conventional systems can prove incredibly challenging due to the complications in accessing real-time updates of the substance's movement in the supply channel and the flow of the corresponding record. This limited visibility constrains successful tracking and mitigates against speedy problem remediation (Singh et al., 2022). Additionally, the difficulties in obtaining real-time updates on activities on the supply chain and limited visibility of the operations hinder effective tracking and slow down the resolution of issues quickly (Singh et al., 2022). Realizing that different traditional SCM systems are highly susceptible to fraud scenarios and activities is also essential. The quick integration and use of software in these systems make it difficult to comply with traceability and transparency standards, which increases the likelihood that fraudulent activities will go undetected and compromises the supply chain's basic integrity (Hasan et al., 2022). Krichen, 2022 suggested that the integration of contemporary technology such as the Internet of Things (IoT), product tracking, effective logistic management, and greater efficiency improves supply chain management (SCM), leading to better profitability. Iyigün, 2021 believed IoT solutions, for instance, assist industries like the food sector in supply chain management, analysis, and monitoring. Having the capacity to track and trace products would help industries like the supply chain become more transparent, effective, and safe for food. These enhancements increase supply chain efficacy and efficiency while also improving consumer happiness and the companies' standing in the market. (Iyigün, 2021). According to Chowdhury 2024, SCM is essential and significant for all businesses because it increases operational efficiency and lowers costs across industries. It's also critical to understand that traditional supply chain management (SCM) systems have several intrinsic issues, such as inadequate system information, difficult product tracking, and the ease with which fraudulent activity can undermine the majority of systems. Chowdhury 2024 conducted a study to examine the role of SCM in integrating blockchain technology. Future developments in blockchain for supply chain management, including multichain and integration with other cutting-edge technologies, indicate that the area is poised to grow in order to provide the supply chain with greater resolution and dependability (Chowdhury 2024). It appears that blockchain technology, which offers an operational wall-built ledger and greatly boosts transparency and traceability rates within supply chain operations, is the foundation of the contemporary SCM solution.

Chowdhury 2024 illustrates the useful benefits and possible drawbacks of blockchain integration into SCM by looking at successful case examples. The major SCM concerns are Transportation, storage, inventory management, and upholding safety and quality requirements are important concerns (Kumar and Sahoo 2025). Mhlanga et al. 2022 examine the growing interest in the circular economy in Africa's built environment, highlighting interdisciplinary collaboration and regional differences for policy implications. Jusoh et al 2021., conducted a bibliometric analysis that revealed trends in irrigation and IoT, showcasing fresh concepts for better agricultural water management.

Sustainable supply chain management (SSCM) presents a more robust system approach than the traditional SCM, whose primary objective is business economic performance. SSCM incorporate environmental and social perspectives in measuring business supply chain management performance; this expansion of focus extends beyond the economic component to encompass the triple bottom line (TBL) (Brandenburg et al. 2014).

Carter and Liane (2011) agreed that the three-dimensional view of sustainability seems to have gained widespread acceptance across several disciplines and businesses. This enables a holistic understanding of incorporating sustainable objectives such as social, environmental and economic concerns intertwined. Carter and Liane (2011) explore an in-depth study on the evolution of sustainable supply chain management and highlight several strata of development in perspective in the concept of sustainability, which comprises a body of research that approaches Social and environmental as a standalone and evolve into the corporate social responsibilities and to a more holistic perspective of Triple Bottom Line and the establishment of SSCM as a framework. The Carter and Rogers (2008) study established the concept of sustainability and its social, environmental, and economic integration. It argued that this can lead to long-term financial viability. Many studies have researched the application of sustainability in three dimensions of supply chain management (Seuring 2013).

Elkington (1998) argues that incorporating TBL is a holistic component of an organisation's pursuit of sustainability and has seen widespread acceptance for consistently becoming more critical for the decision-making process for management, especially in SCM.

Elkington (1997) introduced the concept of the "Triple Bottom Line" (TBL), which consists of People, Planet and Profit, which has gained massive recognition on a global scale. The TBL establishes the fundamental aspects of the area of focus for organisations undergoing the transition towards sustainability; it encompasses three crucial sustainable development components: environmental, social, and economic.

The most common way to visualise this was to represent all three elements in a Venn diagram, showing sustainability as the intersection or overlap of three dimensions. Nevertheless, a drawback of this approach is its failure to demonstrate the level of importance among the three dimensions. Getzner (1999) identifies this presentation as insufficient to capture the full scope of sustainability implementation and proposes an alternative "strong approach" that encompasses a broader environmental system. The nested systems approach views the economy and society as constrained subsystems within the larger environmental context. Researchers widely acknowledge this conceptual framework, known as the Russian Doll model, as a robust foundation for understanding sustainability. According to Lawson and Beckmann (2010), this model emphasizes the crucial importance of ensuring economic activities are in harmony with overarching social and ecological systems.

The goal of sustainability is driven by discontentment with the current condition and issues facing AFSC. A sustainable agrifood system is a recommended approach that promises to benefit the AFSC by optimising economic profits while preserving environmental quality; Zilberman et al. (1997) examined the role of technologies in achieving sustainable agriculture. The pursuit of sustainability in driving agrifood businesses necessitates significant transformations in their performance across the triple bottom line. However, the most intriguing difficulties are not confined to individual domains but rather arise from the intersections and interplay between the economic, social, and environmental dimensions. The concept of "Triple Bottom Line" (TBL) accounting has gained significant popularity in the realms of management, consultancy, investing, and non-governmental organisations (NGOs) in recent years. The underlying concept of the TBL paradigm posits that a business or organisation's overall prosperity or well-being may and ought to be evaluated not solely based on conventional financial metrics but also by considering its social, ethical, and environmental achievements.

According to Govinda (2018), collaboration is needed throughout the supply chain as an essential and crucial requirement for firms to achieve their sustainability objectives. Implementing SSCM can decrease resource consumption, material usage, and waste generation by optimising resource utilisation (Govinda 2018). Li et al. (2014) conducted an in-depth literature review on the SSM in the context of agrifood systems. The academic piece presents the opportunity and challenges of implementing SSM and further delving into innovative technologies fostering SSM in the AFSC. Addressing the issues of SSM in FSC, Cojocariu (2012) focuses on the context of green logistics and sustainable FSC. Govinda 2018 addresses sustainability in the context of production and consumption, listing underlying theories that influence sustainable consumption and production.

2.1.2 Agrifood Supply Chain Sustainability (Farming, Processing, Logistics)

The heavily regulated and protected agri-food sector significantly impacts sustainability practices (Joshi et al., 2020). Its influence spans meeting human needs, maintaining jobs, driving economic growth, and shaping environmental conditions. Growing environmental, social, and ethical concerns, coupled with increased awareness of food production and consumption's ecological impact, have intensified pressure on agri-food businesses from various stakeholders. Global concerns about food supply and quality drive the push for agri-food supply chain sustainability. This is particularly significant given the perishable nature of these products and the considerable volatility in supply and demand (Galal and El-Kilany 2016).

This pressure emanates from consumer advocacy organisations, environmental groups, policymakers, and an array of consumer associations, all urging these companies to confront the social and ecological challenges embedded within their supply chains across the entire lifecycle of agrifood products (Tsolakis et al., 2014; Joshi et al., 2020). In an Indian study conducted by Aggarwal and Srivastava (2016), it was revealed that sustainability factors about the production, distribution, and retailing aspects play a pivotal role in enhancing the resilience of the agricultural-based Indian economy. The study underscores the critical significance of an efficient and sustainable agri-food supply chain system in achieving this objective. It is worth noting that the production and distribution of agricultural products hold a significant position within the global economy, serving as a fundamental supply source for various industries. Moreover, these agricultural systems are often considered the backbone of economic development, particularly in emerging nations (Siddh et al., 2017).

The agrifood supply chain encompasses a wide range of processes associated with managing agricultural products, spanning from the initial cultivation by farmers to the eventual consumption by customers, as highlighted by Mangla et al. (2018). This intricate system comprises diverse individuals and organisations, directly or indirectly connected to the supply chain, working collaboratively towards shared goals. These common objectives encompass guaranteeing the "quality, security, safety, and sustainability of the food supply. In Agnusdei and Colcuccia (2022), it was noted that the sustainability of the agrifood supply chain is essential for the significant changes towards the promotion of sustainability. The Agrifood supply chain needs to achieve sustainable development because this is a challenge for the sector due to its immense contributions to waste and emissions (greenhouse gas) (Mirabella, 2014), both in developing and advanced nations.

According to Carlos et al., (2021), prioritising sustainability as the foundation for improving the AFSC is crucial. It was highlighted by Mangla et al. (2018 that the agrifood supply chain (AFSC) encompasses all the processes and operations involved in the primary production of food, processing, and distribution of agricultural food products, starting from the farmers till it reaches the consumers. Different stakeholders are involved in several activities within the supply chain's upstream, midstream, and downstream. Taylor (2016) argues that the three prospective objectives of sustainable development are economic expansion, environmental protection, and social justice.

Therefore, the AFSC's sustainability hinges on the social, ecological and economic viability of all actors and processes in the agrifood system. Ana Esteso (2022) explores a multi-objective optimisation model for strategic planning activities across the AFSC, highlights how this process helps achieve several sustainable objectives and presents a tool for this approach. To foster the sustainability of AFSC, it is recommended to centrally coordinate the planning of planting, production, and commercialization of crops. A data-driven process to manage planting, processing, and production processes in the AFSC is crucial to achieving sustainability. AFSC sustainable planning aims to align all SC performance objectives to the three pillars of sustainability. Banasik et al., (2017) explored the study on reducing the environmental impact of production and distribution in the AFSC. Yuna and Tara (2020) explored the short food supply chain and their sustainability implications; the study presented the social, economic and environmental benefits of short food supply chains. The study outlines a proposal for future research and development trajectory. It focuses on the role of the short food supply chain in facilitating the transition of the agrifood system into a sustainable outcome. Kneafsey et al. (2013) highlighted several SFSC initiatives, including farmers' markets, community-based agriculture support, and farmers' shops. According to de Keizer et al., (2017) the effectiveness of AFSCs in terms of economic and environmental impact is closely tied to the structure from farm to fork. This includes factors such as the number, kind, and location of facilities and the movement of materials and information between them. As a result, reevaluating the structure of AFSC may improve performance and promote sustainability (Jochem et al. 2019).

Brodhag and Taliere (2006) describe sustainability's environmental objectives as the capacity and integrity of the natural environment ecosystem to remain productive and resilient to maintain and support human existence. Parallel to that, Farazmand (2018) proposed social sustainability as a fair system that provides good livelihoods, alleviates poverty, and promotes fairness and gender equality.

Sustainability is crucial while planning and operating modern AFSC networks, where profitability and environmental implications are carefully managed. (Hassini, Surti, & Searcy, 2012 describe this as an emerging concern among many stakeholders, government, and research communities. Increasing concern arises within the AFSC due to the multilayered activities of the sector and its substantial impact on the environment, including farming, postharvest, transportation, and food manufacturing. This negative impact leads to incurring higher carbon taxes.

It is crucial to address the leading decisions on this approach to build a successful sustainability strategy for the design and management of AFSCs. Tsolakis et al., (2014) explored the possibility of achieving AFSC sustainability, highlighted several decision processes, and presented a framework containing different strategic decisions comprising frame technologies selection, investment, supply chain partnership, and the decision to ensure sustainability.

Several scholars and researchers have examined the efficiency and sustainability of supply chains for AFSC (Higgins et al. 2010). The AFSC stakeholder commitment to sustainability was duly emphasised by Maloni and Brown (2006) as a show of their agribusiness responsibility towards more sustainable practices. Van der Vorst et al. (2009) emphasise that the investment in AFSC focuses on improving its performance and covers a broader scope of improving agri-food product quality and environmental sustainability. Mintcheva (2005) contended that addressing environmental concerns in an AFSC requires a holistic approach rather than tackling them individually at each stage, suggesting incorporating a set of indicators into a comprehensive environmental policy framework for these supply chain networks.

2.1.3 Triple Bottom Line (TBL) Approach

The TBL approach promotes holistic decision-making in the agri-food sector, emphasising sustainability across three dimensions. It seeks to advance practices that benefit profits and the well-being of people and the planet (Ozanne et al., 2016). Adopting this approach helps create responsible and resilient food systems. The people dimension focuses on the social and human aspects of agrifood sustainability. It includes food security, safety, workers' conditions, health, and community well-being (Janker & Mann, 2020). The approach emphasises that a sustainable agrifood system should ensure fair treatment of labour, promote access to nutritious food, and contribute to the overall welfare of people involved in the supply chain. The planet approach emphasises ecological sustainability. Sustainable agrifood practices should minimise carbon footprint, reduce waste, conserve natural resources, and protect biodiversity (El Bilali et al., 2021). The third, which is profits, explains agrifood's economic dimension and financial sustainability; a sustainable agrifood system should ensure that businesses within the supply chain can operate profitably while adhering to ethical and environmental standards (Saitone & Sexton, 2017).

2.1.3.1 Environmental Sustainability

According to the insights provided by Morelli (2011), environmental sustainability can be defined as the capacity to fulfil the resource and service requirements of both present and future generations while upholding the well-being of the ecosystems that supply these essential provisions. This notion extends beyond merely preserving resources; it encompasses a dynamic equilibrium marked by resilience and interconnectedness. This equilibrium enables human society to meet its essential needs and ensures that such fulfilment occurs without surpassing the ecosystem's capacity to regenerate the services required to meet these needs. This principle emphasises that human actions should not reduce biological diversity, preserving the intricate web of life that sustains our planet (Haines-Young & Potschin, 2010). In their comprehensive examination of AFSC, Tasca et al. (2017) delved into the critical aspect of environmental sustainability. They highlighted various proposed strategies to mitigate the ecological footprint associated with food production and consumption. Among these strategies, they emphasised the significance of organic and integrated farming practices, which represent alternative and eco-conscious approaches to cultivation.

Furthermore, in the pursuit of enhanced energy efficiency and climate resilience, Tasca et al. (2017) put forth the idea of adopting alternative distribution systems. These systems, they suggested, could play a pivotal role in driving environmental sustainability within the agri-food supply chain. By optimising how food is transported and delivered, these alternative distribution methods can contribute significantly to reducing the overall environmental impact of the supply chain, ultimately advancing the cause of sustainability. Environmental sustainability within the agri-food sector serves as more than a mere ethical imperative; it stands as a proactive response to the mounting global apprehensions regarding pressing issues such as climate change, the dwindling availability of vital resources, and the degradation of ecosystems (Bogardi et al., 2012). To effectively address these concerns, Zuazo et al. (2011) underscored the significance of embracing several critical pillars of environmental sustainability.

Among these fundamental components, a paramount focus involves the minimisation of water usage, the mitigation of soil erosion, and the promotion of responsible land use. These elements are pivotal in ensuring that agri-food practices are conducted in a manner that respects and preserves the natural environment. Additionally, it's crucial to acknowledge that agri-food operations can substantially contribute to greenhouse gas emissions, as highlighted by Karwacka et al. (2020) and Yue et al. (2017). In response to this concern, their research findings advocate adopting sustainable strategies. These measures involve reducing pesticide use to minimise environmental impact and protect ecosystems while implementing efficient transportation methods to reduce the carbon footprint of agri-food operations. Thus, environmentally sustainable practices in the agri-food industry aim to balance the imperative of food production with the protection and preservation of our planet's ecological well-being (Menaggia, 2021).

2.1.3.2 Social Sustainability

As Melendez et al., (2009) assert, the social dimension of agriculture is an indispensable facet of global agri-food sustainability. The agri-food system grapples with significant social challenges that warrant attention and action. Social sustainability entails enhancing social conditions for farmers (a multifaceted approach aimed at improving the overall well-being of farmers and other rural workers). It encompasses initiatives to strengthen social services, such as healthcare and education, and to create better working conditions. Additionally, it involves fostering opportunities for active participation in civic discourse, cultivating a sense of community, and reinforcing the connection to the land. In practical terms, social sustainability indicators in agri-food systems are valuable instruments for evaluating several essential factors.

Farmer welfare and social sustainability are closely related in the agri-food industry. It includes ensuring food security, which may be accomplished in two ways: either by having the ability to buy food from the market or practising subsistence farming, in which households grow enough food to meet their needs (Fallah-Alipour et al., 2018). It also includes measures of hunger prevalence as a proxy for overall well-being (Hammond et al., 2021). In the agri-food industry, social sustainability also entails assessing food items' nutritional security and conformity to recognised certifications and quality standards (Peano et al., 2014). A critical point that Zanzi et al. (2021) brought attention to is how responsive producers are to customer concerns. This includes protecting supplier rights, fair pricing and clear contracts, and considering price differences when calculating transaction costs.

These components all contribute to fostering social sustainability within the agri-food domain. In essence, social sustainability in agri-food addresses the well-being of agricultural communities. It encompasses the safety and quality of food products, all while emphasising fair and transparent practices within the supply chain (Sannou et al., 2023). The social sustainability of agri-food, according to Baccar et al. (2019), is dependent on the involvement of farmer organisations. This framework emphasizes the interconnections between actors in agri-food systems, highlighting the crucial role of social capital. It evaluates the level of social unity and resilience across diverse stakeholders, encompassing farmers, institutions, and broader society.

2.1.3.3 Economic Sustainability

Agriculture and food industries are vital for millions of livelihoods in both rural and urban settings (Diehl, 2020). The agri-food supply chain (AFSC) sector serves as a powerful tool for poverty reduction and vulnerability mitigation, justifying increased investment in eco-friendly and sustainable practices (Negra et al., 2020). However, food insecurity persists even in developed economies (Galli et al., 2018).

Reflecting on COVID-19's impact on marginalized areas, Bounie et al. (2020, p. 367) advocate shifting focus from merely rebuilding agricultural production to addressing the entire food system. This approach aims to harmonize long-term support for resilient communities and sustainable livelihoods with humanitarian aid. Moreover, climate change necessitates adaptation and resilience-building in rural livelihoods (Butler et al., 2020).

Local and shorter food supply chains significantly boost regional economies, presenting a strong case for their promotion (Scuderi et al., 2017). In Russia, Derunova et al. (2019) identify the inclusive development of the agri-food system as a key driver of sustained economic growth in regional economies.

Hassen et al. (2020) have underlined the crucial role that market dynamics play in addressing the economic sustainability of agri-food systems. Food availability and affordability are tied to economic sustainability (Emes, 2018). Drewnowski et al. (2020, p. 1) recommend rebuilding food systems to deliver an appropriate supply of calories and nutrients at a fair cost. This involves concerns about the pricing and volatility of agri-food products (Pinstrup-Andersen, 2014). To summarize, the complex relationship among economic factors, food availability, and adaptability to worldwide difficulties highlights the diverse aspects of sustainability in agri-food systems.

2.2 Agrifood SCM in Africa

Within the African context, there is a noticeable trend towards commercialising food production, facilitated by the emergence of a pivotal intermediary sector that bridges the gap between agricultural producers and the broader markets. This intermediary sector encompasses various actors, such as collectors, wholesalers, transporters, processors, packaging suppliers, distributors, and caterers (Bricas, 2012). As Bricas (2012) underscored, this agrifood sector predominantly comprises small-scale traders. Their activities are often interwoven with agricultural endeavours in rural regions or are integrated into urban areas as part of domestic cooking practices. This sector, while diverse, plays a vital role by generating many employment opportunities, particularly for women, and significantly contributes to overall income levels.

Mabaya (2022) states that over 80% of Africa's population primarily depends on open-air and largely informal food markets. The subpar sanitation conditions in many of these markets give rise to apprehensions regarding food safety, particularly for the households that rely on them. To fortify and sustain resilient agrifood systems in African nations, there is a need for a transformation in food value chains. This transformation entails a shift from informal micro-enterprises towards the formalisation of firms that offer stable wage employment, income security, and health benefits for their workforce; as Kaneene et al. (2015) emphasised, this transition can potentially enhance food safety standards within the agrifood system in Africa.

A study in Morocco (Badraoui et al., 2020) clarified the unique characteristics of the agrifood supply chain. It emphasised their crucial function in the African agrifood supply chain management context. This pertinence arises from the Agrifood Supply Chain's unique attributes, characterised by specific transportation and storage demands and the challenge of the limited shelf life of perishable food products (Van der Vorst et al., 2011). Consequently, investigating the enabling and constraining factors underpinning collaboration within this sector becomes imperative. Its multifaceted objectives set Agrifood Supply Chain apart from conventional supply chains. While cost reduction, responsiveness, and sustainability remain essential, the Agrifood Supply Chain emphasise two crucial aspects: food quality enhancement and reducing food wastage (Soysal et al., 2012). This dual focus sets Agrifood Supply Chain on a specialised trajectory, where the imperative is not only to streamline operations but also to elevate food quality and concurrently combat the challenge of food waste, aligning closely with the sustainability and food security goals in the African context.

Ortmann (2001) explores the industrialisation of agriculture and how supply networks are essential to raising the competitiveness of South Africa's agri-food supply chains. His study highlights small-scale farmers' difficulties, especially regarding supply chain sustainability and profitability. Additionally, Ortmann and King (2010) highlight the significance of establishing the appropriate institutions to boost the agri-food supply chain's competitiveness and that of small- and commercial-scale farmers. A comprehensive study conducted by Kehinde et al. (2022) examined the contemporary landscape of urban agri-food supply chains in Africa, focusing specifically on Lagos State, Nigeria. The investigation revealed persistent challenges within the system, predominantly stemming from infrastructural deficiencies and significant food waste. The researchers posited that these issues were largely attributable to the absence of timely, real-time data regarding the status and dynamics of the agri-food supply chain. This study underscores the critical role of information systems in optimising supply chain efficiency and reducing food waste in rapidly urbanising African contexts.

Furthermore, a significant study highlighted a noteworthy distinction in the approach toward supply chain sustainability between large agribusinesses and small and medium enterprises. The former, the research noted, appeared to emphasise issues related to food wastage and its mitigation. In contrast, smaller enterprises seemed to lag in this aspect. The study emphasised the significance of stakeholders using real-time data for informed decision-making. This, the research suggested, can effectively reduce waste and drive economic growth within the agri-food supply chain. It called for increased real-time data analytics to tackle food waste and infrastructure issues in African urban agri-food supply chains.

2.2.1 Key Actors and Stakeholders

In the African agri-food domain, many crucial actors and stakeholders hold significant sway in shaping the industry and underpinning its sustainability (Borsellino et al., 2020). These influential participants span a broad spectrum of organisations, entities, and individuals, all deeply engaged in various facets of the agri-food supply chain (Stone & Rahimafard, 2018). These collective contributors wield substantial influence over the dynamics of the African agri-food sector, having a considerable impact on policies, trade practices, sustainability initiatives, and food security endeavours. Effective collaboration and seamless coordination among this diverse array of participants are integral to effectively tackling the distinct challenges and opportunities inherent in the African agri-food landscape.

As outlined by Greenberg (2015), the agrifood industry involves a spate of stakeholders, notably including small-scale and subsistence farmers, as well as their counterparts in the commercial farming sector engaged in large-scale production. Agribusinesses, both large and small, play a pivotal role, as do Non-Governmental Organisations (NGOS) working towards various agrifood-related objectives. Government bodies and regulatory agencies wield authority in guiding and overseeing the sector. Additionally, consumers, the ultimate end-users of agri-food products, significantly influence market dynamics and trends, further enriching the tapestry of stakeholders shaping the African agri-food landscape.

In South Africa, establishing strategic collaborations between agribusinesses and emerging farmers emerged as pivotal drivers for diverse innovations to connect these farmers to the global market stage (Bitzer & Bijman, 2014). Integrating emerging farmers into the worldwide market demanded innovative solutions and cooperative efforts. Such endeavours not only required mutual interest but also necessitated a degree of political pressure to facilitate the partnership and ensure its effectiveness (Bitzer & Bijman, 2015). The relationship that agribusinesses have with up-and-coming farmers in South Africa is seen as a driving force behind revolutionary inventions that enable these farmers to access international markets. The fact that these partnerships have been successfully formed is evidence of the complex dynamics at work, where a convergence of interests, creative problem-solving, and sporadic government stimulus come together to generate growth and development opportunities in the agricultural industry.

2.3 Sustainable Agrifood Supply Chains in the Africa Context

The establishment of resilient and sustainable agri-food supply chains in Africa presents a complex challenge, given the multifaceted sources of uncertainty and risk confronting the continent. This challenge has far-reaching implications for Africa's economic, environmental, and social sustainability (Obonyo et al., 2023). Esteso et al. (2018) propose a framework that categorizes crop-based uncertainties into four distinct groups: Process uncertainties (encompassing factors such as harvest yield, supply lead time, resource requirements, and production variables), Market uncertainties (including demand fluctuations and price volatility), and Environmental uncertainties (comprising weather patterns, pest infestations, disease outbreaks, and regulatory changes).

Lezoche et al. (2020) emphasise that inadequate management of these uncertainties can have deleterious effects on various aspects of the agri-food supply chain. These impacts may manifest as increased waste, compromised quantity and quality of produce, food safety concerns, and the depletion of natural, technological, and human resources. This underscores the critical importance of developing robust strategies to mitigate and manage these uncertainties within the African agri-food context.

The unique challenges faced by the African agrifood community have paved the way for digitalisation and the infusion of technology to enhance and establish Sustainable Agrifood Supply Chains on the continent (Pavageau et al., 2020). The digitisation of supply chains enables real-time monitoring of material flows, making potential risks visible and aiding in developing proactive strategies to address them (Bhattacharya & Charttejee, 2022). The digitalisation of supply chain processes is primarily motivated by two key objectives: firstly, to improve the agility and responsiveness of industrial and logistics systems, and secondly, to strengthen the robustness and resilience of agri-food supply chains (Michel-Villarreal et al., 2021).

2.3.1 Challenges and Opportunities

In the research conducted by Gashu et al. (2019), the African continent has, on the whole, experienced a notable deceleration in the agri-food sector. This deceleration is attributed to a confluence of factors, including the ineffective implementation of agricultural policies, weak institutions, and governance issues that collectively contribute to the sector's sluggish progress. A radical metamorphosis is imperative to foster a transformative shift within the agricultural landscape, transitioning it from a gradually advancing industry to one that robustly bolsters the African economy. These transformational aspirations, however, confront several formidable challenges that warrant attention. The burgeoning growth of the farming population and the ensuing reduced available farmland pose a substantial hurdle. Additionally, climate change impacts, the growing spectre of water scarcity, considerable post-harvest losses, and limited market involvement all compound the complexities of propelling the agri-food sector into a progressive and prosperous force. Africa's agri-food industry has faced significant challenges to its growth and sustainability. Realising that a thorough transformation is necessary is the first step to realising its potential as a dynamic and significant contributor to the African economy. However, it is still evident that these transformative initiatives must tackle and deal with the industry's many issues, such as population expansion, climatic volatility, and economic accessibility.

Because agrifoods are climate- and time-sensitive, Africa can construct infrastructure to facilitate the movement of agrifoods from the farm to processing facilities (Llanto, 2012). The processing hubs also require substantial access to electricity. (Ellis et al., 2022) assert that institutional and bureaucratic infrastructures are critical to preventing quality constraints that undermine customer confidence in the food safety system and force consumers to buy higher-quality goods from producers outside Africa. Furthermore, as emphasised by Kaneene et al., (2015), a consistent supply of well-trained technical and scientific expertise is indispensable to instigate the essential surge in productivity within Africa's food system. This expertise, acquired through robust agricultural education and training programs, bolsters various facets of the agri-food industry. Investing in cultivating a skilled and knowledgeable workforce is pivotal for ushering in the desired productivity improvements across Africa's agri-food spectrum. It serves as the linchpin for driving advancements in agricultural practices (which includes breeding of plants, supply and service of farm inputs, agronomy), supply chain efficiency, food safety, food processing/packaging/distribution and overall sustainability, ultimately contributing to the growth and development of the continent's food system.

2.3.2 Technology in AFSC sustainability

Yadav 2022 presented another paradigm in AFSC sustainability, which is based on the use of Industry 4.0 technologies with promising sustainable AFSC systems. Moreover, this reimaging is possible due to the current progress presented by Industry 4.0 technologies such as "Internet-of-Things (IoT), Blockchain, Big Data (BD), Drones, AI and Cyber-Physical System (CPS)". These arrays of technologies bring distinct capabilities and functions to transition the AFSC supply chain towards sustainability. Technology enables an efficient e-commerce system for global agrifood trade, offers traceability options for monitoring the origin of products, and supports efforts for a circular economy.

Industry 4.0 technology enables AFSC to enhance its sustainability and resilience by promoting the flow of information and stakeholder collaborations. Lezoche et al. (2020) believe that Industry 4.0 technologies can facilitate the coordination of supply chains, which is crucial for maintaining sustainability. This leads to broader advancements in technology and agricultural techniques that have fueled the rise of innovative AFSC operations such as smart farming (SF), resulting in enhanced management of agricultural processes.

The study by Feng et al. (2020) investigated the successful implementation of innovation and its impact on agrifood business sustainability. They thoroughly established the role of Industry 4.0 technologies in supply chain sustainability. The role of Industry 4.0 technologies in data informs better business decisions. The findings indicate that 4.0 technologies facilitate rapid information exchanges among customers and AFSC actors. The adoption of Industry 4.0 technologies has resulted in new agribusiness frontiers; as noted by Spanaki et al. (2021), technologies are giving rise to new agribusiness frontiers. Lowry et al.,2019 describe it as a paradigm shift among the AFSC stakeholders. This technology-driven AFSC presents a digitalised business model and approach, promises efficiency, and prioritises sustainability as the core of all AFSC technology-driven processes. Most of these are new businesses, primarily startups or enterprises in their first expansion phases. However, the challenges of climate change and sustainability have led the AFSC business leaders towards a trajectory of technological solutions to enhance agrifood production efficiency (Yadav 2022).

Alonso et al., 2020 highlighted the role of IoTs and sensors in monitoring and data-driven processes within the AFSC covering crop production and livestock. Pujahari et al., 2022 highlighted how technology provides weather forecasts to AFSC actors to make data-driven decisions better. Technology makes this possible to monitor food conditions across the AFSC, decreasing agrifood waste during distribution. A variety of sustainable agricultural techniques aimed at enhancing soil fertility, boosting crop yield, and promoting environmental sustainability (Alonso et al., 2020).

Efforts to present sustainable agriculture as a 'mitigation' approach rather than just an adaptation or productivity-optimisation approach must acknowledge and address these compromises. This raises concerns about the perspective and trajectory of seeing CSA as a mitigation rather than an adaptation medium across several nations. Bouzembrak et al. (2019) conducted a literature review on the application of IoTs in the AFSC; the study reported that the use of IoTs in food safety is an emerging phenomenon, and food conditions were tracked using Internet of Things technologies, with parameters like location, temperature and humidity. Bouzembrak et al. (2019) discovered that most of this research was from Chinese institutions, focusing primarily on IoT applications in food supply chains to track and monitor food safety and quality. In the study by Kamilaris et al. (2017), on the application of big data in agriculture, the authors concluded that it would provide farmers and AFSC actors with leverage to improve their productivity, even though the application of big data in agriculture is at an infant stage. Feng et al. (2020) explored the study on blockchain technologies in the traceability of agrifood products across the AFSC and presented a framework for AFSC food traceability for sustainability purposes. Lezoche et al., 2020 presented a holistic definition of agrifood 4.0, which shows the relationship between the Industrial Revolution and its impacts on several industries, including agrifood. Agrifood 4.0 can be described as the body team for applying Industry 4.0 technologies in the agrifood system.

2.3.3 Technologies in the Agrifood Supply Chain

Many emerging technologies have made it possible to improve and streamline the traceability of food items in the agri-food supply chain. The technologies in question include a wide range of options, including blockchain, RFID, barcodes, QR codes, RFID, Internet of Things (IoT), information and communication technologies (ICT), and TraceCore XM (Rana et al., 2021). Integration reduces the overall cost of these technologies while simultaneously enhancing their functionality.

Distributed ledger technology (DLT), or blockchain technology, has emerged as a helpful instrument in recent years for enhancing product traceability, transparency, and the velocity of information transfer in supply chains (Behnke & Janssen, 2020). The primary objective of this technology is to instil confidence in consumers regarding food security, sustainability, product quality, and safety (Chen et al., 2021). Additionally, blockchain technology lowers corporate transaction costs (Alonso et al., 2020). When Bitcoin launched in 2009, blockchain was a crucial platform component (Giungato et al., 2017). It functions as a distributed, decentralised, and digital ledger where transactions are successively recorded to create irreversible, unchangeable records. With this method, information is cryptographically secured and kept indefinitely in the ledger, allowing stakeholders to share it safely (Treiblmaier, 2018). Blockchain technology offers a stable and trustworthy means of enhancing the Agrifood supply chain's traceability and transparency while reducing costs and fostering consumer confidence.

In the Internet of Things (IoT)-driven multi-tier food security system, selecting enablers aligns with a three-tiered decision model. These tiers encompass strategic, tactical, and operational levels, each serving distinct purposes in the system's functionality (Krishnan et al., 2021). Long-term planning and the creation of comprehensive strategies occur at the strategic level. The direction of the system, its objectives, and its broad framework are all shaped by decision-makers. The efficacy of the system is built upon these strategic choices. As we reach the tactical level, we emphasise putting the chosen enablers into action and converting the strategic objectives into doable actions (Leleur, 2012). This stage fills in the gaps between broad strategy and specific implementation. At the operational level, the chosen facilitators are put into practice along with actual actions. The regular operations and procedures guarantee the system's efficient functioning. To preserve system integrity, this level requires real-time data gathering, monitoring, and reaction systems (Alesiuniene et al., 2021).

2.3.3.1 Achieving Supply Chain Sustainability in Agrifood 4.0

In addressing the multifaceted sustainability demands within agri-food supply chains, fostering cooperation among diverse stakeholders is imperative. Such collaboration is crucial for attaining a competitive edge that can yield improved environmental, economic, and societal results (Blome et al., 2014). By working together, these stakeholders open up avenues for expanding their market presence, stimulating market growth, and ultimately boosting profit margins. Dania, Xing, and Amer (2018) demonstrate that this collective approach provides stakeholders with a unique opportunity to meet sustainability goals and bolster their standing and influence within the industry—Ail redistribution for consumers. In the works of Potts et al. (2014), sustainable growth within the agri-food supply chain can be realised through a concerted effort to prioritise and implement best management practices throughout the entirety of the supply chain. This approach not only entails enhancing the environmental and social conditions within the supply chain but also underscores the significance of continuous improvement (Saetta & Caldarelli, 2020). The path to sustainable growth necessitates a holistic perspective, wherein the supply chain's performance is optimised at every juncture. This optimisation encompasses various aspects, from the responsible utilisation of resources and the reduction of environmental footprints to the promotion of equitable and beneficial social conditions. As expounded by Karwacka et al., (2020), this comprehensive approach is instrumental in charting the course toward a more sustainable and prosperous agri-food supply chain.

Among the paramount challenges encountered in agrifood production and distribution, one of the most pressing issues revolves around the intricate and cost-effective management of the supply chain. The demand for efficient management has intensified in today's interconnected and globalised agrifood landscape. This is primarily driven by the escalating volumes of goods, processes, and information flowing in multiple directions along the value chain. To navigate this intricate web effectively, modern agri-food networks necessitate adopting multi-tier supply chain management approaches (Oyedijo et al., 2024). According to Lakovou et al. (2016), this is an indispensable requirement for ensuring agrifood supply chains' smooth and seamless functioning.

Agrifood 4.0 has the potential to enhance the sustainability of the agri-food supply chain by fostering the participation of smaller companies, implementing more stringent control, quality, and safety regulations, and driving greater industrialisation of processes. Moreover, it emphasises comprehensive supply chain management improvements. These elements collectively underscore the necessity of addressing sustainability not just in food production but throughout the entire supply chain, encompassing food processing, packaging, distribution, and consumption (Miranda et al., 2019).

2.3.3.2 Agrifood 4.0 and its Implications

The concept of 'Agri-Food 4.0' emerges as a parallel to the widely recognised 'Industry 4.0', evolving from the notion of 'Agriculture 4.0'. This nomenclature draws on the historical progression of industrial revolutions. The initial phase, 'Industry 1.0', was characterized by the advent of steam power, marking the inception of the Industrial Revolution. Subsequently, 'Industry 2.0' was defined by the widespread adoption of electricity. 'Industry 3.0' heralded a significant technological integration. The current phase, 'Industry 4.0', represents the pinnacle of this evolution, distinguished by the comprehensive assimilation and seamless integration of cutting-edge digital technologies, coupled with the promotion of interoperability among these innovations (Lezoche et al., 2020). This framework provides a valuable lens through which to examine the technological transformation of the agri-food sector, mirroring the broader industrial shifts observed across various sectors.

Agrifood 4.0 aligns closely with the overarching concept of Industry 4.0, underscoring the transformative potential of advanced technologies like the Internet of Things (IoT), AI, and big data within the sphere of agriculture and food production (Arora et al., 2020). These technological innovations empower precision agriculture, data-driven decision-making, and real-time monitoring of crops and livestock. A pivotal consequence of embracing Agrifood 4.0 lies in its capacity to fortify sustainability. Precision agriculture techniques usher in the ability to optimise resource utilisation, curb wastage, and foster environmentally responsible practices. IoT sensors and AI systems, in particular, are pivotal in monitoring soil conditions, weather patterns, and pest control. This surveillance capability effectively reduces the necessity for excessive pesticide application and conserves water resources (Karunathilake, 2023). In addition to its sustainability benefits, the digitisation of agriculture presents an avenue for bolstering rural development. It is a magnet, drawing younger generations into farming and creating fresh employment prospects in technology-driven agribusinesses (Sadjadi & Fernández, 2023). This infusion of innovation and economic activity into rural areas holds the potential for revitalisation. Nevertheless, there is a growing concern that more minor, resource-constrained farms might be marginalised if they lack access to these transformative technologies or the requisite skills to harness them effectively.

Agrifood 4.0 holds the promise of ushering in a multitude of advantages that extend to a wide array of stakeholders. This study by Maffezzoli et al. (2022 provides an exposition of what we may term "Benefits 4.0," rooted in the TBL approach which serves as a framework designed to assess performance from three distinct perspectives: people, planet, and profits, as articulated by Maffezzoli et al. (2022). Many benefits come to the fore within this comprehensive TBL approach , encapsulating enhanced economic, environmental, and social sustainability from adopting digital agriculture technologies (Lieder & Schroter-Schlaack, 2021). These benefits represent the dynamic interplay between advancements in Agri 4.0 and their far-reaching impacts on economic prosperity, ecological well-being, and social welfare, collectively fostering a more balanced and sustainable agri-food landscape.

2.3.3.3 Integration of Agrifood 4.0 and Supply Chain Sustainability

The agri-food supply chain in a particular society comprises all the organisations producing and distributing agri-food goods meant for human consumption (Yanes-Estévez et al., 2010). Three measuring scales are typically examined to evaluate food and ecosystem security: ecosystem accessibility, supply chain accessibility, and food chain utilisation. The complex and linked networks that supply food are reviewed for safety and integrity using these scales. Integrating the IoT-based systems is a valuable tool for monitoring these networks, capturing vital information about food materials and safeguarding the ecosystem (Xu et al., 2020). In today's context, where information is often uncertain, particularly during pandemic disruptions, IoT platforms are crucial in offering product traceability information in the agrifood system. This benefits consumers by providing more clarity and transparency, and serves as a means of ensuring food safety. Furthermore, the fusion of IoT and blockchain technologies brings transparency and efficiency to the food supply chain. Combining these two technologies makes the supply chain more robust and resilient, delivering dependable and comprehensive information to consumers and relevant stakeholders (Haroon et al., 2019). This, in turn, fortifies the overall integrity of the agri-food supply chain, particularly during challenging times like the ongoing pandemic.

There are numerous stakeholders in the agri-food value chain, each with a distinct role. They all follow local, state, federal, and worldwide regulations while utilising marketing techniques to promote their goods. Food items and the associated processing stages involve large amounts of data frequently not utilised to inform the final consumer (Carallo et al., 2018). According to Sjah and Zainuri (2020), the agri-food supply chain is the collection of businesses and activities that support the food supply chain from the point of origin to the point of delivery of the product to the end user. These activities are related to production, modification, and marketing efforts (packages, distribution of goods, and selling). The traditional landscape of Agrifood Supply Chain Sustainability has undergone a structural metamorphosis, all thanks to the advent of advanced technologies. This transformation has ushered in a newfound empowerment for stakeholders involved in the AFSC (Lezoche et al., 2020). The once-conventional processes have been reshaped and fortified, enabling more significant influence and control over various aspects of supply chain sustainability.

The dynamics of the AFSC have essentially been redefined by technological integration, leading to greater efficiency, transparency, and adaptability. With a more robust toolkit and profound understanding, stakeholders can respond to opportunities and challenges more quickly and accurately. Because of this, the whole agri-food supply chain sustainability spectrum has developed into a more adaptable and robust ecosystem better suited to satisfy the needs of today's complicated global food environment (Lakovou et al., 2015). The study delves into the practical implications of AI-driven startups working within the agri-food supply chain ecosystems and established industry players in their endeavours to foster intelligent and sustainable digital transformations in agriculture and food production. This involves integrating AI techniques to address the complexities of creating closed-loop, sustainable agri-food supply chains (Skalkos, 2023). Essentially, the study investigates how new and established sector participants use AI to improve the sustainability and efficiency of agri-food supply networks. Their work is crucial in establishing a more sensible and environmentally responsible food production and distribution method. These organisations seek to develop ecologically conscious and self-sufficient agri-food systems by integrating AI technologies.

2.4 Technological advancements in AFSC

Technological advancements AFSC in Farming/Primary Food Production

In response to the imperatives of bolstering agricultural production, enhancing product quality, and meeting the ever-expanding needs of a growing global population, the agri-food industry has, over time, pioneered innovative and sustainable solutions (Konfo et al., 2023). Like virtually all industries, technology has emerged as a linchpin in agri-food operations and strategic decision-making. Against this backdrop, the agricultural sector finds itself at the cusp of a digital revolution, as Konfo et al. (2023) highlighted. Today, computers have become omnipresent in every facet of agriculture-related processes, permeating areas ranging from machinery to sophisticated decision-making systems and from robotic applications to deploying sensors and cyber-physical systems technologies. The integration of these technologies has ushered in a new era where agriculture, driven by the synergistic combination of advanced internet networks and services, stands poised for a profound transformation characterised by heightened intelligence, efficiency, sustainability, and performance (Di Vaio et al., 2020).

The agricultural sector has demonstrated a longstanding engagement with digital innovation, evolving over multiple decades. Significant advancements in Precision Agriculture, robotics, remote sensing technologies, farm information management systems, and agronomic decision-support tools have collectively facilitated a substantial digital transformation in agricultural practices and food production processes (Pedro & Gonzalez-Andujar, 2019). This technological progression has reshaped farming methodologies, enhancing efficiency and sustainability across the agri-food value chain. More recently, a slew of technological developments has further propelled this transformation. Innovations such as IoT) AND Big DatA have ushered in a new era. These cutting-edge technologies can unite disparate development threads into intelligent, interconnected systems. They enable agriculture to develop into an autonomously linked, data-driven, intelligent, and flexible system.

These technologies empower each facet of the agricultural process to seamlessly integrate into the broader food supply chain, all the way to the end consumer (Yadav et al., 2022). Semantically active technologies facilitate this integration, ensuring a seamless flow of information and products throughout the entire ecosystem. Within this context, we can assert that the fourth industrial revolution, characterised by these transformative technologies, is now making its way into the agricultural sector. The World Bank's report in 2016 provided a detailed overview of the advantages derived from the implementation of ICT within the AFSC system. This report meticulously documents the substantial benefits and transformative potential that arise from harnessing the power of ICT in agriculture and food production.

2.4.1 Smart agriculture (Farming)

Smart Agriculture (SA) is an agricultural management approach that leverages information and Industry 4,0 technologies to enhance the efficiency and productivity of complex agricultural systems. Smart agriculture is key in addressing the difficulties associated with agricultural production, including yield, negative impact on the environment, stakeholders' empowerment, and sustainability. Smart agriculture is a massive enabler of sustainable AFSC. Antonucci et al. 2019 conclude that sustainable farming techniques may enhance farmers' ability to regulate and oversee agricultural processes, resulting in improved efficiency and output. Verdouw et al. (2013) present AFSC virtualisation through its operations, which comprises a system that monitors and controls agribusiness operations in real-time via the Internet; the study delves into the role of IoTs in a virtual AFSC system. As a result, the movement of AFSC products can be monitored remotely. Heising et al.,2013, explore the role of IoT sensors in measuring the conditions of temperature and microbial conditions of perishable AFSC; these capabilities function beyond mere monitoring and tracing and include holistic information on the deviation in food quality for better process optimisation.

There is a growing acknowledgement among actors operating in the AFSC sector regarding the significance of harmonising their economic practices and operational strategies with the conservation of essential resources crucial for the sustenance of the Earth and its inhabitants. This requires incorporating innovation focused on sustainability and executing strategies for sustainably managing agrifood supply chains.

Imran et al. (2019) argue in favour of the positive impact of adopting climate-smart agriculture on increasing agricultural output and promoting sustainability. CSA has been proven to increase the effective use of fertiliser and water, increasing agriculture's resilience to climate change and minimising greenhouse gas (GHG) emissions. The idea of CSA was introduced by FAO in 2010. It was described as a novel approach employing technology that effectively improves agricultural production and revenue while promoting sustainability. (FAO, 2010).

Recent research has shown that adopting and implementing CSA practices and technologies can help mitigate the negative impact of climate on agricultural practices. Challinor et al., 2014 and Easterling et al., 2007 all concluded, based on different studies on CSA adoption in both developed and developing nations, that the use of CSA is proven to help by employing simple adaptation methods and increases crop yield and profitability (finance income) for farmers in the midst of pressing issues of climate change. To a similar extent, CSA boosts yield, resource efficiency, and net farm revenue and decreases input consumption, such as fertilisers, due to its possibility to administer inputs based on variations of nutrient needs in the soil and reduce greenhouse gas emissions. Imran et al. 2019 argue for the positive impact of CSA and describe CSA as a novel agricultural management strategy which results in resilience, profitability, and increased productivity.

2.4.2 Digitalisation and data analytics in AFSC in Farming/Primary Food Production

Shepherd et al. (2018) provided an excellent definition of "digital agriculture," which uses extensive digital data to inform and direct decisions at every stage of the agricultural value chain. Practically speaking, this means using Smart Farming Technologies (SFT) or Precision Agriculture Technologies (PAT), with digital inputs being the significant means of deployment on the farm. With data-driven insights, these technologies usher in a new agricultural management and decision-making era. Every aspect of the agri-food process will be improved, from agriculture and resource management to distribution and market responsiveness, as elucidated by Bahn et al. (2021) and affirmed by the OECD in 2019.

The amalgamation of these digital technologies has engendered a transformative impact across various agricultural domains. Specifically, the adoption of technologies, such as sensors, robotics, and digital communication tools, is witnessing significant growth within controlled-environment agriculture. This category encompasses a multitude of controlled agricultural settings, such as greenhouses, indoor farms, vertical farming systems, and hydroponic facilities. In these environments, digital innovations are increasingly instrumental in achieving precise control over growing conditions and resource management, optimising yields, and ensuring product quality. Moreover, the advancement in digital agriculture extends to incorporate more sophisticated approaches that harness cognitive computing, digital technology, mobile solutions, and the Internet of Things (IoT). These cutting-edge technologies synergise to create intelligent and interconnected agricultural systems that provide real-time insights, enhance decision-making processes, and foster greater efficiency, thus representing a new frontier in the evolution of agriculture (Imran et al., 2019).

In response to the increasing demand for data-driven insights within the Agrifood sector, stakeholders increasingly turn to software applications to monitor, efficiently manage, and optimise resource utilisation and production processes. Moreover, these software solutions play a pivotal role in data analytics, facilitating the collection and management of information to yield real-time insights and predictive capabilities of even greater significance (Annosi & Brunetta, 2020). This predictive capacity empowers decision-makers to anticipate trends and plan proactively. Furthermore, the utilisation of software extends beyond the boundaries of individual operations. It catalyses fostering collaboration with various stakeholders throughout the agricultural supply chain (Annosi et al., 2021). Through these digital tools, actors within the AFSC system can seamlessly connect and share information, thereby streamlining processes and enhancing of the supply chain. Software solutions are instrumental in transforming the Agrifood industry into a more interconnected, data-driven, and predictive realm, ultimately driving sustainability, productivity, and collaboration improvements. According to Wolfert et al. (2017), AI adoption in agriculture can assist farmers in mitigating climate change by offering insights into rainfall patterns, the water cycle and decision-making processes.

2.4.3 Automation and Robotics in AFSC in Farming/Primary Food Production

The most formidable challenge facing the food industry revolves around enhancing production while ensuring the highest quality, safety, and security standards. Modern technologies emerge as indispensable tools in tackling these foundational concerns, with robotics and automation systems as prime illustrations of these innovative solutions (Javaid et al., 2022). These advanced technologies play an instrumental role in addressing the multifaceted issues inherent to the food industry, enabling a holistic approach that encompasses elevated production efficiency, preservation of product integrity, and safeguarding consumer well-being. Automation in agriculture enables farmers to manage crop production efficiently, reducing energy consumption and costs. The pressing factors behind the growing interest in agricultural automation among researchers and farmers include labour shortages, an ageing farming population, and escalating agrarian wages. The deployment and advancement of agricultural automation have been significantly facilitated by utilising autonomous robots and specialised equipment like tractors equipped with various implements such as cultivators, planters, multipacks, and chisel ploughs (Mahmud et al., 2020).

In agri-food, automation and robots represent a transformative technological wave with far-reaching impacts on food production, processing, and distribution (Christiaensen et al., 2021). This synergy of automation and robotics can potentially revolutionise the entire food supply chain, including agriculture. Given the labour-intensive nature of farming and an ageing workforce, the agri-food sector often grapples with workforce shortages. Robots excel at performing repetitive and physically demanding tasks such as harvesting, packing, and weeding, reducing the sector's reliance on human labour. Furthermore, automation and robots promote sustainability by curbing chemical usage, reducing resource consumption, and enhancing energy efficiency. The pivotal role of robotics and automation in agriculture extends to its profound influence on preserving future food security. Through the integration of robotics equipment, farmers have gained the capacity to conduct a spectrum of agricultural tasks efficiently and within precise timelines, capitalising on the expansive technological capabilities afforded by advanced systems (Duckett et al., 2018). This transformative integration not only streamlines agricultural operations but also stands as a linchpin in fortifying the foundations of global food security, ensuring a sustainable and reliable supply of food resources for years to come (Taneja,et al., 2023). Robots have become integral in numerous daily tasks, including planting, watering, harvesting, processing, and packing food items (Sun, 2016). Various robot technologies are employed in sectors like meat processing and the quality assessment of baked goods. Furthermore, in the beverage industry, robots autonomously handle tasks such as cleaning, counting, filling, and placing bottles on conveyor belts (Saravacos & Kostaropoulos, 2016).

2.4.4 Digitalisation and Automation in Africa's Agrifood Sector(Farming)

In Ghana, integrating digital technology, mainly through mobile money, offers a promising avenue for formal agribusinesses to facilitate payments to farmers within the agricultural value chain (Loukos & Javed, 2018). Additionally, the application of mobile-based technology has the potential to boost farmers' income and provide them with valuable market insights, weather updates, and production-related information. However, it is essential to note that this potential can only be fully realised by providing the necessary training and resources (Owusu et al., 2017). Several sub-Saharan African studies undertaken in this region show that digital technology can improve agriculture along the whole value chain. Studies conducted in Kenya have shown that several obstacles, including a lack of knowledge and resources, prevent small-scale farmers from reaching markets throughout Africa (Odini, 2014). However, smallholders have found that incorporating information and communication technology (ICT) has successfully overcome these challenges (Okello et al., 2010). Similarly, research conducted in Tanzania's Babati district by Furuholt and Matotay (2011) showed that farmers in outlying locations can access marketplaces and seize opportunities by utilising ICT. Furthermore, studies conducted in Ghana have demonstrated how ICT may link various players in the agricultural value chain. According to Deborah and Asaare (2013), this entails giving price information, creating connections between buyers and sellers, expediting transportation, and improving the general efficacy of crucial information services along the value chain.

Recent empirical evidence underscores the transformative impact of digital technologies across diverse agricultural domains. Silvestri et al. (2020) demonstrate the efficacy of digital interventions in promoting the adoption of sustainable legume-based agricultural intensification practices in Tanzania. Quandt et al. (2020) also found that digital technology has increased maize productivity and farmer profits in Iringa, Tanzania. Sennuga et al. (2020) observed improved farm productivity in Kaduna, Nigeria, facilitated by the integration of digital solutions. These research findings collectively highlight the instrumental role of digital technology in driving agricultural sustainability, productivity, and profitability across different regions and practices in Africa (Kudama et al., 2021).

2.5 Enabling Technologies AFSC in Farming/Primary Food Production

2.5.1 Internet of Things

The Internet of Things (IoT) is a recently developed technological system that integrates intelligent and autonomous devices, sophisticated predictive analytics, and cooperation between machines and humans to enhance productivity, efficiency, and dependability (Kamble et al., 2018). The Internet of Things (IoT) offers a distinct potential for technology to revolutionise several sectors, including agri-food. Brewster et al., 2017 suggested that the agrifood industry has witnessed comparatively limited adoption of the rate of information and communications technology (ICT) and substantial financial commitment for data capture. The Internet of Things (IoT) has become a significant topic in academic and industry research. The role of government-industry-initiated programs has resulted in the rapid expansion of IoT applications, which is evident in intelligent transportation and smart grids (Nukala et al., 2016). The Internet of Things (IoT) enables immediate sensing and rapid data transfer. This allows for the remote control of production processes and the practical cooperation between different actors involved (Kamble et al., 2018).

The emergence of the Internet of Things enables monitoring and tracing any mobile item equipped with a tag as it navigates its immediate surroundings or a fixed device that observes its dynamic environment (Riggins and Wamba, 2015). Most importantly, it is noted that stationary or immobile objects embedded with sensors linked to the internet could provide real-time data and information on the surroundings, monitor the condition, and be equipped with intelligence to make decisions and adjust the surrounding environment based on predetermined parameters. However, the Internet of Things (IoT) has immense promise for revolutionising several sectors of processes and practices (Lezoche et al., 2020). Experts have predicted an enormous expansion in the connective device market, with an average of 6.58 devices connected per individual. IoTs application has seen a wide application across several sectors, and the emerging present industry of applications is within agrifood systems, comprised of applications to agrifood system processes from farm to fork. The Internet of Things (IoT) enables real-time information gathering and exchange. The Internet of Things (IoT) can enhance the sustainability of the AFSC by facilitating enhanced effective communication, seamless coordination, and strong collaboration among all nodes throughout the supply chain (Kamble et al., 2020).

The application of IoT technology has a significant potential for implementation in the agri-food sector, particularly considering the socioeconomic and environmental difficulties this industry encounters. IoT technologies can potentially revolutionise the industry by enhancing food safety measures and minimising the use of agricultural resources, ultimately leading to decreased food waste Brewster et al., 2017**).** In the study conducted by Brewster et al., 2017, the author explores the framework that supports the broader adoption of IoT technologies across the whole supply chain in the approach called ‘’implement large scale pilot,’’ and further preset consideration and difficulties of limitations that must be considered while implementing an LSP deployment of IoT within the AFSC field.

IoT systems in agrifood have presented an avenue for where data and certain agricultural characteristic information, such as water, soil, etc., are available in real-time for better decision-making to improve farm output and performance. Lezoche et al., 2020 outline an intelligent AFSC system that enhances and promotes efficiency across the supply chain. The significance of Carmela et al., 2020 was in how technology promises to enhance AFSC efficiency, especially in the beverage industry. The focus of the research conducted by Astill et al., 2019 was to investigate the traceability and sustainability potential presented using IoTs across the agri-food supply chain, and the author highlighted that the economic dimension is crucial to actors of the AFSC system in terms of profitability and improving productivity. Astill et al., 2019 argue that IoT application has enormous potential to improve the quality management of the AFSC in terms of monitoring and real-time decision-making. Atzori et al., 2010, explore the impact of IoTs on individuals and businesses and critically view the issues associated with adopting, using and implementing IoTs. Riggins and Wamba (2015 view this from a different perspective and explore the problems associated with adopting IoTs on organisational, behavioural, and business issues. Riggins and Wamba, 2015 presented a holistic view of how the IOT will evolve and stated accompanying issues regarding adoption, usage, and impact. Riggins and Wamba, 2015 propose a framework that posits the progression of this technology from a system that monitors interconnected groups of things and eventually to a system of a global network of interlinked things known as the Internet of Things. The adoption of IoTs is carefully presented on several levels, such as individual, organisation, sector and society (Riggins and Wamba, 2015)

Nukala et al., 2016) argue that the application of IoTs ranges to several agricultural activities, primarily focusing on enhancing production and managing livestock. With broader application in precision agriculture, it is an emerging practice in agriculture. It involves the primary use of sensors and wireless systems. Sishodia et al., 2020. explore the application of remote sensing sensors in precision agriculture and how it impacts agriculture productivity. This study was conducted on cultivating potatoes in the agriculture industry in Egypt. Narwane et al., 2022 further explore the adoption of IoT technologies in the context of the Indian AFSC industry and present several factors that significantly impact IoT adoption.

Research conducted by Bangera et al. (2016) investigated the possibilities of an Internet of Things (IoT) based smart village. The author suggested that IoT sensors can provide an avenue to measure plant growth. The author argues that IoT sensors can measure soil moisture, determining plant growth. Miranda et al., 2019. also say that IoT sensors can measure specific environmental characteristics, such as temperature and humidity, which have functionalities used in assessing climate change and types of soil. The paper review of various limitations and opportunities was conducted by Khan and Ismail, 2017, and presented the potential of IoT applications in crop sensing, monitoring, and mapping. Argues that temperature sensors can provide information based on temperature variation in the soil. Kansara et al.. 2015 analysed an automated irrigation system that utilises sensors and IoT technology. The study findings undertaken by Sudha, R., 2021investigated the use of an IoT sensor network to monitor and regulate agricultural fields. Applying IoTs in the AFSC has enabled stakeholders to ensure insight into several sustainability indicators such as fertiliser usage, crop productivity level, and water management. References (Bronson and Knezevic, 2016) . Several authors have agreed on the common challenges facing IoTs in AFSC, such as scalability, investment cost, connectivity, technological complexity, trust and policy (Narwane et al., 2022).

2.5.2 Big Data in AFSC in Farming/Primary Food Production

Wolfert et al. (2017 conducted a review to explore the application and trends of big data (BD) technologies in agriculture, considering smart farming. The study further presented that the application of big data surpasses primary production and argues that BD applications exert an impact throughout the AFSC (Wolfert et al., 2017). BD helps with predictions about agricultural operations, real-time operational choices, and redesigned business processes for a transformative approach towards a viable system. Wolfert et al., 2017 explore the intrinsic factors that influence the BD in intelligent farming and categorise these factors as the pull and push factors.

Kamilaris et al., 2017 aimed to conduct a comprehensive review of existing studies and research in agriculture that use the contemporary BD method to address numerous pertinent issues. The study presented thirty-four different case applications of BD within the agriculture system.

The advent of BD in agriculture has prompted substantial expenditures in data storage and processing infrastructures, with massive potential for real-time data required to provide information, whether for keeping tabs on pests and illnesses in crops or livestock (Nandyala and Kim, 2016). Furthermore, big data is crucial in managing agri-food supply chains, as it helps identify and resolve issues related to safety, food waste reduction and supply inconsistencies.

In support of the significant role of Industry 4.0 technology in the agrifood system, Liu et al., 2020 proposed that this emerging technology will shape the agriculture sector. Liu et al., 2020 conducted a study on the present state of industrial agriculture and the insights gained from agriculture. Further, they presented five leading industry 4.0 technologies applications and emphasised the primary uses of these developing technologies in the agriculture industry and the associated research obstacles. Belaud et al., 2019 presented an innovative approach to managing sustainability in the supply chain by-products, using data-driven agriculture solutions enabled by BD technologies. Lezoche et al., 2019 conducted a thorough analysis of the effects of big data on the AFSC, presented many viewpoints such as socioeconomic, environmental, and functional impacts, and further highlighted the technological, social and organisational challenges associated with the application of BD. Considering the positive perspective the industry 4.0 technologies are presenting, Kamble et al. (2020 conducted a literature review of articles between 2000 and 2017, discovering the vast significance of the data-driven AFSC towards sustainability performance. The study concluded by putting forward a framework for actors in AFSC to focus on the combined factors of supply chain viability and resources as a prerequisite for building data analytics competence and achieving the TBL sustainability agenda. The framework was suggested to help actors strategically allocate their investments to establish a resilient, data-driven AFSC.

Kamble et al.'s 2020 perspective was that the emergence of industry 4.0 technologies is leading the way for transforming the conventional AFSC towards sustainability. In the opinion of Verdouw et al., 2017 the vast amount of data generated by IoTs across the AFSC can be analyzed via BD analytics, which can aid in detecting vulnerabilities in the AFSC. BD technology can significantly facilitate a sustainable agricultural supply chain by enhancing process efficiency using automation and improved decision-making processes, optimising resource utilisation, and reducing the negative impact of food on the environment (Lezoche et al., 2020).

2.5.3 Application of Industry 4.0 in AFSC sustainability in Farming Agriculture-Precision Agriculture and Sustainability Implications

Webster and Oliver 1990 describe the functional properties of PA to be based on the ability to manage variability in spatial (Time) and temporal dimensions (i.e., Time) (Oliver M 2013.). Pierce and Nowak 1990 argue that variability is a significant factor in promoting PA. Precision agriculture includes various subjects such as soil variability, weather conditions, plant genetics, crop diversity, machinery efficiency, and all the physical and several types of inputs used in crop production (Pierce and Nowak 1990).

Bell et al., 1995 assert that PA management should consider that several variables vary in space(land) and time across the agriculture system and duly impact the production and yield. Therefore, it argues that 21st-century sustainable management effectively manages soil and crops in space (Land) and time. Pierce and Nowak 1990, describe this to be the notion of applying input dues to a specific soil condition. Pierce and Nowak 1990 listed key PA-enabling technologies comprising GIS (geographical information system), GPS (global positioning system and sensors.

2.5.3.1 PA Application

Precision agriculture is an advanced management method that uses state-of-the-art technology to monitor and optimise agricultural production processes. Several authors have proposed various definitions of precision agriculture; Zhang et al., 2002 define precision agriculture (PA) as a holistic strategy that aims to restructure the whole agricultural system to achieve sustainable and efficient agriculture with minimal resource inputs.

Precision agriculture (PA) offers a methodological approach to crop production that aligns with environmental sustainability objectives. By leveraging site-specific data and technologies, PA enables the targeted application of agricultural inputs such as fertilisers, seeds, and agrochemicals based on the variability and nutrient needs of the soil.

Shibusawa, 1998 describes PA as a system that aims to restructure the whole agricultural system using a holistic approach to achieve sustainable agriculture that is efficient and requires little input. Bongiovanni et al., 2004 propose that precision agriculture (PA) enables the efficient management of agricultural production inputs while prioritising environmental sustainability. Precision Agriculture (PA) uses site-specific information to precisely adjust the application rates of fertiliser, seed, and pesticides based on the individual soil and environmental circumstances. Tey and Brindal 2012 define precision agriculture as an agricultural production strategy that entails managing crops based on the variation of fields and individual circumstances of each location. Precision agricultural technologies are the specific technologies used, alone or in combination, to achieve precision agriculture. Precision agriculture, often known as precision farming, is an advanced farming management approach that uses digital tools to monitor and improve agricultural production processes.

Precision agriculture (PA) employs techniques and technology to recognise variations in soil and crop conditions within a field, enhance farming methods and maximise the use of agricultural inputs (Khanal et al., 2017)

The adoption and implementation of PA comprises several technology tools which have the potential to transform the agriculture sector from a conventional and manual industry to a more consistently evolving and intelligent sector. Shafi et al., 2019 describe PA as the primary catalyst for automation in agriculture and further suggest that PA use specialised sensors and algorithms to guarantee that crops get precise amounts of resources, maximising production and achieving sustainable outcomes. According to practitioners, applying PA involves collecting real-time data via sensors on specific soil conditions, weather, and crops. High-quality images from satellite or drone systems provide further real-time data for the decision process, which is further processed to gather vital information to offer well-informed decisions in the future.

In the study conducted by Shafi et al., 2019, the author highlighted several uses of sensors and their different applications, which capture a range of applications consisting of soil temperature, plant temperature, photosynthesis, soil moisture, and air humidity within the agricultural domain. Zhang et al. (2002) proposed several drivers that motivated the widespread adoption of PA, comprising public awareness of sustainable practices, environmental policy, traceability, and consumer demand for the deduction of consumption of GMO foods. The author suggested that PA provides farmers with a viable and practical solution to minimise the use of agrochemicals.

In the study conducted by Zhang et al. 2002, whose perspective was on the trajectory of variability and soil management, the author highlighted the impact of PA on the environment and profitability of agricultural practices.

2.5.3.2 Emerging Technologies in PA and Sustainability Implications

Using emerging technologies in precision agriculture has seen significantly increasing attention and acknowledgement within several bodies of literature (Nikkilä et al., 2010). Khanal et al., 2017 suggested that PA employees leverage emerging technologies such as satellite technology, GIS, remote sensing and Information technology across functions in the agriculture sector. Currently, PA has seen the application and use of intelligent sensors, drones, cloud computing, Big data, IoT, mobile Apps and artificial intelligence (AI) (Jha et al., 2019)

Jha et al., 2019 suggested that many PA approaches that deploy IoTs, machine learning and artificial intelligence can address the challenges facing the agriculture and food industry. The contribution of Sartori and Brunelli, (2016) to PA was in applying smart sensors in aquatic farming. Puri et al., (2017) explore the role of drone technology in precision agriculture and argue that deploying this technology presents a massive breakthrough in the agri-food industry. Jagyasi et al. (2013), trajectory application of PA is in the role of mobile sensing applications in Indian agriculture and concluded that this solution could improve agricultural output to satisfy the needs of an expanding population. Based on the study, Jagyasi et al., 2013 discovered that mobile sensing applications might assist farmers by promptly distributing accurate information about planting, water management, pest and disease control, and access to the market. Several studies have suggested that training farmers is a prerequisite for a change of mind towards PA technologies. Ahmed et al., (2018) the application of IoTs in PA and developed a scalable implementation network structure to oversee and manage agricultural activities and farms in rural regions.

Khanal et al., (2017) suggested that thermal remote sensing (RS) has shown promise as a valuable tool for precision agriculture (PA) by accurately monitoring surface temperature estimations because the surface temperature is regarded as a prompt and sensitive indicator of crop stressors, often before their visible signs (Khanal et al., 2017). The application domains of thermal remote sensing in agriculture comprise the detection of diseases in crops, monitoring drought, mapping of soil parameters, and application of irrigation planning (Shafian and Maas 2015). The massive challenge of adopting thermal remote sensing is cost, which has hampered its full potential. Due to recent developments in PA, Khanal et al. (2017 presented the vast potential of unmanned aerial systems (UAVS) such as drones, which provide farmers with low-cost thermal Imaging with excellent spatial and temporal resolutions. This has led to expanding chances to comprehend the variety of crop and soil conditions within a specific field, which is valuable for making informed decisions about agricultural production and practices.

Torky and Hassanein 2020 thoroughly examine the significance of combining blockchain and IoT technologies in creating intelligent apps for precision agriculture. It also highlighted challenges that constitute the IoT-based PA and proposed an inclusive, innovative blockchain model with better outcomes. The review of the blockchain system application within the PA, which includes crops, supply chain and livestock feeding. Torky and Hassanein (2020) highlighted the challenges of developing a combined IoT-Blockchain model for PA and argued that security and privacy are significant challenges.

Far and Rezaei-Moghaddam 2018 examine various factors that affect the impact of Precision Agriculture. The study further concluded that rural development significantly impacts precision agriculture. It was also highlighted that the primary technical impact of PA is enhanced production, improved product quality, and enhanced farm conditions. According to Far and Rezaei-Moghaddam 2018, PA technologies' most notable economic impacts are income growth and the enhancement and advancement of agricultural conditions.

2.5.4 Smart Agriculture and Sustainability Implications (Farming)

Agricultural industrialisation has significantly grown in recent decades. Agrifood businesses are transitioning towards technologically enabled processes characterised by massive production and driven by technological innovations (Martinho and Guine,2021. The use of digital technology in agriculture is leading to a significant change in farming practices. This is accompanied by the emergence of innovative farming technologies (SFT), which rely heavily on data to improve agricultural operations (Wolfert et al., 2017). The emergence of technological innovations, such as sensors in agriculture, resulted in the expanding volume and range of farm data. Agricultural operations will progressively become a data-driven process that will rely on data and be empowered by it for effective management. Smart farming is among the new technological evolutions shaping the agricultural space, with recent advancements powered by the Internet of Things, big data, and cloud computing (Wolfert et al., 2017), Navarro et al., 2020 defined smart farming as using advanced technology in agricultural practices to reduce waste and enhance output. According to (Kernecker et al., 2021), Smart farming technologies (SFT), the latest wave of advances, have the potential to enhance farming practices in different parts of the world by addressing economic, social and environmental concerns, leading to sustainable agricultural development (Kernecker et al., 2020). Shang et al. 202 argue that adopting and implementing digital farming technologies are anticipated to facilitate the conversion of existing agricultural systems towards sustainability (Klerkx et al., 2019). The impact of SFT on agriculture at a large scale may vary depending on how they are integrated. Nevertheless, there is ongoing discussion over how SFT may effectively enhance food production stability and equity while minimising environmental consequences (Klerkx et al., 2019).

According to Sundmaeker et al., 2022 smart farming is a better approach to ensure sustainability than precision farming because Precision Agriculture only considers in-field variability. Still, Smart Farming takes a step further by including management responsibilities that are not only location-based but also data-driven. This is achieved by integrating context- and situation awareness, activated by real-time occurrences. The cyber-physical management cycle proposed by Sundmaeker et al., 2022 implies that the farm system is controlled by smart devices linked to the Internet, increasing autonomy within the farming system. The author also suggested that robotics has a vast application in intelligent farming, reducing human control and planning as the smart farming ecosystem becomes autonomous. In addition, human involvement in the entire intelligent farming ecosystem will continue, but with much enhanced cognitive ability and role.

2.5.4.1 IoTs in Smart Farming and Sustainability Implications

Dagar et al., 2018 suggested that the Internet of Things (IoT) can facilitate enhanced crop management, more efficient allocation of resources, viable agricultural practices, higher crop quality and quantity, and monitoring of crops and fields. Regarding the study conducted by Dagar et al., 2018 an IoT architecture framework was proposed, which comprises several sensors that measure different parameters (pH, moisture, Humidity, water) in the agricultural system, and concluded that the use of IoT devices may enhance the efficiency and accuracy of farming. Navarro et al., 2020 conducted a systematic literature review on IoT applications in smart agriculture. The study objectives were to explore IoT devices, platforms, network systems, connectivity and data processing methods and the applicability of intelligent farming. The review demonstrates an essential change in data processing in recent years. Bhagat et al. 2019 view on IoTs in smart farming projected that IoT usage reduces human involvement, expenses, and time, which are significant agricultural determinants. The study explores IoT's application in soil management, water management, crop monitoring, waste management, and control of pesticides and insecticides. Idoje et al., (2021) argue that Implementing IoT technology in agriculture mitigates the potential hazards posed by pesticides to people and animals that eat the cultivated produce and note that Agri-IoT helps in agricultural productivity and better crop management but cannot safeguard crops against severe weather. Idoje et al., (2021) highlight several limitations in the present body of research that impact the use of IoT in smart farming and propose more research to enhance global food production, improve food management, and promote sustainability worldwide. Bhange and Hingoliwala (2015) investigate the potential of using innovative farming techniques to identify disease outbreaks within the farm using image processing. It can be inferred from their study that farmers can use preventative measures during crop planting to obtain a high crop yield and mitigate the occurrence of disease outbreaks. Recent advancements in technology have enabled the use of data to proactively address agricultural issues and enhance the accuracy of crop diagnostics. Nonetheless, the study's limitation is that it does not provide strategies for emerging new waves of disease outbreaks.

Bhange and Hingoliwala (2015) describe the use of artificial intelligence in livestock to monitor the location of animals within the farm area. Bhagat et al., 2019 highlighted several challenges limiting the application of IoTs in smart farming, which include inadequate storage infrastructure for vast agricultural data, network challenges,

2.5.4.2 Big Data in Smart Agriculture and Sustainability Implications

Issad et al., 2019 describe smart farming as a viable method for addressing the increasing challenges facing the agrifood industry and the surge in demand for food while also fulfilling all dimensions of sustainability. The consensus is that SFT (Smart Farming Technologies) will enhance agricultural sustainability by improving the accuracy of inputs for crops and soils, considering specific contextual and site-specific requirements (Kernecker et al., 2020). Smart Agriculture aims to use information and communication technology to enhance the agricultural industry's productivity, efficiency, and profitability (Iaksch et al., 2021).

Given that information is playing an increasingly significant role in the field of Smart Agriculture. Providing data on weather conditions, resource usage, insects, soil nutrients, and other factors significantly contributes to this industry's economic and sustainable growth. Smart farming has been argued to be agricultural management that encompasses the management process of data collection, gathering and analysing of farm data for meaningful decisions. Given the substantial growth in agricultural data, it is crucial to use robust analytical tools that can efficiently handle and analyse massive volumes of data. This will enable us to collect more trustworthy information and make more accurate forecasts.

Agricultural businesses are employing big data technologies to extract valuable information from vast and varied datasets to address issues promptly. Big data encompasses two perspectives: Big Data and Analytics. The essential role of big data in agricultural transformation is acknowledged since machines are outfitted with various sensors to collect data from their surroundings, which is then used to determine real-time and autonomous response and process management (Garg and Alam, 2023).

Bhange and Hingoliwala (2015) conducted a study on the use of technology in detecting disease in pomegranate fruit, and the study concluded by presenting a web-based application designed to assist farmers in diagnosing fruit diseases via image visualisation. Alonso, et al., 2020 contributed to the study of intelligent farming in the dairy industry and proposed the virtual dairy farm employing several innovative farming technologies and suggested that diary farming needs to develop a system that can gather, combine, control, and examine data from both on-farm and off-farm sources in real-time is crucial for implementing realistic and prompt decisions. The review study by Saiz-Rubio and Rovira-Más 2020 on the intelligent farming management approach aims to enable growers to make informed decisions that save money and safeguard the environment, exploring data usage and application across each step of crop production. The foundation for future sustainable agriculture is laid by data-driven practices that use imaginative farming approaches, including artificial intelligence applications (Saiz-Rubio and Rovira-Más 2020). Astill et al.'s (2020) study investigated the role of big data and the Internet of Things in the innovative poultry approach. Intelligent poultry management systems enhance production efficiency and reduce expenses and resource consumption. Innovative poultry management systems applications within livestock farming include technologies which consist of intelligent sensors, automated farm procedures, and data-driven decision-making platforms. Astill et al. 2020 argue that developing novel technology and sensors allows for gathering substantial data from chicken production activities, while extensive data analytics systems will enable well-informed decision-making.

Wolfert et al., (2017) conducted a study on the role of big data in smart farming in Europe and North America. The author argues that Big Data is their primary and crucial business strategy and considers the use of Big Data as transforming the extent and structure of agriculture via a pull-push process. Addressing the possible adoption challenges is necessary for greater adoption of Big Data applications in agriculture. The use of Big Data is transforming the extent and structure of agriculture via a pull-push process (Wolfert et al., 2017). Garg and Alam 2023 suggested that big data can help farmers get specific information about weather trends, rain, and how much manure they need. They may then use this information to strategically plant crops and harvest them at the optimal times for maximum profit. Alfred et al., 2020 explore the impact of smart farming. The study comprehensively reviews recent advancements in intelligent data processing technology for the agricultural sector, specifically focusing on its use in rice production. In this study, the author shows a framework that outlines the tasks involved in bright farming rice with the data used for data modelling and the machine learning methods used for each task during paddy rice production. It is argued that this will revolutionise conventional rice growing techniques and introduce a new level of intelligence in rice precision agriculture (Alfred et al., 2020).

Giua et al.'s (2022) contribution examined the adoption of innovative farming technologies. It considers the sequential nature of the adoption choice process, which involves formulating intention followed by the actual decision to adopt. It was highlighted that the influence of agribusiness conditions and policy within the supply chain impacts farmers' inclination to embrace intelligent farming technologies. The study by Giua et al., (2022) recorded a positive impact of social influence and facilitating conditions for adopting Smart farming technologies among farmers.

Kernecker et al., (2020) conducted mixed-method research to investigate the significance of continuous technical advancement of Smart farming among European farmers, conducting a comparative research approach between adopters and non-adopters of innovative farming technologies. The study concludes by stating that to enhance the development and spread of innovative farming technologies, it is necessary to consider the variations in agricultural landscape and farming systems throughout Europe. Kernecker et al.'s (2020) findings corroborate prior research on using farmers' views(or perceptions) in innovation processes and provide valuable insights into the current trends concerning implementing sustainable farming techniques in various European agricultural systems. To comprehensively comprehend the potential contribution of SFT to agricultural sustainability, it is crucial to consider and analyse the many aspects that influence farmers' interest in and adoption of innovative farming technologies (Balafoutis et al., 2020). Shang et al., (2021) study objective was to construct a firmly established conceptual framework for accepting and spreading digital agricultural technology among farmers. The study presents a conceptual framework that combines farm-level information on adoption with a systemic approach to technology dissemination based on the observed gaps. Balafoutis et al., (2020) explore the assessment of adoption readiness in intelligent farming technologies, investigating academic and industry publications.

2.6 AFSC in Food Processing/Manufacturing

Food manufacturing 4.0 and sustainability Implications.

Food processing is a method used to transform agricultural products into edible items with an extended period in which they may be stored and consumed. The food manufacturing sector is very resource-intensive. Stakeholders have been considering providing means to mitigate the impact of climate change, evolving consumer preferences, and strict regulations. This resulted in the adoption of industry 4.0 technologies to drive transformation towards sustainability (Jagtap, Saxena, & Salonitis, 2021)**.** Despite the challenges and complexity facing the food manufacturing sector, 4.0 technologies will be essential in managing the increasing complexity of food production processes (Jagtap, Saxena, & Salonitis, 2021).

Modern factories are seen as intelligent ecosystems where people, machines, and devices interact with one another to optimise the production process. Industry 4.0 comprises enabling technologies that facilitate the digital redesign of industrial or conventional processes into technology-driven ecosystems. Once implemented, Industry 4.0 technology significantly enhances organizations' effectiveness, economic viability, and profitability. The adoption has been proposed to result in digitally transforming the manufacturing sector, driven by the rapid advancement of technology such as intelligent robots, autonomous drones, sensors, and 3D printing (Hermann et al., 2016). This concept combines digital manufacturing with information technology, providing a fresh approach to innovative and sustainable production (Machado et al., 2020). Konur et al., (2021) describe the impact of the integrated intelligent manufacturing ecosystem as one that revolutionises the industry by enabling very efficient data collecting and analysis across various machines and equipment, hence allowing much accelerated and more streamlined production and commercial operations. The application of Industry 4.0 results in increased productivity via real-time data collection and analysis from equipment. This leads to improved and adaptable processes and reduced mistake rates and costs (Konur et al., 2020).

In light of transforming food manufacturing into a more sustainable system, Brosnan and Sun (2004) provide a methodology for enhancing food uniformity via image processing techniques. Lee et al., 2015 examine the various technologies and devices in the food industry, including IoT devices and wireless sensors. The author explains that data-driven food manufacturing processes are the core of achieving efficiency and regularity based on gathering and analysing data. Data analysis is the foundation of the most significant technological advancements. This involves gathering and examining data, which is crucial for enhancing efficiency and maintaining uniformity (Lee et al., 2015). Jagtap, Garcia. and Rahimifard 2021 argue that achieving resource efficiency is essential for establishing agrifood sustainability, underscoring the importance of reducing food waste and water and energy usage.

The emergence of Industry 4.0 significantly enables the use of various digital methodologies in the food manufacturing sector. Dadhaneeya et al., 2023 suggested that the food manufacturing industry needs to expedite and transition towards adopting industry 4. o technologies and leverage the potential presented by these emerging technologies. The author investigates the role of IoTs in food manufacturing and lists the relative advantages of technologies to help improve efficient processes, ensure the production of high-quality foods, increase productivity, and maintain the organisation's objectives. Jagtap, Garcia. and Rahimifard 2021 examine the role of IoTs in resource efficiency in the food manufacturing industry. Jamwal et al., (2021) explore the potential sustainability impact of industry 4.0 technologies offer the food manufacturing industry; the study investigates and presents future research on how industry 4.0 technologies can promote sustainable manufacturing.

2.6.1 IoTs and Big Data in Food Manufacturing and Sustainability Implications

IoT can boost sustainability practices, diminish energy use, lower the cost of production, promote worker well-being, ensure food production safety, generate environmentally friendly goods, and create better working environments within the food processing sector (Dadhaneeya et al., 2023). Simultaneously, the Internet of Things (IoT) has ushered in a new phase of food processing. This involves transforming the conventional process into an intelligent process through enhanced data-driven approaches, real-time management, monitoring, and production optimisation. Jagtap, Saxena, & Salonitis (2021 investigated the use of Augmented reality (AR) in food manufacturing and presented several implementation approaches, which resulted in food transparency, food safety, Improved worker training, sales and enhanced operational effectiveness within logistics. Innovative food manufacturing processes with industry 4.0 technology capabilities can perform quality checks, sorting, and packaging functions. This guarantees standardised and secure food manufacturing by enhancing efficiency, reducing labour expenses, and enhancing accuracy (Dadhaneeya et al., 2023). Several studies were conducted to provide a comprehensive literature review that explores the potential of new technologies to transform the food manufacturing process and management of the supply chain, and a thorough analysis of the sustainability implications (Manavalan and Jayakrishna 2019).

The progress in Industry 4.0 offers remarkable prospects for building environmentally friendly manufacturing (Manavalan & Jayakrishna, 2019). The author seeks to investigate the possible prospects of integrating IoT into sustainable supply chains for Industry 4.0 transformation. Hassoun,et al., 2023, provide a comprehensive presentation of the ongoing fourth industrial revolution in the food industry. The authors (Hassoun, Bekhit, et al., 2022) further examine the enablers of the sector 4.0 technologies and green processing techniques and their impact on achieving sustainable development goals in the food industry. Consequently, it is anticipated that there will be an increased adoption of environmentally friendly and technologically advanced solutions in the coming years. These solutions will fully use their capabilities to attain a food future that is healthier, more intelligent, sustainable, and resistant to challenges (Hassoun, Bekhit et al., 2022).

Jamwal et al. (2021) research investigates the potential benefits of Industry 4.0 for the environmental dimension of sustainable development, focusing on the effective use of resources and energy and transparency. And argues that Industry 4.0 technology enhances productivity, reduces waste, and contributes to developing a more efficient production system. Hassoun et al.'s (2023) and Nath et al.'s (2024) study demonstrates the significant contribution of robots, intelligent sensors, AI, IoTs, and big data in facilitating the transformation of food manufacturing. The benefits include enhanced quality control via robots and AI for sorting during processing, improved safety by integrating sensors and equipment with the IoTs, and big data playing a pivotal role in demand forecasting to increase production efficiency. Artificial Intelligence (AI) finds diverse applications within the food processing sector, primarily focusing on four key areas: the sorting and classification of food products, ensuring quality control and adherence to safety standards, facilitating predictive maintenance of processing equipment, and optimizing production processes (Nath et al., 2024). However, Hassoun et al. 2023 suggested an in-depth study to tackle the inherent challenges of integrating these technologies in food processing.

2.7 AFSC in Logistics

Smart Agrifood Logistics and Sustainability Implications

Furthermore, the worldwide food supply chain is intricate and has challenges in meeting the standards for sustainability and safety. To achieve a sustainable AFSC system, it is essential to establish a resilient supply chain framework and practical, innovative supply chain process driven by transformative solutions, such as adopting and implementing Industry 4.0 technologies to improve Agrifood logistics performance and enhance sustainability (Abideen et al., 2021). Economic, social and environmental factors are significant when considering the' impact of technologies on AFSC towards sustainability.

In the coming years, technological innovation will drive the transformation of the logistics system across several industries, including the Agrifood industry. This will necessitate new infrastructure reform needed for the sustainable movement of goods and people within the urban landscape. It will be of great necessity for governments, businesses, and stakeholders to provide the necessary intervention to drive logistic digital innovation, which will significantly impact the possibility of contributing towards the development of smart cities. In the days ahead, the field of logistics and transformation will see a massive effect on innovative movements of goods and people. The transport industry is due to see a disruption caused by automation, moving the transport system from human drivers to artificial pilots. This would create a system where humans only supervise the transformation and leave the actual transportation system to an AI-controlled system. Businesses and stakeholders should envisage the collective possibilities this new technology will offer the logistics and transformation industry (Remondino and Zanin 2022).

Technological innovation can empower logistics actors to achieve efficiency, reduce costs, and present new business possibilities. For instance, through the integration of advanced technology like Big data, Data Mining has presented a very good logistics data management that drives efficiency(Remondino and Zanin 2022).

Data has been the bedrock of logistics, and the integration of advanced technology in data management allows businesses to achieve their goals strategically through a data-driven process. Several factors are considered in business operation efficiency, especially logistics. This logistics transformation provides a competitive advantage for businesses while honing resource management and utilization and reducing environmental impacts. The concept of smart logistics is the integration of advanced technology into the logistics industry, which provides a sustainable framework for most businesses while recognizing the intercept of environmental concerns, management of natural resources and effective logistics operation.

2.7.1 Big Data and IoTs in smart logistics and sustainability Implications

The advancements in big data can potentially provide several advantages to the food logistics industry. The AFSC logistics result in a substantial volume of data due to the vast quantity of food goods that are handled. This data comprises sources, movement throughout the chain, product attributes (such as volume and weight), and conditions of the external environments. and location (Jagtap et al., 2019). Edwards 2017 emphasized that big data is crucial in supporting the AFSC logistics via predicting demand, pricing, marketing, and new food product development. Jagtap et al. (2018) suggested that big data can prevent food waste by providing data and information to optimise truck delivery routes and avoid traffic congestion. Using big data may significantly enhance the efficiency of planning and scheduling by aggregating real-time data on demand, capacity, and available resources, facilitating stakeholders in making more informed decisions (Jagtap et al., 2018).

Hassoun et al., (2023) argue that IoT technology enhances connection and improves efficiency, quality, and profitability across the supply chain. The IoT system provides avenues for information and data exchange throughout the supply chain, simply between several human-machines and machine-machine interactions (Kamble et al., 2018). Jagtap et al.'s 2021 contribution was to explore agrifood logistics 4.0 and present enabling technologies (such as IoT, Robotics and Blockchain), opportunities, and challenges. The primary emphasis of the study was resource and warehouse management, transportation, maintenance planning and data security. Jagtap et al. 2021 argue that real-time traceability, a crucial feature of IoT, enables prompt response in handling product recalls. Along with IoT applications within the AFSC, Gupta and Rakesh, 2018 proposed that an IoT-based approach can solve food fraud challenges within the food supply chain. The author proposed an IoT-based approach, which comprises several sensors to measure different parameters of food to trace food adulteration.

IoT applications also monitor environmental conditions and regulate agrifood product temperature. The IoTs can also identify and prevent possible risks by detecting inappropriate food shipment access and providing real-time tracking capabilities for shipments and specific food goods (Gupta and Rakesh, 2018). A literature study was undertaken by Bouzembrak et al. (2019), on the role of the Internet of Things (IoT) in food safety. Bouzembrak et al. (2019) approach uses IoT devices in conjunction with RFID technology, which monitors agrifood SC to ensure safety and quality, Ensures the freshness of products and detects the presence of harmful chemicals, implements a system to track the origin and of products, and taking measures to prevent the production and distribution of fake agrifood products. Alfian et al. (2017) suggested a traceability system that utilises RFID technology and is combined with the Internet of Things (IoT) in the supply chain. This system is designed to monitor the movement of goods and measure the temperature and humidity of food items. Despite the promising revolution and transformation IoTs can offer AFSC, infrastructure, connectivity, and cost are significant challenges that hinder effective data collection and full-scale adoption (Hassoun et **al., 2023).**

2.7.2 Blockchain in smart logistics and sustainability Implications

The pressing concern of AFSC stakeholders arises from the challenges of food loss at every stage of the supply chain. The strategic response is to explore the prevention of food loss throughout the supply chain. Parallel to the issues of the AFSC, consumers also have increased awareness about the quality and authenticity of purchased food. According to Kayikcia et al. (2020), industry 4.0 technologies present a positive outcome in tackling these challenges by tracking the conditions of agrifood from farm to consumer, fostering transparency and quality, focusing on a blockchain-driven food supply chain, and examining a robust application of blockchain technology in addressing. Significant obstacles include quality, traceability, and trust within the agri-food sector. Aung and Chang (2014) suggested that the increased significance of food quality and compliance with standards can be achieved by ensuring stringent monitoring and operational procedures. Efficient traceability systems may reduce the production and delivery of substandard agrifood products, reducing potential harm and adverse consequences for consumers. This study, conducted by Aung and Chang 2014 thoroughly analyses the traceability of safety and quality within the AFSC. Blockchain technology can enhance the efficiency and visibility of food supply chain operations. The study by Tse et al. (2017) examined the use of blockchain technology to improve the information security of the AFSC in China. It contrasted it with the conventional supply chain method.

2.7.3 Technology Adoption- theory of technology diffusion

The prevalence of several information technologies among individuals, businesses, and corporations has significantly increased. As stated by Westland and Clark (2001), approximately 50% of all investment among companies during the 1980s was allocated to information technology; this capital investment has been associated with business efficiency and competitive edge. For dividends of technologies to be fully actualised, they must be accessible, embraced and used by individuals or by the workforce within an organisation. Continuous concern among industry leaders and business management is to ensure constant acceptance of technology among user groups (Williams et al., 2015). Hu et al. (1999) describe the research of user adoption of new technology as a widely advanced and established field; in this field, the use of the Theory of technology acceptance model (TAM) developed by Davis 1985, is considered to provide the most significant potential. The author further applied the TAM within the medical profession, examining the decision processes by doctors to accept telemedicine technology. The technology adoption research has considered user acceptance as a crucial determinant of acceptance and adoption of technology among user groups within many contexts, which is adequately elucidated, precisely forecasted, and efficiently controlled via many pertinent aspects. Specifically, these parameters include three crucial dimensions: The individual's attributes, the technology's features, and the organisational context's traits (Hu et al. 1999 ; Westland and Clark 2001).

2.7.4 Unified Theory of use and Acceptance of technology

Many bodies of research on technology usage, adoption, diffusion, and acceptance have led to the development of several theories and frameworks that span different disciplines. Such instances include the Theory of Planned Behaviour (TPB), the technology adoption model (TAM), and the diffusion of innovation theory (DoT).

The Diffusion of Innovation theory hypothesis, as proposed by Rogers (2002, 1995), conceptualises the spread of new ideas as a specific kind of communication inside a social system, where the message about the innovation is sent from one member to another. According to Rogers et al. 2002, the dissemination of new ideas is influenced by four primary components, which consist of time, social system, communication channel and innovation; an innovation refers to a novel concept, technique, or item recognised as being new by a person or a user group. The primary research concern is to explore the factors that influence the spread of innovations. Rogers (2002) posited that the rate of innovation adoption is contingent upon the perceived attributes of the innovation as evaluated by people within a social system. The scholar identified five key factors influencing innovations' adoption rate: relative advantage, compatibility, complexity, trialability, and technology demonstration (Rogers (2002).

A substantial body of research has extensively studied technology adoption across different countries, disciplines, and sectors, employing several methodologies. Some research delves into the study by employing a process perspective and thoroughly exploring its intricate process. Beaudry 2005 conducted a survey of technology adoption in the work environment and presented that users employ different strategies to adapt to new technologies based on perceived available appraisals, underpinning the coping theory. Another research perspective examined the adoption of technology and the factors that influence it; such models include TAM and UTAUT. Lai and Li (2005) investigated the consistency of the construct of TAM among different subgroups in the adoption of Internet banking. They argued that there was no variance in the application of the model.

Wu and Wang (2005) used the TAM model to conduct a comprehensive study on the acceptance of mobile commerce by users; this was done by incorporating several other models, such as the innovation diffusion theory and perceived cost and risk to TAM. In the research by Yi et al., (2019) on the factors that influence the acceptance of technology in the work environment of skilled professionals, the TAM model was used comprehensively by adding several other models, such as the theory of planned behaviour (TPB). At the conception of the model, the UTAUT model was used in several studies on different types of technologies. The UTAUT model has identified experience, gender, and age as the most critical moderating factors.

Venkatesh et al. (2003) conducted a thorough study of the eight most prominent models for adopting technology, resulting in the development of a unified theory of acceptance and use. Comprehending the individual's willingness to embrace and use information technology is one of the most well-developed research areas in technology use and acceptance (Venkatesh et al., 2007).

UTAUT has been widely used as a fundamental model since it was first published. It has been used in several technology adoption or use studies in several contexts and applications. The application of UTAUT, according to Venkatesh et al. (2003), spans several varieties in the research context of new technologies, a new group of technology users and different cultural contexts.

Li et al., (2020) applied the UTAUT to examine the underlying factors that influence the use of precision agriculture technologies among farming communities in organisations in China. The research further seeks to assess the variables responsible for adopting PA technologies so that future recommendations can be made. Further, explain that the need for a technology is determined by the degree of compatibility between the apparent capabilities of the technology and the demands of the work at hand. Im et al., 2011 observe the adoption rate of IT technology across different countries; the variations in the adoption of IT may be ascribed to several variables, including government policy, industry leadership, and market conditions. Im et al., (2011) suggested that for UTAUT to be used holistically, culture needs to be considered in technology adoption. Various studies, such as one conducted by Chae. (2004) investigated the influence of culture on the adoption and use of technology. Nevertheless, a more thorough examination is necessary within the framework of swiftly evolving information technologies.

Im et al., (2011) criticise the UTAUT model for its lack of cultural variables due to the comprehensive study of technology adoption conducted in different countries. The author argues that cultural influence has a significant role in the study of technology adoption and duly examines the cultural factors that influence the level of adoption of technology as a comprehensive approach to the use of UTAUT.

The UTAUT theory proposes four fundamental components determining behavioural intentions to use technology. These fundamental parameters are social influence, performance expectancy, effort expectancy, facilitating conditions, and other moderating elements. Despite its drawbacks, the UTAUT model is significant because it integrates eight theories from real-world applications. The UTAUR model has been applied to a wide range of research, from studying the acceptance of mobile data services by (Ovčjak et al., 2015).

2.8 Application of UTAUT parameters in the context of AFSC

Social influence

The adoption of Industry 4.0 technologies among AFSC actors may be positively affected by social influences. To be better put, individuals feel that people or organisations can place significance on better performance through certain technologies or innovations. This underscores the subjective norm stated in the theory of reason behaviour, which underpins the impact of external factors on adopting technology (Venkatesh et al. 2007). This underpins the idea that Individuals are presumed to seek advice from their social network, particularly friends and family, on new technology and might be swayed by the perceived social impact of significant others (Beza et al., 2018)

Performance expectancy

Performance expectancy refers to the extent to which AFSC actors believe that using an Industry 4.0 technology will provide advantages in carrying out specific tasks. Performance expectation refers to an individual's belief in the extent to which adopting a technology would assist them in achieving job-related benefits such as performance. According to Venkatesh et al. (2007), evidence suggests that performance expectancy emerges as the most robust predictor of an individual's intention to adopt and utilise technological innovations.

Effort expectancy

Effort expectancy refers to the ease associated with using Industry 4.0 technologies among AFSC actors (Venkatesh et al., 2012).

Facilitating conditions

‘’Facilitating conditions’’ pertain to AFSC actors' perceptions and the availability of technological infrastructure that assists them in using the system as needed (Venkatesh et al., 2012).

Technology Adoption Readiness

In the agri-food sector, the readiness of stakeholders to use and adopt technological advancements is referred to as technology adoption readiness. This preparedness is contingent upon various factors, including infrastructure, funds, knowledge and skills, cultural beliefs, and institutional frameworks. Feder, Just, and Zilberman (1985) argue that the AFSC actor's capacity to invest in new technologies is contingent upon the availability of financial resources, such as personal savings, access to credit, or grants. Duflo, Kremer, and Robinson (2008) argue that businesses' readiness to adopt and use technology depends on skill and knowledge and that technology adoption is significantly influenced by training and education. The more users are informed, the more likely they are to comprehend and value the advantages of a new technology. Rogers (2003) suggested that the adoption of technology can be influenced by culture, beliefs, and behaviours and suggested that technology might face resistance to adoption if it disrupts traditional practices.

NRI- Network Readiness Index

The World Economic Forum's annual report assesses nations' readiness to use the possibilities presented by information and communication technology and publishes a yearly report. NRI is a framework that examines the impact of technology (ICT) on countries' competitiveness. The NRI framework is built on four pillars: technology, people, governance, and effects. The Technology pillar assesses the technical infrastructure necessary for a country's participation in the global economy, whose objective is reflected in access, content, and future technology. The people pillar assesses the technical environment and demonstrates the skill, inclusiveness, and expertise of a nation's people and organisations using technology resources; this underscores individual and business capacity to integrate technology and government investment in ICT for the nation's better. The government pillars assess the governing provision provided to foster user safety, which underpins trust and regulations. The impact pillar assesses a nation’s technology deployment, resulting in comprehensive economic development and social improvement. These four pillars are the basis for the NRI annual report and show the competitiveness of 149 countries.

Technology adoption and acceptance have various applications and factors influencing decisions across organisations and countries. The network readiness index is a matrix that shows the readiness of a country to adopt and implement technology. It can be established that the NRI of a country is sufficient to measure its readiness to adopt technology but does not capture specific industries within that country. A more holistic framework should consider countries' NRI and specific business sector adoption rates. The sector-specific adoption of technology index will investigate the underlying factors that influence the rate of adoption and acceptance of technology across different sectors. In the AFSC industry, the technology adoption and acceptance rate is low compared to other sectors.

2.9 Industry 4.0 technology adoption readiness

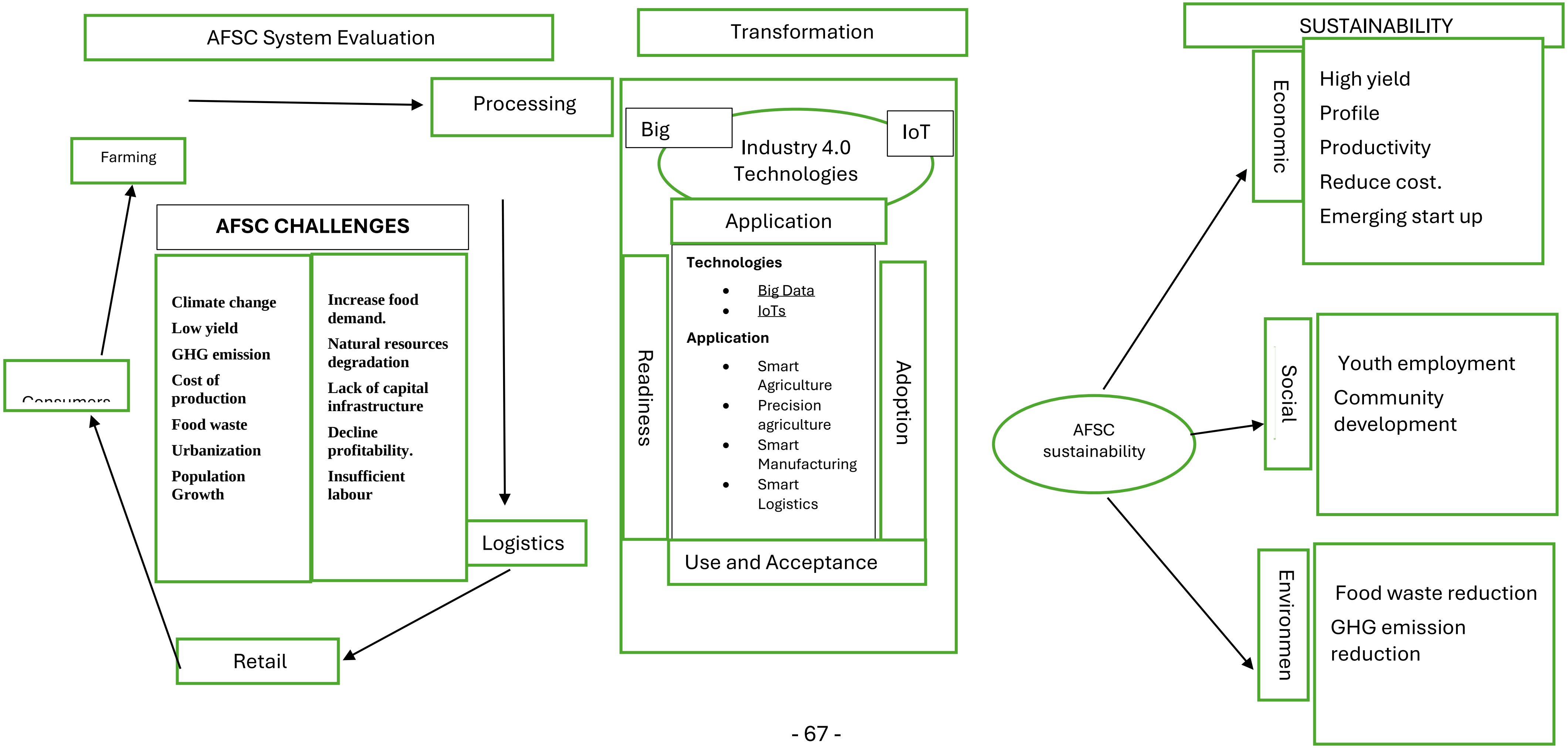
The role of Industry 4.0 technologies in promoting the sustainability of the AFSC has brought a new shift towards data-driven processes and real-time data to manage the agrifood system better. Before adopting Industry 4.0, evaluating the AFSC industry and individual business readiness for deploying Industry 4.0 is crucial (Antony et al., 2023). Krishnan et al., 2021 define Industry 4.0 readiness as how businesses use Industry 4.0 technology across their processes and services. Both scholars and practitioners have presented many models to measure the readiness of the Industry 4.0 technology. According to Antony et al., 2023 business can be categorised as either unready or nearly ready. An in-depth literature review was conducted by Hizam-Hanafiah et al., 2020 and Sony and Naik (2019) on the Industry 4.0 readiness model, and the study presented six essential components of the Industry 4.0 readiness model need to be identified **(**Hizam-Hanafiah et al. 2020). In the survey conducted by Sony and Naik 2019, the author argues that there are several considerations business leaders need to make before implementing industry 4.0 technology and suggested tools for that defence. Khurshid et al., (2023) propose several readiness factors for industry 4.0 readiness in the manufacturing sector in Egypt, which comprises knowledge, infrastructure, technology, compatibility, and sustainability. Hizam-Hanafiah et al., (2020), in parallel, investigate 30 readiness models used in academic and business, consisting of 158 dimensions. The author argues that ‘’ Technology, People, Strategy, Leadership, Process, and Innovation’’ are the dimensions that might be regarded as the most crucial for most sectors, regardless of their size and sector. The most relevant industry 4.0 readiness adoption in the AFSC is suggested to be the Level of knowledge, infrastructure, Internet connection, Financial support, Government, policies, and Sustainability.

2.10 Conceptual Framework

The conceptual framework for the study is seen in Figure 2.1, which consists of three sections. The process evaluation, as discussed in Chapter 2, covers the present challenges the AFSC in Nigeria faces; Section 2 covers the AFSC transformation, viable the enablement of industry 4.0 technologies, which cover application, adoptions, user’s acceptance as described in

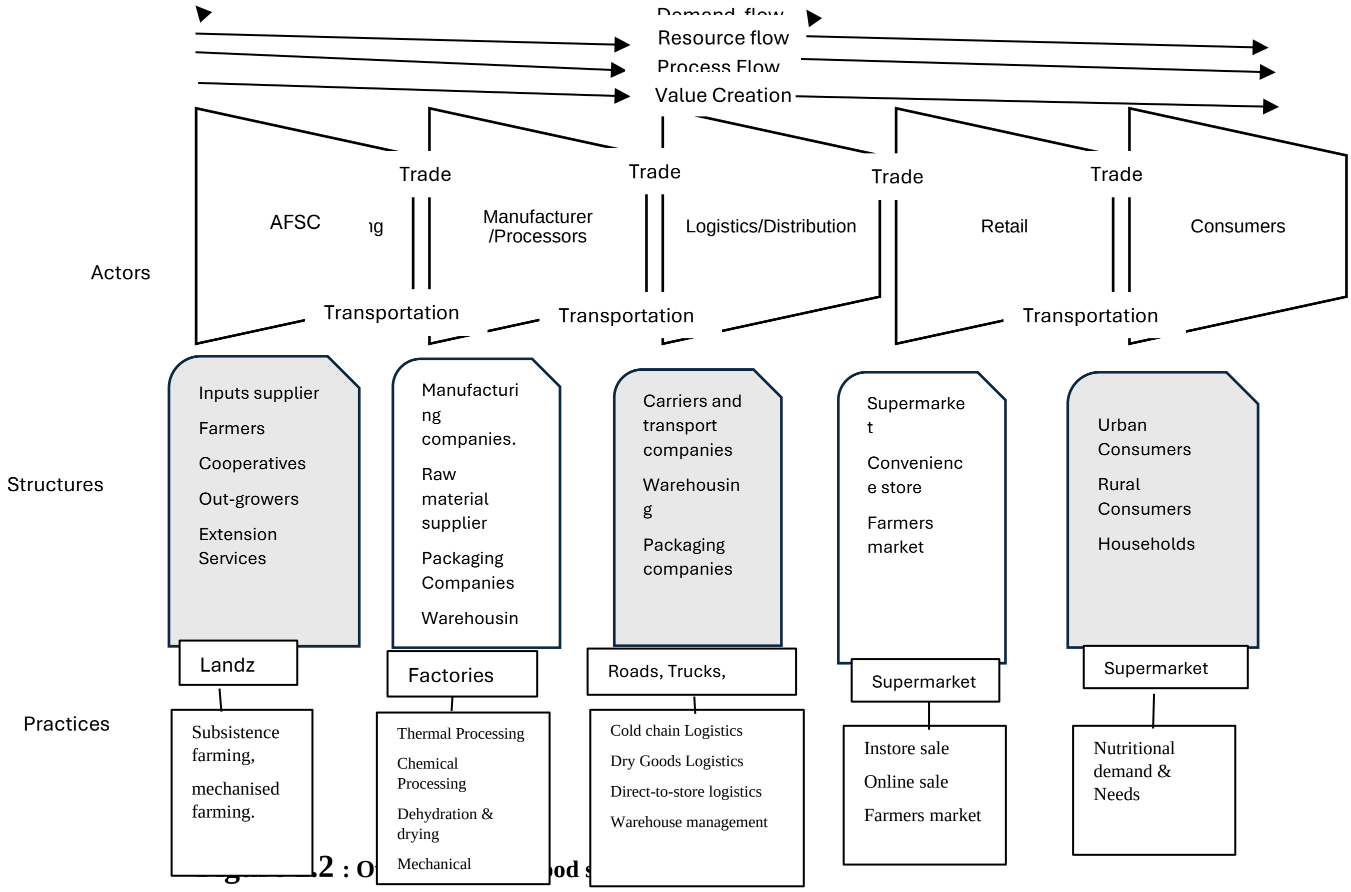
Chapter 3, literature review; section three cover the impact of industry 4.0 technologies on AFSC sustainability- Economic, social, environmental which was detailed in the literature review section. This conceptual framework guides qualitative study and was used in developing the interview schedule for the study. The interview schedule covers all three aspects of the conceptual framework by investigating the challenges of AFSC in Nigeria, AFSC transformation by the adoption of industry 4.0 technology and the sustainability impact of use and adoption of industry 4.0. In chapter 4, the conceptual framework was validated after the analysis of the qualitative data .

Figure 2.1 **Conceptual Framework**



2.11 THE OVERVIEW OF THE AGRIFOOD SUPPLY CHAIN SYSTEM

Agricultural supply chains are comprehensive systems that incorporate many activities, organisations, actors, resources, and operations in producing agri-food products for consumer needs. The food system comprises several interconnected actors involved in the elemental production, processing, distribution, and retail until it reaches the end users (OECD & FAO. 2016.) The agricultural upstream and downstream sectors encompass several activities ranging from the provision of agricultural inputs (e.g., seeds, fertilisers, feeds, medications, and equipment) through the stages of production, post-harvest handling, processing, transportation, marketing, distribution, and retailing. Figure 1 shows the actors, structure, and practices involved in the AFSC and how they interact. In addition, the interaction between this actor in the AFSC and the system also creates an avenue that provides other support services, including research and development and market intelligence.



Overview of Agrifood Industry

2.11.0 The State of Agriculture and food industry in Africa (Nigeria); Logistic, Retail and Trade

Agriculture is a prominent occupation in Nigeria. It is the primary source of livelihood for over 70% of the country's people, directly or indirectly. Agriculture plays a significant role in employment, revenue generation, and food provision for the expanding population while also serving as a primary source of raw materials for agro-based industries.

The agricultural system currently employed in Nigeria should reduce its heavy dependence on unpredictable weather patterns, specifically rainfall, to achieve consistent and sufficient production of raw materials throughout the year. This shift is necessary to support the development of the agro-industrial sector (Elijah et al. Nov 2017).

Due to various factors, including population growth, intensified demand for land resources, and natural and artificial disasters such as drought, desertification, soil erosion, and degradation, the issue of sustainable agricultural production in Nigeria has become increasingly significant. To address such problems as hunger, starvation, diseases, reliance on foreign sources for raw materials, and food importation, as well as to enhance the quantity and quality of food per capita and the well-being of farmers and their families, it is imperative to increase the rate of agricultural production growth in Nigeria significantly (Oruma, Misra and Fernandez-Sanz 2021).

Nigeria and other developing nations should acknowledge that achieving self-sufficiency in food and raw materials is an internal matter for their respective countries. It is crucial to prioritise implementing a well-designed agricultural development plan, as this will serve as the basis for modernising the entire economy(Afolabi et al. 2021)

Nigeria's agricultural sector mainly relies on manual labour, accounting for 90% of the labour, and a mere 3% employs engine-powered technology. Given that over 70% of the population is involved in agriculture, achieving self-sufficiency in food remains an elusive goal. Enhancing rural farmers' educational and technological capabilities is imperative (Elijah et al.., 2017). This will enable the development of a genuine entrepreneurial ability within rural areas, facilitating competitive access to local and worldwide markets. While women are indeed involved in rural farming, it is imperative to implement specialised programs that specifically cater to their needs. This is due to their significant responsibilities as primary agricultural producers, merchants, and givers of nutrition.

The agricultural sector in Nigeria has exhibited a lack of competitiveness on the global stage in various aspects such as quality, quantity, compliance with standards and investment opportunity. These challenges have crippled Nigeria's agriculture commodity and limited agribusinesses' participation in the global food trade. However, few agribusiness owners believe that regulations and standards for international trade are hindering Nigeria's full participation in trade. A significant concern is that inconsistent policy creates an unstable regional agriculture trade market. This situation is expected to persist until there are improvements in infrastructure and the implementation of policies and institutional measures that support and promote the sector.

2.11.1 Agricultural Transformation

Agriculture has undergone a gradual and progressive transformation over time, progressing from Agriculture 1.0 to 4.0, as evidenced by the available evidence. During the 19th century, significant advancements and widespread use of steam engines played a pivotal role in enhancing various sectors of society and industry, encompassing agriculture. The advent of Agriculture 2.0 marked a significant shift in farming practices, characterised by farming operations and farmers employing on-farm machines and widespread use of chemical inputs by farmers. Implementing Agriculture 2.0 has resulted in a notable enhancement in the efficiency and productivity of agricultural practices(Zhai et al., 2020). However, this significant enhancement resulted in adverse repercussions: The era of revolution at hand encompasses chemical contaminations in various fields, the detrimental impact on the ecological environment, the excessive consumption of energy resources, and the wasteful utilisation of natural resources. The emergence of Agriculture 3.0 in the 20th century can be attributed to the tremendous advancements in computing and electronics (Taechatanasat and Armstrong 2014). Using computer programs and robotic technology has facilitated the efficient and intelligent execution of operations by agricultural equipment. In response to the challenges encountered in Agriculture 2.0, adjustments were made to the tactics employed in Agriculture 3.0 (Oruma, Misra and Fernandez-Sanz 2021).

Implementing a rational allocation of work to agricultural machinery has resulted in a reduction in the reliance on chemical inputs and an enhancement in the precision of irrigation practices, among other benefits. In contemporary times, the agricultural sector is undergoing a transformative phase called Agriculture 4.0. This advancement is made possible by integrating cutting-edge technologies such as the Internet of Things, Big Data, Artificial Intelligence, Cloud Computing, and Remote Sensing. Elijah (2017 explores the utilisation of these technologies as having the potential to significantly enhance agricultural practices' operational effectiveness in the Nigerian agriculture industry.

2.11.2 Food Logistics

Numerous African nations possess a flourishing agricultural industry characterised by cultivating diverse crops and rearing livestock, which have prospects for meeting food manufacturers' and consumer products' Agri commodities needs.

Agrifood logistics is the movement, storage, and distribution of agricultural and food products, from where they are made (like fields and processing plants) to where they are used (like stores, restaurants, and homes). The agricultural business is vital to ensuring customers get fresh and processed agricultural products on time and in a safe way that meets quality and safety standards (Djimgou Tchakounte and Fiankor 2021). The rise and intensification of food demand resulting from population growth necessitate implementing innovative strategies for food distribution networks. The increasing prevalence of urbanisation and evolving consumption habits have resulted in a heightened need for enhanced cold chain infrastructure to facilitate the transportation of perishable goods (Therien, Guelph and Therien 2017). Indeed, the dynamics of supply and demand have transcended national and regional boundaries, evolving into global phenomena (Amanor 2009). There has been a growing scholarly focus on the environmental impacts associated with agrifood logistics, contributing to an increase in the GHG emissions of post-production in the African sector (FA0 2022). The growing distinction between areas of production and areas of consumption requires the management of territories and their interconnections to ensure food security (Jagtap 2021). The expansion of food value chains encompasses an increasing level of interconnectedness over broader geographical and regional participation, necessitating the establishment of more intricate distribution networks.

Some of the most important parts and aspects of agrifood transportation are the transportation, storage, and delivery of food, which are some of the most essential parts of the agrifood logistics business (Adeleke, 2022). The distribution segment of food value chains encompasses several actors, such as collectors, wholesalers, transporters, and retailers (Kamariotou and Kitsios, 2018). The agri-food logistics sector in Africa is crucial in facilitating the adequate transportation and distribution of agricultural and food commodities throughout the continent. The agri-food logistics business in Africa encounters a range of distinctive difficulties and opportunities due to the continent's diverse climates, geographies, and agricultural techniques. Inadequate transportation infrastructure, encompassing roadways, ports, and railways, can impede the optimal conveyance of farming commodities (Djimgou Tchakounte and Fiankor 2021). The presence of distribution channels plays a crucial role in facilitating the proper functioning of the market and ensuring that households have access to food. The process involves moving farming goods from their origins on farms and in production facilities to different places where they can be sold. Different kinds of transportation, like cars, trains, ships, and planes, depend on the type of goods, the distance to be travelled, and how quickly they need to get there. To keep the overall quality and freshness of agricultural goods, the right places to store them must be set up. Cold storage, temperature-controlled warehouses, and other specialised storage are used to keep goods from going bad and maintain their quality (Jagtap et al., 2021). Insufficient availability of appropriate storage infrastructure, particularly in rural regions, can result in post-harvest losses and diminished product quality. Inefficiencies and lack of connectedness can arise across the agricultural value chain, from production to consumption, due to weak links (Kuteyi and Winkler, 2022). Various stakeholders, including international organisations, governments, and private sector entities, are allocating resources to enhance infrastructure and bolster logistics capabilities (Adeleke, A., 2022).

The current trend in food supply chains involves a rapid shift towards globally interconnected systems characterised by a wide range of complex interactions (Adeleke, 2022). This trend also impacts the methods employed in producing, processing, and distributing food, including agri-food logistics. Sustainable growth within agri-food logistics can be attained by optimising management techniques throughout the supply chain and enhancing social and environmental consciousness and measures among actors. (Pérez-Mesa, et al. 2021). Several intriguing factors that can improve the sustainability of this supply chain include the engagement of smaller enterprises, implementation of more stringent regulations about control, quality, and safety, increased industrialisation of processes, and overall enhancement of management practices (Kuteyi and Winkler, 2022).

In a contemporary globalised context, where agricultural and food products are manufactured and distributed long distances before reaching the final consumer, it is crucial to possess comprehensive information regarding the conditions under which these goods are processed and transported (Amanor 2009). This necessitates implementing systems that monitor and record product alterations throughout the supply chain, from the initial producer to the end users. The primary objective of such systems is to ultimately identify damaged products and reconstruct their journey from the farm to the consumer and potentially back again. The process of tracking necessitates the acquisition of a distinct sequence of data points, wherein the product is actively subjected to scanning. This scanning activity primarily yields historical information acquired when the scanning is executed at a specific instant. In the agrifood sector, it is necessary to maintain specified conditions, such as temperature and humidity, to prevent the deterioration of commodities. This is crucial for ensuring the continuation of company operations and minimising risks within the supply chain. There is an increasing inclination towards using novel approaches such as mobile applications, blockchain technology, and Internet of Things (IoT) devices to enhance transparency and efficiency within supply chain operations.

2.11.3 Food Retail

The sale of food and non-food products to end users is the primary purpose of the retail system. Food retailing comprises around 40% of global retail sales, but over time, most conventional food retailers tend to diversify their operations by incorporating non-food retailing. The retail industry comprises different types, including supermarkets, convenience stores, grocery stores and hypermarkets. With global leading retail businesses in other parts of the world, as seen in Walmart in the USA and Tesco in the UK, and a fast-moving retail chain in Africa called Shoprite.

The food retail system is the closest point of the agrifood system to end users. It provides consumers a platform to purchase value-added agri-food products (Nickanor et al., 2020). This serves as a bridge between agrifood producers and consumers, promoting convenience shopping to customers. It is widely acknowledged that food selling has existed for at least a millennium or more. Ancient markets and open market systems have been, as evidenced by historical records. Food was one of the fundamental goods exchanged or sold within these marketplaces. (Pérez-Mesa, et al. 2021)

The agrifood retail system has developed globally recently and experienced increased innovations. Over the years, several innovative shopping experiences were presented to customers, from home delivery to supermarket the weekly meal (Therien et al., 2017). There are innovative payment experiences, from cash to contactless payment methods, to improve customer experiences (Das Nair, Chisoro and Ziba 2018). They are also innovative solutions to meet the needs of customer health consciousness by providing customers with information about agrifood products from farm to store so that customers can be aware of the source of their food, increasing transparency and traceability (Das Nair and Landani 2021)

The agrifood retail system has evolved from corner shops into multi-billion-dollar supermarkets across developed countries. In recent years, there have been increasing agribusiness retail chains in African regions. The evolution of agrifood retail in developing African countries will not be fully grasped without highlighting the role of a street food system and farmers' market that prevails in some African countries, contributing to the economic capacities of some of its citizens (Campbell 2016; Dannenberg 2013). The street food system is a subset of the retail store, which serves as a significant supplier of agrifood products to them. These street food actors sell processed foods, fruit and vegetables at low profit margins to customers on the road or in traffic. This street food system is not efficient because of the low profitability and massive child labour that is paramount with it. The increasing indulgence in street food sales in Africa shows the level of poverty present across the countries. The farmer’s market is an open space market system where agrifood commodities are displayed for buyers (Dannenberg 2013). The market system is prevalent in African rural areas, which exemplifies the short-supply food chain, where consumers have direct contact with the producers of the food they purchase. This agrifood retail system demonstrated a massive level of transparency and traceability. Which promises fresh agrifood produce with monumental quality (Dakora 2012). The accelerated expansion in contemporary food retailing within emerging nations and its consequential effects on the broader food system have garnered significant attention among stakeholders, leading to investigations into the change in food systems, particularly in recent years.

The growing number of supermarkets in many developing countries, especially in Africa, has generated significant attention, leading to the development of the whole food system, with a specific focus on the effects of improving the livelihoods of small-scale producers (farmers). Supermarkets play a crucial role in the food system, contributing to modern life and feeding the growing population (Reardon et al. 2003). They achieve this by ensuring a steady availability of high-quality agrifoods and non-food products that are differentiated based on quality. Additionally, supermarkets drive improvements in supply chains and logistics to enhance efficiency. This leaves the consumer with many options to shop for their food needs. South Africa and Kenya are leading nations driving the advancement of supermarket chains across the African continent. Both countries saw a massive expansion of supermarket chains in the early 2000s. One noteworthy characteristic observed in the progress of retail outlets in Africa is the significant role played by indigenous business leaders and international businesses, as seen in the case of Kenya and South Africa (Nickanor et al., 2020). There is a lack of readily available data regarding the scale and structure of food retailing in West Africa. Accurately assessing the dimensions and composition of the food retail industry poses significant challenges due to its wide variety and the substantial role played by informal economic activities.

2.11.4 Trade

Global trade has played a significant role in ensuring food's raw materials are exchanged between nations and businesses for production and processes to meet the nutritional demands of consumers (Djimgou Tchakounte and Fiankor, D., 2021). It is important to note that trade in agrifood has played a crucial role in our mainstream society over the years (FAO 2022*)*. Today's magnitude of food and agricultural trade is unparalleled; during the past 50 years, international flows have expanded almost fivefold, but the expansion has been unevenly distributed among areas(FAO 2018b). For a significant portion of this time, it would not be unfair to claim that the wealthy nations outperformed the developing ones in the area where they are meant to have a comparative advantage (Teignier, M. 2018). On this note, it is impossible to determine whether developing countries' overall development has improved or declined based on how their net agricultural trade balance has changed. Hence, the number of emerging nations comprises various distinct nation- and commodity-specific circumstances (F.A.O.O., 2021). There has been an increased discourse on global trade and globalisation. The increase of food and agricultural trade had significant growth during the 2000s. The food and agricultural trade network increased in volume, with massive opportunities for engaging food trade emerging between nations (Bown 2017). Additionally, there was an enhanced involvement of low- and middle-income countries in this network, expressed in the export and imports of agrifood commodities across borders. Several countries see agrifood trade as an avenue to compete in the global market and increase foreign exchange. The opening up of trade at international and regional levels has been a significant component of this globalisation trend. Between 1995 and 2019, the global system for trading food and agricultural products got a bit more decentralised. During 1995, a few prominent commercial centres mostly controlled the trade network. In recent years, the trade sector has seen the massive entry of new players in agrifood commodities trade, resulting in a notable increase in the number of hubs and a decrease in the influence held by specific trading hubs. The significant openness of the agrifood commodity trade sector brought about innovation and several transactions within the industry. The decentralisation of the food trade was possibly increasing globalisation ((FAO 2022*)*. Recently, there has been a significant increase in the global capacity and volume of agrifood commodity trade (OECD & FAO. 2016.). Tremendous pressure is placed on natural resources to meet the demand for exporting different agricultural and food commodities. In the 21st century, the importance of trade in commodities has grown in the global economy, and the proportion of global output that was traded increased dramatically (Diao, Hazell and Thurlow 2010).

The growth of the trade of agrifood commodities throughout the 21st century can be attributed to heightened connections among nations. Many nations have broadened their involvement in global agrifood, transforming the trade's terrain and geography. For instance, in just 20 years, Sub-Saharan Africa may have seen its percentage of global exports fall from 11% to less than 3%(Djimgou Tchakounte, A., and Fiankor, D., 2021). The region's late 1980s trade surplus of $500 million in recent years has grown to a 10-billion-dollar deficit. Rising net imports of livestock and cereal goods and imports from the oilseed complex by numerous significant emerging nations other than China have played an essential role in defining the growing agricultural deficit in developing countries.

A few decades ago, agrifood commodity trade experienced a notable increase in regional bias where countries were inclined to engage in more trade activities within their regions as opposed to outside the areas; it is observed that nations tend to establish trade clusters and engage in higher levels of trade within these clusters. These clusters may appear within their region or encompass multiple countries spanning different areas(Fox, E.M., 2021). This may be due to several factors such as geographical proximity, trade agreements, shared values, the peculiar relationships between them and possible agrifood commodities the nation produced (FAO 2022). Trade agreements like the African Continental Free Trade Area (AfCFTA) promote regional trade within African countries(Fox, E.M., 2021). The global agrifood commodities trade has experienced stability in recent years. An increasing number of nations have established connections with more trade partners, enhancing the potential of agrifood trade sufficiency (FAO, IFAD, IOM & WFP. 2018).

However, it is essential to note that most of the value exchanged is concentrated in a limited number of nations. At the same time, only a select few countries source a diverse range of food and agricultural products from several exporters. Trade fosters connections between agrifood systems and individuals, facilitating the exchange of goods and services. This trade industry plays a huge role in ensuring an adequate supply of diverse and nutritious food. Additionally, it serves as a source of economic enablement in terms of employment for individuals and profit ventures for several actors in the supply chain and contributes to countries' GDP(Diao, Hazell and Thurlow 2010).

It is worth noting the huge importance of indigenous and international organisations in pursuing the African agrifood industry towards sustainability, as shown in Table 2.1. Several authors have highlighted the importance of international organisations in the African agri-food industry. Adenle, Wedig and Azadi 2019 explore the role of international organisations in sustainable agriculture and achieving food. The study highlights that security in Africa suggests that enhancing agricultural production relies heavily on promoting sustainable agriculture, technological innovation plays a crucial role in promoting sustainable agricultural growth, and the African government should provide a conducive policy framework to support sustainable agriculture.

Table 2.1 List of International Organisations in African Agriculture

International Organization	Role and functions
The Forum for Agricultural Research in Africa (FARA)	FARA is the primary regional institution tasked with coordinating and promoting agricultural research for development (AR4D). The Africa Union Commission's technical division, FARA, specifically addresses agricultural innovation, science and technology issues. The inception of FARA took place in the late 1990s, spearheaded by a dedicated group of individuals comprising African scientists and enlightened donor aid officials. This collective recognised the capacity of agriculture to alleviate poverty in the continent. However, they acknowledged that this objective could only be accomplished by consolidating and enhancing the weak and

	fragmented agricultural research. The primary purpose of FARA is to enhance the capabilities of persons and institutions, focusing on women, youth, smallholder farmers, and agribusiness, to facilitate agricultural transformation responsive to climate change. The program clusters of FARA encompass several areas, such as innovative collaborations, knowledge management, capacity development, and research management. These clusters are designed to fulfil the objectives of the Malabo-CAADP agreements effectively and contribute to ensuring food security across the African continent.
Alliance for a Green Revolution in Africa (AGRA)	AGRA is a passionate African-led organisation with a primary objective of expanding the reach of agricultural innovations that contribute to the economic growth of small-scale farmers, leading to enhanced income levels, improved quality of life, and heightened food security. The primary objective of AGRA IS to stimulate the development of sustainable food systems throughout Africa. This will be achieved by exerting influence and leveraging partnerships to establish a solid enabling framework that promotes the expansion of the private sector and empowers smallholder farmers to generate an ample supply of nutritious food. AGRA's objective is to actively foster an inclusive agricultural revolution across Africa's food system, mitigate hunger, enhance nutritional standards, and adapt to the challenges posed by climate change. The primary objective of AGRA is to facilitate a significant shift in the livelihoods of smallholder farmers, transitioning them from a state of individual struggle for mere subsistence to one where their agricultural enterprises flourish. Since 2006, AGRA has collaborated with many stakeholders, including partners, governments, non-governmental organisations, and private sector firms, to implement practical strategies to support smallholder farmers and indigenous African agricultural enterprises. Placing smallholder farmers at the forefront is AGRA's priority, which acknowledges the crucial role they play in the economic development of nations since no country has successfully

	transitioned from a low-income status to a middle-income one without undergoing significant agricultural reform.
Consultative Group for International Agricultural Research (CGAIR)	The worldwide collaboration serves as a unifying platform for multinational organizations involved in researching the topic of food security. The primary objectives of CGIAR research encompass the reduction of rural poverty, enhancement of food security, promotion of human health and nutrition, and the sustainable use of natural resources. The research conducted by CGIAR is implemented throughout 15 centres across the globe, which engage in collaborative efforts with many stakeholders, including national and regional research institutes, civil society groups, academic institutions, development organisations, and probate sectors. CGIAR collaborates with partners across six prominent areas to tackle the complexities associated with food, land, and water systems. The challenges and dangers faced by agriculture and fisheries, especially those related to climate change, exhibit regional variations and necessitate region-specific responses. CGAIR impact spans Climate adaptation and mitigation, and biodiversity. They work to enhance the resilience of small-scale farmers and mitigate greenhouse gas emissions within the food chain. Increasing productivity in food systems while staying within environmental boundaries and maintaining biodiversity
CGIAR Platform for Big Data in Agriculture	The primary objective of the CGIAR Platform for Big Data in Agriculture is to bring about a transformative impact on agricultural practices in developing nations via the effective utilisation of data and information technologies. The Platform aims to enhance the effectiveness of agricultural development and tackle issues such as hunger, poverty, and climate change by facilitating widespread access to farming data and advocating for decision-making processes that are informed by data.

	The Platform operates worldwide, facilitating the connection of specialists and cultivating partnerships to advance pioneering initiatives and techniques capable of revolutionising the agricultural industry. This endeavour aims to position CGIAR as a prominent influencer in big data in agriculture and development internationally.
International Institute of Tropical Agriculture (IITA)	The International Institute of Tropical Agriculture (IITA) is an institution that prioritises research and advancement to tackle issues of food scarcity, poverty, and environmental deterioration throughout the African continent. Since its establishment in 1967, the International Institute of Tropical Agriculture (IITA) has collaborated with many stakeholders to enhance the quality of life, provide food security, generate employment opportunities, and promote environmental sustainability. The organisation aspires to establish itself as a prominent research collaborator in pursuing agricultural remedies to combat hunger and poverty in tropical regions. Its primary objective is to foster research collaborations that tackle hunger, poverty, and environmental concerns, specifically within sub-Saharan Africa. The International Institute of Tropical Agriculture (IITA) emphasises many core principles: innovation, cooperation, professionalism, quality, respect, multiculturalism, integrity, inclusivity, equity, and multidisciplinary.
The Food and Agriculture Organization (FAO)	The Food and Agriculture Organization (FAO) is a specialised United Nations organisation dedicated to pursuing food security for all individuals and eradicating hunger and poverty. The Food and Agriculture Organization (FAO) has been extensively engaged in various projects and programs, including resolving pressing food-related issues, advancing responsible fisheries, and promoting sustainable agriculture. The Food and Agriculture Organization (FAO) has been instrumental in several worldwide endeavours, including

	successfully eradicating Rinderpest, formulating responsible land and resource governance principles, and executing Sustainable Development Goals (SDGs) about food and agriculture.

As the African agrifood sector is responsible for most of the employment opportunities created in the region, the success and development of the industry are crucial to the socio-economic sustainability of most African countries (UNIDO 2013). Growing bodies of knowledge, both in literature and practices, validate the role of agrifood sector expansion and viability to long-term socio-economic sustainability; it is widely agreed upon that such development may significantly contribute to overall economic growth (Adenle, A.A. *et al.* 2017, Johnston, B.F., 1968, FA0 2014, and FAO, IFAD, IOM & WFP. 2018.).

2.12 SUSTAINABILITY

In the forthcoming years, the global food systems are anticipated to encounter an unparalleled convergence of challenges. If the pattern continues, there will be a significant detrimental impact on our future global ability to provide food and the corresponding economic advantages required to ensure an adequate food supply. If there is no substantial alteration in direction and the subsequent patterns in food and agriculture practices, the industry will face further intensified challenges. Doing things differently guarantees a more positive outcome (Gallego et al. 2021)

In the vein of several challenges the agrifood industry faces, there is a need to do something different across many operations and functionalities from farm to work. An ongoing concern among stakeholders is developing ways to make the agrifood sector resilient and sustainable. To achieve the sustainability of the agrifood system, changes and transformations need to occur in both the processes and structures (Aivazidou et al. 2015). There is a need to reconsider AFSC processes by implementing better ways in which the system can overcome its present challenges despite the underlying limitations hindering full-scale transformation (Guliyeva and Lis, 2020). The use of better solutions to bring efficiency will be a significant consideration between the shareholders and the government, and most leading organisations or businesses in an industry lead by implementing enhanced business operations aided by tools and machinery to drive competitiveness. The essential business transformations occur by adopting and implementing solutions that support efficiency, backed by shared value between business leaders, government and research organisations (Golinska-Dawson and Pawlewski 2015).

This idea of sustainability and equitable growth was established nearly thirty years ago in the October 1987 report published by the World Commission on Environment and Development. This report, known as the Brundtland Report, identified three fundamental sustainability principles. Businesses often include discussions on the three essential aspects of sustainability, namely environmental, social, and economic, in their sustainability reports.

Environmental awareness emerged during the 1970s, marked by the United Nations Conference on the Human Environment. This conference emphasised the necessity of implementing appropriate measures to address the challenges posed by environmental issues. However, it was not until the 1980s that the concept of sustainability began to gain more clarity. This occurred when the World Commission on Environment and Development introduced sustainability as a widely accepted notion. It defined it as a way of life that satisfies the current generation's demands without damaging future generations' ability to satisfy their needs. Elkington (1997) introduced the concept of the "Triple Bottom Line" (TBL), which consists of People, Planet and Profit, and has gained significant recognition on a global scale (Getzner 1999). The TBL establishes the fundamental aspects of the area of focus for organisations undergoing the transition towards sustainability; it encompasses three crucial sustainable development components: environmental, social, and economic.

Over the years, multiple definitions of sustainability have been proposed. FAO has defined sustainable agricultural development, which encompasses the responsible management and preservation of natural resources and the trajectory of technical advancements in a way that provides the ongoing satisfaction of human requirements for both current and future generations *(*FA0 2020). Our goal for sustainable food and agriculture is a global scenario where food is healthy and readily available to all individuals while concurrently ensuring the responsible management of natural resources (Norman and MacDonald, 2004). This management approach aims to preserve ecosystem services, supporting humanity and future requirements (Ceccarelli et al. 2022).

The capacity of humanity to establish sustainable development is crucial to satisfy the requirements of the current generation while safeguarding the potential of future generations to fulfil their demands. The notion of sustainable development encompasses the recognition of some limitations, but not absolute ones. These boundaries are determined by the current level of technology and social structure, which restricts environmental resources (Becker and Ellis 2017). Additionally, the capacity of the biosphere to assimilate the impacts of human activity also sets constraints on sustainable growth (Schroeder, Lampietti and Elabed 2021)

Sustainability encompasses a broader scope than simply safeguarding the foundation of natural resources and includes making the economy viable and ensuring social security (Kaufmann and Panni 2014; Elijah et al. 2018). To achieve sustainability, the agrifood sector must effectively cater to the demands of current and future generations through all means of its services to humanity (Correia 2019). This must be done while guaranteeing financial viability, environmental well-being, and social and economic fairness (Müller and Pfleger 2014). To achieve the sustainability of the agrifood system, changes and transformations need to occur in both the processes and structures (Haysom et al.,2019). Agrifood functions from farm to fork must adopt better work implementation methods despite the underlying limitations hindering the innovations *(*FA0 2020). The use of better solutions to bring efficiency will be a significant consideration between the shareholders and the government, and most leading organisations or businesses in an industry lead by implementing enhanced business operations aided by tools and machinery to drive competitiveness (Correia 2019). The essential business transformations occur by adopting and implementing solutions that support efficiency, backed by shared value between business leaders, government, and research organisations (Guliyeva and Lis 2020).

A sustainable agrifood supply chain is increasingly imperative, driven by economic and regulatory standards, socioeconomic trends, and growing societal environmental consciousness (Haysom, G. et al.,2019). Developing agrifood sustainability will enhance productivity, help mitigate the impact of climate change, improve nutrition, reduce hunger and poverty, and promote shared prosperity among stakeholders. Given the significant reliance of agriculture on ecosystem services, it is essential for sustainable agricultural practices to realign the agrifood sector towards prosperity while simultaneously maximising present potential and increasing capacity (Lisa Baures 2020). This may be achieved through the protection, conservation, and enhancement of natural resources and their effective utilisation.

Realising sustainable agrifood necessitates formulating proactive strategies that enable prudent decision-making to accomplish diverse goals (Correia 2019). Enhanced efficiency in resource utilisation may alleviate strain on ecosystems and natural resources while concurrently bolstering profitability. However, this increased profitability may unintentionally foster industrial growth, thus causing resource depletion and degradation (Houessou et al., 2020).

Contemporary supply chains, particularly those operating within the agri-food industry, are intrinsically shaped by historical influences akin to their modern corporate counterparts. Most are driven by culture and ancestral practices (Norman and MacDonald 2004). Adopting more sustainable methods means overcoming cultural barriers and constraints (Mukatia, Githii and Ombati 2018). In many parts of Africa, where most farming is done in the rural areas, their belief systems are shaped by culture and religion that are passed down generationally to agriculture. However, methods will need to be exchanged for a more sustainable practice. A huge concern is ongoing when farming communities are linked to floods, and irregular rainfall, religious beliefs, not realising it resulted from the negative impact of climate change due to the interaction of unsustainable human practices with the ecosystem.

Food Sustainability hinges upon collective global efforts to assist emerging nations in establishing adequate infrastructure, enhancing income-generating prospects, and alleviating financial limitations (Golinska-Dawson and Pawlewski 2015). The many stakeholders participating in agri-food supply chains are driven to actively pursue strategies and initiatives to improve and promote sustainability (FAO. 2018.). Nevertheless, they must embrace a more comprehensive outlook by actively involving several external stakeholders in pursuing innovation.

The practical solutions to the issue at hand lie in the collective engagement of governments, international organisations, private enterprises, and the global populace, which is vital for ensuring agrifood along the whole food supply chain, including the entire process from seed production to consumption (Roth and Valentinov 2020). The prosperity of the agrifood system hinges on the collaboration of stakeholders to find ways to implement sustainable production guidelines and capacity collectively and to enforce compliance (UNIDO 2013). The allocation of resources towards agricultural research and development, alongside agrarian technology, will play a pivotal role in attaining an agrifood-sustainable agenda. As research drives development and innovation, investment in research is critical to achieving sustainability. Several challenges have been the issues of low participation of developing countries in sustainability innovation, which is highly concerning; the pressing challenges are not merely climate change and food insufficiency, but are plagued with changes of bad government, poor leadership and low investment in the country's infrastructure (Becker and Ellis 2017).

2.13 Research Gaps: Industry 4.0 in African Agrifood Supply Chains

An extensive literature review conducted in chapter 2 (literature review) showed that there are limited industry 4.0 technology applications within the agrifood industry in Africa and Nigeria. Most published papers and research are conducted in Asia and most developed countries; the application and research on industry 4.0 within the Africa and Nigeria agrifood industry present critical research gaps worth investigating.

Firstly, it is worth noting that there exists a substantial knowledge and application gap between the application of industry 4.0 technologies in Africa and developed economies. Despite the voluminous body of knowledge and literature that exist in this field, the application of industry 4.0 in the Africa agrifood supply chain is underrepresented within the body of literature; because the continent has its uniqueness (60% of world's arable land and young population), and its story of adoption and use of industry 4.0 technology needs to be studied.

Secondly, the current body of literature and studies on Agrifood 4.0 does not sufficiently address Africa's agrifood system's unique socioeconomic, infrastructure and readiness limitations. Having the majority of farm workers be smallholders, with a digital literacy gap, poor rural infrastructure and an ageing population of farm workers, this all contributed to unique acceptance and use of industry 4.0 technology across the agrifood supply chain, which has not been thoroughly studied in the current body of literature.

Thirdly, the African agrifood industry needs a contextual technology adoption framework specific to the African agricultural systems. The current research only presented a general adoption model that overlooks the characteristics of African agrifood practices, which requires a region-specific context adoption framework and research, the methodological gaps of which are addressed in this study.

Finally, there is limited or no empirical data to support the huge potential of the use and acceptance of industry 4.0 technology in tackling Africa agrifood challenges such as climate change, food waste and loss, youth employment and profitability to the actors.

CHAPTER THREE (3)

METHODOLOGY

3.1 Introduction

This methodology explains the research philosophy underpinning the study, supported by appropriate justification. This study methodology adopted Saunders et al.'s 2007 research onions, which consist of several essential parts of a research study. The researcher structures this section based on the several parts of the research onions: Research Philosophy, research approach, research strategy, research choices(or design), research techniques and procedures (Data collection), justification, and the appropriateness of the method(Saunders et al., 2007).

3.2 Research Philosophy

Research philosophy explains the set of beliefs and principles that guide the development of knowledge by a researcher. It serves as a framework that provides understanding and guidance of the nature and study of knowledge, clearly detailing the assumptions that guide the research methods and strategies (Saunders et al., 2007). Research philosophy is an essential feature of research that drives the researcher's processes and approaches towards addressing a research problem. Researchers' philosophical views vary depending on what needs to be studied and the methods for the study (Saunders et al., 2012; Avgousti, 2013). Saunders et al. (2015) clarify that research philosophy facilitates consistency in the research process and provides appropriate justification for choosing research methods and strategies. Hence, researchers need to identify the research philosophy underpinning their studies to enhance the credibility and reliability of their research findings.

Nevertheless, studies highlight three major research philosophies popular in literature: positivism, interpretivism or constructivism and pragmatism (Fenstermacher, 1986; Panya & Nyarwath, 2022; Gannon et al., 2022). Other scholars, e.g., Saunders et al. (2015), reveal that critical realism and postmodernism are additional research philosophies that underpin studies. Notwithstanding, positivism, interpretivism or constructivism, pragmatism and critical realism are widely emphasised in the literature (e.g., Saunders et al., 2007; Ali, 2023). Importantly, each research philosophy or paradigm has four main components: ontology, epistemology, methodology and axiology (Saunders et al., 2007; Saunders et al., 2015; Khatri, 2020). However, these components are extended by authors, e.g. Mbanaso et al. (2023), by adding doxology, which is believed to be accurate. These developments show how important the concept of paradigm or research philosophy influences the conduct of research.

Hence, researchers need to understand the philosophical components of the research; thus, ontology, epistemology, methodology, and axiology are essential. The ontological assumption of research philosophy is important when developing hypotheses or selecting the research topic. It deals with the nature of existence or reality. This branch of philosophy explains the researcher's assumptions to substantiate that something made is real or makes sense (Scotland, 2012). Hence, ontology concerns the level of reality in particular objects and events that modify or drive our perceptions of those objects and events. It enables the conceptualisation of the nature of reality and what one believes can be studied concerning that reality. The ontological perspective guides the researcher to rethink what constitutes reality's nature and asks fundamental questions. The ontological view helps the researcher understand the events and objects that make the world or reality known (Scott and Usher, 2011; Khatri, 2020). This leads to understanding other research philosophical or paradigm components that underline the study of phenomena. Epistemology refers to knowledge derived from different sources. It simply explains how we come to know (Trochim, 2000). Researchers adopt an epistemological stance to enable them to explain how they know reality. Furthermore, Khatri (2020) highlights the knowledge, its forms, nature, how it is gained, and how it is communicated to others. Methodology is another essential component of research philosophy. It refers to the research design, approaches, methods, and procedures utilised for inquiry or examination (Saunders et al., 2007; Khatri, 2020). Methodology in paradigm considers the data collection instrument, the participants, the data analysis technique and the approach through which a research question is addressed and knowledge is gained. It is essential to mention that methodological considerations of a paradigm explain the systematic research flow for researching the question. Methodology clarifies the assumptions, limitations, and mitigation – focusing on how we gain knowledge or know the world (Saunders et al., 2015; Khatri, 2020). Moreover, axiology explains the significance of ethics and values in understanding a phenomenon or reality. The work of Saunders et al. (2015) clarifies that researchers need to handle the study participants and their values adequately. Critically, the axiological choices of a researcher emanating from the impact of the researcher's beliefs and values on the study should be positive. It is essential to show your axiological skills by explicitly demonstrating the values or ethics underlying the appropriateness of the study's choice, method and approach (Heron, 1996).

Positivism

The positivist philosophical stance considers observable reality to create lawlike generalisations (Crossan, 2003; Saunders et al., 2015). Crossan (2003) argues that positivist researchers adopt a precise quantitative method to examine phenomena. Further, strong advocates of positivism, e.g., Kaboub (2008) and Park et al. (2020), stress that social entities and organisations are real, like the way natural phenomena and physical objects are real. It promises accurate knowledge and avoids ambiguity. Hence, observable and measurable phenomena can produce meaningful outcomes (Crotty, 1998; Crossan, 2003). It enhances opportunities for searching relationships that exist in the data collected from the phenomena to produce lawlike generalisations. This then helps to clarify and predict events and behaviour.

Positivism represents a philosophical position that aligns with the paradigm of a natural scientist, which entails working with an observable social reality to produce law-like generalisations(Johnson & Gill, 2010). The work of Saunders et al. (2015) clarifies that positivist researchers utilise extant theory to develop hypotheses. Moreover, the hypotheses are tested and validated either in part or whole or rejected, contributing to theory development, which is further re-developed by further research. However, this does not imply that positivist researchers need to start with extant theory, but can start from observations made and data collected before formulating and testing hypotheses. Advocates of positivism ensure that they are detached and neutral from their research and data collection to avoid influencing research findings. Further, positivists stress that they are external to the research process, including data collection, and less can be done to change the relevance and substance of the data. Johnson and Gill (2010) emphasise that positivist researchers utilise structured methodologies, such as quantifiable observations that enhance repetition and statistical analysis.

Interpretivism

Interpretive research philosophy explains that humans create meaning, differentiating them from physical phenomena. Interpretivism iterates that different people have different social and cultural backgrounds, which vary in their applicability and relevance depending on the specific context and temporal factors creating different meanings and social realities (Saunders et al., 2015). Contrary to positivism, which creates a universal approach that resonates with everyone, interpretivism believes different people have rich insights and should not be narrowed down to lawlike generalisations. Hence, interpretive researchers create more decadent, new, in-depth interpretations and understandings of the social world and its contexts. Generally, interpretivists focus on the relevance of history, language and culture in shaping the experiences and interpretation of the social world (Crotty, 1998). Having much focus on the richness and complexity of the underlying phenomena, meaning-making and multiple interpretations, interpretivism is subjective. Interpretivist researchers acknowledge that their explanation of the research approach, materials, instruments, data collection, personal beliefs, and values play vital roles in the research process (Saunders et al., 2015). Interpretative perspectives are relevant for management and business research due to individual uniqueness and complexities in the management and business fields. Interestingly, critics express that interpretivists understand the world from their perspective after encountering the social world of the research participants.

Pragmatism

Pragmatist researchers acknowledge that a phenomenon or the world can be understood in different ways and that there is no single approach to reveal the entirety of a phenomenon (Saunders et al., 2012). Pragmatism aligns with subjectivism and objectivism; thus, both contextualised experiences, narratives and interpretations, and practical knowledge and facts. Further, pragmatist researchers consider concepts, theories, hypotheses, ideas and research findings practically. Notwithstanding that, Kelemen and Rumens (2008) argue that the pragmatic concept is only essential where it supports action. Pragmatist researchers usually begin with a research problem and strive to contribute practical implications to enhance future practice. The pragmatist paradigm focuses more importantly on the research question and how to address those research questions. The research question and how to address it become the critical factor for a pragmatist research design and strategy. Hence, pragmatists are more concerned about practical outcomes. This study aligns with a pragmatist perspective. This is due to the different approaches adopted for analyses of the role and impacts of Industry 4.0 technologies in the agrifood supply chain system towards the sustainability of Nigeria. Therefore, the research.

Critical Realism or Critical Theory

The philosophy of critical realism explains the nature we see and experience that modifies our observable events (Saunders et al., 2015). Having a layered and structured ontology, critical realists consider nature or reality necessary (Lawani, 2021). Further, proponents of critical realism see reality as independent and external, which is not directly available through existing knowledge. Critical realists argue that our senses can be deceptive and assert that our experience is empirical (Patomäki and Wight, 2000). Advocates of this philosophy suggest two approaches to understanding nature or the real world. The first approach is the event we experience, and the second is processing the event we experience. These steps help us understand the underlying world's causatives or reality. Hence, regarding critical realism, there is “retroduction” (Reed, 2005). Essential researchers of realism look for the bigger picture of what they see and the social structures underlying the studies (what we intend to study). This enabled them to focus on observable events by searching for mechanisms, avenues and causes through which sound social structures help modify everyday life. Therefore, critical realism researchers consider social structure analysis and how such events have changed (Reed, 2005; Lawani, 2021). This implies that researchers are informed about how their social-cultural experiences and backgrounds can influence their research and adopt approaches that reduce biases and enable them to shift towards objectivity.

Guba and Lincoln (1994) propose a framework for understanding research paradigms, which identifies three core questions that shape a researcher's approach: What is the nature of reality? How do we understand and explain what we know? How should we go about discovering knowledge? And what guidelines should we adhere to?

Heron and Reason 1997 further presented their work's different philosophical paradigms, components, and comparisons. Tables 3.1 and 3.2 show the essential philosophical components and comparisons between the research philosophies.

Table 3.1 Philosophical Components

Ontology focuses on the fundamental nature of reality. Ontology prompts inquiries about researchers' underlying assumptions about how the world works and their intense dedication to perspectives. In business research, there are two aspects of ontology: objectivism and subjectivism. **Objectivism-** This statement asserts that social entities have an objective existence outside the individuals (Social actors) who are conscious of their existence. **Subjectivism** -posits that social phenomena arise from the perceptions and subsequent acts of the individuals(social) involved in their existence. Saunders et al., 2015 emphasise the need to examine the intricacies of a situation to comprehend the actuality or an underlying truth. This is often linked to social constructionism (or constructionism). This stems from the interpretive standpoint that it is essential to delve into the subjective interpretations that drive the actions or behaviour of social actors in society for the researcher to comprehend these actions**.** Social constructionism posits that reality is formed and shaped by social processes and interactions**.**
Epistemology- Epistemology underlines the criteria for determining constituted knowledge that is valid or acceptable within a particular field of study**.**
Axiology - Axiology is a philosophical discipline that is concerned with the evaluation of values and Ethics of the Study.it is better put that there is a significant role that the researcher's value play plays in all stages of the research process and links to the credibility of the findings in the study

Adapted from (Heron and Reason 1997; Saunders et al., 2015)

Table 3.2 Comparison Between Research Paradigms

Philosophical Components	Positivism (naive realism)	Interpretivism (Constructivism)	Critical Realism (Post-positivism)	Pragmatism
Ontology - fundamental nature of reality	The conventional understanding of the nature of reality is often expressed via time-independent and context-independent generalisations, including cause-effect rules. This shows that social actors are independent and objective to the nature of reality.	Realities are intangible mental constructs shaped by social and experiential factors. These constructs are specific to local contexts, although some elements may be shared among individuals and cultures. Individual perspectives and characteristics influence the form and content of these constructs.	The existence of reality is postulated, although its comprehension is hindered by inherent limitations in human cognitive faculties and the inherently complex character of things. Critical Realism asserts that statements about reality should undergo extensive vital analysis to understand reality better. This is usually an objective.	Pragmatist researchers acknowledge that a phenomenon or the world can be understood in different ways and that there is no single approach to reveal the entirety of a phenomenon.
Epistemology- underlines the criteria for determining constituted knowledge.	The researcher and the examined "object" are separate entities, with the researcher having the ability	Subjectivist. The researcher and the topic of inquiry are said to be intricately connected,	The focus is on external "guardians" of objectivity, such as critical traditions, which assess whether	Pragmatism aligns with subjectivism and objectivism; thus, both contextualised experiences,

	to study the object without exerting any impact or being affected by it. Only observable occurrences or reality are the only source of reliable data.	resulting in the "findings" being generated in real-time as the investigation progresses.	the results align with established knowledge and community (such as editors and professional peers) Only observable occurrences or reality are the only source of reliable data. Concentrate on providing explanations within a specific framework or set of circumstances.	narratives and interpretations, and practical knowledge and facts.
Methodology- the choices of research model	Quantitative	Qualitative	Quantitative or qualitative	Quantitative and qualitative (mixed method design)
Axiology (Values and Ethics of the Study)	Researcher is neural and detached	Researchers are part of what is studied and not neutral.	Researcher admits bias by world perspectives	Value-driven and usually neutral

Source: Adapted from Saunders et al. (2012), Saunders et al. (2015) and Gannon et al. (2022)

Justification for Research Paradigm.

All research philosophical approaches are acceptable for understanding the phenomena or a study. Notwithstanding several authors, for example, Mogran 2017 contended that no single research method can thoroughly investigate the truth about reality or the subject of study. Applying the pragmatic paradigm is not a new approach in research within social science; Goundar 2012, argues that pragmatics is commonly associated with mixed-method research. Consequently, the pragmatic paradigm is the worldview the researcher adopted in this study, where quantitative and qualitative research methods are employed. This study's mixed-methods research design is sequential, where the qualitative studies inform the quantitative. The qualitative research was conducted using interviews as a research tool and then a survey as a quantitative research tool, in a sequential manner, as explained by (Saunders and Lewis, 2017; and Anthony and Nancy 2005). Pragmatist researchers acknowledge that a phenomenon or the world can be understood in different ways and that there is no single approach to revealing the entirety of a phenomenon (Morgan, 2017). Pragmatic research assumes that a unitary reality exists that is not divided, and each participant has their own perceptions. Anthony and Nancy 2005 argue that pragmatic research sees research holistically and comprehensively, enabling extended involvement and consistent observation, which helps the researcher visualise the link between existing literature and data or findings Gannon et al. (2022). This research paradigm allows for an in-depth study on the role of technology in achieving a sustainable agrifood supply chain in Nigeria; the research considers each participant has a unique experience in using this technology and has different experience in the impacts on their operations within the AFSC; this paradigm enables the researcher links the findings writing the study to existing data; that will enables the bridge of gap between theory and practices, and it is application in the context of Nigeria which is the largest economy and populous economy in Africa

3.3 Research Approach

Deductive

The deductive theory is the most prevalent perspective on the nature of the connection between theory and social research. The researcher formulates a hypothesis (or hypotheses) based on existing knowledge and theoretical considerations in a specific field. This hypothesis is tested via empirical investigation (Collis & Hussey 2003). The hypothesis will include ideas that must be converted into things that may be studied via research. The social scientist must proficiently derive a hypothesis and, after that, articulate it in practical terms. Consequently, the social scientist must precisely determine the methods for gathering data relevant to the ideas underlying the hypothesis (Bryman, 2008). Saunders et al., (2007) argue that deductive research is purely theory testing. In the academic work of Robson 2002, the author outlines a series of five consecutive steps that entails when undergoing deductive research, which is establishing a hypothesis, Formulating the hypothesis in operational terms, specifying the precise methods for measuring the ideas or variables and proposing a link between two particular concepts or variables; Evaluating this operational hypothesis; Assessing the result of the hypothesis; modifying the hypothesis based on the discoveries. Saunders et al., (2007) pointed out significant characteristics of the deductive approach to be the pursuit to elucidate relationships between variables. Blaikie 2007 argues that deductive research evaluates the hypotheses by comparing them to the available data.

Inductive

The inductive approach aims to derive findings organically from the data itself. It allows key themes to surface naturally from the data and information, free from the constraints of preconceived concepts and methodologies. This method emphasises letting the data speak for itself, revealing prominent or significant patterns without imposing preexisting expectations. Deductive analysis imposes a narrative on raw qualitative data through an approach to experiment, hypothesis testing, data collection and analysis, leading to the obscurity of meaning arising from data.

The broad inductive technique was developed with many underlying aims. The objective is to summarise massive and diverse unprocessed textual data succinctly. The aim is to create explicit connections between the study goals and the concise conclusions drawn from the original data. These connections should be evident to others and justified based on the research objectives: To construct a model or theory about the underlying framework of experiences or processes observed in the raw data.

According to Strauss and Corbin (1990), the inductive technique is used in several forms of qualitative data analysis, particularly grounded theory. Saunders (2006) observes that proponents of the inductive approach often challenge the deductive approach due to its tendency to create a rigid framework that limits the exploration of alternative explanations for observed phenomena. Selecting theories and forming hypotheses in deductive research can seem overly deterministic, potentially constraining the scope of inquiry and interpretation.

An inductive research approach prioritises examining the specific events, experiences, or circumstances in which these occurrences occurred. Hence, using a small sample of subjects may be more suitable for an industrial approach than a big one, as with the deductive technique. Easterby-Smith et al. (2008) contend that understanding various qualitative research approaches empowers researchers to modify their study strategy to accommodate limitations. Bryaman 2008 highlighted the relationship between theory and research approaches, as shown in Figure 5, which explains the relationship between deductive and inductive procedures in theory.

The inductive coding process thoroughly examines the text and contemplates its implicit interpretations. Subsequently, the researcher finds text segments that include meaningful components and generates a designation for a new group or classification to which the text segment is allocated, and relevant text parts are added to the corresponding category (Blaikie, 2007). At a certain point, the researcher may formulate a first depiction of the significance of the category and document it in a note, including relationships, connections, and consequences. The category may also be linked to other categories by interactions, such as a network, a hierarchical arrangement of categories, or a causal sequence. Creswell 2002 highlighted guidelines used to analyse qualitative data in an inductive approach, as shown in Table 3.3.

Table 3.3 Thematic Analysis Process Adapted from Creswell, 2002

Initial read through text data	Identify specific segments of information	Label the segments of information to create categories	Reduce overlap and redundancy among the categories	Create a model incorporating most important categories
Many pages of text	Many segments of text	30-40 categories	15-20 categories	3-8 categories

Corley and Gioia (2006) applied an inductive approach to the analysis of qualitative data within the framework of grounded theory. The study pinpointed several guidelines for in-depth inductive data analysis, consisting of a data structure and table, commonly used in grounded theory. This research adopted an inductive approach to the qualitative data and adopted the method proposed by Gioia for in-depth analysis, incorporating the data structure and table.

3.2.1 Justification of Research Approach

This study's qualitative method employed an inductive research approach to create explicit connections between the study goals and the concise conclusions drawn from the original data. Based on the study in the AFSC in Nigeria, the inductive approach will help to facilitate the emergence of research results based on the prevalent, dominant, or noteworthy themes that arise from the qualitative data drawn from the experience of the study participants. This study(Qualitative) will employ an inductive approach to analyse the qualitative data derived from 25 semi-structured interviews of AFSC stakeholders in Nigeria. The researcher adopted the procedures highlighted by Corley and Gioia (2006) and Creswell (2002), which outline guidelines for conducting an inductive qualitative data analysis. These procedures consist of initial reading through transcript data, making notes of segments of relevant information, coding, grouping the codes into subthemes, and finally grouping subthemes into themes.

This study's quantitative approach adopts the deductive approach, which aligns with Collis & Hussey's 2003 statement that the researcher formulates a hypothesis (or hypotheses) based on existing knowledge and theoretical considerations in a specific field. The quantitative study developed a hypothesis using UTUAT theory and other variables that emerged from the Qualitative study to investigate the use and acceptance of Industry 4.0 technology among the AFSC actors in Nigeria. The quantitative survey was developed in a deductive way using

UTUAT theory and variables that emerged from the interview; 158 participants from the AFSC in Nigeria responded to the survey questionnaire to deduce meaning based on the preconceived theory of UTUAT.

3.4 Research Strategy

Several research methodological approaches have been employed for different studies. For example, Ayan, Güner and Son-Turan 2022; Zhao et al., 2020. These researchers' methodologies conform with specific research philosophies underpinning the appropriateness of the study's research strategy. Drawing on the discussion of pragmatist philosophy, this study adopts its methodological approaches, which focus on utilizing multiple approaches or research methods (ways) to understand a phenomenon – the role and impacts of industry 4.0 technologies in the Agrifood supply chain system towards sustainability of Nigeria. Hence, the study provides the choice of methodologies used and explains how to corroborate the furtherance of the research.

According to Saunder (2012), the pragmatist worldview provides an in-depth approach and facilitates practical actions to address problems. Due to the nature of the phenomenon under study, the research will employ qualitative and quantitative data in a mixed-methods research design. Table 3.4 presents an overview of the qualitative design.

Table 3.4 Qualitative Design

Qualitative Design	Suitable enquiry for design	Academic field of study	Analysis	Mode of data collection	Strategy for data analysis
Case Study	A case study bound by time and place for a particular research enquiry	Law, political science, medicine, Psychology	Analysis of events or programs of more than one individual	Multiple data collection approach: interview, observations, artefacts and documents	Case and theme description of the collected data
Grounded Theory	When there is no existing theory or when the present theory is insufficient	Sociology	An approach characterised by the involvement of several individuals	Mostly Interview	The coding approach consists of an open, selecting, and axial coding approach.

			or participants.		
Narrative	A detailed story aids in comprehending the issue of inquiry	Humanities	One or more participants	Interview and Documents	Elements of a story are arranged in chronological.
Phenomenology	When a researcher aims to comprehend an individual's encounter with a particular phenomenon	Education, Psychology	A group of participants who have a shared experience	Interview, observations, Artefacts and Documents	Putting things in order, words, meaning units or themes, literary description, structure description, and getting the core of the phenomena of inquiry
Participatory Action Research	Addressing the issue of a community to foster change	Social science, Philosophy	Span a whole Community	The approach depends on the community's needs and can be qualitative or quantitative.	The community are involved in the process of data analysis.

3.4.1 Research choices- Mixed methods, Qualitative and Quantitative

Justification of Mixed Method for the Study

Adopting a mixed methods approach – using qualitative and quantitative methodological approaches can enable the researcher to study the constructs to enhance generalisation intensively. The study findings on promoting sustainability in Nigeria's agrifood supply chain system through Industry 4.0 technologies can be generalised and adopted for development, applications, and improvements in other economies within the region, developing countries or developed countries. Rossman and Wilson (1991) argue that employing a multi-method approach in policy research can enhance our understanding of the intricate phenomena in our social world. This approach allows us to view the world from various perspectives and utilise diverse methodologies more effectively, addressing the concerns of multiple stakeholders involved in policy issues instead of relying on a single method or approach.

Mixed Method Overview

A mixed-method study is a research approach that combines qualitative and quantitative techniques of data gathering and analysis within a single study. This study design allows researchers to understand complex occurrences and explain these phenomena using quantitative methods such as statistics, charts, and basic statistical approaches. Fielding & Fielding (1986 describe a mixed-method study as a study that uses quantitative and qualitative methods for gathering data, analysis and presenting findings within a single research study. The mixed-method approach involves collecting and analysing data, integrating the results, and drawing conclusions using both qualitative and quantitative techniques within a single study (Tashakkori & Creswell, 2007). This approach is not confined to traditional data collection methods but is guided by the core research questions that form the foundation of the study(Creswell, 1994). Tashakkori and Creswell (2007) highlighted that a mixed methods study has both qualitative and quantitative components, and challenges typically occur when the researcher tries to establish the relationship between these two parts. According to Ivankova and Creswell (2009), mixed methods research emphasises the relevant incorporation of qualitative and quantitative data. It may provide a comprehensive and extensive analysis that cannot be achieved using a single methodology. However, recent papers in this field have attempted to establish the significance of fully integrating both methods of such are (Hanson et al., 2005; Bryan, 2007). Researchers have differing opinions about what mixed methods research is, leading to an inconsistency in the field (Bryman, 2007). Tashakkori and Creswell (2007) contend that due to the ongoing development of mixed methods research, it is essential to maintain an open conversation over its precise definition. Johnson et al., (2007) propose that the meaning and application of mixed methods research will evolve as this research method grows. Tables 3.5 and 3.6 show the Rationale and steps for mixed-methods research.

Table 3.5 Rationale for using mixed methods

Reason	Description

Triangulation	Triangulation refers to using several independent data sources or data-gathering techniques to validate research results within a study. Triangulation enhances the credibility of research by finding corroboration between qualitative and quantitative data.
Facilitation	Researchers may employ one data collection method or research approach within a single study to complement and reinforce another. This strategy involves integrating qualitative and quantitative techniques in various ways. For instance, qualitative methods might be used to generate hypotheses that are then tested quantitatively; this helps to leverage the strengths of each approach, enhancing the overall depth and validity of the investigation.
Complementarity	The use of several research methodologies allows for the integration of various components of an inquiry. For instance, a combination of qualitative and quantitative questionnaires may be employed to address gaps in data. In contrast, quantitative and qualitative questionnaires can be used to explore different topics.
Aid interpretation	The use of qualitative data to elucidate the connections between quantitative variables.
Study different aspects	In this case, quantitative analysis is used to examine macro-level factors, whereas qualitative analysis is used to investigate micro-level factors.

Reason for using mixed methods Source: developed from Bryman (2006)

Table 3.6 Steps for conducting mixed method research

Basic Steps	Overview
Step 1- Assess the need for a mixed-method approach to investigate the issue.	Identifying the research problem or question follows an in-depth literature review to assess the need to address a specific issue; it is essential to establish whether the topic needs to be more adequately explored or understudied. In such cases, it may be necessary to consider

	using a mixed-method study to investigate the problem thoroughly. The following are primary justifications for undertaking mixed-method research. 1. Converging or triangulating the data from qualitative and quantitative approaches provides more information or more accurate information than relying on just one method. 2. The results obtained from one approach may be expanded using another method.
Step 2- Assess the feasibility of conducting mixed-method research.	Mixed method researcher should consider the following: the study is addressing a real problem, there are resources and access to effectively collect relevant information for the study, conducting a study that is of interest (to the researcher and others), aligning the project with career objectives and required skills and financial support to cover cost during data collection (Creswell, 1994)
Step 3- examine whether the written research question can be investigated using qualitative and quantitative methods.	Can these research questions (or hypotheses) be examined using both qualitative and quantitative approaches? A qualitative question aims to get a detailed description of the subject under investigation. Quantitative inquiries establish the precise

	correlation between independent and dependent variables.
Step 4- Evaluate and determine the methods for gathering quantitative and qualitative data.	Qualitative approaches include four main types of data collection: observations, interviews, documents, and audio-visual material (Creswell, 1994). The key concept in the quantitative approach is that the data may be quantified or expressed as a numerical value that can be used for statistical analysis.
Step 5- Evaluate the weight or comparative significance of each approach in the study.	How much weight or importance should qualitative and quantitative aspects of research have compared to one another? According to Morse (1991), research may be conceptually led by quantitative or qualitative methods. Morse (1991) employed capital letters to indicate which approach the investigator (Researcher) deemed more essential or weightier.
Step 6- Present a visual model of the mixed-method research design.	The simultaneous and sequential model for mixed method research may be graphically shown. Figure 80 shows the mixed-method research model. **Three mixed method research model:** sequential model convergence model instrument-building model,
Step 7- Establish the approach for data analysis based on the selected mixed-method research design	Selection of the appropriate mixed method research model in which data analysis is

	conducted and the subsequent interpretation of the findings. An example is the sequential model; data analysis is conducted sequentially, starting with data analysis from the first technique. The results of this analysis are then utilised to guide the direction of the second method.
Step 8- Evaluate the criteria used to establish the study's quality.	Creswell, 1994 and Miller, 1991 proposed the requirements for establishing the study quality of qualitative and quantitative research, respectively. Creswell proposes a well define guidelines to examine the quality of the mixed-method research study, which include the following : ● Does the research use at least one quantitative and one qualitative method in a single investigation? ● Has the author justified the need to do a mixed-method study? ● Is the research viable, considering the data volume, financial resources, time constraints, and necessary expertise? ● Have research questions been formulated for both the quantitative and qualitative methodologies used in the study? ● Have the qualitative and quantitative measurement and analysis procedures been explicitly determined and defined? ● Has the methods' implementation specification been provided,

	particularly regarding their sequencing (simultaneous or sequential)? ● Has the author provided a graphical representation (Visual Model) of the mixed method research procedures?

Table 3.7 Six Basic Designs of a mixed-method research

Convergent parallel It is a design in which a researcher simultaneously incorporates both quantitative and qualitative strands in the same phase of the research process. The methods are given equal importance, and the strands are kept separate during analysis. The researcher then combines the results during the presentation of the overall findings.
Explanatory Sequential This two-step mixed-method research design involves collecting and analysing quantitative data, followed by collecting and analysing qualitative data to provide more insights into the original quantitative findings.
Exploratory Sequential This two-step mixed-method research design involves collecting and analysing qualitative data, followed by collecting and analysing quantitative data to validate or support the original qualitative conclusions.
Embedded In this approach, the researcher gathers and examines quantitative and qualitative data inside a conventional quantitative or qualitative framework (Design) to improve the overall design.
Transformative The researcher produces this design within a transformational theoretical approach to meet the unique requirements of a particular demographic and advocate for change.
Multiphase

In this mixed-method research design, the researcher integrates both sequential and concurrent approaches to gather data over a duration and the execution of several projects or tasks.

Adapted from (Creswell and Plano Clark’s 2011; Guest et al., 2014; Guest and Fleming 014)

Qualitative and Quantitative in Mixed Method Research

At its most basic level, quantitative research involves collecting numerical data through various instruments. Conversely, qualitative research focuses on gathering textual data (such as interview transcripts or field notes) or visual materials (like photographs or videos) from participants within a specific context. In qualitative research, the researcher serves as the primary instrument for data collection rather than depending on pre-existing tools (Bogdan & Biklen, 1992).

In a typical quantitative study, a researcher collects data using various methods, such as a mailed survey, an instrument administered during an experimental intervention, or through the analysis of current or historical policy documents. The study by Ostlund et al. (2011) on the combined use of qualitative and quantitative approaches in mixed research highlighted its importance in health sciences. Ostlund et al. (2011) suggested that employing triangulation as a methodological tool can help integrate qualitative and quantitative data, enabling researchers to clarify their theoretical positions and the basis of their findings. This approach not only leads to a more thorough understanding of the relationship between theory and empirical evidence but also opens up the exciting possibility of challenging existing theoretical assumptions and fostering the development of new theoretical frameworks.

Qualitative research (Inductive Research approach)

Qualitative research is a valuable tool for investigating an individual's or group's experiences related to a social or human experience. It involves the collection of textual data (such as interview transcripts or the researcher's field notes) or visual materials (like photographs, videos, or other media) from participants within their natural settings. For a more comprehensive list of qualitative data collection methods, refer to Creswell (1998).

In qualitative studies, the researcher is the main tool for gathering data using predefined tools(Bogdan & Biklen, 1992). The qualitative research paradigm encompasses a multifaceted process that commences with the formulation of the pertinent research questions, methodological approaches and data collection within the participant environment and engages in a rigorous analytical procedure to analyse data and generate meaningful insight for the scope of inquiry.

This study's qualitative method employed an inductive research approach to create explicit connections between the study goals and the concise conclusions drawn from the original data.

Based on the study in the AFSC in Nigeria, the inductive approach will help to facilitate the emergence of research results based on the prevalent, dominant, or noteworthy themes that arise from the qualitative data drawn from the experience of the study participants. This study(Qualitative) will employ an inductive approach to analyze the qualitative data derived from 25 semi-structured interviews of AFSC stakeholders in Nigeria. The researcher adopted the procedures highlighted by Corley and Gioia (2006) and Creswell (2002), which outline guidelines for conducting an inductive qualitative data analysis. These procedures consist of initial reading through transcript data, making notes of segments of relevant information, coding, grouping the codes into subthemes, and finally grouping subthemes into themes.

Quantitative research

At its core, quantitative research entails collecting numerical data through various instruments. This approach explores objective concepts by examining the relationships between variables. These variables are often measured using tools that generate numerical data, which can then be analyzed through statistical methods. In a typical quantitative study, researchers may gather data through mailed surveys, instruments used as interventions in experiments, or by analysing current or historical policy documents. Table 3.8 gives an explicit overview of the comparison of different methodological approaches.

This study's quantitative approach adopts the deductive approach, which aligns with Collis & Hussey's 2003 statement that the researcher formulates a hypothesis (or hypotheses) based on existing knowledge and theoretical considerations in a specific field. The quantitative study developed a hypothesis using UTUAT theory and other variables that emerged from the Qualitative study to investigate the use and acceptance of Industry 4.0 technology among the AFSC actors in Nigeria

Table 3.8 Comparison of Methodological Approaches

Description	Qualitative	Quantitative	Mixed Methods
Nature of Data	Image, Text, Patterns, Document	Variables – values	Combination of words, images, variables, patterns and values
Analysis of Data	Search for contextual relationships between	Search for the statistical relationship	Quantitative results supported with

	patterns and critical themes		qualitative observations or qualitative observations supported by quantitative findings
Results	Results are particularistic	Results are generalised	Corroboration based on the results from the two methods
Form of Final Report	Interpretative report	Statistical Report	Pragmatic and Eclectic

Sources: Adopted from Saunders et al. (2007) and Saunders et al. (2013)

3.5 Qualitative Methodology

Pilot Study

Several studies have used a qualitative methodology to explore individuals' subjective experiences, attitudes, and beliefs that cannot be quantitatively assessed (Percy et al., 2015). Across all variations of the paradigm, interviews are the primary method for data collection (Majid et al., 2017). They are essential for the researcher to comprehensively understand the phenomena based on the individual's experience (Merriam, 2016). Furthermore, doing a face-to-face interview is commonly recognised as an appropriate method for qualitative research to gather perspectives from individuals who have encountered or are currently encountering the issue in question (Collingridge & Gantt, 2008). Hence, conducting pilot interviews is essential to evaluate the questions and get practical experience in the interviewing process (Tashakkori & Teddlie, 2003). Pilot studies often use quantitative methods to assess a specific research tool. The existing literature has emphasised both the concept and importance of pilot studies. Unquestionably, the application of the pilot study has been extended to qualitative studies, where it is conducted as a preliminary study for the main study. Tashakkori & Teddlie, 2003 pointed out that a pilot study is essential for conducting robust qualitative research and serves as a first step in preparing for a comprehensive investigation, irrespective of the research paradigm. Castillo-Montoya 2016 highlighted the pilot study's significance in improving the interview protocol's quality. Majid et al., 2017 argue that a pilot study helps to identify any deficiencies or constraints in the interview design that may need essential revisions to the primary research. According to Harding (2013), the need to pilot qualitative interviews may not be immediately apparent due to the tendency of interview protocol to improve as the interview progresses. In 2017, it pointed out that a pilot study utilises an experimental design to enhance the likelihood of achieving a high-quality result in a research project. Parallel to that, Majid et al., 2017 suggested that a pilot study serves as the first phase of a research investigation and is distinguished by a reduced sample size, along with adjustments made before the primary study, to enhance the calibre and efficacy of the main study. Hassan, Schattner, and Mazza (2006) assert that a pilot study entails using a small-scale investigation to evaluate the effectiveness of the research instrument and other research techniques because of the larger-scale study. It is vital to note that the application of the pilot study crosses across qualitative and quantitative studies (Bryman, 2016).

Majid et al. 2017 presented procedures for performing the pilot study shown in Figure 3.1, which presents a comprehensive summary of the sequential steps in conducting a pilot study.

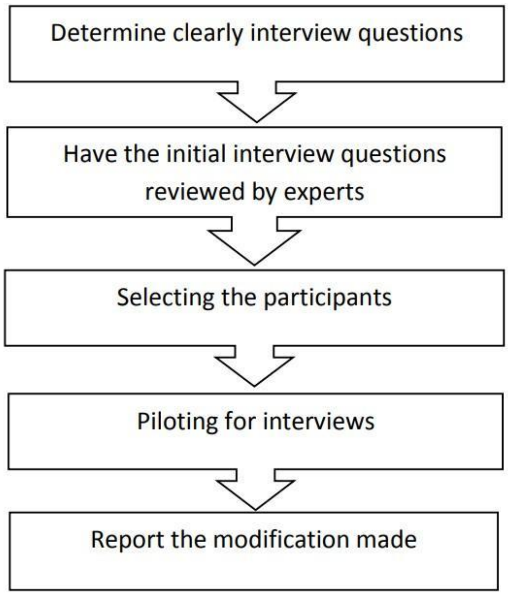


Figure 3.1: Process of conducting Pilot interview (Adapted from Majid et al. 2017)

The process of the pilot study was carried out based on the guidelines proposed by Majid et al. 2017, which consist of five steps: development of precise interview questions, expert review of interview questions, participant selection, conducting the pilot interview and reporting the changes made.

3.5.1 Qualitative Pilot Study

In the first step in conducting the pilot study, a draft or a preliminary version of the interview questions about the research question was developed. The research instrument for the pilot study was explicitly designed to address research questions. This is in agreement with the suggestion within the body of literature with the perspective that a pilot study helps to enhance the effectiveness of research questions and achieve the significance and objectives of the study (Castillo-Montoya 2016). Majid et al., 2017 reiterated the importance of this as a crucial need since it guarantees that a researcher has included all essential questions that encompass the idea or phenomenon. During the second phase, the researcher included the director of studies in evaluating the interview questions in terms of their relevance to the study, grammatical structure, effectiveness in addressing the research questions and painless delivery of information to participants. Afterwards, the researcher had a peer review of interview questions with four experts in the field, who were drawn from two academic institutions in the UK (Nottingham Trent University – 3 participants and Teesside University -1 participant). During the third step, the researcher selected participants who met specific criteria as respondents and, therefore, formally requested permission from the AGRA and other actors within the AFSC in Nigeria to carry out a pilot study. The researcher recommended a timeline after receiving permission to conduct the pilot study. Three pilot interviews were scheduled, but two were successfully conducted; the interviews took place online via MS Teams. During the fourth stage, the pilot study was conducted via MS Teams, following the interview protocol, ensuring good rapport, using effective communication, and duly following the prescribed recommendations made by Jacob and Ferguson 2012**,** emphasising that good communication will enable accurate and better answers from participants. The last step included analysing to assess the dependability and accuracy of the research instrument, followed by making necessary adjustments to the questionnaire based on insights gained or findings from the pilot study. The researcher used this last step to make essential revisions and modifications, impacting ethical requirements during the main study (Majid et al., 2017).

3.6 Research technique and procedure

Research strategy – Interview, Survey

This study employed semi-structured interviews and surveys for qualitative and quantitative components of the research design. The researcher used a semi-structured interview to investigate the research question among the agrifood supply chain stakeholders and sequentially employed a survey to further examine the research question, as described by Saunder in the sequential mixed method research. Both research techniques were tailored to investigate the impact of technology on the sustainability of the agrifood supply chain in Nigeria, which consists of farmers, food processors, and logistics. This research technique was designed to gather information from respondents chosen within the Nigeria AFSC sector, among AFSC stakeholders deploying the use of Industry 4.0 technologies or applications within the agrifood space, as part of the researcher's investigation of the impact of this group of technology on economic, social and environmental outcomes on the stakeholders and nation. This research included a combination of primary and secondary data sources. The researcher acquired primary data by using semi-structured interviews, oral interviews, and surveys (online questionnaires and facilitating discussion among participants in the AFSC sector in Nigeria. The researcher gathered secondary data via a comprehensive literature analysis described in Chapter Three. This process revealed gaps in the subject area to limited or no studies conducted to explore the role of industry 4.0 technologies (Big et al.) in the context of Africa, using Nigeria as a case study, considering the National Agricultural Technology and Innovation Policy (NATIP).

Interview

In recent decades, interviews have emerged as a significant tool for inquiry in social science research.

Social scientists explore several aspects of human experience via qualitative interviews. As pointed out by Kvale 2006, qualitative researchers aim to comprehend the world from the participants' perspectives (Subjects) and unravel the significance of their lived experiences. The interviews provide a platform for ordinary individuals to express their living experiences in their own words, fostering a direct and intimate connection between the researchers and the interviewees (Creswell 2013). Kvale and Brinkmann 2009 proposed seven steps in interviewing a researcher; this was also supported by Rubin and Rubin (2012) who presented a model for interview inquiry called responsive, which serves as guidelines for conducting the interviews. Mcgrath, Palmgren and Liljedahl (2018)

It was precise, highlighted the application of interviews in medical research, and highlighted twelve tips: decide the interview's appropriateness to the study and prepare to be the primary. Investigator of the study: Create an interview guide and evaluate interview questions; consider the cultural construct of the interview; establish rapport (establish a strong connection with the participants); the research is the primary data collection instrument; listen while engaging, allow the participant to talk more; adjust research guide if necessary; prepare for unfavourable emotions from participants; Efficiently transcribe the interviews responses promptly; go through data; start analysis.

Survey Questionnaire

The questionnaire is a crucial component of every survey, and its effectiveness depends on the design. A questionnaire is a compilation of inquiries in the form of questions driven by researchers' research questions that a responder fills out to express their viewpoint. A questionnaire serves as the primary method for gathering quantitative primary data. A questionnaire facilitates the systematic collection of quantitative data, ensuring consistency and coherence of data suitable to address the research questions. Martin (2006) proposes that a questionnaire should contain a definite purpose directly linked to the study goals, and it is essential to establish how the results will be used from the beginning. A questionnaire is a cost-effective tool that may be used when resources are limited. It is relatively cheap to create and distribute and efficiently utilises time, a valuable resource. The questionnaire safeguards participants' privacy, which is crucial, as it encourages them to provide honest responses when their identities are concealed and confidentiality is upheld. Tashakkori and Creswell, 2007 thought that creating research questionnaires is crucial in quantitative and qualitative research methodologies. This is because these questions guide the study's aim and purpose towards more precise inquiries that the research will investigate. Roopa and Rani (2012) propose five steps in developing a survey questionnaire: The initial stage considerations: developing and phrasing survey questions; the layout and sequence of the survey questions; conducting the pilot and review; and finalising the questionnaire (Roopa and Rani 2012).

Measures and Scales

The survey questionnaire design for this study was constructed on a 5-point Likert scale to gather the perspectives and viewpoints of the participants. The survey instrument was developed to measure eight variables, which examine how Effort expectancy (EE), Social influence (SI), Performance expectance (PE), Technology Dividends (TD), Technology adoption readiness (TAR), price value (PV), enabling conditions (EC) on behavior intention (BI) and user behaviour(UB). This helps the researcher to investigate variables that promote the use and adoption of Industry 4.0 technologies within the AFSC in Nigeria. The 5-point Likert scale is 1- Strongly Disagree; 2- Disagree, three Neither Agree nor Disagree, 4- Agree, and 5- Strongly Agree. The survey instrument was developed, and a peer review was conducted with four academic professionals within Nottingham Trent University and Teesside University, followed by a pilot study and a main study. The survey was set on the JISC platform and distributed electronically to target participants (mainly AFSC actors using Industry 4.0 technologies in their operations).

Sampling Approach

To address the research questions, it is often impractical for the researcher to collect data from every instance. As a result, selecting a sample becomes pertinent. The population refers to the whole group of cases from which researchers take their sample. Sampling approaches provide several strategies to minimise data collection by focusing on a subset rather than all potential elements or cases. To conclude, some research concerns may necessitate using sample data for the whole population from which your sample has been selected. Several authors, Saunder et al.,2006; Taherdoost 2016 outline the sequential stages typically involved in the process of sampling procedures for qualitative research, which are selecting the target population, Choosing the Sampling Frame, choosing a Technique for sampling, deciding the appropriate sample size, Data collection, and evaluating the rate at which responses are received (Taherdoost, H., 2016). Henry 1990 was quoted by Saunder et al.,2006 that employing sampling methods to the target research population will allow for greater overall accuracy.

Three considerable guidelines were presented by Miaoulis and Michener (1976) in determining suitable sample size., which are sampling error (the extent to which measurements are accurate and free from errors), confidence level (the level of confidence accounts for the potential risk of error while doing hypothesis testing; degree of variability in measure entity. The researcher carefully considered precision and prevalence as crucial factors in selecting the target group and calculating the sample size. According to Conroy (2015), precision refers to the degree of inaccuracy in measurement, whereas prevalence relates to the level of uniformity(homogeneity) in the features of the target group. The researcher carefully examined several sampling procedures outlined in the literature on qualitative research, which informed the decision to make a suitable approach for selecting and justifying the sample size for this study's target population.

Consequently, purposive sampling seems appropriate and was chosen for this study.

Purposive Sampling

Purposive sampling is a non-probability sampling strategy, mostly called judgemental or subjective sampling, which primarily enables the primary investigator (Researcher) to choose specific units of the target population based on specific criteria (Neetij & Thapa 2015). Maxwell, 1996 stated that in purposive sampling, researchers select participants intentionally to gather crucial information regarding the research questions (Maxwell, 1996). Purposive or judgmental sampling allows researchers to use discretion in selecting key research informants that will optimally facilitate answering the research question and achieving research objectives. Neuman, 2000 argues that purposive sampling methods are often used when dealing with very tiny samples, such as in case study research, and when one wants to choose a highly relevant case. Saunders et al., 2006 highlighted that most researchers conducting grounded theory or inductive research may also use purposive sampling. Patton 2002 suggested that research questions and objectives are the primary criteria for determining the chosen purposive sample methods.

Justification of Sampling Technique

Specific attributes considered as significant criteria for a good research sample design by Neetij and Thapa 2015; Patton 2002; Saunders et al., 2006, are: representative sample is reflected within the sample design, resulting in minimal sample error; must realistic in terms of resources (finance) available for the study; the design should enable the controlled of systemic bias; the sample should be representative enough to allow for the generalisation of the study's findings to the whole population with an acceptable degree of certainty. According to Patton 2002; Saunders et al., 2006 principles and guidelines on sampling strategy, purposive sampling was the appropriate approach in recruiting participants for the research. The researcher selected AFSC actors using or deploying industry 4.0 technologies in their operations: farming, food processing, and logistics/distribution. This participant with the selected criteria will help with relevant information to answer the research questions.

Study Population and Sample Size

To get relevant AFSC actors in Nigeria who can act as key informants with experience in using Technology 4.0 can help answer the research questions. The participants were drawn from AGRA, IITA, and NAERLS. Integrated Precision Agriculture LTD, OLAM Precision Farming, Eco tutu, Sahel LTD. Table 10 shows the participants' information on the part of the AFSC, the work, capacity, and technology employed by them.

Table 3.9 overview of participant's information

Participant	Industry	Role	Capacity	PA	(IoTs)	Big Data	Weather forecast	Sensors	Drones	GPS
1	Precision Agriculture	Manager	Large scale - OLAM Precision Farming	✓	✓	✓	✓	✓	✓	✓
2	Farming	Business owner	Large Scale farming				✓	✓		
3	Logistics	Manager	Small Scale		✓			✓		✓
4	Logistics	Deputy director	Large Scale		✓		✓			✓
5	Food manufacturing	Production manager	Large Scale					✓		

6	Food manufacturing	Production Supervisor	Large Scale					✓		
7	Food manufacturing	Production Manager	Small Scale			✓		✓		
8	Agriculture	Farm manager	Large Scale	✓	✓			✓		✓
9	Agriculture	Business Owner	Large Scale Framing		✓					✓
10	Logistic/ Agriculture	Manager	Ecotutu-small scale		✓		✓			✓
11	Logistics	Operation Supervisor	Large Scale				✓	✓		✓

12	Agriculture /Research	State Director	AGRA-10,00-50, 000 farmers	✓	✓	✓	✓	✓	✓	✓
13	Agriculture research Org	State Director	NAERLS – Large Scale Framing	✓	✓	✓	✓	✓	✓	✓
14	Logistics /Farming	Manager	Large Scale			✓	✓	✓		✓
15	Farming	Small scale farmer	Large scale				✓	✓		
16	Farming	Bus9ines owner	Large scale	✓	✓		✓	✓		✓
17	Farming	Business owner	Large scale	✓	✓			✓	✓	

18	Food manufacturing	Production supervisor	Large scale					✓		
19	Farmer/ Digital extension agent	Farmer	Large scale	✓			✓	✓		
20	Farmer/ Digital extension agent	Staff/ Worker	Small Scale	✓			✓	✓		
21	Food manufacturing	Production supervisor	Large scale					✓		
22	Food Manufacturing	Food manager	Large scale					✓		

23	Farming	Farmer	Large scale	✓				✓		
24	Farming	Business owner	Large scale				✓	✓		
25	Farming/ Livestock	Farm manger	Small Scale		✓		✓			✓

3.7 Data analysis

The Overview of the data analysis approach for Qualitative data

Thematic analysis is a systematic approach to uncovering, analysing and reporting recurring patterns within a data set. It minimally organises and explains collected data comprehensively. However, it often extends beyond this and analyses several sections of the research topic. (Boyatzis, 1998). Brown and Clarke 2006 suggested that thematic analysis offers intuitive and logical methods for obtaining codes and themes from qualitative data. Codes are the essential elements of analysis that capture significant data insight that evolved within the qualitative study and are pertinent to the research query or questions. Bryman (2006) further describes codes as the fundamental components of themes, which are overarching patterns of significance that evolve from the study query, supported by a central organising notion. Themes serve as a structure for categorising and presenting the researcher's analytical findings. The purpose of thematic analysis is not only to summarise the data but to recognise and analyse the most relevant aspects of the data driven by the research question.

Thematic analysis uncovers patterns in data reflecting participants' lived experiences, viewpoints, and behaviours. This method excels in experiential research, offering insights into individuals' thoughts, feelings, and actions (Creswell and Clark 2007).

It has been argued that using thematic analysis helps demonstrate rigour and outstanding qualitative research analysis. A theme captures something important about the research question's data and represents some patterned response or meaning within the data set. A crucial inquiry in the coding context is: What qualifies as a pattern or theme, and what is the minimum scale required for a theme? This question pertains to the extent or frequency of occurrence regarding the amount of space used by each data item and the overall occurrence across the data collection. Neuman 2000, argues that there is no rule to the characteristics that determine a theme. Moreover, the significance of a theme is not contingent on quantitative metrics but rather on its ability to encapsulate anything of importance in connection with the underlying research questions. Therefore, a researcher's judgement is essential in determining the themes of the research query (questions). Lochmiller (2021 suggested that flexibility is critical to researchers during thematic analysis. Thematic analysis allows for identifying patterns or themes within data using either an inductive or deductive approach. According to Frith & Gleeson (2004)**,** the inductive approach, or the 'bottom-up' approach, involves deriving themes directly from the data. On the other hand, the deductive approach, or the 'top-down' approach, consists of applying pre-existing theories or concepts to the data to identify themes (Boyatzis, 1998; Hayes, 1997).

Inductive Thematic Analysis

An inductive method in thematic analysis demonstrated a link between the discovered themes and the data, and the detected themes may correlate little with the precise questions posed to the participants. This technique has some similarities with grounded theory. The inductive data analysis approach derives meaning from data without conforming the processes to the influence of researchers' preexisting conceptual framework; here, the data speaks for itself based on the experiences of the participants**.**

According to Patton 2002, It can be concluded that the inductive thematic analysis approach is data-driven, meaning that it is based on the data itself. Nevertheless, Braun and Clarke 2006 contended that it is crucial to acknowledge that researchers cannot detach themselves from their theoretical and epistemological beliefs, and data cannot be analyzed without considering the underlying epistemological framework. This study adopted the inductive thematic analysis highlighted by Braun and Clarke (2006) and employed a data structure and a data table for the qualitative data presentation. This study employed inductive thematic data analysis, which is suitable for the study inquiry within the AFSC in Nigeria, as the researcher believed that the study should be pure data-driven, based on AFSC experience in Nigeria and not analyse data to conform to existing ideology or pre-established coding framework.

3.7.1 Data Analysis Approach- Interview and Survey

Multiple analytical approaches are employed to make sense of the data collected and in an attempt to address the research questions. Thematic analysis suggested by Braun and Clarke (2012) and the recommendations of Lochmiller (2021) on thematic analysis is first utilised to analyse the qualitative data – interviews. The thematic analysis is chosen over other qualitative analytical approaches such as content analysis (Stemler, 2001), grounded theory analysis (Charmaz, 2006) and discourse analysis (Brown, 1983; Potter, 2004) due to its rigorous standards and capability of providing more valuable findings and sense from the data (Castleberry & Nolen, 2018). The analysis is therefore performed using the computer software program NVivo 12 (QSR International, 2023). Structural equation modelling (SEM) analysis (Ullman & Bentler, 2012) is employed for the quantitative data survey to test and validate the findings of the thematic analysis of the interview data. The study utilised SEM analysis using the computer software package SmartPLS (SmartPLS, 2023). SEM is preferred over multilinear regression (MLR) (Uyanık and Güler, 2013) due to its ability to account for measurement error while examining the causal relationships among variables (Beran & Violato, 2010; Ullman & Bentler, 2012).

3.7.2 The interview and survey data analyses.

Analysis of Interview Data

The interview was conducted in person in Nigeria, and recorded using an intelligent recorder, and manually transcribed over 2 months, the quality of the transcribed data was ensured by thoroughly reviewing the data to o maintain the authenticity and integrity of participants' ideas and experiences The transcribed data was transferred to Nvivo 12, where the thematic analysis was conducted. It is essential to clarify that the coding of transcribed data was employed to reveal the data's richness and facilitate thematic analysis. Coding qualitative data helps make sense of textual data (Basit, 2003). The electronic coding method is adopted following the recommendation of Rivas (2012) and Elliot (2018), which provides the coding process for qualitative data. Hence, Braun and Clarke's (2006; 2012) recommendations are utilised for the thematic analysis of the interview data using NVivo 12 software. Braun and Clarke (2006) suggest six critical steps for conducting thematic analysis. These steps are employed for thematic analysis of the interview data as shown in table 3.10. First, the researcher familiarises with the data – by reading and re-reading the transcripts. Here, responses from the participants were read repeatedly to understand the 'content' and 'context' of each reaction – helping the researcher to figure out the kind of codes and themes that can emerge from the data. Secondly, the researcher generates initial codes emerging from the data. After rereading the transcripts, codes are created - phrases, sentences or sentences. Third, themes are searched by looking for relationships and patterns among codes to generate potential themes. At this point, the codes are conceptualised as similar codes or building blocks (Dawadi, 2021) to create themes concerning the research question. Fourth, the themes are reviewed. This implies intentionally and systematically grouping the initial themes to ensure consistency, coherence and distinctions between the themes. Fifth, the researcher provides appropriate definitions and names for themes. At this stage, the relevance and specifics of each theme are carefully identified, organised, and refined. The final step is to write the findings (report) about the research questions, highlighting the analysis's clarity, rationality, and validity. It is essential to mention that NVivo 12 software is used for the thematic analysis throughout the six steps explained and followed. Hence, contributions of Industry 4.0 technologies towards Nigeria's agrifood supply chain supply are identified in addition to crucial factors that promote acceptance and usage of Industry 4.0 technologies.

Table 3.10 Thematic Analysis of the Interview Data – An Example

Steps	Action/Meaning	Data Extract or Example from the Data
1. Become familiar with the data	Read the extract of 2 respondents repeatedly for context and clarity.	The interview transcript was read, the discourse was clarified, and its links to research questions were noted.
2. Generate initial codes	Possible codes that emerge from the participant's response or statement regarding the interview question are highlighted.	Inadequate Infrastructure Conventional Practice Climate change
3. Search for themes	From the collection of codes identified and highlighted throughout the dataset, patterns and relationships between the codes are drawn to form an overarching theme.	Process Evaluation/Challenges of AFSC.
4. Review the themes	The themes formed are reviewed to ensure consistency and coherence.	Themes are reviewed
5. Define and name themes	The themes are further defined to capture an appropriate theme, ensuring that main themes reflect and correspond with sub-themes, codes and extracts from the data.	Clear names and specifications are given to each theme,
6. Writing-up	The findings are written as reports about the research objectives and research questions.	Findings were reported.

Corley and Gioia's 2004 approach to inductive research demonstrated research rigour by showing how codes evolve from the data. For this study, the researcher adopted the approach to inductively analyse the research data by adopting a data structure and table. This helps to demonstrate rigour and clarity within the research process. Figure 3.2 and Table 3.11 show the sample of the qualitative data analysis approach adopted by the researcher in this study.

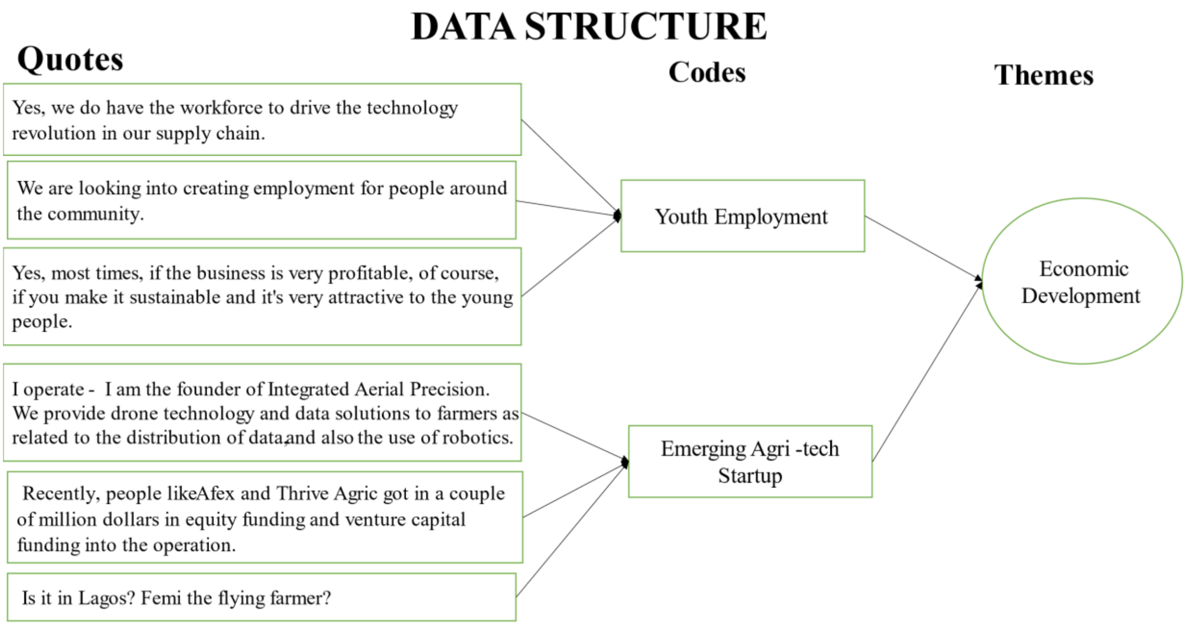


Figure 3.2 Sample of Study Data Structure

Table 3.11 Sample of Data Table used in this study

Themes- Digital Impact	
Codes	**Quotes**
Youth employment	• So, of course, the majority, about 80% of our workforce here, are youths. • We're also trying to extend that to other seed companies so that they also make agriculture attractive for the youths. • Yes, we do employ young people in our company. • To have a lot of young people on our team. Some of them are still in school, and some of them have just completed their NYSC. • We are looking into creating employment for people around the community

3.7.3 Analysis of Survey Data

The data collected through the JISC survey is analysed using SmartPLS Structural Equation Modelling (SEM). SmartPLS SEM provides latent variable modelling, which is user-friendly and sparks an intuitive graphical user interface (Ullman and Bentler, 2012). SmartPLS software offers more predictive and robust modelling than the AMOS statistical software package (Barnidge & De Zúñiga, 2017) – focusing on the relationships between the latent variables and their indicators (Purwanto, 2021). After cleaning, the survey data is uploaded to the software (SmartPLS) in MS Excel for SEM analysis. SEM is a multivariate data analysis method that tests supported linear and additive causal models (Wong, 2013; Hair et al., 2021). Researchers can use SEM to visualise the relationships between constructs or unobserved underlying variables, helping to resolve the research problem. Hence, SmartPLS SEM is employed to analyse the factors and implications of industry 4.0 technologies in Africa's Agrifood supply chain system to achieve sustainability, using Nigeria as a case study.

3.8 Models – ethical considerations

Models

This study adopts partial least squares Structural Equation Modelling (PLS-SEM) over covariance-based SEM (CB-SEM) (Afthanorhan, 2013) — another popular method in SEM analyses. While CB-SEM can reject or confirm the underlying hypothesis and their theories, PLS provides a causal-predictive technique (Hair et al., 2021), capable of interpreting the variance in the dependent variables of the model (Chin et al., 2020; Hair et al., 2021). Apart from the problem of multicollinearity, if not dealt with, PLS is suitable for SEM in business research and other related fields, including marketing (Guenther et al., 2023), management information systems (Assrfa et al., 2020) and behavioural science (Roni et al., 2015). It is also suitable when the data distribution is skewed and there are limited participants (Wong, 2013; Sarstedt et al., 2021). For example, the survey collected data mainly from AFSC actors, and it appears that many respondents are usually employed by business researchers to simultaneously estimate and model complex relationships among multiple independent and dependent variables. Hence, PLS-SEM is utilised to examine how Effort expectancy (EE), Social influence (SI), Performance expectance (PE), Technology Dividends (TD), Technology adoption readiness (TAR), price value (PV), enabling conditions (EC) on behaviour intention (BI) and user behavior(UB). This helps the researcher to investigate variables that promote the use and adoption of Industry 4.0 technologies within the AFSC in Nigeria. Figure 3.3 shows the proposed hypothesis adapted from UTAUT and interview questions to further explore the correlation between several independent variables on AFSC BI to continue using industry 4.0 technologies. The Smart PLS-4 software for PLS-SEM was used for this analysis. The analysis conducted on the proposed hypothesis to measure both the measurement model and structural model is: convergent validity, Discriminant validity, and convergent validity as suggested by Wong 2013. Hence, the model provided aligns with Wong's recommendation (2013). It is essential to mention that the study tests for internal reliability, consistency reliability, convergent reliability (Hair et al., 2012) and discriminant validity (Fornell & Larcker, 1981).

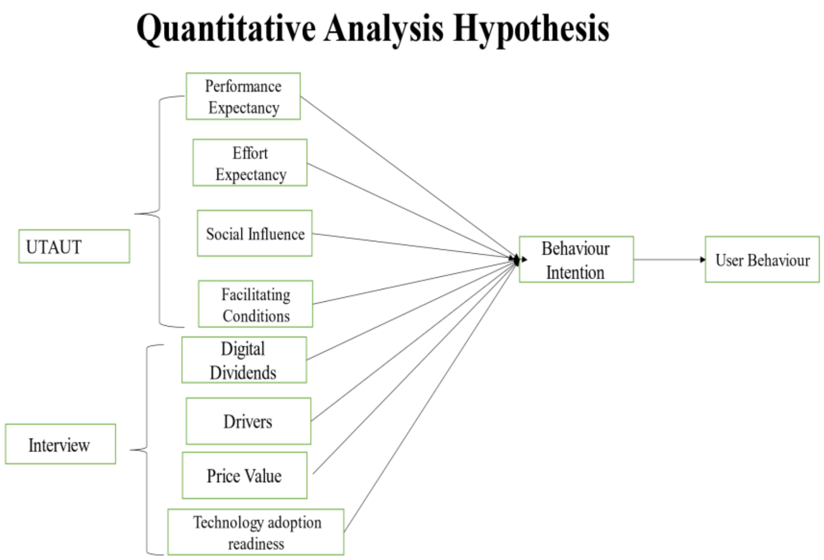


Figure 3.3: study model

Ethics of the Study

Before conducting the study, ethical considerations are made following the guidance and approval from the College Research Ethics Committee (CREC) of Nottingham Trent University (NTU). The ethics document provides the research aim, objectives, questions, and how the researcher plans to collect data, clearly detailing the brief of the research project, the participant information sheet, and the consent form. These two documents (PIS and consent form) are shared with participants to ensure they understand the research project and are willing to participate voluntarily. Receiving approval for the ethics considerations implies that the researcher follows and complies with ethical protocols duly set by CREC of NTU.

Summary

This research study seeks to investigate the role of technology in achieving sustainable agrifood supply chain in Nigeria. It examines how adopting the technology promotes economic, social and environmental sustainability, as suggested by several authors like Belaud et al 2019; Lezoche et al. 2020. The study adopted mixed methods research (Sequential Qual then Quan), inductive thematic analysis, and pragmatism paradigm. The respondents for the research are stakeholders using and form of industry 4.0 technologies. Figure 3.4 shows the study map for my research, the overview of the journey. Chapter Four provides a comprehensive discussion of the research methods used in this study, including a detailed explanation of the study's philosophical foundation. The selection of pragmatism was based on thorough investigation and careful evaluation of its suitability for addressing this study's research objectives and inquiries. The research extensively covered the methods of data collecting and data analysis techniques. It also provided a detailed explanation of the strategy used for data gathering, which included conducting semi-structured interviews and administering questionnaires.

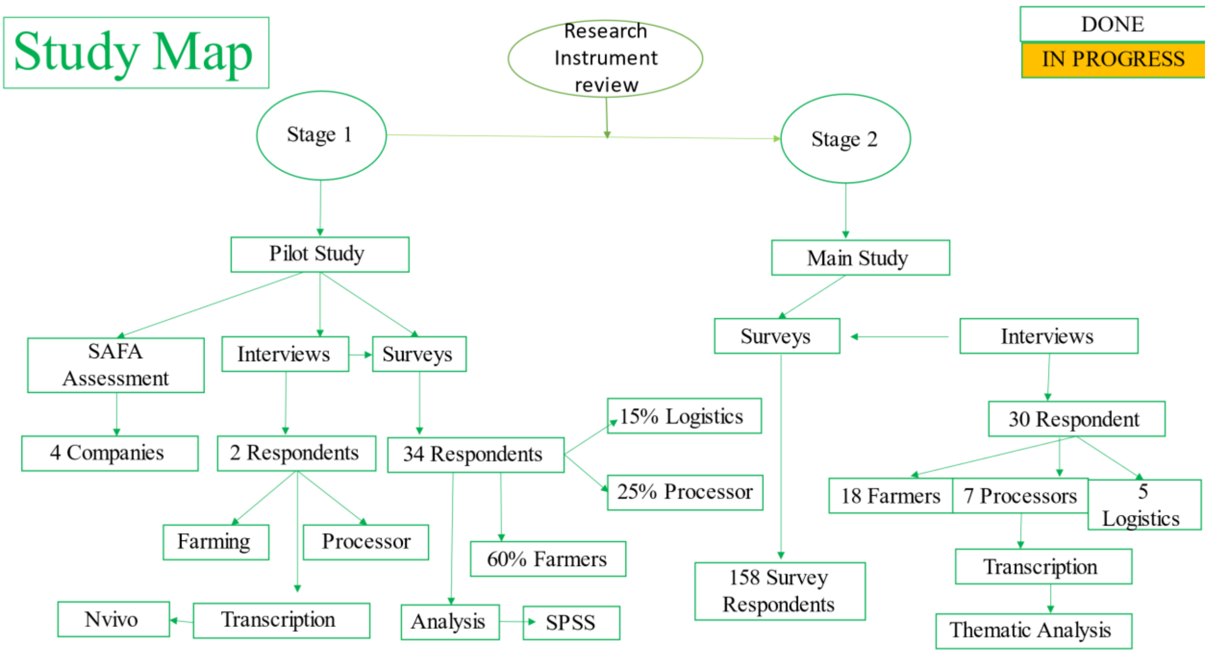


Figure 3.4 Study map

CHAPTER FOUR (4)

4.0 QUALITATIVE DATA ANALYSIS (Inductive)

4.1 Introduction

This chapter covers the study's qualitative approach. As clearly stated in the methodology section, a mixed-method research design is used in this study, and the qualitative analysis and approach serve as the leading data and analysis technique. This study's mixed-method approach is exploratory sequential, a two-step mixed-method research design that involves collecting and analysing qualitative data, followed by collecting and analysing quantitative data to validate or support the original qualitative conclusions.

The qualitative data gathering was conducted with AFSC actors in Nigeria. A total of 25 semi-structured interviews were conducted in line with the research objectives and to answer the research question. The interview schedule protocol was designed based on the guidelines highlighted by Saunders et al 2006. The interview schedule protocol had six sections, starting with the introduction (building rapport) and transitioning into the main inquiry. The interview questions were structured to answer all three research questions, which are majorly grouped as the impact of industry 4.0 technologies on the AFSC in Nigeria, how industry 4.0 technologies promote AFSC transformation, and what the underlying factors are that promote the adoption of this technology among current users within the agrifood industry in Nigeria. A purpose sampling method was used to select semi-structured interview participants as respondents who are presently using any form of Industry 4.0 technologies in farming, processing and distribution, or logistics. These are mainly big data, IoT, smart agriculture (Drones, Sensors, GPS), precision farming, smart logistics, and food processing 4.0. The participants were drawn from agribusiness, Federal Ministry of Food and Agriculture initiatives, international organisations, and large and small agribusiness within the Nigerian AFSC industry. The research made this choice in the hope that this broad participant selection will serve as key informants and contribute richly to the study due to their experience and involvement in the Nigerian AFSC context. This study analysis used an inductive thematic approach using the NVIVO 12 software. The qualitative data analysis contains a thematic analysis approach as seen in Tables 4.1 and 4.2.(Steps 1 and 2)1, data analysis result presentation in the form of the data table(Table 4.3), and data structure (Figure 4.1) as stated in Corley and Gioia 2006.

4.1 The Qualitative Data Analysis Process

Table 13 Step 1 Thematic Analysis of the Interview Data – An Example

Steps	Action	Example from the Data
1. Become familiar with the data	The researcher diligently acquaints himself by thoroughly reading and re-reading the transcripts of the interviews. This is to better understand the context and ensure clarity. Additionally, notes are meticulously gathered from the early stages. .	The interview extract provides insight into the sustainability impacts of industry 4.0 technology adoption among the AFSC actors in Nigeria: "I operate in the agricultural technology space and the industry. I am the founder of Integrated Aerial Precision. We are presently outsourcing the use of sensors in our distribution channel. We assemble drones. More than 80% of what we use in the production is brought into the country".

		The researcher recorded the Connections between the transcript extract and the research question.
2. Generate initial codes	Possible codes from the participant's response or statement regarding the interview question are highlighted. With the research questions and objective in mind, the researcher analysed and coded sections of the data relevant to the research questions using an inductive approach, drawing on the guidelines provided by Creswell, 2002 on conducting an inductive qualitative data analysis. Furthermore, the researcher carefully examines the data, analysing each word or sentence line by line to identify relevant patterns or information that address the research questions. A more flexible coding strategy may also be adopted. This strategy analyses, reconsiders, and adjusts codes before proceeding with the remaining transcripts. This facilitates the modification of	Identified codes in the Transcript extracts: ‘’ I am the founder of Integrated Aerial Precision’’- Coded as new agritech startup ‘’So what we are doing is that we are leveraging on drone technology and the power of data to generate drone technology, satellite imagery, to empower farmers with aerial intelligence, insights and actions that make smart agriculture possible’’ - Coded as an innovative AFSC process Jobs for Young People: ‘’ We are creating employment for people around the community, To have a lot of young people on our team. Some of them are still in school, and some of them have just completed their NYSC’’ – Coded as Jobs for Young People :

	current codes or the creation of new ones.	
3. Search for themes	From the collection of codes identified and highlighted throughout the dataset, patterns and relationships between the codes are drawn to form an overarching theme.	The coded extracts are analysed and categorised under "Food emerging Agri-tech start-up" and youth employment. ". Emerging Agri-tech start-up: ‘’ I am the founder of Integrated Aerial Precision’’-Coded as new agritech startup ‘’so what we are doing is that we are leveraging on drone technology and the power of data to generate drone technology, satellite imagery .to be able to empower farmers with aerial intelligence, insights and actions that make smart agriculture possible’’ - Coded as innovative AFSC process Youth employment: Jobs for Young People: ‘’ We are creating employment for people around the community, To have a lot of young people on our team. Some of them are

		still in school, and some of them have just completed their NYSC'' – Coded as Jobs for Young People :
4. Review the themes	The researcher guarantees the process of making sense by thoroughly examining, adjusting, and refining the initial themes or sub-themes. Then, the sub-themes are categorised under a primary theme, which serves as an umbrella for all subthemes with the same meaning and implications in regard to the research questions.	**Sustainability Economic Impact.** From the processes in step three, all codes were grouped under the theme of sustainability economic impact; this theme details the effects of adoption and use of industry 4.0 technologies in the AFSC process, resulting in job creation for young people, emerging new agri-tech startups, which in general results into positive economic.
5. Define and name themes	The themes are further defined to capture an appropriate theme, ensuring that the main themes reflect and correspond with sub-themes, codes, and extracts from the data.	For example, the theme of Sustainability Economic Impact captures or reveals the positive impact of technology within the AFSC industry in Nigeria. It shows job creation for youth, new business initiatives and efficient, innovative and data-driven AFSC processes.
6. Writing-up	The findings are written as reports about the research objectives and research questions.	The output and findings of the analysis are presented in the qualitative data analysis section of this chapter, which

		covers data analysis and data presentation using a data table.

Braun and Clarke (2006).

Table 4.2 STEP 2- Inductive data analysis (Gioia methodology)

Steps	Activity	Sample
1. Research Design	The research clearly describes a specific phenomenon of interest and formulates research questions focusing on understanding the ideas and their interrelationships. This begins by thoroughly reviewing the existing literature while remaining open and refraining from forming conclusions. This approach will enable the identification of novel insights.	This study investigates the role of technology(Industry 4.0 technologies) in Nigeria's sustainability of the AFSC. This process was accompanied by an extensive literature review to understand the body of existing knowledge, trends, and gaps in the literature.
2. Data Collection	Gather data and information from participants, where informants' opinions are fully expressed, and they are knowledgeable participants. The study's key informants were chosen using purposive sampling methods, targeting AFSCs that employ certain Industry 4.0 technologies in	The researcher contacted 40 potential AFSC actors; they were selected based on their experience and work within the AFSC industry in Nigeria. A total of 25 interviews were conducted in person; see Table xx for the interview participant profile.

	farming, food processing, and logistics.	
3. Data analysis 1st Order Concepts : 311 1st order Initial quotes obtained and simplified to 272 quotes based on synonyms and similarity	The interview was recorded and manually transcribed into Word documents. The researcher read through the transcribed interview file to familiarise the participants' ideas, thoughts and experiences. This was followed by conducting initial data coding, which involved taking and highlighting phrases, sentences, and ideas that the participants mentioned in the transcript that hint at the research objectives and answer the research questions. The researcher ensures the integrity of first-order (informant-centric ideas and experience) terms. The research develops a comprehensive compendium of 1st-order terms or concepts.	1st Order Concepts When you come to farmers directly, farmers need good roads to connect them to the market. So, power is significant for a company because once you are done on the field, you have to bring your produce to the factory for processing. They want to stick to what they know. Yes, so it is not easy. Rain outbreaks, unpredictable rainfall duration and intensity, and episodes of drought all increase the risk.
3.2 data analysis : 42 2nd order themes obtained	Organize 1st-order codes into 2nd-order (theory-centric) themes	**2nd Order Themes** **Inadequate Infrastructure**

	This involves creating academic or theoretical descriptor phrases as umbrella labels for several first-order concepts that share the same meaning and ideas.	**Conventional Practice** **Climate change**
3.3 3rd Order -Aggregate dimensions 7 3rd Order Aggregate dimension obtained	Aggregate the 2nd-order themes into overarching theoretical dimensions that capture the entirety of the 1st-order concepts. This dimension is the theoretical meaning of ideas evolving within the dataset.	**Challenges of AFSC**
4. Data presentation	The findings can be presented in the form of data structure and data table by assembling 1st Order Concepts, themes and dimensions into a topical representation.	Check Table 8 and Figure 9 for a data structure and table sample.

Table 4.3 – Data Table

3rd Order Aggregate Dimension	2nd Order Themes	1st Order Quotes
Trust	Technology Misconception	● When you work with maybe one or two of these people, you would have built trust with that person because

		he's in that community. I've seen him they know him before. ● Some of them from the beginning there are some organizational or companies that used to come and deceive people. From the beginning when we came to introduce the program to them, they are thinking that maybe we are deceiving them ● You could have a beneficial technology, but if the person who is using it does not see it as beneficial, there is no point ● Yes, if it is to their advantage. The biggest challenge we see in Africa, not just Nigeria is the concern that bringing in robots will lead to a loss of staff members
	Technology Threat	● This will make them frightened so they prefer to keep the old method by preserving their jobs rather than bringing in robots that will replace human labour causing them to lose their jobs ● Therefore, people tend to use things that have been established because they are familiar with the brands. Therefore, if you are introducing a better initiative, they might not be inclined to go with it because they don't have evidence to support them making this change

	• Transparency and support	• They heavily rely on international bodies for support, and some organisations are not transparent about this to their farmers so they keep this support to themselves rather than using it to develop the organisation and support the farmers. • This, therefore, makes some farmers sceptical and quite reluctant to adopt the technology. Even when you are transparent with them, they have a perception that they may be defrauded

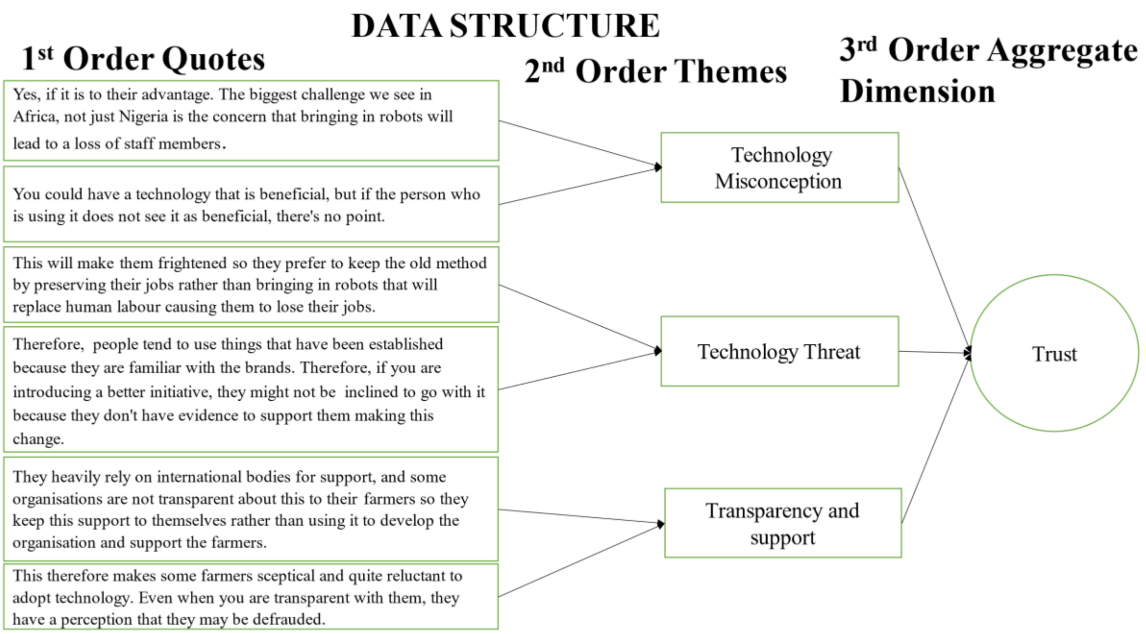


Figure 4.1 -Data Structure

4.3 Review of the Research Questions

Research question 1: How does using industry 4.0 technologies contribute to the Agrifood Supply Chain (AFSC) sustainability of Nigeria?

Purpose: This research question will examine the role of technology in building the socioeconomic status of the local communities in Nigeria and the level of adaptation this technology provides AFSC actors to face pressing challenges facing the continent's agrifood supply chain sector. Several studies (Wolfert, S. et al., 2017; El Bilali, H., and Allahyari, M.S., 2018; Klerkx, L., Jakku, E. and Labarthe, P., 2019) have highlighted the socioeconomic impacts of technological adoption in the AFSC. According to the research carried out by Schimmelpfennig and Lowenberg-DeBoer 2021, on precision agriculture, the author highlighted the positive socio-economic impact of technology usage among farmers. This RQ will explore the effects of adopting and using Industry 4.0 technologies on Africa's social, economic and environmental context, using Nigeria as the country of consideration. This will provide a holistic view of the potential these technological solutions can offer the agrifood practice, structure, and actors of the AFSC.

Research question 2: How will using industry 4.0 technologies in the AFSC promote agribusiness transformation into more sustainable practice in Africa (Nigeria)?

Purpose: Will this improve AFSC practice and create investment opportunities and a new business model?

This Research Question seeks to explore the possible transformation industry 4,0 technologies bring into the AFSC in Africa. It duly sits on scholarly work on academic literature, which explores the impact of industry 4.0 technologies on the transformation of the agrifood system.

Lezoche provided scholarly evidence of the agrifood transformation using industry 4.0 technologies (M. et al. 2020) and Panetta, H. et al. 2020; both kinds of literature explain the new frontiers and possibilities industry 4.0 offers across the supply chain in terms of a data-driven process that comprises monitoring and a new decision-making model.

The studies further explored the impact and application of IoTs, Big Data, and Precision agriculture on economic, social, and environmental issues. Alonso R.S. et al. (2020) further explored the use of the Internet of Things in the livestock industry and highlighted huge possibilities for promoting health with this technology. Most research conducted in this area is in developed countries. Therefore, this research will add to knowledge by exploring the questions in the context of Nigeria.

Research question 3: What underlying factors can promote the use and acceptance of technology in Africa(Nigeria)?

Purpose This research question will examine factors that promote the adoption of Industry 4.0 technologies in the AFSC in Nigeria. Several studies used Roger. E.M. 2003, diffusion of innovation theory, across many disciplines. Feder, G., Just, R.E. and Zilberman, D., 1985 employed the diffusion theory of innovations to examine the underlying factors that promote agricultural innovations in developing countries; Pannell, D.J., et al. 2006 in his study also argued the importance of this theory of diffusion in promoting innovative practices among rural farmers.

Venkatesh V. et al. 2003 and Venkatesh V. et al. 2012 researched factors influencing users' behavior to accept and use technology and proposed a theory of unified use and acceptance of technology (UTAUT), with later research presenting the upgraded theory model. Many researchers have used this theory in different fields; Ronaghi, M.H., and Forouharfar, A., 2020 applied the theory to using IoT technologies in smart farming. Ronaghi, M.H. et al. 2020 conducted research in the Middle East to identify factors that influence the adoption of intelligent farming among farmers in that region. This research question will explore factors influencing the use and acceptance of industry 4.0 technology among agrifood supply stakeholders in Africa (Nigeria|) in their journey towards a sustainable AFSC system.

4.3.1The Study Qualitative Data analysis(Indutive) for the AFSC in Nigeria

4.3.2 sustainable impacts of industry 4.0 in the Nigeria AFSC

In the attempts to answer RQ1, the interview questions were tailored to lead the inquiry, where participant experiences on the impact of industry 4.0 technologies were discussed. The transcription was done manually, and analyses using NVivo 12 software. The thematic analysis followed an inductive qualitative data analysis as stated by Creswell, 2002 and data presentation was adopted from Corley and Gioia 2006 comprised of data structure and data table. It is essential to clarify that coding of transcribed data is employed to reveal the data's richness and facilitate thematic analysis. Coding qualitative data helps make sense of textual data (Basit, 2003). The electronic coding method is adopted following the recommendation of Rivas (2012) and Elliot (2018), which provides the coding process for qualitative data. Hence, Braun and Clarke's (2006; 2012) recommendations are utilized for the thematic analysis of the interview data using NVivo 12 software. The analysis of the data shows the quotes (participants' verbal responses to questions), codes, and themes.

Firstly, to address research question 1, the researcher tries to understand the challenges of AFSC in the context of Nigeria, which the researcher terms as AFSC process evaluation. The analysis generated 1 theme, 6 codes, and 83 quotes, and 25 quotes were selected and presented.

Subtheme I- Inadequate infrastructure; several participants thought based on their experience in the AFSC in Nigeria that the major challenge facing the Nigeria AFSC is the lack of infrastructure, which comprises electricity and power supply, roads, and increased prices. They suggested that the lack of capital infrastructure is hindering the potential of the industry to feed its growing population and compete in the global Agri-commodity trade. Some participants think that these infrastructure issues cut across the entire food supply chain and are major contributors to post-harvest waste due to poor warehouse systems and inconsistent power supply for processing.

Our major challenges will be access to good roads and funding tools because most of these solutions don't come easy..Participant 1

I think this is peculiar to Nigeria. I think everybody knows that our major challenge has been power and now that the cost of diesel has skyrocketed, production is very difficult. Not just for us, but other sectors too .. Participant 25

Subtheme II—Conventional Practices: The participant points out the impact of culture on the way agriculture is practiced within the Nigerian space. They suggest that farmers might struggle to take on new approaches to farming because of the conventional farming practices that are passed down through generations. Other participants view this as a way of implementing a new way of farming that will reduce physical labor within the AFSC system.

I don't think the average staff working on the processing line finds it difficult to adopt new things and wants to just easily change from practices they have known for years.. Participant 5

Well, I would not lie to you, the adoption of new technology is quite difficult at first. It's quite difficult because farmers don't want to try something new. They want to stick to what they know. Yes, so it's quite difficult… Participants 14

Subtheme III - Climate change; the impact of climate change resulting in inconsistent rainfall, severe weather conditions, erosion, and floods has a significant impact on farming, food processing, and logistics. A hike in agrifood commodity prices due to the scarcity of raw materials has caused a major increase in the cost of production of processed food. Many farmers have lost farm produce to flood as mentioned by some participants. The vulnerability of AFSC stakeholders to the impact of climate change and severe weather conditions are also mentioned in some participant's responses.

I was talking to one of our partners in Jigawa State who narrated how his farmland was affected; 20 hectares for rice farm, everything was flooded… Participant 8

We have soil degradation; we have erratic rainfall patterns, we have floods, we have insect attacks, and even problems with the soil. Participant 17

We have soil degradation, we have erratic rainfall patterns, we have floods, we have insects attack, even problems with the soil. That is why we are actually pushing. Our technology actually comes to *mind with climate-smart agriculture like zero tillage agriculture, soil conservation and regenerative agriculture. This keeps you mindful of the soil….* Participant 17

Subtheme IV- Cost of production

The increase in the cost of production has been increasingly high in recent years in the AFSC; this experience was common in farming, with an increase in the cost of inputs like seeds, fertilizer, and energy use; food processing companies experienced an increase in the cost of production due to the fall in Foreign exchange, increase in prices of Agri-commodities or raw material for food products

*So cost of production is on the high. I knew that in some cases, prices of the farm inputs have doubled. Looking at a trend, taking from 2020 having its own issue, into 2021 and then 2022..*Participant 2

*Yes, the cost of production has increased. The first thing we take care of is making sure our products are still the same irrespective of the cost. Most of our products are not Nigerian made. We have various solutions. We have cooler bags majorly for vaccine transportation both locally and internationally. Then we have fresh boxes, cooling hubs and cooling trucks. For instance, the smallest size of our cooling hub was #13,200,000 about 6 months ago. So, the major challenge that we face is Forex and exchange rate. We are accustomed to the change of price in the market, so we ensure that we purchase excess products so that the change in price (exchange rate) will not be so obvious. In this way, our clients are not affected….*Participant 4

Subtheme V- Food waste

Food waste is a common challenge most AFSCs in Nigeria face; this occurs at different points from production to consumption, which leads to economic loss and a negative impact on the environment. The participants highlighted the challenge of poor post-harvest infrastructure as a major leading factor in food waste among farmers and food processors, the inability to be able to store agrifood produces in good conditions, and the inability to get data and information on the conditions of stored foods as a resultant effect to leads to waste. Participants highlighted that the rate of waste generated varies depending on the kind of agrifood products, and a huge parallel was drawn to the vulnerability of food waste incurred among perishable foods across the supply chain. The use of chemicals to preserve perishable agrifoods was questionable based on its usage and safety. Another participant argues based on their experience that food waste occurs among farmers, for instance, because there is no ready market for the produce. Other participants highlighted the valorization of food waste, for example turning almost tomato food waste to paste and feed.

So actually, it's not more food waste but more of very poor post-harvest management practices. You can visit our site to get some information about the previous project. 40 to 60% of food produce is lost due to poor post-harvest management practices. So, we must find ways to strengthen our farmers to either undertake value addition or link them to organizations that will uptake this materials from them for value addition… Participant 15

For us, there are different angles and then the losses at different percentage depending on the commodity. For example, there is more waste with vegetables because they are highly perishable…Participant 19

Subtheme VI-Lack of Manpower

Human resources is very much a critical requirement to drive AFSC towards sustainability. Participants mentioned the lack of manpower in the AFSC, especially in farming. The young people of Nigeria leave the rural environments for urban areas to seek better lifestyles for banks and tech job opportunities, thus resulting in a reduction in the manpower that can drive the agricultural economy. The present rural manpower is aging and there is a need for young people to venture into farming and support the struggling system. Some participants spoke to the huge workload in the food manufacturing sectors due to the lack of staff and the strenuous working experience in the industry. Some food manufacturing organisations pay meagre salaries compared to other industries, which results in talents leaving these seamingly strenuous jobs. The health and safety of workers is also not prioritised.

That's why I find Chinese companies, Indians, Lebanese, and all that investing here. Because if you look at the percentage of the cultivable arable land in this country, we have over 80% of very viable lands. In that 80%, only less than 40% of that is being cultivated right now. So all the success stories you hear are less than 40%. We've got the resources. All we need is also harness the potential of the industry by bringing more workers, especially the youth… Participant 6

Yes, can achieve a smart logistics system by employing more equipped youths.. Participant 4

I will look for other opportunities that gives me more money in a faster way. Yes, we have the workforce but people keep leaving the country and engaging in other jobs because they are not hopeful of better income and don't want to end up like their parents. So, there is a silent revolt happening in the workspace… Participant 21

Table 4.4 Data Table Challenges of AFSC

3rd Order Aggregate Dimension	2nd Order themes	1st Order –Quotes
Challenges of AFSC	**Inadequate Infrastructure**	• When you come to farmers directly, farmers need good roads to connect them to the market. • So, power is very important for a company because once you are done on the field, you have to bring your produce to the factory for processing. • then of course, that means there'll be more farmers and their harvest isn't going to waste.
	Conventional Practice	• Yes. Number 2; is something that is also going to ensure that the labor or drudgery in farming is greatly reduced. Yes, farmers cultivate with hoe, cutlasses etc. but the internet is making them more exposed and they are looking for ways to make farming easier. If it is technology, how does it reduce the labor or physical energy required to do these things. • They want to stick to what they know. Yes, so it's pretty difficult. • And that's why it looks like innovations are not working. People are sticking to what they know because once there is a break in the chain, it topples the farm operation and nobody wants that to happen.
	Climate change	• Onsets of rains, unpredictable duration of rain, the intensity of rain, and episodes of droughts, all increase the risk. • Yeah, in the practice? So what I see is that there are several challenges, particularly the most recent one is the climate change. That's the basic thing that is happening now. We are not able to even predict what it is. • But with all these natural disasters, that you can continue somehow, you may not be able to achieve your goal. So it's a bit difficult.

	Cost of production	● If the cost of production increases, it will affect farmers. ● Let me put you in the general way Nigerians say "the dollar has increased". So, yes. The cost of getting materials has increased. Definitely. The high cost of production. ● We have the challenge of exchange rates, right, because a lot of these components and materials that we use for producing the hardware are not being produced locally.
	Food waste	● For me, most food waste I think it is more at the storage point. ● When it comes to grains and maybe cereals, there are several attempts and efforts to help reduce waste. Right from production, I know that the use of Aflasafe is there to reduce contamination by aflatoxin but then some people still query how safe Alflasafe is? ● For me, most food waste I think it is more at the storage point. ● I want to attribute that to this concept that you produce to sell. Food waste is attributed to these things. Why? Because what is the market for what I'm producing? ● For instance, let me say tomato. I was opportune to see this tomato waste produce made into paste and feed farmer, a woman company in Jos.
	Lack of Manpower	● We don't have many challenges, but one is staff shortage. ● Nigeria does not have that workforce. ● Most food manufacturing does not pay their staff well, and worker leave because of that. ● Casual workers are use mostly in here, most of them complain of bad pay and they don’t feel valuable to the company. ● the system in Nigeria, I don’t know how to put it, and I don’t know how to explain it, but Nigeria does not have it.

Secondly, in the attempts to answer the RQ1, the researcher undergoes a process to access the level of sustainability knowledge or awareness among the AFSC actors in the Nigeria Context,

Subtheme I Sustainability Awareness

The awareness of the AFSC actors in Nigeria was accessed to check if they were aware of what sustainability is, understanding, and its practices. Some participants think sustainability is to be taken seriously and considered in processing and practices with the AFSC. Some participants assume that the sustainability approach has economic importance in minimizing the cost of production. Sustainability knowledge has been seen as a major approach among many participants' businesses and seen as a part of the business process

And now, farmers have started realizing that what we do is very important and by next season, we can get more people or more customers that are registered with us because they see certain examples from their colleagues.

So, sustainability is such that it's a key. If we get to a point where we achieve, let's say even not even 100%, because you can't see 100% sustainability, at least you can keep the system going at a very minimal cost, such that all the necessary ingredients; what you need to be in production, you have it.

Subtheme II Sustainability Knowledge

Based on the AFSC actor's experience, sustainability means different things to different participants in different contexts. Some view sustainability as the ability to maintain production year after year with minimal damage to the soil conditions. Some view sustainability as the ability to meet today's needs and not destroy future usage of the material of production. In another perspective of the food manufacturing sustainability, approach is the use of the 4Rs. Reduce, Reuse, Recycle, Rework approach. Business expansion is another sustainability knowledge perspective discussed among statehooders. The ability to support a process independently and continuously is seen as sustainability. The knowledge of sustainability varies in different contexts and experiences.

For farmers, sustainability means being able to grow, and you can still grow it year after year without any damage on the soil or on the environment.. Participant 23

Sustainability means something trying to meet the need of today without hampering the future usage of those materials Participant 7

Making use of the 4Rs. Reduce, Reuse, Recycle, Rework… Participant 5

Subtheme III Environmental Consciousness

This subtheme shows the level of sustainability consciousness arising among stakeholders. There is an increased consciousness or awareness of the impact of AFSC activities on the environment. Some view this as ensuring environmental preservation in the production processes. Environment-friendly processes are seen as a measure to preserve the environment and this approach is becoming popular among actors. Another view from participants is the awareness of harmful practices to the environment and avoiding them.

By the kind of practices that we employ, we ensure as much as possible that the environment is reserved.. *Participant 19*

So, we need to ensure that whatever practices are being executed, these three things are taken into consideration. First, what's the impact on the environment? Secondly, what's its impact on human beings, that is, the stakeholders in that space? And then lastly, on the profitability or the economic development of those needs… *Participant 16*

Any of these things, you are doing them in such a way that you can continue to do them without any harm on the environment. For instance, we do such operations in a manner such that the environment is not harmed. You don't put anybody at risk… *Participant 3*

Subtheme IV Technology & Sustainability

These subthemes explain the importance of technology in the sustainability approach within the AFSC in Nigeria. Technology and real-time data were viewed as critical approaches to achieving AFSC sustainability. Some viewed technology as a major approach to improving the food system based on their experience with the food system. The use of technology for waste reduction is an approach some agrifood businesses in Nigeria are employing, and a considerable suggestion was the wide acceptability and accessibility of this. Some curiosity, however, arises about the availability of technology within logistics and distribution, which can promote food shelf-life. Some participants' view is that technology adaptation is a critical approach to ensure the solutions meet the needs in our context

However, when I think our approach to using technology for sustainability is to reduce food waste in the agricultural sector, I think we need to work to make this widely acceptable and accessible. So if we go for international competition, we hear people talk about plant safety, reducing the effect of microbes, etc *Participant 13*

For me, right now, I think all the technologies we use are good. But I'll be much more interested in technology around distribution, and that can aid the shelf life of the products. *Participant 10*

Table 4.5- Data Structure; Sustainability Consciousness

3rd Order Aggregate Dimension	2nd Order Themes	1st Order Quotes
Sustainability Consciousness	**Sustainability Awareness**	• So the issue of sustainability, yes, it's something we really have to take very seriously • Because now that organizations are giving the messages, creating awareness to them, now they learn good agronomy practice, so it's helping them. They are willing to get more education about farming activities and every time they are asking us to learn more about it. • Yes, we are concerned about sustainability and it is part of what we do.
	Sustainability Knowledge	• We have different product lines to ensure sustainability. • Sustainability simply means a continuous support process over a long period of time of agricultural activities.
	Environmental Consciousness	• First, what's the impact on the environment • Any of these things, you are doing them in such a way that you can continue to do them without any harm to the environment. • *The very essence of what we do is sustainability, and we always ensure that our practices themselves are environmentally friendly,*
	Technology & Sustainability	• Yes, technology and real-time data can help to promote sustainability • Seriously, technology can improve food a system • This is the advantage first world countries over an economy like Nigeria's. There are several technologies on the field like greenhouse technology and precision farming. These tools are

		being used and they are the key to sustainability. So yes, the answer is yes. 100% technology promotes sustainability ● Technology has to be adapted to provide sustainability

4.3.3 Assessing the impacts of industry 4.0 technologies within the AFSC in Nigeria.

After establishing the challenges of AFSC in Nigeria and the level of awareness among stakeholders, the RQ1 was assessed to investigate the impacts of industry 4.0 technologies within the AFSC in Nigeria.

Theme 1: Economic Impacts

Subtheme I **Youth Employment and Job Opportunities**

Several young people have been employed in technological roles within the smart agriculture sector. Using a barcode tracking system to monitor the sales of seeds within the inputs industry has been seen as a major attractiveness for young people in that sector, which comprises roles like tracking officers and digital extension agents. These agri-tech companies drew talent from the immediate rural environment; that is, the workforce to fill this role was from local sources.

There are some other support services, like logistics; young people are using logistics these days. They're going into technology; website management for agriculture companies, social media management, spatial imagery, etc *Participant* 4

I don't know him personally, but I've seen him on LinkedIn. He is the only person I know who has such technology. Then there is another person who is into irri-tech. He's also on LinkedIn. He got some grants; I think two years ago or last year. I know he does something around irrigation. For precision farming, I think a couple of really big farms, maybe not on the crop side or the animal side, do quite some precision in their operation. Min the poultry or in the cattle space.. *Participant 12*

Subtheme II Emerging Agri-tech Startup

Several indigenous Agri-tech startups in farming, processing, and logistics have arisen due to the inception of technology within the sectors. Startups like Precision Agricultures (Employing drones, IoT, GPS, and sensors) have risen to help gather agricultural data and pest services within the sectors. Some approaches were to train farmers on the use of drones to precisely spray insecticides on the field. Start-ups within the logistics industry employ technology as a transparent medium for agrifood distribution, functioning as an outsourced service. Some startups venture into building drones and sensors for agrifood usage, which seems cheap for the Nigerian context. Few Agri-tech in the AFSC were able to access funds, grants, and loans to drive their business. The participants highlighted that there are numerous government supports for Agri-tech startups going into the AFSC space. Some startups within agrifood logistics started by outsourcing digital services and are in the process of full implementation. Internship opportunities have been offered to students who are interested in AFSC technology-driven jobs.

I operate in the agricultural technology space in, in the industry. I am the founder of Integrated Aerial Precision. What we do is provide drone technology and data solutions to farmers related to the distribution of data, as well as the use of robotics, like aerial drones, to offer solutions to farmers and help them monitor their crops digitally. With drone data, we help farmers make smart decisions and make farm management easier. Regarding our spraying drones, we offer crop protection services to farmers autonomously, broadcasting operations, fertiliser seeds, etc. Right now, we are also dealing with the manufacturing part of things and assembling our sprayer drones. I am also a farmer and run a farm alongside the technology service provision.. *Participant* 2

We have people who probably employ technology such as robotics and programming in their operations for feeding, watering, insemination, artificial insemination, eggs, etc. But in the crop space, I don't know how wide Femi's operations are, but Femi and the other person involved in irri-tech. There's also Cold Hub. I think he worked on a Feed the Future project or a USAID project and has localised cold houses where people can come and store their tomatoes for a fee for daily usage. I don't know if there's any other technology they employ for that.. *Participant 12*

Subtheme IV Efficiency

Agrifood food production processes have gained significant efficiency through technology. Smart farming and precision agriculture promote resource efficiency by minimising inputs based on data from the field. A very good example of livestock management was seen in the application of IoTs in livestock farming. Food waste reduction and resource efficiency were promoted within the agrifood logistics through outsourcing services provided within the industry in AFSC in Nigeria.

And the more accurate your operations are, the more profitable you'll be. Because you are spot on. At the time when you need to do aerial applications, they are doing them. At the time *when you need to make changes in your water regimen or water use efficiency, you are doing all those things, so it becomes more efficient…* Participant 1

*Here, for instance, in our precision farming, our precision farming is the largest in Africa, where we cultivate rice, this approach has helped us to reduce input costs and gain more. We have data information on all our processes …*Participant 2

Theme 2: Social Impacts

Subthemes I- Investment Opportunity

Agrifood's supply chain business has seen expansion and increasing opportunities due to the integration of technology within its processes.

Several government initiatives have allowed stakeholders to apply for technology grants to scale up their businesses, and several assume that ROI is assured. Stakeholders have benefited from the use of data that fosters better decision-making processes, such case is the weather forecast data provided to farmers to make good decisions on farming processes.

These technological solutions create an enabling environment that supports enterprise development, to be honest, we have also got opportunities for investors to explore how processing lines… Participant 6

Our business in previous years applied for agrifood tech grants and got Grants and investments. Our investment approach is what I term "patient investment". And we expect to get great ROI but not immediate ROI. Participant 2

Keywords

Subthemes II Skill Transfer

Many working staff within the AFSC have experienced upskill in the use of technology, through training and technological demonstration internally (within the company) or externally (several government or Ministry of Agriculture and Food initiatives). AFSC actors were taught the use of sensors to gather data and the application of the data for decision-making. The AFSC industry has training and skill transfer in the use of drone applications in precision agriculture and smart farming systems. This skill transfer has equipped the workforce in the AFSC sector to be able to drive the sector sustainability revolution. A huge concern was the immigration of digital literates within the industry who are travelling abroad where they are paid more money for their digital prowess within the same AFSC industry. Another perspective is that technology skill development among staff or workforce with the AFSC has a huge impact of the business scale.

Through training and workshops. Then you have a demonstration farm in the local areas. You go down to the grassroots and engage with those people. You must know their problem before you deploy technology. Don't just go to China and bring something because it's working for them in terms of weather, in terms of value system and all that. So you must come down to know the challenges. Then you have a tailor-made solution to each of those challenges. In that way, you are encouraging sustainability even when you leave. They know that this method is better than what they were doing before… *Participant 16*

Yes, there is a huge continuous plan to transfer knowledge and application of digital solutions within our staffing team…. *Participant 13*

Subthemes III: Improved livelihood

Several factors have led to financial improvements through the deployment of technology in the AFSC processes, which occur through either waste reduction, weather information, or increased chance of profitability, especially in finances and income generation.

An average farmer like us now has a digital extension agent that helps with the right decision during farming. Weather data has saved a lot from the bad impact of drought on farming this season. See our out-growers farmers now make a decent living and more cash over the last year. *Participant 15*

We have created that technology, and it has impacted the lives of smaller farmers by giving them weather forecast information and market reach… *Participant 14*

Theme 3: Environmental Impacts

Subthemes I- Waste reduction.

Agrifood waste reduction has seen an increasing possibility within AFSC processing in farming, food processing, and logistics or distribution. The application of technology has helped actors reduce the risk of food waste and post-harvest loss through post-harvest data-driven warehouse storage. Continuous training in postharvest storage technology has enabled data and information on the condition of stored agrifood raw materials. Visible conditions of Agrifood commodities can be measured using sensors, which help with information that keeps the AFSC actors informed about issues related to waste.

We can do that by being innovative. Being innovative comes with being premium in an economy like Nigeria's. These sensors in our operations make us more innovative with what to do; coming up with newer technologies that impact the farmer, help them make more money and reduce the wastage and losses. If we can increase our innovative edge, we will be able to make more money…. *Participant 8*

Yes. By using technology, we have helped reduce food waste directly or indirectly.. *Participant 2*

Subtheme II- Reduction in Input Usage – Fertilisers

The reduction of input use by farmers helps to reduce costs and results in a negative impact on the environment due to the technological approach of farming, such as smart farming. Increase awareness of the negative impact of fertilisers, like CO2 emission, which has gained increasing attention within the industry.

Smart farming has enabled us to reduce input costs. Because we have information on soil profiles, we do not need to spend more money on fertilisers and can apply them based on the soil's needs… 2

Table 4.6 Data Table: Economic Impact

3rd Order Aggregate Dimension	2nd Order Themes	1st Order Quotes
Economic Impact	**Youth employment**	• *So, of course, the majority, about 80% of our workforce here, are youths.* • *We're also trying to extend that to other seed companies so that they also make agriculture attractive for the youth.* • *Yes, we do employ young people in our company.* • *To have a lot of young people on our team. Some of them are still in school, and some of them have just completed their NYSC.* • *We are creating employment for people around the community*
	Emerging Agri-tech Startup	• *Recently, people like Afex and Thrive Agric got in a couple of million dollars in equity funding and venture capital funding into the operation* • *Is it in Lagos? Femi the flying farmer?* • *For precision farming, I think a couple of really big farms; maybe not on the crop side or the animal side, do quite some precision in their operation. Min the poultry or in the cattle space.*

		• *Of course, we do. We have people like Femi. We have met quite a lot of people who are into that space already.* • *So if you have several of them like that and across the landscape of the country, definitely you know what I'm talking about. It's the key sector and it supports MSME.* • *They also help emerging youths in the agricultural sector to access loans and grants.* • *this is a very dicey question because for us, we are still early in the business* • *I operate in the agricultural technology space in, in the industry. I am the founder of Integrated Aerial Precision. We are presently outsourcing the use of sensors in our distribution channel* • *Our company just started less than a year* • *We assemble drones. More than 80% of what we use in the production is brought into the country.* • *We then assemble, put them together, make them a whole and a working machine.* • *so what we are doing is that we're actually leveraging on drone technology and the power of data to generate drone technology, satellite imagery .to be able to empower farmers with aerial intelligence, insights and actions that makes smart agriculture possible*.
	Job Opportunities	***Job Opportunities***

		• *For now, yes, but we are looking at employing more hands.* • *Recently, I've had 50 people from LinkedIn, especially food technology students who just graduated and are looking to work on the skill set that they've been able to acquire from school.* • *We also run a shift-based work system which has helped us to employ more hands.* • *We create job opportunities. Because* • *Our solution ensures everyone has a job*.
	Efficiency	• And the more accurate your operations are, the more profitable you'll be. Because you are spot on. At the time when you need to do aerial applications, they are doing them. At the time when you need to make changes in your water regimen or water use efficiency, you are doing all those things, so it becomes more efficient. • Here, for instance, in our precision farming, our precision farming is the largest in Africa, where we cultivate rice, this approach has helped us to reduce input costs and gain more, we have data information on all our processes. • Our approach is in the use of IoT sensors in the livestock industry, this helps us to monitor livestock health and movement on the farm, although we are still looking for funds to expand. • Yes we helped to minimise waste for our customers that use our services for transportation of their agrifood commodities.

Social Impact	**Investment Opportunity**	● Using IoTs and data analytics our production and supply chain has seen expansion, new opportunities, and customers. ● Grants and investments, especially what I term "patient investment". An investor cannot expect immediate ROI. ● We have created that technology and it has impacted the lives of smaller farmers by giving them weather forecast information and market reach.
	Skill Transfer	● Yes, there is a huge continuous plan to transfer knowledge and application of digital solutions within our staffing team. ● The answer is dicey. Although, we have more youths learning digital skills, a good number of them are leaving the country ● to increase their skill so that we can increase scale.
	Improved livelihood	● as we reduce waste in our production, more is saved ● In our supply and distribution we have helped our clients to minimize the risk of the spoilage of goods and increase the chance of profit. ● Yes, farmers do. If they didn't, they would have quit a long time ago. They are making a decent living but can do better. ● Yes. Majorly, one of our visions is to see how we impact the lives of small older farmers. We have been able to do that by creating some bundle technologies. ● I believe if we can market other products and services and get mass orders, we can promote good livelihood
Digital Impact - Environment	**Waste reduction.**	● Confirm, technology has help reduce food waste

		• The best way that farmers can reduce food waste is by training them on the use of post-harvest and pre-harvest technologies • And we encourage them on the use Pix packs. It's a new improved crop storage bank. It's a sack that has three layers and it's very good in storing some of the cereal crops and legumes so that pests infestation will not cause a lot of damage to the crops that farmers cultivated. • Yes. It may help us. If they can have silos or warehouses where they can keep their crops, it can help a lot. • Yes, of course. Since it will help you to reduce gaps. I mean, to reduce wastage. Maybe there are some signs you're looking out for visually, but this system sensors can help you to even detect those things. Maybe, let's say, ammonium level in terms of their droppings and all that
	Reduction in Input usage – Fertilizers	• We are aware that reduction fertilizer helps reduce the negative impact on the environments

4.3.4 assessing the role of industry 4.0 technologies to promote agribusiness transformation into more sustainable practice within the AFSC in Africa

Research question 2: How will using industry 4.0 technologies in the AFSC promote agribusiness transformation into more sustainable practice in Africa (Nigeria)?

Business Change and Adaptation

The implementation of technology within the Agri-Food Supply Chain AFSC has led to changes in business models and processes. The adoption of technology is driving modifications in AFSC processes, necessitating adaptations to effectively integrate these technologies into the Nigerian context.

Well, I would not lie to you, adoption of new technology is quite difficult at first. It's quite difficult because farmers don't want to try something new. They want to stick to what they know. Yes, so it's quite difficult. But that is why we talk and do and the best way to deploy such technologies, to make them shift. That is why we have demonstration field in places… Participant 7

We tell them to do what they do while we work with the new thing we are bringing. So that at the end of the day, you compare which is best. That is the best way to deploy technology because these farmers are not educated. So, you have to speak in a way they understand. So, we demonstrate to them and once they see, they don't waste time in adopting it at all… Participant 1

All we have done is increase the number of food processing lines. Then we introduced different flavours of products, on food. So, if you don't like orange, you go for pineapple. If you don't like pineapple, then you go for exotic, which is a mixture of coconuts and other orange fruits.. Participant 22

We are working towards incorporating these technologies, especially IoT. We are expanding our use of that particular technology because we live in a technological age, and you can hardly have certain businesses without technology. Our management is beginning to tell us a lot of things will change, and staff will need to learn new skills… Participant 15

Data-Driven process

The use of technology has promoted a data-driven process within the AFSC. actors use technology to collect AFSC process data to inform real-time decisions. Farming methods such as precision agriculture and smart farming enable actors with soil data, weather data, and suitable approaches for sustainable farming while reducing the vulnerability presented by climate change. Data are generated to monitor the distribution of Agri commodities within the supply chain. The use of drones, GPS, and IoT, Sensors has helped actors with data capturing and better decision-making processes. Another view is the application of this technology in the context of Nigeria, for instance, technological solutions developed to meet the current needs and challenges Nigeria AFSC faces. Other AFSC companies develop apps to capture farmers' data and promote a data-driven process for a sustainability approach.

Another technology we have been able to do is data capture. I think one of the challenges we have in Nigeria is having data to actually work with. So we, as a company, have different apps and software that we have actually deployed to capture the data of farmers. That would not just help us as a company, but also help Nigeria in case there is a demand for data of farmers, maybe rice farmers or maize farmers. We should be able to have that information handy. So, we have some apps like the ODT, Rice Advice and many others that I cannot remember now… *Participant 16*

You're making decisions based on data that you have on the ground and based on information that you have on the ground. So you have to go a long way in making sure that you don't lose too much. But we have those apps that we have been using to collate information from the farmers. In terms of maybe your location, coordinate of the farm, field size, your age, your BVN, your name, your bank account, etc., it's a very robust data that we have been collecting over time and it has been helpful… *Participant 19*

Technology Adoption Readiness

The technology adoption readiness deduced facts from the participants on several parameters that help to measure insight into Nigeria AFSC's preparedness for full industry 4.0 transition, resulting in the industry's sustainability goals. The following are 1st order quotes deduced from the qualitative data.

This industry needs a solid enabling environment, like good technology infrastructure, e.g., the Internet, to maximize its technology potential. The government needs to help us with electricity, for example, which will make technology much more easily adopted. So, there is a need for skill to adopt technology efficiently… *Participant 1*

You can send technology to accompany and there is no one with required skills to operate such technology. Another challenge is skill level and capacity which affects the adoption.. *Participant 2*

They just drop it because they couldn't sell. And then the other component is that promoting sustainability must be premised; that is, situated within what the farmers are doing improving their own system, not importing the system and then superimposing on what they have. But to *see how the system that they have is gradually modifying they are more amenable to accepting those kinds of modifications than when the technology is completely new..* <u>*Participant 25*</u>

Table 4.7 Data table; Agribusiness Transformation

3rd Order Aggregate Dimension	2nd Order Themes	1st Order Quotes
Agribusiness Transformation	**Business Change and Adaptation**	• We are also looking at expanding our business by using technology • Because it's just like we are trying to create changes and make cultural changes • They just drop it because they couldn't sell. And then the other component is that promoting sustainability must be premised; that is, situated within what the farmers are actually doing, improving their own system, not importing the system and then superimposing on what they have. But to see how the system that they have is gradually modifying that they are more amenable to accepting those kinds of modifications than when the technology is completely new
	Data-Driven process	• We generate data from communicating with people, IoT and data collection from other sources. • But yes, technology has a big role to play, but it may not necessarily be high-tech. • Honestly, I believe they do. But then, scaling and the right application to Nigeria's current issue is what we need to look into. • There are times when we don't have access to cold storage. We have a team that monitors our technology. • So, if we disseminate information by the farmer's helpline, universal information, say for planting itself, some people are going to receive it exactly at the time of planting, while some are going to receive it when they have finished planting. • Another technology we have been able to do is data capture. • So we, as a company, have different apps and software that we have actually deployed to capture the data of farmers.

		• That would not just help us as a company, but also help Nigeria in case there is a demand for data from farmers, maybe rice farmers or maize farmers. • But we have those apps that we have been using to collate information from the farmers. In terms of maybe your location, coordinates of the farm, field size, your age, your BVN, your name, your bank account, etc., it's a very robust dataset that we have been collecting over time, and it has really been helpful. • It captures farmers' details as well, and you can use it for their payrolls, give out input loans such as seeds and other inputs
	Technology Adoption Readiness	• It doesn't matter where the investment has been made and the infrastructure put in place. Even with the skills and capacities, when there's no market, it all falls apart. • The working population is available, but there is a skill gap.

4.3.5 Assessing Factors that can Promote the Use and Acceptance of Technology in Africa(Nigeria)

Research question 3: What underlying factors can promote the use and acceptance of technology in Africa(Nigeria)?

Social Influence

The study further examines the factors that influence the adoption of US Industry 4.0 technology among current users. The social influence emerges in the interview with the participants. In the instance of farmers, there were highlights on the role of social networks or farming communities in the influence of technology adoption and approval within the industry. In rural regions, community leaders can be a leading influence in promoting the use and adoption of this technology. It is also observed that community validation builds trust for technology adoption and users. Therefore, technology can be easily transferred through social networks between actors and actors and between community leaders and users.

Everyone gives community leaders their respect because they know everything. So, they mobilise people. They also mobilise participants and create awareness for them. We also support the community leaders to create awareness in the community so that *everyone will believe. Because to help them, that's why we need community leaders…* *Participant 13*

Their group leaders can influence them to adopt technology. Because normally, some farmers are in groups. So, if their group leaders adopt it, then definitely, the followers will adopt it. These group leaders are the influencers… *Participant 15*

Industry influence

Industry influence played a major role in the wider acceptance and adoption of technology within the industry. This subtheme explains that leading a business in an industry can influence the use or adoption of technology if other business sees the competitive advantage of using the technology. Another pointer is that the adoption of technology becomes possible if industry experts endorse it within the practice of the industry.

We see some leading companies in the industry deploying some profitable technologies in their farming and distribution channels. We see this as a company, and we endeavour to also get a competitive edge over your other competitors by leveraging this technology. So, I know these things. I'm not limited to finance, but once I deploy, before I deploy, I teach people about the benefits and how it works… *Participant 6*

Influence is very powerful. It is commonly said that if an expert or celebrity introduces something, they can change world view by 4%. It means that if you have 25 experts and they each endorse the same thing; you can get about 100% adoption rate… *Participant 3*

Community-Based Advisory (CBA)

This sub-theme explains the impact of creating technology awareness through the community advisory service. This emphasises the use of an intermediary service that primarily functions as a community ambassador to promote the adoption and use of the technology. The CBA is also a tech business that functions as a technology outsourcing firm in the industry, offering technological services to SMES and AFSC businesses that are not financially viable to invest in the use of technology. They outsource services like field mapping, weather forecasting, drone usage, etc.

We also support the community leaders to create awareness in the community so that everyone will believe. Because of that, we need community leaders. We also support the community leaders to create awareness in the community so that everyone will believe. Because to help them, that's why we need community leaders… *Participant 24*

We do digital extension and advisory services. We also do farm mapping, selling of farm inputs to farmers.. *Participant 23*

Technology Demonstration

Technology demonstration describes the ideas from the experience of participants as a medium of transfer of technological knowledge and skill to intended users. Participants highlighted that seeing is believing, i.e. teaching AFSC stakeholders about the uses of technology will provide them with confidence in the use and applicability to adopt the technology. In terms of farmers, participants referred to certain scenarios where they have technology demonstration farms, to show actors the application of sensors, IoTs, and Drones in crop production to tackle input application and field nutrients management.

If you have a proven technology, you don't just dump it on them. You work with them through it. You work with them through that technology. You know, they say seeing is believing. So they need to be able to relate, especially under their condition… *Participant 2*

Yes, like pushing these technologies to the farmers. They need to be engaged, and they need to see these things happen in their own fields, for instance, in their own communities. But that is why we talk and do, and the best way to deploy such technologies to make them shift. That is why we have demonstration fields in places. We tell them to do what they do while we work with the new thing we are bringing…. *Participant 15*

Technology Transfer

The technology transfer process speaks of the medium by which the use of technology is transferred through training, education, and workshops among AFSC actors. Several AFSC businesses implement several methods for technological transfer.

Training and workshops is the best through training and workshops. Then you have a demonstration farm in the local areas. You go down to the grassroots and engage with those people. You must know their problem before you deploy the technology. Training is key for technology transfer to people and communities… *Participant 5*

In the food manufacturing industry in Nigeria, there have been several access training sessions in Sensors and improved process manufacturing. This hands-on training and innovations will promote sustainable production .. *Participant 7.. Participant*

Profitability

These subthemes describe profitability as a factor that influences technology adoption among the AFSC actors in the agri-food industry. The adoption of technologies hinges on the profitability that AFSCa actors assume the solutions will bring to their business practices, processes, and economic returns. Most AFSC businesses will adopt technology if there is evidence of profitability associated with the use of those solutions.

So, the next time the farmer sees the benefit, he comes to ask for it. In that way, we are creating demand through that, and we don't just leave you. We hold your hands together and show you when new technology is available. If I want you to leave your old means, I must ensure that the new method gives you an edge.. *Participant 12*

For me, adopting this principle to improve Sustainability involves achieving a balance between profit, and we need to make more money. But if you're able to make it whatever you're saying to them makes sense in the way they understand it. Honestly, they will adopt it.. *Participant 10*

Competitive Advantage

Competitive advantage is a factor that emerges to influence the use and adoption of technology in the AFSC industry in Nigeria. Based on the participants' experience, it was found that actors will prefer to adopt industry 4.0 technological solutions at any point in the supply chain if it can give them a competitive edge in the industry.

We hold your hands together and show you when there is a new technology. If I want you to leave your old means, I must ensure that the new method gives you an edge. if we can increase our innovative edge, we will be able to make more money…. *Participant 22*

Context design/Need

Participants discussed that several technologies have been presented to them over the years, either through research or through awareness, and most of these technologies were imported from developed countries. The discussion led to the failure of the technology, and participants explained that the technology might be working in the developed country but could not meet the needs of the AFSC sector in Nigeria. Technology context design is a subtheme that explains the need to tailor technological development to the needs and context of the users. Therefore, technology context design is seen as a driver of the adoption of industry 4.0 technologies in Nigeria. Users will adopt technology if designed in the context, challenges, and needs of users.

I think it all comes down to understanding who you are creating technology for. They don't understand their users. The solutions might be okay but at some point, you might need to pivot and ask yourself if you need to tweak this because of Nigeria. You cannot use a Ghanaian model to work in Nigeria. For technology adoption, understanding your users is key… *Participant 2*

Exactly, let it be centered around users. I am not saying you should not be futuristic but let the process be gradual. Take it from one step to the other. Understand them and give them what they want. Allow them to trust you. When you give them what they want, they will anticipate what they will need in the future. This helps you stay ahead of them By the time they become *familiar with the current one, introduce another one before someone else enters as a competitor… Participant 17*

Then you have a tailor-made solution to each of those challenges. By that way, you are encouraging sustainability even when you leave. They know that this method is better than what they were doing before… Participant 5

Perceive usefulness.

The AFSC actors discussed the benefits of users' perception of the usefulness of technological solutions to influence their decision to adopt and use the technology in their production processes. The clear benefits of the technology will influence the acceptance and adoption of the technological solutions. To the participant, the adoption of technology within their industry or business can be influenced by the perceived usefulness of technology.

Farmers are willing to accept the technology especially if it is fully important to their lives; something that can improve their livelihood, and food production and either directly or indirectly will increase their income…Participant 7

So, the next time the stakeholders need to see the benefit, they come to ask for it. In that way, we are creating demand through that, and we don't just leave you. Farmers are always seeking solutions that will improve their productivity; access to input… Participant 19

They just dropped it because they couldn't sell it. And then the other component is that promoting sustainability must be premised; that is, situated within what the farmers are actually doing, improving their own system, not importing the system and then superimposing on what they have. But to see how the system that they have is gradually modifying that they are more amenable to accepting those kinds of modifications than when the technology is completely new.. Participant 25

Ease of use

The technicality of the use of technology affects the adoption of technology. This subtheme describes Ease of use as a factor that influences the acceptance and use of technology. AFSC actors will adopt, accept, and implement technology if it is easy to use and apply to their production processes. Participants discussed that the ease of use of technology increases technology accessibility among different kinds of users with several educational backgrounds.

If the technology is as simple in a way that an individual who does not have a Western education from primary and secondary school can use it without seeking assistance from one or two personnel, then it will help… Participant 7

Financial investment

The ability to invest in technological solutions influences the adoption. Financial commitment to purchase new solutions are major concern among stakeholders in adopting technological solutions in their operations. Access to loans and technology grants are mediums provided by governments to support digital AFSC transformation within the AFSC industry in Nigeria. If there is no financial capability venturing into technological solutions for AFSC sustainability will not be considered by stakeholders.

Sure, yes. If you have sufficient investments? Of course. Now, as it is, the early adopters are investing a lot of money that they may not be able to recoup. Because they are early adopters, they are trying to see how beneficial this will be. They are the pioneers and the ones paving the way for every other person to enter. *Participant 1*

By also making substantial investment that will reduce the cost implication of adoption by small agribusinesses… *Participant 13*

Role of International Government and International Organization

The role of government and international organisations in technology adoption was highlighted by many interview respondents. The government's role in technology is based on participants' response to access to technology. The government is highlighted to be responsible for making access to investment for stakeholders and supporting international investors that build the support eh growth of the industry. The key role of the government is to establish policies that can help shape the transition and adoption of technology with the AFSC in Nigeria. The role of international organizations like AGRA, IITA, AATIF(Africa Agriculture Trade Investment Fund), AATF (Africa Agriculture Technology Foundation), CGAIR Big data in agriculture played in Africa and Nigeria AFSC sustainability and technology resourceful to actors is well noted.

The government plays a part because when the government is better structured, it makes a lot of things easier. It means adoption is easier, it makes implementing easier. There are a lot of people that don't use certain technology because of the government, regulation and taxes.. *Participant 2*

I stated earlier that we are called AGRA (Alliance for a Green Revolution in Africa). And what we majorly do is to sustainably grow the agricultural food systems in Africa, that's what we do. We do this in partnership with other stakeholders in the agricultural sector. And AGRA is an organization that is funded by partners. Big funders is Bill and Melinda Gates Foundation, USAA, the KFW, UK Aid, Rockefeller Foundation.. *Participant 19*

Above all, the integration of ICT (technology) into whether it is BT, whether it is communication technology, whether it is biological technology, genomics, etc. Also, bringing it into our farming system has likely been promoted by international bodies… Participant 8

Table 4.8 Data Table Technology diffusion

3rd Order Aggregate Dimension	2nd Order Themes	1st Order Quotes
Technology diffusion	**Social Influence**	• Such technologies are managed by fellow farmers in the communities, in the localities that they can relate to. • We also support the community leaders to create awareness in the community so that everyone will believe. Because in order to help them, that's why we need community leader. • You can even visit their and tell them about training and venue. The community leaders also help talk about • When you work with maybe one or two of these people, you would have built trust with that person because they're in that community. I've seen him, they know him before. • In Nigeria, when you want to embark on such initiatives and you are going to deal with the end farmer, you need some government support for security and getting the farmers' attention. You need to go through the leaders, like the chief of the village
	Industry influence	• When a successful business in a region is using technology, other businesses and SMES will want to emulate it. It's happening in the food manufacturing company in the lead. • Yes. Influence is very powerful. Influence simply means people have seen your life, like something about your life and in the strength of that, believe everything that comes from you is

		genuine and can change their lives. It is one of the reasons you are where you are. ● We use community activities and operations. If they have maybe a festival, somebody is around there and he's trying to introduce guests, so he just chips in a new technology that has come to town. We are conscious of what the contents and the messaging are. We try to have in-house control before it goes out ● Where you have the agro-dealers in the main community, in that small hamlet, a lead farmer from there will train him and then work with the seed companies to give them small quantities, you make them a commission agent ● Somehow, they want to see a familiar face. So, what we try to do is to go through their village heads, their chiefs, and first of all, convince them that this is what we are bringing
	Community-based advisory (CBA)	● Yes, we are sending messages to the farmers. We are using our mobile phones to map their farms using GPS, and then we are calling them. ● Some farmers are outsourcing digital solutions with the help of community digital extension services. ● We also work with them to collect regular updates every two or three days. ● I think when we have more extension activity going on, which the farmers can relate to, there will be more discussions around adoption ● So we really need to create awareness in terms of innovations that are adaptable, not bringing things and dumping technologies here in Nigeria
	Technology Demonstration	● So, you have to speak in a way they understand. So we demonstrate to them, and once they see, they don't waste time in adopting it at all.

		• Demonstration? Of course, it will hasten the adoption because they will see the immediate benefits to themselves, and it will drive them to want to adopt. • Yes, showing people how technology works will promote its adoption and usage. Training and workshops, and then through networks.
	Technology Transfer	• They also have assistance, mentorship, and training, those kinds of things. • Knowledge transfer is through Training? • It was practical, someone coming through to train us to tell us how it is been done and also train us how to maintain it personally.
	Profitability	• But if you're able to make it, make whatever you're saying to them make sense in the way they understand it. Honestly, they will adopt it • One of the things farmers will be happy with is things that will increase their yields essentially and directly. For instance, I used to get 2 bags, but now I am getting 5 bags. That is number one. • Yes, and smart seed. It helps them to make money. • For now, there is little to talk about profitability. This cuts across to big and small businesses.
	Competitive Advantage	• We hold your hands together and show you when there is a new technology. If I want you to leave your old means, I must ensure that the new method gives you an edge. • If we are able to increase our innovative edge, we will be able to make more money. • The last question was whether we employ technology, we will be able to get the reduction. • I totally agree. If we had local farmers who had better equipment, of course, they would be able to harvest better • We are used to following the trend of technology and software development and have to make provisions around the food itself

	Context design/Need	. ● I think the real issue for us is how to develop the content and how to make sure that the content is understood and that the content is properly timed. ● The ones that are very adaptable to the country are the ones that can increase the stability in terms of awareness. ● It depends, and we are open to technology. But it has to be a technology in line with our work. ● Generally, I think any technology to be adopted needs to be customised because you cannot have a one-size-fits-all solution for every industry. ● Exactly. Everybody cannot adopt a particular technology. What if it does not address specific issues in the industry? Therefore, every technology must address specifics for it to be optimally efficient
	Perceive usefulness	● I think technology can only be adopted if it is made to appear beneficial to the farmers ● So, we have to let them know that these things will provide them some respite. They will increase their profitability, and if you do that, of course, they will adjust. There is nobody who doesn't want to make more money.
	Ease of use	● The government researches and makes the technology as simple as it is to the lowest level that every individual can easily understand it and adopt it. ● If the technology is as simple in a way that an individual who does not have a Western education from primary and secondary school can use it without seeking assistance from one or two personnel, then it will definitely help.
	Technology reliability	● If you have a proven technology, you don't just dump it on them ● So that we can now disseminate everywhere.

		• If it is available, we can really appreciate it, and it will change our previous method. • So we need some kind of support, really
	Financial investment	• We are so committed, and when we have more money, • The ability to sustain innovation will also tie our workers into what we are trying to do because we are so committed, and when we have more money, we can take care of them in a better way as well. • Let's say a group of farmers or a business has a lot of money, they have a lot of capital, they have a lot of investment and loans from a bank.
	International Organization	• I think the first rule that international bodies are doing is to just remind our government that they need to invest in the sector. That is the most important. • enabling policies and implementation of these policies, monitoring, and evaluation; support and provision of governance to manage violations of regulations by issuing penalties. The biggest problem is the lack of accountability.
	Role of Government	• They are neglecting these kinds of things. So if the government can provide this input and timely access, and supply farming inputs like technology and machinery • Whoever is going to be doing that in partnership with the government creates opportunities. • The role of government is to make technology accessible.

4.3.6 Assessing the Challenges of adoption of industry 4.0 technologies among the AFSC stakeholders

Technology Misconception

Technology misconceptions evolved during the interview with the actor in AFSC actors in Nigeria, which describe misconceptions of financial grants made available by the government and technology misconceptions among stakeholders. Most of the time, technology grant provider by the government towards technology acquisition seems like free money to users and end up not being fully used for technology adoption or acquisition. Some actors in the industry have misconceptions about the nature of this technology and think it requires high technical skill to run it, and mostly think of AFSC technological solutions to be software development, computer programming or coding skillset.

At the initial stage, we assume we can not use IoTs and sensors in our distribution because we think it requires skills like software engineering. To be honest, many people think of technology as software or coding, and it affects their openness to it… _Participant 1_

Technology Threat

The study further examines the challenges to technology among AFSC stakeholders in Nigeria. This subtheme describes threats that actors assume that the adoption of technology will bring into the industry, the threat of loss of jobs to machines, and technological mindset issues actors are facing in the industry. In this study, AFSC assumes that they can be replaced by machines leading to job loss and a reduction in human labor.

Yes, if it is to their advantage. The biggest challenge we see in Africa, not just Nigeria is the concern that bringing in robots for instance, means losing 50 members of staff… _Participant 6_

Trust

This subtheme describes trust as a factor that inhibits technology adoption. Trust occurs in different ways among technology providers and users. Most users presume that technology development is merely for the gain of the technology companies, this is due to the fact that most actors feel profit is the core motivation for technology developers, not the needs of the actors in the industry.

So, people tend to use the one that has been on the ground before now because of the brand that they are aware of. So if you are introducing something that is better, they might not jump on it because they don't have any stories, there are no confirmations, and all that… _Participant 15_

For example, someone introduced a solution to our company, and we did not try to test-run it at all because we didn't trust him. Most people who offer technology are most concerned about their gain, not the gain of the users. For example, you can for this study (Research), primarily *because of it, favour your work, not because you are interested in food production in general…* *Participant 19*

Enabling Environment

Creating an environment that supports technology adoption is essential for widespread industry and business integration. Such enabling environments include the necessary infrastructure to ensure the seamless implementation and utilisation of technological solutions. Government policy and support have been seen by some respondents as the bedrock on which an enabling environment is built. The government needs to create policies that would enable businesses of any size to function and create infrastructure like power, roads, and skills, thus making the adoption of these technological solutions viable.

Also, we need to start building our technology background as a country because imagine you want to buy a component for $5 and you are spending about $50 to bring it into Nigeria.. *Participant 10*

Last but not least, I think there has to be an enabling environment for the agribusiness to adopt and see these great technological solutions. By an enabling environment, I mean the right government policies and support. Not just policies, but also for small-scale farmers, so that they have financial aid and they have aid in the form of input. They also have assistance, mentorship, and training, those kinds of things… *Participant 22*

Many people are struggling to fully implement this technology. The government needs to invest in infrastructural development and cannot keep waiting for grants and foreign aid to invest in infrastructure. If there is an investment in electricity and internet facilities, the rate of production in the country will skyrocket… *Participant 1*

Access to Loan

Adoption of technology requires the AFSC stakeholders' financial capabilities to be able to purchase desired technological solutions within their operations. Several AFSC respondents have highlighted the challenges of access to technological loans as a limitation to the full implementation and scale of technology solutions within the

AFSC. Some assume that technological loans are available, though they are not appropriately distributed within the industry and have a lot of political interference within it.

Quite a few of them are available. But the conditions are a little bit stringent, such that it becomes difficult to access those loans. Some are readily available that everybody can get, but the financial sum or the sum of the money that is being given out may not be able to sufficiently help them in adopting that new technology. That's my own opinion…. Participant 12

Table 4.9 Data table; Challenges of Adoption

3rd Order Aggregate Dimension	2nd Order Themes	1st Order Quotes
Challenges of adoption	**Technology Misconception**	**Financial** ● It is just a thing in Nigeria. When people see that something comes in the form of grants, they are less likely to take it seriously. In Nigeria, when you want to embark on such initiatives and you are going to deal with the end farmer, you need to some government support for security and getting the farmers' attention. You need to go through the leaders like the chief of the village. Once they see that you are coming through that route, they almost believe you're coming from the government. So, you're coming with free money. Free money means it is our national cake and we are going to eat out of it or not do what you want us to do with it. That is what I think based on personal experience. ● At the initial stage we assume we can not uses Iotas and sensors in the our distribution because we think is require skill like software engineering. To be honest with many people think of technology as software or coding and it affects their openness to it. ● You could have a beneficial technology, but if the person who is using does not see it as beneficial, there's no point. He will never talk. ● I think when Nigerians or when some of the entrepreneurs in our community hear about technology, what comes to their mind is software

		• Farmers can trust their community head to adopt a technology • And then you also have suspicion
	Technology Threat	• This will scare them off, and they will rather prefer to keep the old method and keep their jobs than to bring robots that will take over from them, causing them to lose their jobs • Yes, if it is to their advantage. The biggest challenge we see in Africa, not just Nigeria is the concern that bringing in robots ot the use of technology means job loss, for instance, means losing 50 members of staff.
	Trust	• When you work with maybe one or two of these people, you would have built trust with that person because he's in that community. I've seen him they know him before. • The role of government, yes. They have been trying, but they heavily rely on international bodies for support. And once this support is giving still, like I stated earlier, we have people that really want to pocket such intervention; pocket such support for themselves instead of what it meant for the farmers, they want to have it for themselves. • The other one is suspicion. What you don't know, you always look at it, you don't accept it. Except if somebody comes to give his life story that I have used it and it has work • Farmers can trust their community head to adopt a technology

	Enabling Environment	• Also, we need to start building our technology background as a country because imagine you want to buy a component of $5 and you are spending about $50 to bring it into Nigeria. • Finally, I think there has to be an enabling environment for these small-scale farmers. By an enabling environment, I mean right government policies and support
	Access to loan	• There is limited access to loans for new technology, we have tried as a business but the big fish in the industry get all the funds. You need to know someone in the bank and government to access these loans. • If the government or either public or private organizations make it easy for them to access credit, they enhance the production process by adopting this solution and competing in the something to the structure.

4.4.1 Nvivo matrix coding

The principal investigator of this study further explores the AFSC supply chain respondents from Nigeria vertically, comprising a group of cases, mainly farmers, food manufacturers, and logistics. The method employed was a Matrix coding tool within the NVIVO 12 Plus, which allows the researcher to run a query of all 3rd codes(Themes) against each AFSC case, which allows. Matrix Coding inquiries may be used to inquire about various patterns within coded data and get access to the corresponding content that exhibits these patterns.
The matrix coding queries help the researcher facilitate the visualization of ideas, codes, and different experiences in the context of each study case group and the interaction of varying views presented among AFSC case groups (Farmers, food manufacturers, and logistics). This approach enables the research to do a comparative analysis approach between each AFSC case group against the 3rd codes(themes). Tables 10 and 11 show the participant representation based on the sectors within the AFSC they operate in.

Table 4.10 Participant Information

Participant	Industry	Capacity
1	Precision Agriculture	Large scale -OLAM Precision Farming
2	Farming	Large Scale farming
3	Logistics	Small Scale
4	Logistics	Large Scale
5	Food manufacturing	Large Scale
6	Food manufacturing	Large Scale
7	Food manufacturing	Small Scale
8	Agriculture	Large Scale
9	Agriculture	Large Scale Framing
10	Logistics/Agriculture	Ecotutu-small scale
11	Logistics	Large Scale
12	Agriculture /Research	AGRA- 10,00-50,000 farmers
13	Agriculture research Org	NAERLS – Large-Scale Framing
14	Logistics/Farming	Large Scale
15	Farming	Large scale
16	Farming	Large scale
17	Farming	Large scale
18	Food manufacturing	Large scale
19	Farmer/Digital extension agent	Large scale
20	Farmer/Digital extension agent	Small Scale
21	Food manufacturing	Large scale
22	Logistics and farming	Large scale
23	Farming	Large scale
24	Farming	Large scale
25	Farming/Livestock	Small Scale

Table 4.11 AFSC Case Group

Actors	Farmers	Food manufacturing	Logistics
No of Cases	15	5	5

Figure 4.2 contains the initial coding against all the AFSC case groups and contains about 1321 reference quotes. These quotes were references from the interview codes; The 1st order codes contain 311 total references, which comprise quotes from participants during the interview. The 2nd-order codes contain 54 referencing-based aligning and grouping codes and ideas that evolve within the 1st-order codes. The 3rd order codes, which are referred to as the aggregate dimension or themes, comprise 6 themes, as shown in Table Y. Table Y shows each case study group's experiences and responses as related to the themes derived in this study.

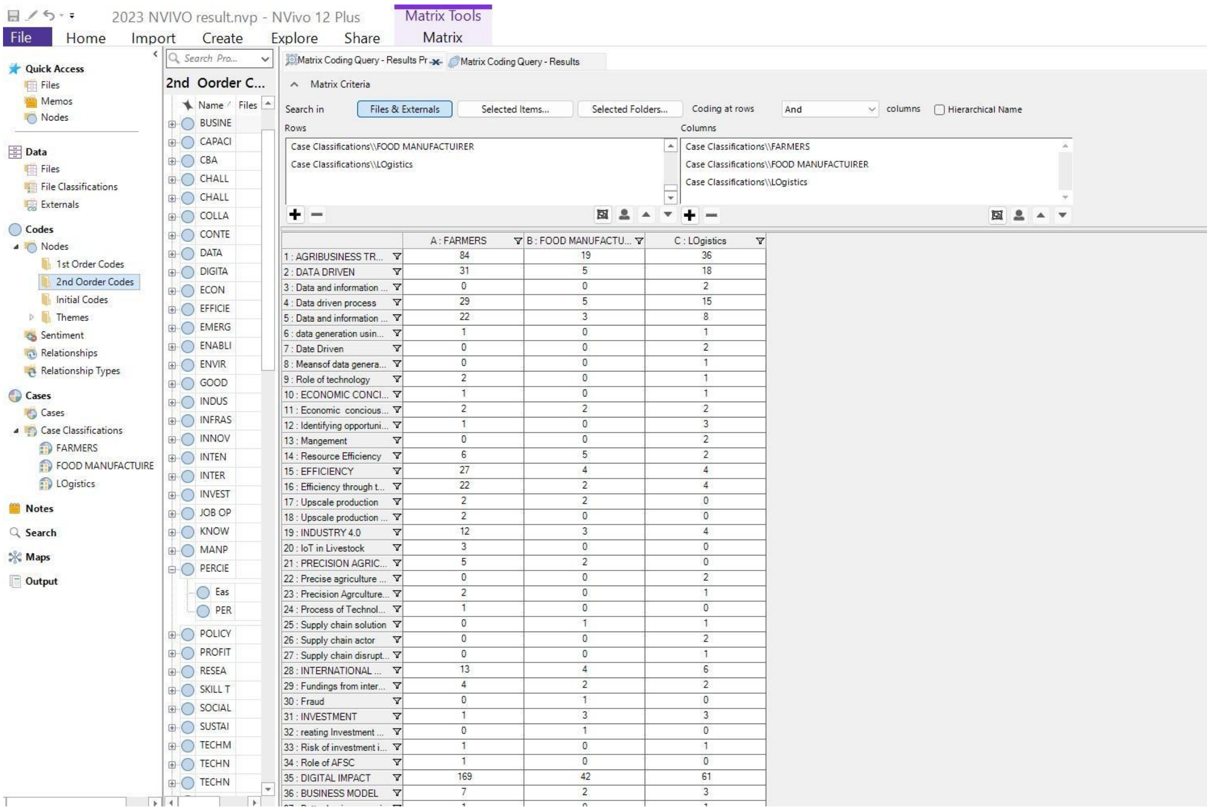


Figure 4.2; Initial quotes, codes and Referencing

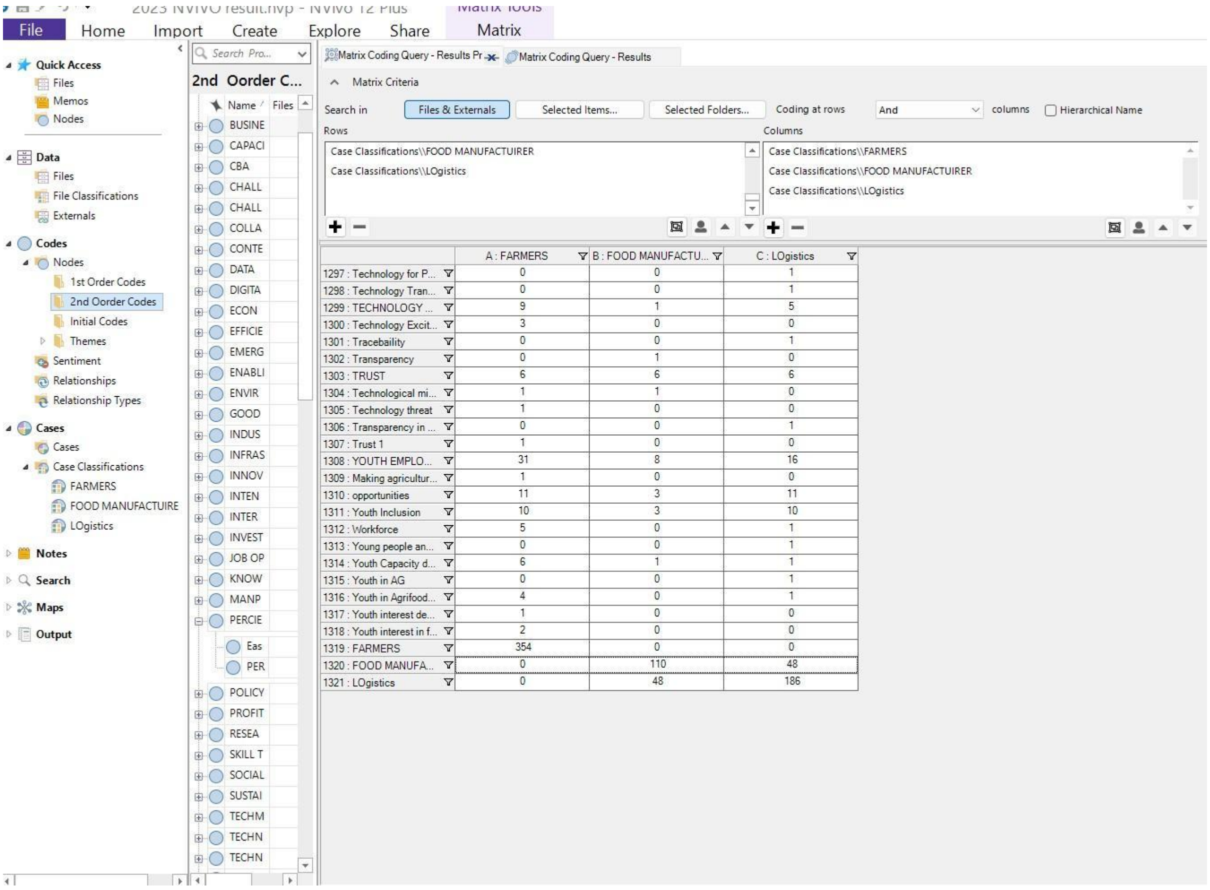
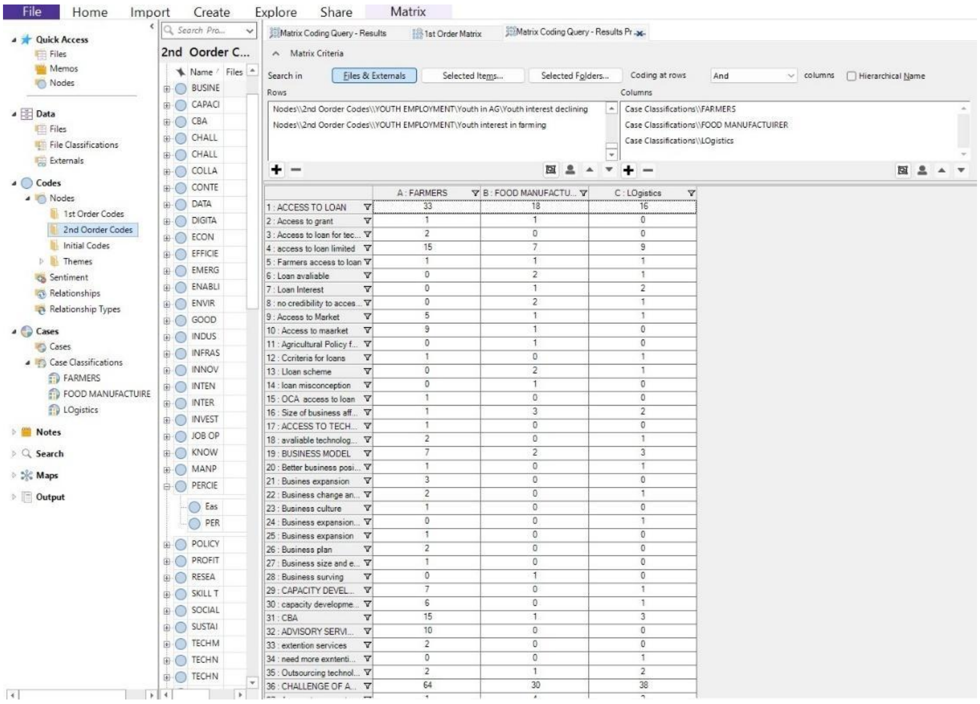


Figure 4.3-Sample of Matrix Coding from Nvivo

Figure 4.4; **The 1st Order** Code



	A : FARMERS	B : FOOD MANUFACTU...	C : LOgistics
1 : ACCESS TO LOAN	33	18	16
2 : Access to grant	1	1	0
3 : Access to loan for tec...	2	0	0
4 : access to loan limited	15	7	9
5 : Farmers access to loan	1	1	1
6 : Loan avaliable	0	2	1
7 : Loan Interest	0	1	2
8 : no credibility to acces...	0	2	1
9 : Access to Market	5	1	1
10 : Access to maarket	9	1	0
11 : Agricultural Policy f...	0	1	0
12 : Ccriteria for loans	1	0	1
13 : Lloan scheme	0	2	1
14 : loan misconception	0	1	0
15 : OCA access to loan	1	0	0
16 : Size of business aff...	1	3	2
17 : ACCESS TO TECH...	1	0	0
18 : avaliable technolog...	2	0	1
19 : BUSINESS MODEL	7	2	3
20 : Better business posi...	1	0	1
21 : Busines expansion	3	0	0
22 : Business change an...	2	0	1
23 : Business culture	1	0	0
24 : Business expansion...	0	0	1
25 : Business expansion	1	0	0
26 : Business plan	2	0	0
27 : Business size and e...	1	0	0
28 : Business surving	0	1	0
29 : CAPACITY DEVEL...	7	0	1
30 : capacity developme...	6	0	1
31 : CBA	15	1	3
32 : ADVISORY SERVI...	10	0	0
33 : extention services	2	0	0
34 : need more exntenti...	0	0	1
35 : Outsourcing technol...	2	1	2
36 : CHALLENGE OF A...	64	30	38

Figure 4.5 Order Matrix Coding

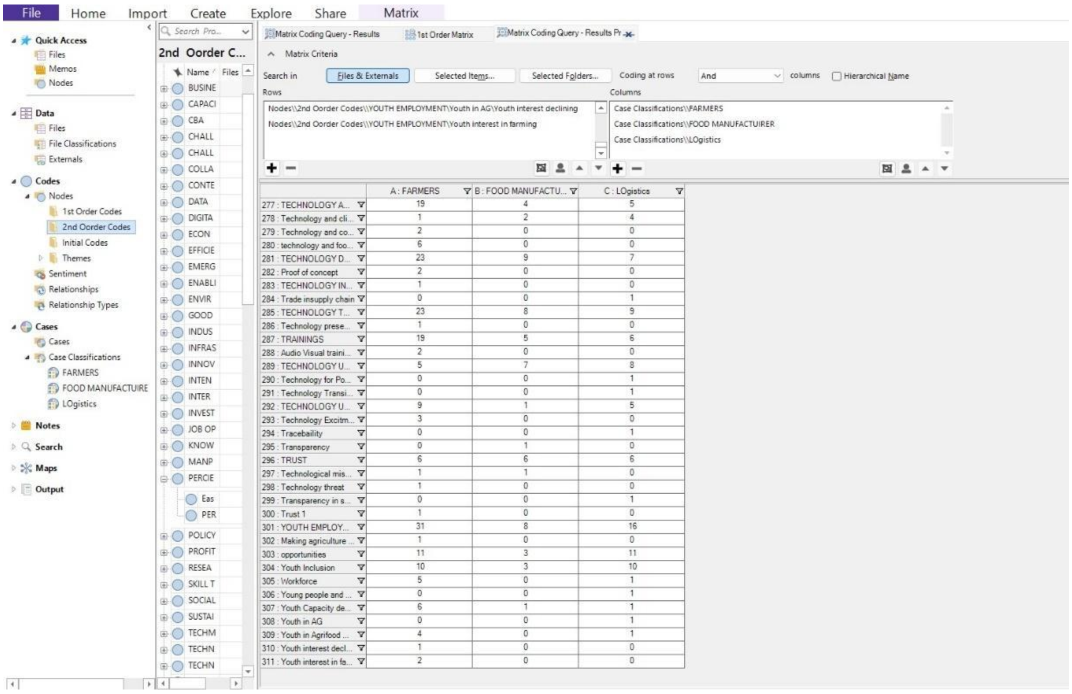
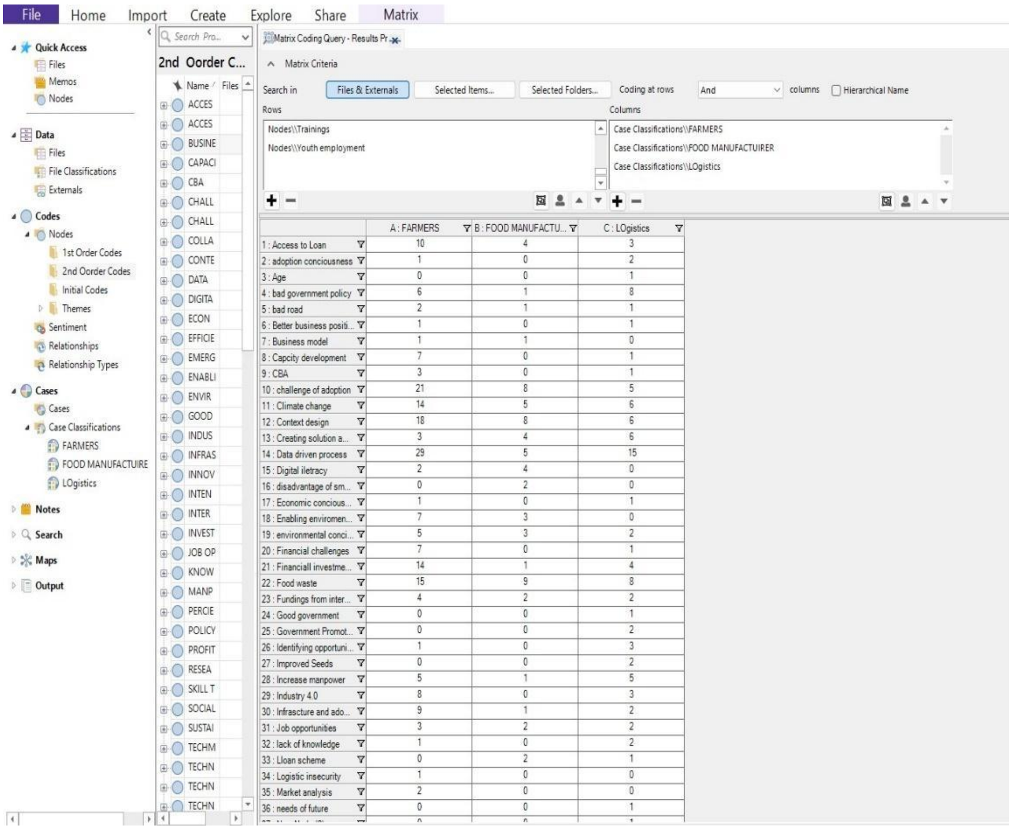
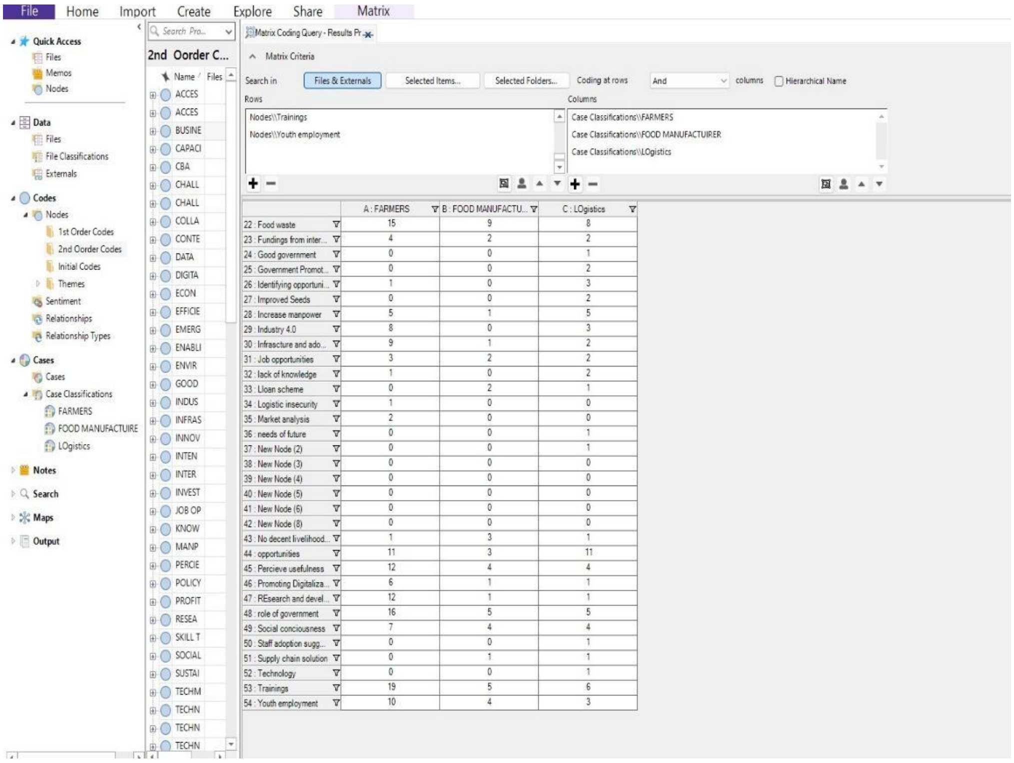


Figure 4.6; 2nd Order Matrix Coding



	A : FARMERS	B : FOOD MANUFACTU...	C : LOgistics
1 : Access to Loan	10	4	3
2 : adoption conciousness	1	0	2
3 : Age	0	0	1
4 : bad government policy	6	1	8
5 : bad road	2	1	1
6 : Better business positi...	1	0	1
7 : Business model	1	1	0
8 : Capcity development	7	0	1
9 : CBA	3	0	1
10 : challenge of adoption	21	8	5
11 : Climate change	14	5	6
12 : Context design	18	8	6
13 : Creating solution a...	3	4	6
14 : Data driven process	29	5	15
15 : Digital iletracy	2	4	0
16 : disadvantage of sm...	0	2	0
17 : Economic concious...	1	0	1
18 : Enabling enviromen...	7	3	0
19 : environmental conci...	5	3	2
20 : Financial challenges	7	0	1
21 : Financiall investme...	14	1	4
22 : Food waste	15	9	8
23 : Fundings from inter...	4	2	2
24 : Good government	0	0	1
25 : Government Promot...	0	0	2
26 : Identifying opportuni...	1	0	3
27 : Improved Seeds	0	0	2
28 : Increase manpower	5	1	5
29 : Industry 4.0	8	0	3
30 : Infrascture and ado...	9	1	2
31 : Job opportunities	3	2	2
32 : lack of knowledge	1	0	2
33 : Lloan scheme	0	2	1
34 : Logistic insecurity	1	0	0
35 : Market analysis	2	0	0
36 : needs of future	0	0	1

Figure 16; 2nd Order Matrix Coding



	A : FARMERS	B : FOOD MANUFACTU...	C : LOgistics
22 : Food waste	15	9	8
23 : Fundings from inter...	4	2	2
24 : Good government	0	0	1
25 : Government Promot...	0	0	2
26 : Identifying opportuni...	1	0	3
27 : Improved Seeds	0	0	2
28 : Increase manpower	5	1	5
29 : Industry 4.0	8	0	3
30 : Infrascture and ado...	9	1	2
31 : Job opportunities	3	2	2
32 : lack of knowledge	1	0	2
33 : Lloan scheme	0	2	1
34 : Logistic insecurity	1	0	0
35 : Market analysis	2	0	0
36 : needs of future	0	0	1
37 : New Node (2)	0	0	1
38 : New Node (3)	0	0	0
39 : New Node (4)	0	0	0
40 : New Node (5)	0	0	0
41 : New Node (6)	0	0	0
42 : New Node (8)	0	0	0
43 : No decent livelihood...	1	3	1
44 : opportunities	11	3	11
45 : Percieve usefulness	12	4	4
46 : Promoting Digitaliza...	6	1	1
47 : REsearch and devel...	12	1	1
48 : role of government	16	5	5
49 : Social conciousness	7	4	4
50 : Staff adoption sugg...	0	0	1
51 : Supply chain solution	0	1	1
52 : Technology	0	0	1
53 : Trainings	19	5	6
54 : Youth employment	10	4	3

Table 4.12 shows the aggregated data references for each theme when analysed against each sector in the AFSC This was possible through Matrix Coding functionality in the NVIVO 12 plus software. This enables deeper analysis of different experiences that AFSC actors face as peculiar to the domain. The principal investigator of the research explores further differences in experience to certain themes. Table 4.13 shows the matrix coding and contains each unique experience presented by each stakeholder.

4.4.2 Assessing the Digital Impact

Youth employment- Farmers view that the adoption of technology within the agricultural sector makes agricultural jobs attractive to youth in Nigeria. The food manufacturing sector thinks that adopting industry 4.0 solutions in their production line will create youth employment and redefine the role of education in driving growth within the industry. Logistics companies think that data management jobs are beginning to emerge, and this is creating employment for young people.

Waste Reduction- The impact of industry 4.0 technologies in waste reduction has varied experiences across the supply chain. Farmers leverage the use of technology to minimise waste by several advisory services available to them, such as information on weather conditions, providing farmers with the best farming method and, in the end, reducing waste. Waste reduction in food manufacturing is mainly achieved through the implementation of technology on the production line. The actors in food manufacturing think that they have experienced food waste reduction through the direct use of these technologies. The experience of most logistics companies in food waste reduction has been due to the outsourcing of some technologies within their agrifood logistics operations.

Technology Diffusion

The adoption of Industry 4.0 technologies within the AFSC in Nigeria has varying experiences and decisions across the supply chain. The experience of farmers is different from that of food manufacturers and logistics. The farmers decide to adopt and use technologies based on individual perceived usefulness and are mainly influenced by their social networks. The food manufacturing sector sees the decision to adopt and use technology as the company's Management responsibility and is often influenced by industry trends. The logistics sector thinks that the decision to adopt and use technology depends on management being influenced by competitive advantage. Each sector of the AFSC has several ways of technological transfer. Within the farmer's domain, technology transfer is believed to be through demonstration and training; the food manufacturing domain views technology transfer through staff training and development; their logistics domain views technology transfer through staff training. The major influence of farmers to make decisions for technology adoption and use in their social networks, whereas food manufacturing and logistics assumes the idea that the majorly influence for technology use and adoption is industry influences, this is due to the facts that the leading business in their sector can inspire other to use the same technology, if the profitability of the technology is known.

4.4.3 Assessing the challenges of adoption

Technology threat

The challenges of adoption and use of Industry 4.0 technologies within the AFSC have been mentioned by the participants as a technology threat. Some farmers think technology will take their jobs in the future, which in turn will affect young people's influx into Agri-tech jobs. The food manufacturing domain thinks that robots can eliminate manual jobs in the food manufacturing industry. The logistics business agrees that the technology threat is there, but its occurrence will take years in Nigeria.

Trust

Many farmers feel sceptical when introduced to new technologies, often perceiving them as a way for companies to profit at their expense. They're concerned that many technologies were not designed with users in mind. The food manufacturing actors express concerns about technology salespersons' alleyways over-hyping the benefits, application, and use of the technologies in their context or business. The logistic actor thinks that most technologies present are based on a one-size-fits-all approach by technology-developing companies, and it sometimes lacks relevance to grassroots challenges and needs of FASC actors.

Table 4.12 3rd Order Codes (Themes)

3rd Order Codes (Themes)	FARMERS	FOOD MANUFACTURER	Logistics
AGRIBUSINESS TRANSFORMATION	84	19	36
DIGITAL IMPACT	169	42	61
PROCESS EVALUATION	112	56	62
SUSTAINABILITY CONSCIOUSNESS	15	4	4
5 TECHNOLOGY ADOPTION	72	27	44
6 CHALLENGES OF ADOPTION	6	6	6
3 : ENABLERS AND INHIBITORS	61	15	19

Table 4.13 The thematic Matrix data analysis of each Sector in the AFSC

3rd Order	FARMERS	FOOD	Logistics

		MANUFACTURER	
2 . DIGITAL IMPACT	**Youth Employment - Attractiveness** These days, young people are beginning to see agriculture, especially farming, attractive through the inception of several digital tools, which means the job in farming is becoming more than planting. In our business, training has been offered to young graduates for example digital extension services. **Waste Reduction- Advisory** Yes. I believe technology can help reduce food waste, For instance when this organization NAERLS gives predictions on whether there will be flooding in a particular area. Then we advise farmers on how and when the flooding is expected to happen and what they can use for them to be on the safer side. If the flooding is expected to come around September, then technically we are likely to advise them to use early maturing variety of crop. So that even if their crop is not 100% matured, it will be a little bit taller to the extent that the flood may not affect them totally and may not condemn all their production.	**Youth Employment- Improve livelihood.** In this industry, the level of education determines how young people feel about it. So, youth employment has various views. The uneducated feel they only work as a casual worker within the production line, they will say bad things about working in the industry and will not assume employment here ie good for the youth. But the well-educated with degrees, work as heads of departments and have the prospect of climbing the ladder, to them this a very wonderful place to work. These are various experiences despite the level of the digital solutions we adopted. **Waste Reduction- Technology Implementation** Yes, of course. Technology plays a very key role in reducing food waste. One of the way our organization ensures this is through infrastructure and technological solutions. Our well-controlled warehouse can manage the stored raw material before and after processing with sophisticated tech solutions. The business also	**Youth Employment – employment options** You can see that many young people in the industry are thinking about logistics and offering several services. We are beginning to see the emergence of logistics support services and data management. We also have a chat system to offer delivery information for B2B. **Waste Reduction- Outsourcing Solutions.** We are a logistic business; we have been able to create solutions that work especially to reduce food waste. And mostly interested in technology around data and consumer-cantered solutions, which are majorly agrifood companies. When we deliver Agri-commodities within the industries, we offer real-time data and information on the state of the commodities, the location and delivery time, this is made possible through our outsourcing technologies partner, that helps us with this solution on our logistics vehicle and helps with software we use.

	Farmers can reduce food waste by training them to use post-harvest and pre-harvest technologies.	implemented this principle of resource efficiency, these are possible by technology in our production line that gathers data on the raw material use, waste incurred, and how it is disposed of, this gives us insight into the waste produced and management thinks about how to curb it.	
Technology diffusion	**The decision of Adoption-** **Based on individual perceived usefulness and influenced by social networks** The adoption of these technological solutions is based primarily on the decision of individual farmers, which links to the benefits they think it will offer them and also the influences of their social communities. **Social Influence**: The diffusion of technology among farmers is mainly through Social Influence, Community heads, recommendations from people in their networks, and government intervention. **Technology Transfer:** Training, technological demonstration,	**Decision of Adoption by Management and influences by trends** The production manager can be of good influence to promote digital adoption. The decision is made by the management. Of course, it cuts across all sectors. If, for example, within the industry, we learn about new technological solutions that people are using, it is up to me to present them to the management and convince them that they are good. The management makes the final decision. **Industry Influences:** Industry influences shape most adoption of technology. When a leading organization in the industry uses one technological solution and we see the benefits, it motivates others to adopt the same solution. **Technology Transfer:** Technology transfer is through staff training and	**Decision adoption – is dependent on Management being influenced by competitive advantage.** I think is the responsibility of the management of the various businesses to decide on the adoption of technological solutions. Everybody wants to chart a course. Of course, l, you need a cutting edge, competitive edge over your other competitors. You compare what you used to do with what you are doing now. Definitely, everybody will key in to new trends of possibilities. . **Industry Influences:** Industry influences shape most adoption of technology. When a leading organization in the industry uses one technological solution and we see the benefits, it motivates others to adopt the same solution.

	Workshop, and Pilot field study	development	**Technology Transfer:** Technology transfer is through staff training and development
7: Challenges of adoption	**Technology Threat** A good level of technology inclusion into agriculture operations is needed, bearing in mind that we have a limited workforce and are trying to attract young people into the industry. We need to be careful that we don't occupy the technology with the jobs our young people will do and jeopardise their employment. I am an advocate for agrifood digitalisation, but we need to strike a balance for youth employment, too. **Trust** For instance, when you introduce technology to farmers, they are sceptical and quite reluctant to adopt the technology. Even when you tell them I have the importance, they think maybe you just want to dupe them. Or maybe it's not true. The best approach is the spread of technology information among fellow farmers in the communities, in the localities that they can relate to, and this is because they can trust them. So, now they are carried along and they also share farmer-to-farmer experiences and not	**Technology Threat** Yes, if it is to their advantage. The biggest challenge we see in Africa, not just Nigeria, is the concern that bringing in robots, for instance, means losing 50 members of staff. This will scare them off, and they will instead prefer to keep the old method and keep their jobs rather than bring robots that will take over from them, causing them to lose their jobs. **Trust** In my experience, technology salespeople who sometimes promote technology mostly overlook its advantages and appropriateness to our context, and they do not understand the users' needs here.	**Technology Threat** The risk or threat in technology adoption is mainly around jobs, but I think it is still far ahead. For instance, robotics truck drivers will take a long time to overtake present jobs like logistics drivers. The threat is still far away, but it is something we need to consider. **Trust** There is not really a thing as all solutions fit all, what we experience is some lies on the usefulness of the technology. When most of us adopt them we realize they don't deliver the dividends they promise, this is causing issues with adaptation presently in Nigeria.

	just a producer or researcher trying to pass this on to the farmer. Now it's a farmer carrying out what the researcher said in his own field and other farmers seeing it and being able to relate. I think when we have more extension activity going on which the farmers can relate to, there will be more discussions around adoption.		

4.5 Validating Conceptual Framework

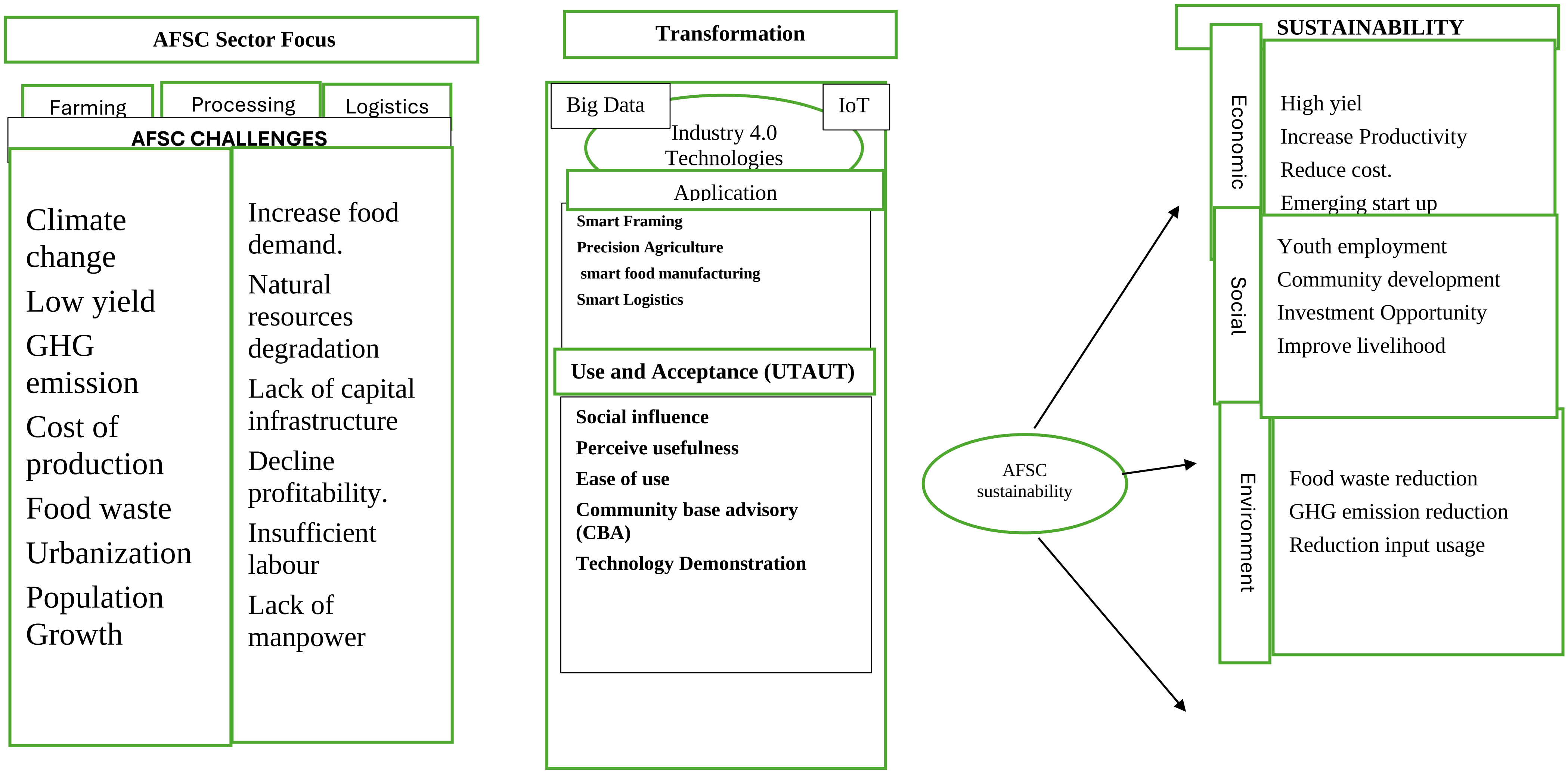
This conceptual framework proposed for this study was developed and presented in Chapter 2, Figure 2.1. The conceptual framework comprises three aspects, firstly, the evaluation of the AFSC system, which presents the different challenges facing the agrifood supply chain industry; it also contains the AFSC sector (Majorly farming, processing, Retail, logistics and consumers) intended to cover. Secondly, the conceptual framework contains the transformation section, which proposes that the adoption and use of technology will lead to AFSC transformation, resulting in sustainability outcomes. The technologies proposed are industry technologies such as Big Data, IoTs, Drones, and process applications such as Smart farming, smart processing, and smart logistics. Thirdly, the conceptual framework section contains the proposed sustainability outcomes of the use and adoption of the Industry 4.0 technologies as described in Chapter 2.

After conducting the qualitative study (interview) for both the pilot and main studies, the proposed conceptual framework was modified based on the findings from the study. In the first section of the conceptual framework, it was now established that the study only focuses on three sectors in the AFSC industry, mainly farming, processing and logistics. The identified AFSC discovered from the study are climate changes, Climate change, Low yield, GHG emission, Cost of production, Food waste, Urbanization, Population Growth, Increase food demand, Natural resources degradation, Lack of capital infrastructure, Decline profitability, Insufficient labour and lack of manpower are the challenges that emerged from the findings in the study, this was modified and validates the proposes conceptual frame work in chapter 2. The transformation section of the conceptual framework was modified based on the findings from the study; the AFSC actors from the study use IoTs, sensors, Big Data, smart farming, precision agriculture, Drones, Smart Logistics and smart food processing technologies, as updated in the conceptual framework. The factors that promote the use and adoption of technologies emerge from conducting the interview data are Social influence, Perceived usefulness, Ease of use, Community-based advisory (CBA) and Technology Demonstration, which corroborate with the unified theory of use and acceptance of technology. This further informs the quantitative study for further inquiry using the UTUAT framework to develop the quantitative hypothesis. The sustainability impact of the use of Industry 4.0 technologies within the AFSC in Nigeria was validated and modified in the conceptual framework. The sustainable impacts that emerge base of the findings of the study were : Economic (High yield, Profile Productivity, Reduce cost., Emerging start up), social (Youth employment, Community development, Investment Opportunity, Improve livelihood) and environmental (Food waste reduction, GHG emission reduction, Reduction input usage).

This chapter used NVivo software 12 to thematically analyse the interview data from the AFSC actors who participated in the study. This enabled the researcher to determine the sustainability impacts of the adoption and use of several Industry 4.0 technologies within the AFSC industry in Nigeria.

The outcomes demonstrated that the main sustainability impacts of Industry 4.0 technologies are the following: environmental, economic, and social. And further established the factors that influence the use and adoption of the technologies to be Social influence, Perceived usefulness, Ease of use, Community-based advisory (CBA) and Technology Demonstration. Based on the insights and conclusions from the inductive thematic analysis of the interview the proposed conceptual framework in chapter was validated and modified.

Figure 4.7 Validating Conceptual Framework



4. 6 Conclusion

The chapter provides an overview of the qualitative data from semi-structured interviews conducted with the AFSC actors in Nigeria. The thematic analysis was performed using Nvivo, and several concepts and themes emerged from the experience of the AFSC actors which are recorded and highlighted. The 1st order codes have 311 codes, 54 2nd order codes, and 6 3rd order codes (Themes). The thematic analysis was conducted on two levels, horizontal and vertical, with the horizontal view of the supply chain being one entity. The vertical analysis further explores the study with the approach that considers each section of the AFSC different and distinct with very experienced. The themes were discussed, and several themes. The themes highlighted were the challenges of AFSC actors, sustainability consciousness, economic impact of technology, agribusiness transformation, technology diffusion, and challenges. The effect of the adoption of technologies over economic, social, and environmental; the interview with the AFSC actors has presented evidence to support the fact that adoption and use of technology within the supply chain has linked to youth employment, emergence of new Agri-tech startups, food waste reduction, resources efficiency, data-driven processes and improve livelihoods of actors.

CHAPTER FIVE (5)

5.0 QUANTITATIVE DATA ANALYSIS (Deductive)

5.1 Introduction

This chapter presents qualitative data from 158 participants and respondents to the survey questionnaire. This questionnaire was developed based on the UTAUT framework, and some variables peculiar to the study context were added. The quantitative data collected and analysed in this chapter are adopted to complement the qualitative data analysis in chapter four, as qualitative research is the main instrument in mixed-method research, followed by the triangulation method in the next chapter. The data is analyzed mainly in the descriptive method and Structural equation methods (SEM). The survey data was constructed in a reflective measurement approach, and analysed using Smartpls 4 software. The structure of this chapter is as follows: the descriptive discussion of the survey data and, afterwards, the SEM data analysis. The descriptive section of the data analysis focuses on describing the AFSC stakeholders' responses to each construct and indicator. The research focuses on visualising the response based on the number of participants who chose each scale on the Likert 5-point scale on the survey. Table 5.1 shows the survey respondents' specific attributes, including age, education level, and the industry they operate in.

Table 5.1 Participant profile

Profile of Survey Participants					
AGE		Education		Sector	
18-24	27	No education	1	Inputs	14
25-30	51	SSCE	18	Farming	73
31-35	28	BSc	92	Food Manufacturing	59
35-40	24	MSc	49	Logistics	46
40 Above	28	PhD	8	Retail	21

DEVELOPMENT OF THE RESEARCH HYPOTHESES

Theoretical background and hypothesis

Drivers of sustainability

Several regional and global-level occurrences, including conflicts, natural and artificial disasters, climatic changes, population growth, urbanisation, dietary change and natural resources degradation, pose a danger to agri-food supply chains (AFSCS) sustainability, as discussed in chapter one. Chauhan, Debnath and Singh 2018 argue that agrifood waste management drives sustainability in the agrifood industry. Wijerathna-Yapa and Pathirana 2022 thought climate change drives agri-food industry sustainability. Zhao et al. (2024 examine the role of Industry 4.0 technologies on agrifood supply chain sustainability. This construct examines the correlation between the drivers of sustainability and the use and acceptance of Technology, leading to the study's hypothesis 1. This latent variable emerges during the qualitative data collection and analysis.

Hypothesis 1: Will the driver of agrifood sustainability result in the use and acceptance of Industry 4.0 technologies among the AFSC actors?

Technology benefits

There are several benefits that the adoption and use of technology present to businesses across the world. In the agrifood industry, as stated in chapter two of this academic work, Yadav 2022 presented another paradigm in AFSC sustainability, which is based on the use of Industry 4.0 technologies with promising sustainable AFSC systems. Moreover, this reimaging is possible due to the current progress presented by Industry 4.0 technologies such as "Internet-of-Things (Iot), Blockchain, Big Data (BD), Drones, and smart farming.Lezoche et al. (2020) believe that Industry 4.0 technologies can facilitate the coordination of supply chains, which is crucial for maintaining sustainability. This leads to broader advancements in technology and agricultural techniques that have fuelled the rise of innovative AFSC operations such as smart farming (SF), resulting in enhanced management of agricultural processes. The study by Feng et al. (2020) investigated the successful implementation of innovation and its impact on agrifood business sustainability. They thoroughly established the role of Industry 4.0 technologies in supply chain sustainability. The role of Industry 4.0 technologies in data informs better business decisions. The findings indicate that 4.0 technologies facilitate rapid information exchanges among customers and AFSC actors. The adoption of industry 4.0 technologies has resulted in new agribusiness frontiers; as noted by Spanaki et al., (2021) technologies are giving rise to new agribusiness frontiers. Lowry et al.,2019 describe it as a paradigm shift among the AFSC stakeholders. This construct examines how the benefits of technology influence AFSC actors in the use and acceptance of technology, which resulted in the development of hypothesis 2.

Hypothesis 2: do the benefits of technology influence AFSC actors in Nigeria's behavior intention to use and accept technology

Performance expectancy

Performance expectancy refers to the extent to which AFSC actors believe that using an industry 4.0 technology will provide advantages in carrying out specific tasks. Performance expectation refers to an individual's belief in the extent to which adopting a technology would assist them in achieving job-related benefits such as performance. According to Venkatesh et al. (2007), evidence suggests that performance expectancy emerges as the most robust predictor of an individual's intention to adopt and utilise technological innovations.

Hypothesis 3: AFSC actors in Nigeria's performance expectancy of Industry 4.0 technology will influence the behavioural intention to use technology.

Effort expectancy

Effort expectancy refers to the ease associated with using Industry 4.0 technologies among AFSC actors (Venkatesh et al., 2012). Some AFSC actors may be more industry 4.0 technology than others in the context of their application within the agrifood landscape, and as a result, they should have less trouble using their industry 4.0 technologies. This resulted in developing the hypothesis measured in this study.

Hypothesis 4: Effort Expectancy may have a positive impact on behaviour intention to use technology among the AFSC actors.

Social influence

The adoption of Industry 4.0 technologies among AFSC actors may be positively affected by social influences. To be better put, individuals feel that people or organizations can place significance on better performance through certain technologies or innovations. This underscores the subjective norm stated in the theory of reasoned behaviour, which underpins the impact of external factors on adopting technology (Venkatesh et al. 2007). This underpins the idea that Individuals are presumed to seek advice from their social network, particularly friends and family, on new technology and might be swayed by the perceived social impact of significant others (Beza et al., 2018).

Hypothesis 5: social influence will positively impact behaviour intention to use technology among the AFSC actors in Nigeria

Enabling conditions

Enabling conditions pertain to AFSC actors' perceptions and the availability of technological infrastructure that assists them in using the system as needed (Venkatesh et al., 2012). This construct examines if the AFSC in Nigeria perceive that the availability of technological infrastructure has impact on their intention to use technology.

Hypothesis 6: Facilitating conditions will positively impact AFSC's Behaviour intention to use technology.

Technology Adoption Readiness

In the agri-food sector, the readiness of stakeholders to use and adopt technological advancements is referred to as technology adoption readiness. This preparedness is contingent upon various factors, including infrastructure, funds, knowledge and skills, cultural beliefs, and institutional frameworks. Feder, Just, and Zilberman (1985) argue that the AFSC actor's capacity to invest in new technologies is contingent upon the availability of financial resources, such as personal savings, access to credit, or grants. Duflo, Kremer, and Robinson (2008) argue that businesses' readiness to adopt and use technology is dependent on skill and knowledge and that the adoption of technology is significantly influenced by training and education. The more users are informed, the more likely they are to comprehend and value the advantages of a new technology. Rogers (2003) suggested that the adoption of technology can be influenced by culture, beliefs, and behaviours and suggested that technology might face resistance to adoption if it disrupts traditional practices.

Hypothesis 7: Technology Adoption Readiness will positively impact AFSC's Behavior intention to use intention to use technology.

Technology Cost: the price value in terms of the cost of technology, as shown by several studies to have positive impact on the actor's behaviour toward using technology; this aligns with Roger's 2005 theory of technology diffusion, which argues that the price of the technology has factors that influence the diffusion of technology.

Hypothesis 8: Technology Cost or price value of technology will positively impact AFSC's behaviour and intention to use technology.

Behavioural Intention: according to Venkatesh et al., 2012, this examines the intention to use or will continue using technology by users. The latent variable examines whether behavioural intention correlates with user behaviour in using technology

Hypothesis 9: behaviour intention has a positive impact on user behaviour in using technology

Table 5.2 lists the survey's latent variables, Indicators and related questionnaire statements

Latent Variable	Indicator/Description	Statement
Driver of sustainability (Emerge from Interview)	DS The latent variable examines the drivers of sustainability if it correlates with technology adoption	What are the drivers of sustainability? DS 1- Climate Change DS 2- Food waste DS 3- Natural resources degradation DS 4- Overpopulation
Technology Benefits **(Emerge from interview)**	TB The latent variable examines the technology benefits if it correlates with technology adoption.	TB 1 -Digital solutions can promote agri-food sustainability TB 2-Technology can provide Real-time monitoring of environmental conditions TB 3- Adopting technology can improve local communities' social and economic status. TB 4 - Adoption of technology can promote youth employment in the agri-food sector
Behavioural Intention (from UTUAT theory)	BI The latent variable examines if behaviour intention has correlation with user behaviour in using technology	BI 1 - I intend to use or will continue using technology (IoT, Big Data, and precision Agriculture technologies) in the future. BI 2 - I always try to use technology(IoT, Big Data, and Precision Agriculture technologies) in every activity across the agri-food supply chain. BI 3 - I plan to use or continue using Technologies more frequently in the future. BI 4 - I will suggest to the other AFSC actors that they use technology (IoT, Big Data, and Precision Agriculture technologies).
Performance Expectancy **(from UTUAT theory)**	PE The latent variable examines whether performance expectancy correlates with	PE 1: Using the IoT and Big Data technologies will increase my chances of achieving higher production and crop productivity

	user behaviour when using technology.	PE 2: If I use IoT and Big Data technologies will increase my chances of increasing my income. PE 3 Using IoT and Big Data will give me a real- time information on the state of my AFSC processes P4: Using IoTs and Big Data will make me more efficient and help me make better decisions.
Effort Expectancy **(from UTUAT theory)**	EE The latent variable examines whether effort expectancy correlates with user behaviour in using technology.	EE 1 -My first impression of IoT and Big Data technologies was clear, favourable, and comprehensible EE 2 - Learning to use the IoTs and Big Data technologies is easy. EE 3- I found the IoT technologies easy to use EE 4- Acquiring skills needed for IoT and Big Data technology in the agri-food supply chain is easy.
Social Influence **(from UTUAT theory)**	SI The latent variable examines whether social influence correlates with user behaviour when using technology.	SI 1- People who are important to me think that I should use technologies (IoT, Big Data, Precision) SI 2 - The people who have influenced my behaviour think that I should use technologies(IoT, Big Data, Precision)

		SI 3- The people whose opinions are valuable to me prefer to use IoT technologies. SI-4 The leading agribusiness in the agrifood supply chain is using IoT technologies
User Behaviour **(from UTUAT theory)**	UB The latent variable examines that user behaviour correlates with several latent variables that determine the use and acceptance of technology.	UB 1 -I clearly know how to use IoT and Big Data systems in farming, Food Processing, and logistics. UB 2- I will use IoT and Big Data technologies in farming/Food Processing/Logistics. UB 3- I use all the relevant IoT and Big Data related applications.
Enabling conditions **(from UTUAT2 theory and Interview)**	EC The variable examines enabling conditions such as skills, technology compatibility, and facilities that help with technology adoption.	EC 1- I have the facilities necessary to use IoT and Big Data technologies relevant to the agrifood supply chain. EC 2- I know how to use IoT and Big Data Technologies EC 3 - I have the skills to use IoT and Big Data Technologies. EC 4- IoT and Big Data technologies are generally compatible with the current technologies I use.

Technology Cost **(From Interview)**	TC This construct examines the impact of technology costs on technology adoption	TC 1 The price of technology is a significant concern for usage TC 2- IoTs, Big Data, and precision technologies are costly. TC 3 - I can make financial investments toward technology adoption.
Technology Adoption Readiness **(from Interview)**	TAR This construct measures the readiness of businesses of industry (e.g. agri-food industry) to experience technology adoption	**Drivers of Digitalization** **TAR 1** investment **TAR 2-**Infrastructure **TAR 3-**Knowledge **TAR 4-**skill **TAR 5 –** Access to technology

5.2 Data Presentation -Descriptive

Table 22-31 shows the construct and indicators; the survey questions serve as indicators to measure the extent to which the survey respondents believe the indicators influence the construct. Table 21 represents the construct that explores what participants believe are drivers of sustainability, which are based on a 5-point Likert scale. 43% of respondents agree that climate change is a driver for sustainability in the AFSC industry, the majority of survey respondents disagree that food waste serves as a driver of sustainability, and 87 participants agree and firmly believe that natural resources degradation is a driver of sustainability with the AFSC in Nigeria. Table 23 constructs measures the dividends of the usage of industry 4.0 technologies. One hundred forty participants agree and strongly agree that technologies(Digital solutions) can promote agri-food sustainability, and 139 survey respondents agree and strongly agree that Technology can provide Real-time monitoring of environmental conditions. Table 24 represents the construct for behaviour intent to use technologies; 129 survey respondents agree and strongly agree that they intend to use or will continue using technology (IoT, Big Data, and precision Agriculture technologies) in the future, 105 survey respondents agree and strongly agree always to try to use technology(IoT, Big Data, and Precision Agriculture technologies) at every activity across the agri-food supply chain. Table 25 represents the construct for performance expectancy for the use of technologies among AFSC survey respondents; 142 respondents agree and strongly agree that

Using the IoT and Big Data technologies will increase their chances of achieving higher production and crop productivity, 142 survey respondents agree and strongly agree that If they use IoT and Big Data technologies, it will increase their chances of increasing my income. Table 26 represents the construct for effort expectancy for the use of technology, 96 survey participants agree and strongly agree that their first impression of the IoT and Big Data technologies could be described as clear, favourable, and understandable, and 87 participants agreed and strongly agree that Learning how to use the IoTs, Big Data technologies is easy for me. Table 27 represents the construct for social influence and measures the impact of social influence on the use and acceptance of technologies among the AFSC. One hundred survey respondents agree and strongly agree that People who are important to them think I should use technologies (IoT, Big Data, Precision), and 101 survey respondents agree and strongly agree that the people whose opinions are valuable to me prefer IoT technologies. Table 28 represents the construct for user behaviour for the use of technologies; 76 survey participants agree and strongly agree that they have a clear idea of how to use the IoT and Big Data systems in farming/Food Processing/Logistics, whereas 15 participants neither agree nor disagree and 44 participants disagree. Table 29 represents the enabling conditions that are required to promote the use of technology within the AFSC. Sixty-six survey respondents agree and strongly agree that they have the facilities necessary to use technologies IoT and Big Data relevant to the agrifood supply chain, whereas 33 respondents neither agree nor disagree, and 37 survey respondents disagree with having an enabling environment that promotes the use of technology within the AFSC. Table 30 represents the construct that examines the impact of cost on the use of technology within the AFSC sector; 143 survey respondents agree and strongly agree that the price of technology is a significant concern for usage. Table 31 represents the construct that examines the drive for digitalisation within the AFSC, which includes investment, knowledge, infrastructure, skills, and access to technology. One hundred forty-four survey respondents agree and strongly agree that investment in the AFSC will be the primary driver, and 146 survey respondents agree and strongly agree that access to technology will drive digitalisation within the AFSC industry in Nigeria.

5.2.1 Descriptive analysis of survey Questionaire

Table 5.3 Construct for the driver of sustainability
Questions: What are the drivers of sustainability?

Scale	Climate Change	Food waste	Natural resources degradation	Overpopulation
Strongly Disagree	10.75% participants	17% participants	13.3% participants	12% participants
Disagree	9.5% Participants	31.6% participants	21.5% participants	25.3% participants
Neither Agree or Disagree	9.5% Participants	13.3% participants	9.5% participants	8.2% participants
Agree	43.6% participants	22.7% participants	33.5% participants	30.4% participants
Strongly Agree	26.5% participants	13.3% participants	21.5% participants	23.4% participants
Total Response	158	158	158	158

Table 5.3 Construct for Technology Dividends

Questions: What is the role of technology?

Scale	Digital solutions can promote agri-food sustainability.	Technology can provide Realtime monitoring of environmental conditions.	Adoption of technology can improve the social and economic status of local communities.	Adoption of technology can promote youth employment in the agri-food sector.

Strongly Disagree	3.7% participants	3.7% participants	4.4% participants	3.1% participants
Disagree	3.7% participants	3.7% participants	2.5% participants	3.1% participants
Neither Agree or Disagree	3.7% participants	4.4% participants	8.2% participants	4.4% participants
Agree	37.9% participants	41.1% participants	40.5% participants	34.1% participants
Strongly Agree	50.6% participants	46.8% participants	44.3% participants	55.1% participants
Total Response	158	158	158	158

Table 5.4 Construct for Behavioural Intention

Scale	I intend to use or will continue using technology (IoT, Big Data, and precision Agriculture technologies) in the future.	I always try to use technology(IoT, Big Data, and Precision Agriculture technologies) in every activity across the agri-food supply chain.	I plan to use or continue using Technologies more frequently in the future.	I am going to suggest to the other AFSC actors that they use technology (IoT, Big Data, and Precision Agriculture technologies).
Strongly Disagree	4.4% participants	4.4% participants	2.5% participants	3.2% participants
Disagree	3.7% participants	6.9% participants	1.3% participants	1.3% participants
Neither Agree	10.1%	22.1%	12.6%	6.9% participants
or Disagree	participants	participants	participants	

Agree	42.4% participants	44.3% participants	44.3% participants	46.2% participants
Strongly Agree	39.2% participants	22.1% participants	39.2% participants	42.4% participants
Total Response	158	158	158	158

Table 5.5 Construct for Performance Expectancy

Questions: What are your performance expectations?

Scale	Using the IoT and Big Data technologies will increase my chances of achieving higher production and crop productivity.	If I use IoT and Big Data technologies, I will increase my chances of increasing my income.	Using IoT and Big Data will give me real-time information on the state of my AFSC processes.	Using IoTs and Big Data will make me more efficient and help me make better decisions.
Strongly Disagree	2.5% participants	1.8% participants	2.5% participants	3.1% participants
Disagree	1.2% participants	2.5% participants	2.5% participants	3.7% participants
Neither Agree or Disagree	6.3% participants	5.6% participants	8.2% participants	8.2% participants
Agree	46.8% participants	50% participants	47.4% participants	42.4% participants
Strongly Agree	43% participants	39.8%	36.7%	42.4%
		participants	participants	participants
Total Response	158	158	158	158

Table 5.6 Construct for Effort Expectancy

Scale	My first impression of IoT and Big Data technologies was clear, favourable, and comprehensible.	Learning to use the IoTs and Big Data technologies is easy.	I found the IoT technologies easy to use	Acquiring skills needed for IoT and Big Data technology in the agri-food supply chain is easy.
Strongly Disagree	4.4% participants	3.1% participants	3.7% participants	4.4% participants
Disagree	12% participants	18.3% participants	10.7% participants	11.3% participants
Neither Agree or Disagree	22.7% participants	23.4% participants	28.4% participants	18.3% participants
Agree	48.7% participants	44.9% participants	46.8% participants	44.3% participants
Strongly Agree	12% participants	10.1% participants	10.1% participants	21.5% participants
Total Response	158	158	158	158

Table 5.7 Social Influence Construct

Scale	People who are important to me think that I should use technologies	The people who have influenced my behaviour think that I should use	The people whose opinions are valuable to me prefer to use IoT	The leading agribusiness in the agrifood supply chain is using IoT

	(IoT, Big Data, Precision)	technologies(IoT, Big Data, Precision)	technologies.	technologies.
Strongly Disagree	3.7% participants	3.7% participants	3.7% participants	3.2% participants
Disagree	10.1% participants	10.1% participants	6.9% participants	6.3% participants
Neither Agree or Disagree	22.7% participants	25.9% participants	25.3% participants	22.7% participants
Agree	46.2% participants	43.6% participants	44.9% participants	44.9% participants
Strongly Agree	17% participants	16.4% participants	18.9% participants	21.5% participants
Total Response	158	158	158	158

Table 5.8 Construct User Behaviour (UB)

Scale	I have a clear idea of how to use IoT and Big Data systems in farming, Food Processing, and logistics.	I will use IoT and Big Data technologies in farming/Food Processing/Logistics.	I use all the relevant IoT and Big Data related applications.
Strongly Disagree	8.2% participants	5% participants	5.6% participants
Disagree	27.8% participants	5.6% participants	19.6% participants

Neither or Agree Disagree	15.8% participants	10.7% participants	22.1% participants
Strongly Agree	37.9% participants	58.8% participants	40.5% participants
Strongly Agree	10.1% participants	19.6% participants	12% participants
Total Response	158	158	158

Table 5.9 Enabling conditions construct :

What are the enabling conditions for using technology?

Scale	I have the facilities necessary to use IoT and Big Data technologies relevant to the agrifood supply chain.	I know how to use IoT and Big Data Technologies.	I have the skills required to use IoT and Big Data Technologies.	IoT and Big Data technologies are generally compatible with the other technologies that I use currently.
Strongly Disagree	10.7% participants	6.9% participants	5.6% participants	6.3% participants
Disagree	23.4% participants	17.7% participants	17.7% participants	15.1% participants
Neither Agree or Disagree	20.8% participants	16.4% participants	18.8% participants	24.6% participants
Strongly Agree	35.4% participants	48.1% participants	48.1% participants	38.6% participants
Strongly Agree	9.4%	10.7%	9.4%	15.1%
	participants	participants	participants	participants

Total Response	158	158	158	158

Table 5.10 Technology Cost construct

Questions: Does the cost of technology affect adoption and usage?

Scale	The pr of technology is significant concern usage. for	IoTs, Big Data, and precision technologies are very costly.	I can make financial investments toward technology adoption.
Strongly Disagree	1.8% participants	1.8% participants	2.5% participants
Disagree	3.7% participants	8.8% participants	9.4% participants
Neither Agree or Disagree	3.7% participants	10.7% participants	22.1% participants
Agree	48.7% participants	41.1% participants	46.8% participants
Strongly Agree	41.7% participants	37.3% participants	18.9% participants
Total Response	158	158	158

Table 5.11 Technology Adoption Readiness Construct

Scale	investment	Infrastructure	Knowledge	Skill	Access to technology

Questions: What are the things needed to drive the digitalisation of the Agrifood supply chain?

TAR	Investment	Infrastructure	Knowledge	skill	Access to technology
Strongly Disagree	0.6% participant	1.8% participants	1.2% participants	0.6% participant	1.2% participants
Disagree	3.1% participants	1.8% participants	1.2% participants	0.6% participant	0.6% participant
Neither Agree or Disagree	1.2% participants	3.7% participants	1.2% participants	1.8% participants	3.1% participants
Agree	54.4% participants	55% participants	53.1% participants	54.4% participants	50.6% participant
Strongly Agree	40.5% participants	37.3% participants	43% participants	42.4% participants	41.7%participants
Total Response	158	158	158	158	158

5.3 Quantitative Data Presentation

5.3.1 Structural Equation Modeling (SEM)

Wold, a Swedish econometrician, dedicated his efforts in the 1970s and 1980s to developing models and methods for the social sciences. He focused on dealing with "soft models and soft data," which is common in this field. Wold's work in the 90s gave rise to partial least squares route modelling, which subsequently developed into partial least squares structural equation modelling (Hair et al. 2011). The research work of Wold on principal component analysis resulted in the formalisation of PLS-SEM in 1979, with its first reference to PLS-SEM being made in 1985 (Wold, 1985). Several developments in the research approach have been made by numerous scholars, such as the noted work of Chin & Newsted, 1999 and several other authors whose input has resulted in enhancing and perfecting the PLS-SEM algorithm. Several researchers have expanded and enhanced Wold's original work, improving and fine-tuning the algorithm (Lohmoller, J.B., 2013). PLS-SEM utilises a combination of principal components analysis and regression-based path analysis to estimate the parameters of a set of equations in a structural equation model (Hair et al. 2011). PLS-SEM (Partial Least Squares Structural Equation Modelling) is a popular method for analysing complex path models involving latent variables and their relationships. The PLS-SEM has seen wide acceptance in several fields, such as hospitality, management, accounting, supply chain, tourism, and operational management, which is due to its crucial advantage in giving the researcher a medium to analyse a very intricate model with various constructs and variable(indicators) mainly when the study aims to make predictions (Akter et al. 2017).

PLS-SEM is widely used for estimating complicated route models that include latent variables and their relationships. Path modelling is a commonly used approach in social research to articulate hypotheses. In the field of structural equation modelling, two prevalent paradigms have emerged which are partial least squares (PLS-SEM), which can be traced back to the contribution of work of Wold (1982), and covariance-based analysis (CB-SEM), which draws inspiration from the research conducted by Jerebko (1978). These two modelling approaches are the prevailing procedures used in social science. Unquestionably, PLS-SEM has gained significant popularity in survey research since its inception in 1966 by Herman Wold (Akter et al. 2017). The primary motivation for the advancement of PLS-SEM lies in its benefits in distributional assumptions, lack of factor indeterminacy, and the ability to handle models with a more significant number of parameters than observations (Dijkstra and Henseler 2015). The PLS-SEM is considered a variance-based method for Structural Equation Modelling (CMEM) (Tenenhaus et al.,2005). It is valued for its ability to estimate factors and composites (Henseler, Hubona, and Ray 2016). PLS-SEM was created as a substitute for CBSEM to estimate intricate connections and prioritise prediction while also reducing the requirements for data and relationship specifications (Dijkstra 2010). In contrast to CBSEM, PLS-SEM is designed to estimate latent variable proxies, also known as latent variable scores, based on a proposed model using a series of iterative ordinary least-squares regressions (Wold 1985). The primary function of a path diagram is to visually depict the connections between the latent variables representing ideas and the indicators (Chin 2010). A fully implemented route diagram might be considered a conceptual framework that can be used to direct further analysis and is suitable for an algebraic model in statistics (Akter et al. 2017). Translating a route model to a structural equation model (SEM) is a typical practice for analysis.

5.3.2 SOFTWARE

Structural equation modelling (SEM) is a widely used statistical technique in most social sciences for multivariate data analysis (Sarstedt, Ringle, and Hair 2021). One of the primary factors contributing to its widespread usage is its capacity to foster the analysis of relationships within linear and non-linear among unobserved variables within the study. The methodology has a high degree of flexibility since it incorporates conventional statistical techniques, including linear regression, path analysis, and factor analysis, with more sophisticated approaches such as confirmatory factor analysis, latent growth curve modelling, and multilevel modelling. Users may use this tool to estimate theoretical models, including latent and observable variables. It allows users to account for random measurement errors when evaluating the associations between latent variables that reflect the theoretical constructs in the statistical model (Westland, J.C., 2015.). Several PLS-SEM software are available for analysis, which have applications on an array of studies and can be accessed either as open source or commercial software; of such software are WarpPls, ADANCO, passed, and SmartPLS. This study employed the use of SmartPLS.

5.3.3 The Basic Concept of PLS-SEM

The formal structure of Partial Least Squares Structural Equation Modeling (PLS-SEM) comprises two distinct sets of linear equations: the structural (inner) model and the measurement (outer) model (Akter et al. 2017). The structural model delineates the interrelationships among latent constructs, whereas the measurement model elucidates the associations between each latent construct and its corresponding observable indicators. Integrating these structural and measurement components yields a comprehensive partial least squares model, enabling the analysis of complex multivariate relationships.

5.4 Measurement model for this study

Bollen 2002 describes a path model as a graphical representation that illustrates the hypotheses and the connections between variables to be evaluated within the SEM research approach. Constructs, often known as latent variables, are fundamental components within statistical models that represent the measures the researcher wants to examine in the proposed theoretical underpinning of the study. The path model has two components: the structural and the measurement models. The structural model shows the relationship between the construct, while the measurement model illustrates the relationship between the indicators and the constructs. Within the context of PLS-SEM, the structural model is referred to as the inner model, and the measurement model is described as the outer model.

For this study, the principal researcher graphically presents the structural model and measurement model underpinning it, as shown in Figure 5.1. The study proposed that Drivers of sustainability, Technology dividends, Performance expectancy, effort expectancy, social influence, enabling environments, process value of technology, and technology adoption readiness have direct correlations. Please refer to the survey questionnaire attached in the appendix.

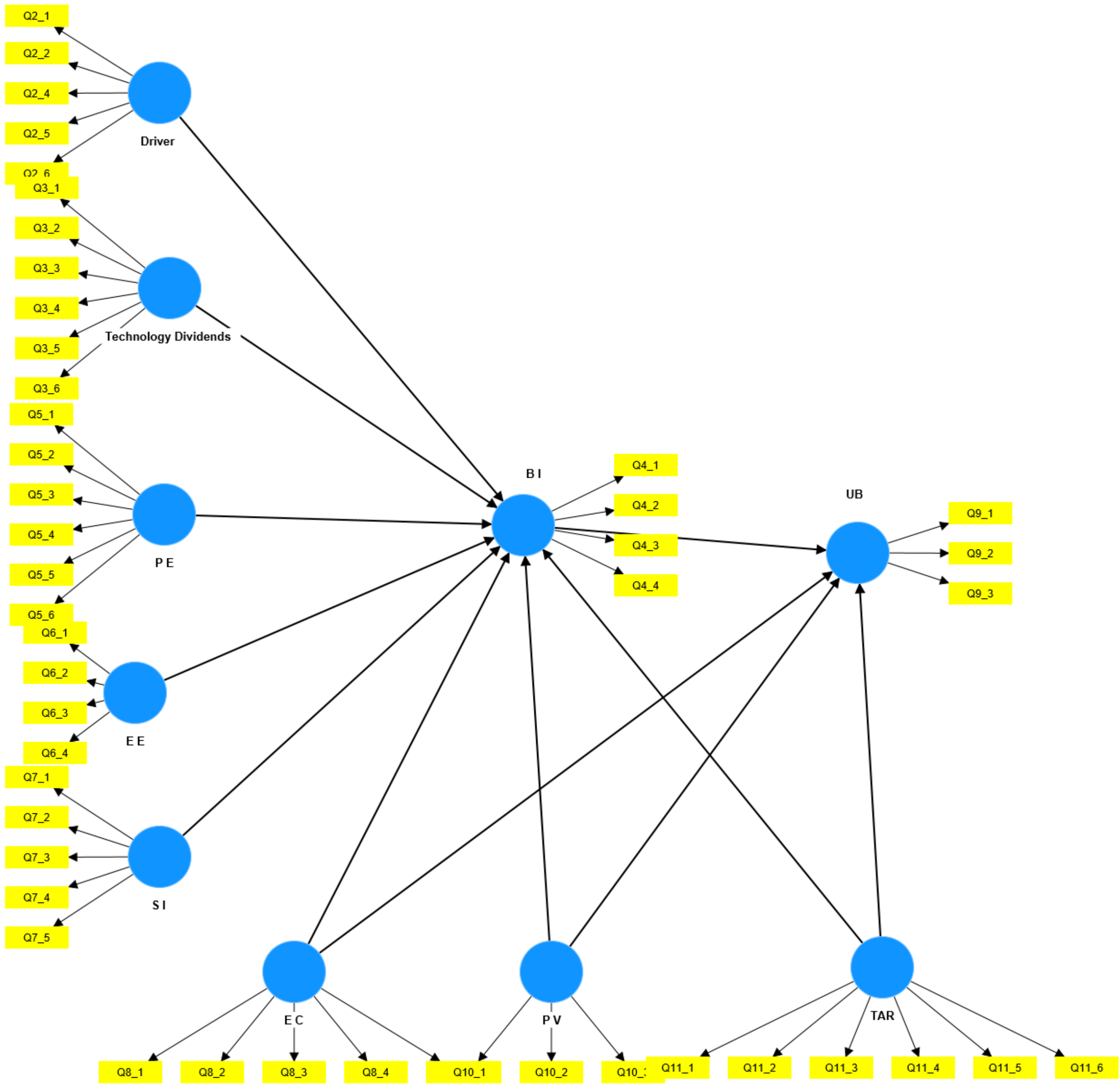


Figure 5.1: Structural equation model for this study

The measurement model describes the approach for quantifying latent variables. Researchers often can choose from two distinct kinds of measuring models. Several authors, such as Westland J.C., 2015, have identified ways to measure models, which are reflective and formative measurement approaches. The structural theory identifies the latent variables that should be considered while analysing a specific occurrence and their interconnections. The placement and arrangement of the constructs are determined by theoretical frameworks and the researcher's expertise and broadened understanding. The formative and reflective measurement models describe the connection between indicators and the underlying construct to which they are linked. Constructs do not possess an intrinsic tendency to be either formative or reflecting(Sarstedt, Ringle, and Hair 2017). Instead, they may be represented as having formative or reflective indications, depending on the researcher's theoretical assumptions about their relationship. According to Bollen 1989, reflective measurement models establish direct connections between the construct and the indicators, seeing the indicators as expressions of the underlying build prone to errors. That is, the relationship is from the construct to the indicators. As Bollen (2002) described, formative measurement occurs when the relationship is from indicator to construct. On the other hand, under a formative measurement approach, the construct is formed by a linear combination of a collection of indicators, where the link between the indicators and the construct is established. This study employs a reflective measurement model.

5.4.1 Evaluation of Result

Over the years, different researchers have presented several recommendations on approaches to evaluate the findings of PLS-SEM (Götz et al., 2010). The approach to assessing PLS-SEM results often covers model assessment and structure guidelines. The evaluation provides principles for sufficiently evaluating findings. Figure 5.2 shows the guidelines for adequate PLS-SEM evaluation procedures and the two stages of the formative model. The review of formatively stated constructs differs from that of reflectively assessed constructs. The convergent validity, collinearity of indicators, and statistical significance evaluate the formative model of the measurement model. This study employed a formative measurement approach; therefore, the resulting evaluation will be in one stage, as Sarstedt et al. (2014) stated, Shown in Figure 18 and employed.

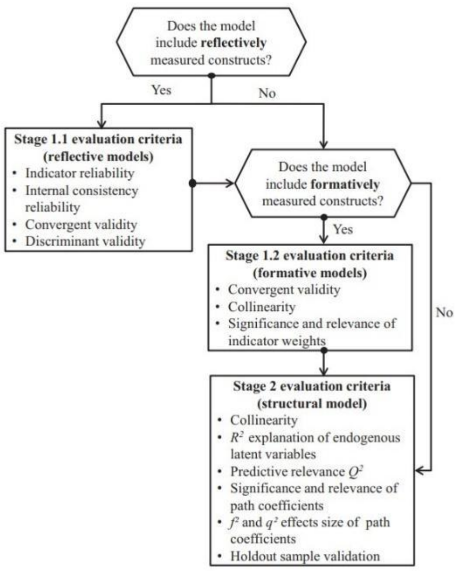


Figure 5.2; PLS-SEM evaluation procedures (Adapted From Sarstedt, Ringle, and Hair 2017)

5.4.2 Evaluation processes for reflective measurement

The first step in reflective measure followed in this study is conducting an indicator loading. The indicator loading above 0.70 indicates that the construct accounts for more than 50% of the variation seen in the indicator, hence establishing an acceptable level of dependability. The next step of evaluation involves the examination of the internal consistency reliability, which is majorly assessed by composite reliability, as described by Joreskog 1971 and Sarstedt et al. 2014. When evaluating the composite reliability, larger values correspond to greater degrees of reliability. Several scholars consider a value ranging from 0.60 to 0.70 as acceptable in exploratory research, and composite reliability values between 0.70 and 0.95 indicate reliability levels that are deemed satisfactory. Nevertheless, values beyond a threshold of 0.95 pose a concern, as they demonstrate significant similarity and redundancy among the components. Another approach to evaluate internal consistency reliability is Cronbach's alpha. Convergent validity is the subsequent stage in evaluating reflective measurement models, which pertains to the degree to which a construct converges in its indicators by elucidating the variance of the items. The assessment of convergent validity involves examining the average variance extracted (AVE) across all indicators linked to the construct. This measure is also known as commonality. Estimating the Average Variance Extracted (AVE) involves determining the indicator average squared roots associated with the construct. After successfully establishing the reliability and convergent validity of reflectively assessed variables, the following examination evaluates their discriminant validity. The discriminant validity examines the degree to which a construct exhibits distinctiveness from other constructs, which covers how a construct differs from other constructs and the exclusiveness of each indicator represented by each construct. The PLS-SEM discriminant validity is majorly examined using the heterotrait-monotrait ratio (HTMT. The HTMT examines the mean value of all indicators in all constructs.

5.5 The reflective measurement approach for this study

Measurement Model

According to Chin's 2009 procedures on reporting PLS-SEM findings, Hair et al., 2011 and Sarstedt, Ringle, and Hair 2017 on appropriate measurement criteria for both the structural and measurement models. This study adopted measurement criteria such as Indicator reliability, internal consistency, convergent validity, and discriminant validity. The factor loading measures the indicator reliability, internal consistency is tested by composite reliability and Cronbach's alpha, convergent validity is tested by the average variance extracted (AVE), and the discriminant validity is tested by Heterotrait-monotrait ratio (HTMT), Fornell-Larcker criterion and Cross loading. (Sarstedt, Ringle, and Hair 2017).The measurement model for this study is presented in Table 5.12 – 5.16; it can be concluded that all four measurement model criteria satisfy the appropriate assessment criteria. The indicator reliability is tested, and the results are presented from the factor loading which is above 0.70, indicating high reliability, expected for indicators 2.2 and 2.4 with a factor loading less than

0.70, which was deleted as suggested by Hair et al., 2011 in a reflective PLS-SEM design. The internal consistency reliability is measured by composite reliability and Cronbach's alpha, whose result values are above 0.70, signifying that all indicators demonstrate high internal consistency reliability. The AVE value is above 0.50, indicating strong support for the measures' convergent validity.

The discriminant validity was established by evaluating the HTMT criterion, Fornell-Larcker criterion, and cross-loading (Sarstedt, Ringle, and Hair 2017). discriminant validity was established by employing the HTMT criterion, whose value is less than 0.85 across all indicators and construct. The discriminant validity was also established using the Fornell-Larcker criterion, which is the diagonal elements, and best explained as the square roots of AVE more significant than the inter-construct correlation, with diagonal value (Fornell-Larcker criterion) more critical than the correlations.

Table 5.12 Factor loading

	B I	Driver	E C	E E	P E	P V	S I	TAR	Technology Dividends	WEB
Q10_1						0.937				
Q10_2						0.900				
Q11_1								0.878		
Q11_2								0.825		
Q11_3								0.923		
Q11_4								0.833		
Q11_5								0.888		
Q11_6								0.731		
Q2_1		0.818								
Q2_3		0.727								
Q2_6		0.852								
Q3_1									0.794	
Q3_2									0.872	
Q3_3									0.776	
Q3_4									0.846	
Q3_5									0.820	
Q3_6									0.814	
Q4_1	0.823									

Q4_2	0.752									
Q4_3	0.840									
Q4_4	0.792									
Q5_1					0.835					
Q5_2					0.829					
Q5_3					0.828					
Q5_4					0.796					
Q5_5					0.843					
Q5_6					0.815					
Q6_1				0.892						
Q6_2				0.802						
Q6_3				0.879						
Q6_4				0.806						
Q7_1							0.840			
Q7_2							0.880			
Q7_3							0.875			
Q7_4							0.818			
Q7_5							0.884			
Q8_1			0.777							
Q8_2			0.836							
Q8_3			0.869							
Q8_4			0.819							
Q8_5			0.735							
Q9_1										0.845
Q9_2										0.733
Q9_3										0.839

Table 5.13 AVE and Composite Reliability

	Cronbach's alpha	Composite reliability (rho_a)	Composite reliability (rho_c)	Average variance extracted (AVE)	Convergent Validity
B I	0.815	0.817	0.878	0.644	Establish
Driver	0.730	0.770	0.831	0.557	Establish
E C	0.867	0.871	0.904	0.654	Establish
E E	0.867	0.884	0.909	0.715	Establish
P E	0.906	0.908	0.927	0.680	Establish
P V	0.817	0.845	0.915	0.844	Establish
S I	0.912	0.914	0.934	0.739	Establish
TAR	0.921	0.932	0.939	0.720	Establish
Technology Dividends	0.903	0.906	0.925	0.674	Establish
WEB	0.732	0.743	0.848	0.652	Establish

Discriminant Validity

Table 5.14 Heterotrait-monotrait ratio

	B I	Driver	E C	E E	P E	P V	S I	TAR	T D	WEB
B I										
Driver	0.531									
E C	0.491	0.316								
E E	0.526	0.243	0.745							
P E	0.803	0.554	0.363	0.476						
P V	0.418	0.402	0.147	0.198	0.532					
S I	0.579	0.358	0.483	0.613	0.660	0.429				
TAR	0.594	0.360	0.211	0.227	0.597	0.505	0.405			

Technology Dividends	0.836	0.564	0.282	0.347	0.715	0.412	0.426	0.534		
WEB	0.580	0.371	0.842	0.726	0.542	0.380	0.723	0.250	0.349	

Table 5.15 Cross-Loading

	B I	Driver	E C	E E	P E	P V	S I	TAR	Technology Dividends	WEB
Q10_1	0.358	0.307	0.098	0.156	0.458	0.937	0.369	0.447	0.353	0.276
Q10_2	0.270	0.245	0.043	0.161	0.382	0.900	0.312	0.376	0.299	0.243
Q11_1	0.509	0.289	0.125	0.227	0.538	0.481	0.346	0.878	0.523	0.130
Q11_2	0.464	0.290	0.230	0.216	0.450	0.375	0.365	0.825	0.386	0.212
Q11_3	0.467	0.322	0.209	0.201	0.522	0.443	0.331	0.923	0.466	0.179
Q11_4	0.387	0.167	0.155	0.090	0.376	0.260	0.267	0.833	0.356	0.100
Q11_5	0.452	0.251	0.159	0.186	0.528	0.418	0.345	0.888	0.419	0.187
Q11_6	0.339	0.200	0.087	0.084	0.353	0.272	0.235	0.731	0.346	0.097
Q2_1	0.307	0.818	0.237	0.131	0.326	0.255	0.207	0.215	0.327	0.206
Q2_3	0.324	0.727	0.210	0.212	0.371	0.165	0.295	0.250	0.378	0.238
Q2_4	0.201	0.551	0.174	0.114	0.274	0.264	0.175	0.149	0.179	0.180
Q2_6	0.385	0.852	0.138	0.119	0.370	0.248	0.183	0.272	0.484	0.178
Q3_1	0.520	0.312	0.148	0.172	0.446	0.294	0.205	0.303	0.794	0.153
Q3_2	0.571	0.405	0.187	0.278	0.562	0.299	0.381	0.409	0.872	0.218
Q3_3	0.695	0.389	0.266	0.354	0.563	0.252	0.332	0.403	0.776	0.298
Q3_4	0.620	0.416	0.196	0.201	0.536	0.353	0.280	0.474	0.846	0.196
Q3_5	0.558	0.436	0.265	0.307	0.512	0.237	0.360	0.364	0.820	0.263
Q3_6	0.575	0.400	0.197	0.228	0.572	0.323	0.348	0.468	0.814	0.236
Q4_1	0.823	0.399	0.289	0.350	0.586	0.285	0.394	0.403	0.639	0.322
Q4_2	0.752	0.322	0.465	0.510	0.488	0.239	0.472	0.287	0.406	0.475
Q4_3	0.840	0.342	0.279	0.314	0.627	0.306	0.403	0.479	0.634	0.357
Q4_4	0.792	0.279	0.310	0.271	0.526	0.279	0.337	0.500	0.645	0.252
Q5_1	0.584	0.346	0.235	0.315	0.835	0.484	0.487	0.486	0.554	0.366
Q5_2	0.531	0.367	0.247	0.367	0.829	0.349	0.525	0.467	0.507	0.402
Q5_3	0.519	0.388	0.271	0.348	0.828	0.416	0.495	0.442	0.526	0.357
Q5_4	0.633	0.397	0.310	0.336	0.796	0.380	0.520	0.423	0.550	0.392

Q5_5	0.608	0.362	0.278	0.422	0.843	0.285	0.462	0.423	0.520	0.276
Q5_6	0.545	0.372	0.280	0.304	0.815	0.370	0.479	0.491	0.561	0.322
Q6_1	0.440	0.212	0.564	0.892	0.394	0.158	0.485	0.224	0.326	0.538
Q6_2	0.376	0.124	0.437	0.802	0.370	0.265	0.520	0.092	0.273	0.458
Q6_3	0.390	0.165	0.607	0.879	0.329	0.110	0.431	0.192	0.246	0.506
Q6_4	0.286	0.135	0.575	0.806	0.337	0.020	0.410	0.183	0.212	0.472
Q7_1	0.423	0.256	0.343	0.475	0.460	0.257	0.840	0.297	0.333	0.441
Q7_2	0.468	0.186	0.382	0.524	0.538	0.327	0.880	0.302	0.337	0.511
Q7_3	0.402	0.280	0.402	0.479	0.466	0.350	0.875	0.278	0.273	0.514
Q7_4	0.410	0.304	0.428	0.444	0.571	0.309	0.818	0.337	0.372	0.525
Q7_5	0.442	0.215	0.315	0.429	0.541	0.361	0.884	0.402	0.356	0.515
Q8_1	0.242	0.155	0.777	0.509	0.173	-0.107	0.263	0.031	0.134	0.480
Q8_2	0.297	0.131	0.836	0.555	0.223	0.061	0.331	0.054	0.138	0.560
Q8_3	0.299	0.130	0.869	0.606	0.173	0.080	0.341	0.090	0.108	0.591
Q8_4	0.386	0.274	0.819	0.512	0.344	0.130	0.409	0.235	0.286	0.597
Q8_5	0.432	0.291	0.735	0.415	0.390	0.122	0.385	0.337	0.356	0.516
Q9_1	0.302	0.217	0.658	0.541	0.264	0.154	0.433	0.097	0.208	0.845
Q9_2	0.498	0.232	0.411	0.369	0.551	0.396	0.547	0.321	0.352	0.733
Q9_3	0.283	0.196	0.564	0.492	0.251	0.165	0.448	0.047	0.137	0.839

Table 5.16 Fornell-Larcker criterion

	B I	Driver	E C	E E	P E	P V	S I	TAR	T D	V
B I	**0.803**									
Driver	0.419	**0.746**								
E C	0.416	0.247	**0.809**							
E E	0.449	0.192	0.642	**0.846**						
P E	0.696	0.451	0.329	0.424	**0.825**					
P V	0.346	0.303	0.080	0.172	0.461	**0.919**				
S I	0.500	0.286	0.433	0.548	0.600	0.373	**0.860**			
TAR	0.521	0.304	0.193	0.206	0.551	0.452	0.376	**0.848**		
Technology Dividends	0.726	0.481	0.259	0.318	0.652	0.357	0.389	0.495	**0.821**	

WEB	0.438	0.265	0.683	0.585	0.427	0.284	0.583	0.182	0.281	[illegible]

5.6 Structural Model Measurement

According to the reflective measurement guidelines provided by Sarstedt, Ringle, and Hair 2017, in Figure 5.2, the evaluation criteria for the structural model measurement are VIF, path coefficient (consisting of P value and T value both at 95% confidence level), R squared, F squared and model fit. Firstly, the structural model is assessed for collinearity problems by evaluating the VIF; Table 36 shows the VIF records of all the structural model indicators. The VIF in Table 36 for this structural model measurement is less than 5 for all indicators, indicating no collinearity issue. Secondly, the R squared of the structural model in Table 37 shows all indicator's effects on BI(0.657) and the direct impact of BI on UB to be 0.55; this concluded that the model explains 65.7% variance of BI and 55.1% variance on UB which seems high and acceptable as the research seeks to examine the factors(variables) that influence Be4haviour intention (BI) and behaviour intention (BI) to use technology among AFSC stakeholders in Nigeria. Thirdly, the path coefficient of the model is examined, considering the P-value and T-value of the model at a 95% confidence level, as clearly shown in Table 38, which records five strong relationships supporting the proposed hypothesis in the PLS-SEM model. The direct correlation between BI and UB was supported by the analysis, with BI→UB (T value 1.993, P value 0.046), EC→UB (T value 7.66, P value 0.00), PE →BI (T value 2.110, P value 0.035), PV→UB (T value 2.994, P value0.003) and TD→BI (T value 3.334, P Value 0.001). Firstly, the relationship between TAR→UB (T value 1.798, 0.072) is Worthy of note. Though this path coefficient does not meet the required level of significance, I propose that technology adoption readiness has little effect on user behaviour regarding the use of technology. Secondly, another path coefficient worth considering, even though the P value and T value do not meet the required accepted level, is EC → BI (T value 1.759 and 0.079), which suggests that enabling conditions have little impact on Behaviour intention to use technology among the AFSC Stakeholders in Nigeria.

Fourthly, the study examines the F square and Q square, which measure the difference in R squared when an exogenous variable is eliminated, which describes the effect size. The Q square is a metric that evaluates a model's predictive relevance, indicating whether it has predictive capabilities; a value ≥ 0 has predictive relevance, according to Cohen 1988. As a guideline, $f2$ values of 0.02, 0.15, and 0.35 represent an exogenous latent variable's small, medium, and large effects (Cohen 1988). Effect size values of less than 0.02 indicate that there is no effect. Table 39 shows the value for F squared for this model recording EC →BI with a large effect size of 0.588 and TD →BI with a medium effect size of 0.273. Table 40 shows the predictive relevance of the model, measured by the Q square. The recorded Q-squared values are 0.580 and 0.499, which signifies the model has predictive relevance.

Table 5.17 VIF

	VIF
B I -> UB	1.668
Driver -> B I	1.411
E C -> B I	1.781
E C -> UB	1.232
E E -> B I	2.076
P E -> B I	2.692
P V -> B I	1.616
P V -> UB	1.417
S I -> B I	1.942
TAR -> B I	1.602
TAR -> UB	1.533
Technology Dividends -> B I	1.985

Table 5.18 R square

	R-square	R-square adjusted
B I	0.657	0.638
WEB	0.551	0.540

Table 5.19 Path Coefficients

Path (Hypothesis)	**Original sample (O)**	**Sample mean (M)**	**Standard deviation (STDEV)**	**T statistics**	**P value**	**Significant**

				(T ≤ 1.96)	(P ≤ 0.05, 0.1)	
B I -> UB	0.148	0.145	0.074	1.993	0.046	***Supported**
Driver -> B I	0.024	0.018	0.058	0.412	0.680	Not Supported
E C -> B I	0.134	0.126	0.076	1.759	0.079	**** Supported**
E C -> UB	0.570	0.578	0.074	7.666	0.000	***Supported**
E E -> B I	0.074	0.078	0.086	0.870	0.384	Not Supported
P E -> B I	0.256	0.275	0.121	2.110	0.035	***Supported**
P V -> B I	-0.020	-0.011	0.057	0.343	0.732	Not Supported
P V -> UB	0.278	0.270	0.093	2.994	0.003	***Supported**
S I -> B I	0.043	0.048	0.066	0.642	0.521	Not Supported
TAR -> B I	0.114	0.111	0.073	1.571	0.116	Not Supported
TAR -> UB	-0.138	-0.141	0.076	1.798	0.072	****Supported**
Technology Dividends -> B I	0.425	0.403	0.128	3.334	0.001	***Supported**

This study employed the 5% and 10% significant levels for P-value as stated By van et al., 2006; Ferguson-Aikins and Ramanathan 2020 ; Ritter, and Muñoz-Carpena 2013; Razali and Wah, 201,

(*) Represent P-value with a 5% significant level.

(**) Represent P-value with a 10% significant level.

Table 5.20 F square

	f-square
B I -> UB	0.029
Driver -> B I	**0.000**
E C -> B I	0.030
E C -> UB	0.588
E E -> B I	**0.007**
P E -> B I	0.072

P V -> B I	**0.001**
P V -> UB	0.122
S I -> B I	**0.003**
TAR -> B I	0.024
TAR -> UB	0.027
Technology Dividends -> B I	0.273

Table 5.21 Q squared

	Q^2predict	RMSE	MAE
B I	0.580	0.668	0.479
WEB	0.499	0.716	0.517

Table 5.22 Model Fit

	Saturated model	Estimated model
SUMMER	0.077	0.079
d_ULS	6.098	6.468
d_G	2.239	2.268
Chi-square	1813.783	1831.875
NFI	0.689	0.686

5.7 Chapter Summary

The chapter employed survey data from AFSC stakeholders in the Nigerian industry who voluntarily participated in the study. The survey is constructed using the findings derived from the thematic analysis and also used to support the thematic analysis result. This chapter described each participant's responses to all constructs within the study. To statistically establish the factors influencing the use and acceptance of industry 4.0 technologies within the AFSC to promote sustainability, the study adopted the PLS-SEM measurement model and structural model guidelines stated by Sarstedt, Ringle, and Hair 2017 in reporting the PLS-

SEM statistical findings. Firstly, the measurement model was analysed to establish convergent validity, discriminant validity, internal consistency reliability, and indicator reliability. Secondly, the structural model was examined, And the path coefficients suggested a correction between Behaviour intention to use technology (BI) and User behaviour (UB); Enabling conditions (EC) and User behaviour (UB); performance efficiency (PE) and Behaviour intention to use technology (BI); Technology dividends (TD) and Behaviour intention to use technology (BI); Price Value and User behaviour (UB). Although technology adoption readiness (TAR) and user behaviour (UB) show lower Pvalue and T statistics than the significant level, it can be considered a potential variable that influences user behaviour in Nigeria's use of technology within the AFSC.

CHAPTER SIX (6)

6.0 FINDINGS AND DISCUSSIONS

6.1 Introduction

Given the challenges facing the global agrifood system and Africa's significant vulnerability to pressing issues, as briefly stated in Chapter 1, this study's primary purpose is to contribute to knowledge and practices by examining the role and impact of Industry 4.0 technologies in Africa's AFSC system, with a specific focus on Nigeria. The study further explores the level of knowledge and awareness of sustainability among agrifood actors in Nigeria; it identifies the sustainability impacts of employing Industry 4.0 technologies by agrifood stakeholders in Nigeria and highlights the underlying enablers and challenges that are responsible for the use and acceptance of Industry 4.0 technologies with the AFSC in Nigeria. The active participation and insights of these stakeholders, who are the very heart of the AFSC, have been instrumental in shaping the study's findings, underscoring their crucial role in the AFSC.

This section will discuss the findings obtained from qualitative data (interview) analysis and quantitative data (survey) analysis, which serve as the only sources of information the researcher derived while answering the study inquiry. This section examines the qualitative data results from 25 AFSC actors in the Nigeria agrifood industry and quantitative data results from 158 AFSC actors in the Nigeria agrifood industry that participated in the study. The results from the thematic analysis of the 25 participants' interviews indicate that several environmental, social, and economic positive impacts are seen as a result of the use of Industry 4.0 technologies within the AFSC; the AFSC has experienced agribusiness transformation into more sustainable practices in Nigeria; and the study highlights nine elements that underpin the use and acceptance of Industry 4.0 technologies. The findings from the quantitative approach, which is a trajectory, developed a survey based on the unified theory of us and the acceptance of technology (UTUAT) framework, as well as a few variables that evolve within the qualitative study. The quantitative data analysis of the survey data using SEM indicates that 5 out of the proposed survey hypotheses were supported within significant path coefficients, T value and F-square. Table 6.1 shows the summary findings in alignment with the research question and objectives of the study

Table 6.1 **Summary of findings**

Research Question	Key Findings
How does using industry 4.0 technologies contribute to the Agrifood Supply Chain (AFSC) sustainability of Nigeria	This study finds that Industry 4,0 technologies such as IoTs, GPS, Drones, etc, help AFSC sectors create employees and jobs, seeing a lot of increased interest in a career in agrotechnology jobs. This study also finds that new emerging technology startups are arising within the nation that leverage technology. Several actors that respond in the research believe that investment opportunities are coming within the country for AFSC efficiency by leveraging technology. The study also finds that AFSC actors' empowerment in the form of skill and knowledge transfer is also seen within the country. Some actors are of the opinion that the use of APPS, drones, and IoTs helps them to reduce waste, make better decisions in farming processes, reduce fertiliser usage in terms of precision farming, and overall minimise the cost of production.
How will using industry 4.0 technologies in the AFSC promote agribusiness transformation into more sustainable practice in Africa (Nigeria	This study finds that the use and adoption of technology have led to new agribusiness transformations, new business models, and new approaches to doing things. This study finds out the emerging data-driven process from farming, food processing, and agri-food commodity distribution, and several actors suggested that they made better decisions because of technology. The study was able to identify that several industries adopt technology at different rates, and several countries adopted technology at different rates; this enabled the study to examine the technology adoption rate within the AFSC in Nigeria and study the levels that influence the AFSC technology adoption readiness.
Research question 3: What underlying factors can promote the use and acceptance of technology in Africa(Nigeria)?	This study examines the factors that influence the adoption of technology among the AFSC actors and finds that social influence, industry influence, community-based advisory (CBA), technology demonstration, technology transfer, profitability, and competitive advantage are factors that promote the use and adoption of industry 4.0 technologies within the AFSC in Nigeria. The quantitative findings suggested that user behaviour (UB) is influenced by behaviour intention, enabling conditions, and price value of technology. The study also finds that Behavioural intention to use technology has strong correlations with performance expectancy of

	technology, technology adoption readiness, and behaviour intention to use technology.

6.2 Overarching challenges within the AFSC in Nigeria

Based on the viewpoints and opinions provided by the participants of this study on the challenges facing the AFSC in Nigeria, the impact of climate change and food waste is at the forefront of the discourse, and how it hinders the potential of the AFSC industry in the region. Drawing upon findings from Chapter 4 of the findings, 1st order quotes extract, such As: 1)'' So actually, it's not more food waste but more of poor post-harvest management practices. You can visit our site to get some information about the previous project. 40 to 60% of food produce is lost due to poor post-harvest management practices''; 2) '' For us, there are different angles and then the losses at different percentages depending on the commodity. For example, there is more vegetable waste because vegetables are highly perishable'': 3) ''I was talking to one of our partners in Jigawa State, who narrated how his farmland was affected. Twenty hectares of rice farmland were flooded'': 4: ''We have soil degradation, we have erratic rainfall patterns, we have floods, we have insect attacks, even problems with the soil''. This 1st order quote clearly shows participants' argument that several AFSC actors have suffered losses from floods, inconsistent rainfall, drought, and several natural disasters, leading to loss of profit and agricultural products and severely impacting the actors' economies and livelihoods. This further weakens the stability of food systems, leading to a decline in food security and the access and quality of nutritious food. Additionally, the participants argue that this negative effect has put some vulnerable populations at risk of experiencing various types of malnutrition in some areas of the country. These findings align with Owino et al., 2022, who argue that climate change affects food systems at various levels, such as altering soil fertility and agricultural productivity, modifying the content and nutrient availability in foods, increasing pest resistance, and raising the risk of malnutrition. Gregory, Ingram and Brklacich 2005; Lake et al., 2012; El Bilali et al., 2020 finding also establish the impact of climate on food security. Ukhurebor and Aidonojie 2021 support these findings by presenting an argument on the severity of climate change on agricultural production and argue that agricultural innovation technology processes such as climate-smart agriculture can help achieve a sustainable agrifood industry. Abraham 2012 highlighted that determined that changes and inconsistent rainfall patterns and increases in average annual temperature are plausible ways climate change affects food availability in Nigeria. The study by Apata et al., 2009 examines the Nigerian public and stakeholders' views on climate and the means employed to adapt. It further encourages the collaborative participation of all stakeholders in the management and pursuit of agrifood sustainability and the development of means to minimise climate change's impact.

Ciccullo et al., 2021, agree that food waste is a significant challenge to the agrifood industry, with negative implications for society, the economy, and the environment. Parfitt et al., 2010, presented that available statistics indicate that food losses are significantly more significant during the post-harvest stages in developing countries, and perishable food waste is higher in developed and developing countries. Mohan et al., 2023 findings suggested postharvest loss occurrence in the Indian agrifood industry and further explored the feasibility analysis of the available technology to tackle food waste in the industry. Owino et al., 2022 agree that establishing sustainable and resilient food systems, together with climate-smart agriculture, is necessary to guarantee a sustainable agrifood industry. Ramanathan et al., 2023 argue food waste is a significant global issue due to further exploration of the utilization of contemporary digital technologies, commonly referred to as Industry 4.0 technologies, to minimise waste within food supply chains. The study aligns with Ramanathan et al., 2024 on agrifood businesses making efforts to reduce waste in their supply chains and further stated that there is no theoretical framework that's underpin the response of food companies in reducing food waste

This study also gathered findings from AFSC interview respondents who expressed their view that the cost of production has been a significant challenge facing the industry due to the lack of electricity, the price of raw materials, and the increase in the exchange rate. Deducing from the 1st Order quotes findings of chapter 4 such as: 1)''So production cost is high. I knew that in some cases, prices of the farm inputs have doubled. Looking at a trend, taking from 2020 has its own issue'': 2)'' Yes, the cost of production has increased. The first thing we take care of is making sure our products are still the same irrespective of the price. Most of our products are not Nigerian made''.

Based on the experiences of the AFSC actors, this study also established that the AFSC industry faces a challenge due to a lack of infrastructure; this is deduced from the 1st Order quotes such as: 1) ''Our significant challenges will be access to good roads and funding tools because most of these solutions don't come easy''. 2) ''I think this is peculiar to Nigeria. I think everybody knows that our major challenge has been power, and production is complicated now that the cost of diesel has skyrocketed. This aligns with Ruteri and Xu's 2009 study on challenges facing the food industry in Tanzania, not just for us but for other sectors. The study finds that the food industry has long been plagued by inconsistent electricity and water supplies, leading processors to use generators during power shortages and increasing production costs. This study also finds that AFSC actors who responded to the interview presented their views on the industry's lack of manpower due to low salaries, working patterns, and urbanisation among young people in rural communities. These findings and discussion establish some of the challenges facing the AFSC in Nigeria based on qualitative data deduced from several participants' experiences.

6.3 Sustainability impacts of Industry 4.0 technologies within the AFSC in Nigeria

This section of the discussion examines the impact of Industry 4.0 technologies on the sustainability of the AFSC industry. The emerging ideas from the study range from the economic, social and environmental impact of industry 4.0 technologies within the AFSC industry.

6.3.1 Economic Impact of Industry 4.0 in the AFSC in Nigeria

The findings in this study are based on the opinions of the AFSC stakeholders who were engaged in the interview. Most of them agreed that approximately 80% of our staff consists of young individuals, several of them listed initiatives they are employing to make agrifood career more appealing to young people through the innovative technology processes their business is engaged in and that they are merging off-farm jobs available for the youth. Other suggested that youth employment within the agrifood industry in Nigeria has been in the forefront of their business. Drawing upon the findings in chapter 4, from several 1st Order quotes such as: 1) ‘‘of course, the majority, about 80% of our workforce here, are youths; Yes, we do employ young people in our company; 2) ‘‘We are fortunate to have many young people on our team. Some are still in school, and some have just completed their NYSC. We are creating employment for people around the community’’. This data extract suggested that youth employment are forefront in AFSC industry 4.0 business. Adesugba and Mavrotas (2016) emphasise the role of youth employment in the agrifood sector, which will result in agricultural transformation and increase manpower for the region's food industry. Sumberg et al., 2015. argue that young jobs and employability in the farming sector promote national economic growth and mitigate rural-urban migration. The findings in this study align with those of Addo (2018) and Geza et al. (2022), which emphasise the importance of youth employment and agripreneurship within the agrifood industry, especially the graduated and educated ones and highlight that youth involvement will help with the ageing of the present workforce in the industry.

Haggblade et al., (2015) on youth engagement in agribusiness careers in Kenya, the findings suggested that rural young individuals pursue jobs in agribusiness due to their clear recognition of rural needs and the proven profitability of non-conventional agriculture and agribusiness prospects. On the other hand, urban youth in Kenya pursue agricultural careers due to their exposure to science education. They are also becoming more aware of the various professional options and commercial prospects of modern agribusiness The findings in the study also corroborate the findings of Kwakye et al., 2021 on the factors that influence Ghana youth in participation in agriculture. The study highlighted the role of technology as a crucial determinant factor for youth career pursuit, farming and entrepreneurship pursuit in the country. Lohento and Ajilore, (2015) argue that ICT is a significant pull of youth engagement and employment in the agricultural industry in Africa.

The research findings also established several emerging agri-tech startups in the AFSC industry in Nigeria due to the adoption of several industry 4.0 technologies. This can be deduced from qualitative data extract of the 1st order quotes from the participants experiences, such as; ‘‘so what we are doing is that we're actually leveraging on drone technology and the power of data to generate drone technology, satellite imagery .to be able to empower farmers with aerial intelligence, insights and actions that makes smart agriculture possible’’; ‘’I operate in the agricultural technology space in, in the industry. I am the founder of Integrated Aerial Precision. We are presently outsourcing the use of sensors in our distribution channel ‘’. This data shows the emergence of startups in the agrifood industry due to the use of Industry 4.0 technology. These findings correspond to Narayanan, Dayal and Dublish (2021) argument on emerging agri-tech startups in India leveraging modern technologies such as IoT, GIS, AI, and data analytics. Sharma and Mathur 2018 Agri-tech startups are innovative and emerging businesses in the agriculture industry, working diligently to revolutionise traditional farming practices by integrating technology. Technology-driven firms are utilising mobile applications, the Internet, and advisories to implement entrepreneurial efforts that significantly simplify and enhance the profitability of farming processes, surpassing traditional farming methods. The findings also align with Suresh et al. 2024 findings, which indicate that the primary factors influencing the adoption of agri-tech are sustainability, changing business models, laws, and macroeconomic situations. India is expected to become a frontrunner in the agritech industry by revolutionising agriculture through groundbreaking innovations, resulting in increased production efficiency, sustainability, and inclusivity. These anticipated technical advancements in agriculture will likely generate numerous employment prospects for the youth(Suresh et al., 2024).

6.3.2 Social Impacts Industry 4.0 in the AFSC in Nigeria

The interview participants gathered evidence of investment opportunities for emerging agri-tech startups, with several grants and investment opportunities offered to the new agri-tech businesses. Drawing upon the findings of this study, it can be established that the use of industry technology promotes the livelihood of farmers and rural and workforce empowerment through skill and knowledge transfer as seen in several 1st Order data extracts such as: 1)‘‘Yes. One of our significant visions is to see how we impact the lives of small, older farmers. We have been able to do that by creating some bundle technologies; 2) ‘‘Using IoTs and data analytics, our production and supply chain has seen expansion, new opportunities, and new customers'': Yes, there is a vast continuous plan to transfer knowledge and application of digital solutions within our staffing team. This aligns with Kondapi 2020, investment opportunities were seen in the Indian agrifood industry, with agri-tech startups and food sector startups raising around $65.6 million and $516 million, respectively, in 2018; this shows enormous potential investment technology adoption and agritech business bringing into the agri-food industry. Technology skill transfer has been recorded among AFSC stakeholders and youth within the industry. Knowledge of the use of Drones, sensors, GPS, weather Apps and intelligent contracts is seen within the Nigeria AFSC due to the revolution of industry 4.0 technology. Some interview respondents agree that farmers and agrifood employees have experienced Improved livelihoods due to new skills acquired, profitability, access to the market, and waste reduction within business operations. Mayor et al. 2022 argued that farmers' skill needs are primarily in sustainability and digital skills, while food company workers need communication and strategic skills for effective agrifood operations. Kuaban et al., 2022 argue that the skill and knowledge gap is a significant challenge for the full adoption and use of IoTs in the agrifood industry in Africa and, therefore, develop IoTs courses to promote equipped actors and AFSC practitioners. Andreoni et al., 2021 argues that industry 4.0 technology, the AFSC industry presents a huge potential for digitalisation and skill development in the sector

6.3.3 Environment Impacts Industry 4.0 in the AFSC in Nigeria

Hassoun et al., , 2022 argue that industry 4.0 technologies can help transform the AFSC system and deliver all aspects of sustainability and mitigate the negative impact on the environments Onwude et al., 2020. Argues that Industry 4.0 technologies have the potential to decrease food waste and energy consumption and enhance resource management. The use of IoT can help tackle the issue of food waste. Van et al., 2022, developed a system that measures food waste, which gives insight into factors that influence waste generation and develops IoT-based smart farming with success in food waste reduction. Jagtap e al., 2019 defend this with their findings, which present the reduction of potato waste in food manufacturing using IoTs technologies. Musa and Basir 2021 argue that industry 4.0 technologies such as Big data, IoTs and blockchain can help to promote resource efficiency and increase yield . Ramanathan et al., 2023 provide insight into the adoption of technologies to reduce food waste among food companies in Europe, the findings further established the need to examine possible business models for technology companies to collaborate with food companies in order to decrease food waste.

6.3.4 Agribusiness transformation within the AFSC Nigeria in the era of Industry 4.0 technologies

The findings in this study present results on the agrifood business transformation by the use of industry 4.0 technologies; the findings deduce that several AFSC businesses are experiencing transformation due to the use of industry 4.0 technologies, resulting in business change and adaptation to new possibilities, data-driven processes and creating an avenue to view the readiness of the AFSC industry in response to adoption and use of technologies. Several AFSC actors have experienced business expansion due to the deployment of AFSC, creating avenues for changes in AFSC business processes and AFSC cultural practices. Data-driven processes are the possibilities presented by industry 4.0 technologies to the AFSC actors in Nigeria; the agribusiness experiences better decision-making processes from real-time data capturing through the use of sensors, IoTs, drones, and satellite imagery.

The findings from this study align with Sharma 2022, who agrees and submits that the current study emphasises the numerous digital transformations occurring in converting conventional agricultural supply chains into digital ones. It emphasises the utilisation of several Industry 4.0 technologies in agricultural supply chains. Sharma 2022 further argues that industry 4.0 technologies in the AFSC are expected to yield numerous advantages and facilitate the transformation towards sustainable agrifood practices, thereby achieving the United Nations Sustainable Development Goals. The finding of this study aligns to Latino et al. 2021, which argue that industry 4.0 technologies in the AFSC are widely accepted as sustainable innovations that can generate new knowledge and transform production techniques and business models are necessary within the AFSC. The findings in this study correspond to Hassoun et al.'s 2023 study, which argues that implementing Industry 4.0 technologies has brought about an enormous transformation, resulting in sustainability within food manufacturing and leading to considerable impacts on the environment, economy, and human health. Sonar et al., 2024 argue that implementing Industry 4.0 technologies can make the AFSC flexible, smart, data-driven, and decision-making and improve its interconnectedness. The findings in this study also align with Aris et al., 2021 study that highlighted that technology readiness is one of the important factors in the pull-push towards agrifood 4.0 digitalisation in Malaysia. In Sonar et al.'s 2024 study on evaluating the impact of Industry 4.0 in the AFSC, the author concludes that market competitive advantage, skill development, knowledge, job creation, resource efficiency, and social equity are the significant sustainability impacts of Industry 4.0 technologies' adoption and use among AFSC actors.

6.4 Contextualisation of the factors that influence the use and acceptance of Industry 4.0 technology in the crucial AFSC industry in Nigeria.

6.4.11.Social Influence

The thematic analysis shows that social influences are significant in using and accepting Industry 4.0 technologies among the Nigeria AFSC social. In terms of the farmers(rural), it was noted that community heads could be a bridge between technology providers and users because of the level of respect and trust farmers within the community have for the community heads. They helped mediate and spread information about the technological solutions and their benefits and facilitated group conversation and cooperation to adopt the technological solutions.

Social networks are primary influences where technological solutions can be spread abroad; this occurs mainly by word of mouth within the farmer's network, recommendations by trusted family or friends, proof of success story for using a particular technological solution and referral from fellow farmers. The food manufacturing and logistic companies also experience the use and acceptance of technology being influenced by their social network in the form of the technological recommendations within the industry associations, adopting a technological solution due to seeing a successful leading business in the industry adopt the solutions, and due emerging trends discourse within industry and collective efforts stakeholders for provide efficiency in the sectors, which positively will leads to use and acceptance of technology. These findings, underpinned by the impact of social influences in the adoption of Industry 4.0 technology within the AFSC in Nigeria, correspond with the findings of Lorenz and Buhtz, 2017 research which demonstrated that social influence has a significant impact on human behaviour overall and specifically on the adoption of technology. The finding of this study also aligns with the argument and results from the research conducted by Ronaghi and Forouharfar 2020 on factors that influence the adoption of Internet of Things technology for smart farming in Middle Eastern countries, which suggested social influences have positive impacts on the adoption of IoTs. The study conducted by Radulescu and Toader C. (2024) investigated implementing blockchain technology in agri-food supply chains using an extended UTAUT model. The study argues that social influence (partner preparedness), performance expectancy, and organisational readiness impact the decisions to adopt technology. Peng et al. (2017) explored the role of a user's social influence on other users on a mobile social network. Identifying significant people in mobile social networks is beneficial for understanding the design of social platforms and applications.

6.4.2 Industry influence

The results of this study show that industry influences the adoption of technology among food manufacturing and logistics businesses. This occurs in the form of competitive advantage, industry trends and industry practices, which are exhibited among firms in the agrifood industry. These findings collaborate with arguments and results presented by the study conducted by Saghafian, Laumannand, and Skogstad (2021) to examine factors influencing organisational technology adoption, which emphasises the significance of industry practices and environmental factors in influencing the technology adoption process. Herold, et al., 2021 the study examine the adoption of technology in the logistics and supply chain industry and argues that industry influences and practices influence the adoption of technology.

6.4.3 Community-based advisory (CBA)

This study's findings reveal the role of community-based advisory services (CBAS)in the use of technology in Nigeria's agricultural industry. A CBA is a technology-savvy professional who helps farmers use and apply technology on their farms, interprets data, and gives insight to farmers based on the data from their farms. This is an emerging aggrotech service for the agri-tech industry to help farmers without the appropriate skills and knowledge to leverage the potential of technology. These findings collaborate with the findings of Kutter et al., 2011 on the role agricultural contractors play in promoting the implementation of precision agriculture technology in the next decade, particularly in regions with smaller farms. Another emerging service is the technology outsourcing service for agricultural data processing by service providers, which is widely recognised for helping users with issues about the possible misuse of data, excessive regulation, and data-driven agribusiness decisions.

The CBAS idea that emerges from this study is consistent with Roger's innovation diffusion theory in 1962, which elucidates the process by which new ideas and technologies are disseminated or spread. Rogers (1962) argues that the spread of inventions or technology is influenced by four essential components: innovation itself, communication, time, and social networks. CBAS within the AFSC industry in Nigeria serves as a communication channel for the spread of technological innovations and a social network where technological solutions can be spread abroad.

6.4,4 Technology Demonstration

Technology demonstration emerged from the qualitative data analysis in this study as a factor that influences the adoption of Industry 4.0 technologies among the AFSC actors in Nigeria. The importance of technology demonstration in adoption was clearly stated by seeing and believing, meaning that it was straightforward for people to adopt technological solutions if they were taught how to use them. Some actors mentioned the precision farming demonstration field, where a network of farmers gathers to learn the application of sensors in measuring soil pH. The actors highlighted the benefits of technology demonstration to help solution providers provide hands-on skills transfer and promote the significance of adopting technological solutions. Some agreed that in their experience, technology demonstration occurs within training and workshop scenarios. The food manufacturing industry and logistics actors argue that technology demonstration through staff training is a method employed in adopting technology in their businesses. The technology demonstration, which emerges as a factor influencing technology adoption, collaborates with Rogers's theory of technology diffusion and innovation. Rogers 2003 highlighted that technology demonstrations are fundamental factors in the adoption and diffusion of technology.

The study Wang, Liu and Jiang 2023 on technology demonstration for the adoption of tillage in China supports the finding of this study; this is also supported by the argument of Huluka and Negatu (2016), who propose the impacts of training on the adoption of agricultural technologies in Ethiopia among maise farmers. Furthermore. Liu (2022) collaborates with this by presenting evidence of the effects of technological training on farmers' adoption of biopesticides in China. Pierpaoli 2013 argues in their findings that farmers prefer in-field demonstrations of technology precision agriculture technology, free trial sessions, and support services associated with adopting new technologies, as these activities enhance the view that the technology is user-friendly. Technology demonstration that emerges from this study also aligns with the diffusion of innovations theory, proposed by Rogers (1962), which argues that the adoption rate of innovations depends upon the perceived attributes of five crucial elements, including trialability. Trialability is the extent to which an innovation can be tested on a small scale. Rogers 1962 argues that when an individual is given the chance to experiment with an innovation, there is a higher probability that the individual will adopt the innovation. The ability to engage in experimentation with the innovation reduces uncertainty for potential adopters, hence increasing the likelihood of adoption.

6.4.5 Technology Transfer

The thematic analysis of this study also implies that technology transfer is crucial in influencing the use and acceptance of Industry 4.0 technologies among AFSC stakeholders. The AFSC actors highlighted incubator networks, training workshops, staff training mentorships, and learning from adopted processed prototypes as significant impacts on adopting and using Industry 4.0 technology. These findings align with different arguments across several industries.

Drawing upon the findings from the qualitative data analysis presented in Chapter 4, with several extract such as : ‘’They also have assistance, mentorship, and training, those kinds of things’’ ; ‘’Knowledge transfer is through Training’’; It was practical, with someone coming through to train us, telling us how it has been done and also teaching us how to maintain it personally''. This suggested that training and practical use of this technology promote technology transfer among the AFSC in Nigeria. These findings align with Singhai et al., 2021, who identify factors for effectively transferring technology: communication, innovativeness, knowledge, product quality, and motivation, present in the technology-transferring experiences of the AFSC actors in this study.

Kastelli, Tsakanikas and Caloghirou 2018. Technology transfer among organisations is defined as the transfer of know-how, technical knowledge, or technology between various external actors and sources. This transfer occurs within an interactive context and positively affects the development of capabilities and firms' economic and innovative performance. Kastelli, Tsakanikas and Caloghirou 2018 further establish that Technology transfer agreements in the food manufacturing industry have a crucial impact on advancing novel inventions and enhancing efficiency through process advancements. Dhehibi et al., a 2020 study examining the best practices of technology transfer among tunisa farmers, concluded that the most beneficial agricultural transfer strategies were farmer training, demonstration, and farmer-to-farmer interactions. The comparative study conducted by Mgendi, Shiping, and Xiang in 2019 showed that a developed country agrifood industry like China has strong ties, dedication, and collective involvement from all stakeholders in the planning and execution of agricultural technology transfer initiatives. The study concludes that local governments must provide institutional structures and policy environments that promote and facilitate agricultural technology transfer to the advantage of rural farmers.

6.4.6 Profitability

Profitability emerges as a determinant factor for business within the AFSC in Nigeria when determining the adoption and use of Industry 4.0 technologies. It was noted that any solutions with the potential for more profit would be quickly adopted among the AFSC actors. The precise dividends of the technologies to the agribusiness processes and financial return will create an eagerness to adopt among AFSC users. This means that the technology provider presents the applicability of the technological solutions in their context, meeting the needs, solving the challenges and increasing their economic returns. These findings are in collaboration with Rogers 2003, who highlighted that profitability is a fundamental factor influencing technology adoption and diffusion. Masi et al. (2022) presented in their study that precision agriculture tools are used and how they can help farmers be more profitable and use sustainable farming methods. This research looks at how blockchain technology changes the agrifood supply chain, focusing on how it improves safety, speed, and traceability, all of which are important for making more money. The study by Yogarajan et al., 2023, presents a finding that suggests that blockchain technology is adopted based on the perceived profits it offers AFSC actors. Ensuring food safety, traceability, transparency, environmental care, and reducing food waste are some of the most important reasons the agri-food business is adopting blockchain technology. All these academic arguments align with the findings in this study that reveal that technological profits are a determinant factor in adopting the industry 4.0 technology among the AFSC actors.

6.4.7 Competitive Advantage

In this study, AFSC actors suggested that they will adopt and use technology if it has the potential to create a competitive advantage. The stakeholder argues that technology adoption can make the AFSC process efficient, which in turn leads to a competitive advantage. This aligns with Davenport's (1998) findings that technology adoption in business processes improves competitive advantage. The study by Kamble et al. (2020) suggested using blockchain technology to facilitate traceability in the agricultural supply chain, improving competitive advantage by promoting transparency.

6.4.8 Context design

Participants discussed being exposed to various technologies throughout the years, either through research or being informed about them. Most of these technologies were imported from developed countries. The concern of the AFSC stakeholders in Nigeria is that most of the technologies presented to them do not meet the needs of the Nigeria AFSC industry. The stakeholders' concern is that the actors' needs should be centred on developing technology solutions for adoption in the AFSC industry. Technology context design emphasises the need to customise technological advancements to suit the requirements and circumstances of the AFSC users. They emphasise that technology should be designed to meet users' needs and tailored to their context. The users assume that some technologies presented to them were incompatible with the reality of the Nigeria AFSC industry. Users are more like use and adopt technology if it is developed to address their specific context, challenges, and needs. These findings underpin a belief among the AFSC actors that if technology is designed to meet the potential user's needs, it increases its usefulness, which means users believe that a technology that meets their needs and challenges is helpful. These findings align with the technology acceptance and use technology framework of Venkatesh et al., 2003 which makes a significant note on the impact of user-perceived usefulness and ease of use of technology on the user's behaviour and intention to accept and use technology. Roger EM's 2003 theory of diffusion of innovation supports this through the lens of perceived profitability presented by technology as having a significant impact on technology adoption. The findings in this study also validate the findings by Davis (1989) on how to examine factors that influence user adoption of computers accurately, showing that perceived usefulness correlates more to the use of technology. Straub, E.T. (2009) suggests that effectively promoting the acceptance and use of technology requires addressing potential users' contextual considerations. Adenle, Wedig and

Azadi 2019 argue that governments can help to encourage technology adoption in the agri-food industry in Africa by promoting policies and technology solutions designed to meet the needs of all AFSC actors in their context.

6.4.9 Perceive usefulness

Studies conducted using TAMs demonstrate that Usefulness and Ease of Use are central aspects of technology adoption, provided that these aspects do not cause a significant increase in production cost. If so, creating a low-performance tool with few "useful" characteristics seems more effective in attaining a lower purchase price. Literature refers to these situations in discussions regarding "disruptive innovations", a definition that could apply even to agriculture. Sugandini et al., 2018 argue that perceived usefulness directly impacts technology adoption decisions. Several authors, such as Beza et al., 2018 Li et al., 2020 and Ronaghi and Forouharfar 2020 , established certain variables' role in adopting industry 4.0 technologies in the AFSC industry, including the perceived usefulness of technology.

6.4.10 Ease of use and perceived usefulness

This study also finds that use and perceived usefulness have criteria for AFSC actors in use and acceptance of technology**.** AFSC actors suggested that they can embrace technology if it is presented as advantageous to them. Therefore, we must inform them that these technological solutions will benefit them. Other actors suggested that if technological solutions can enhance their profitability, they will naturally make necessary adjustments. Everyone desires to increase their wealth.

This ideas emerges from the findings presented in chapter for of this study which draws upon 1st Order quotes from participants such as : ‘‘I think technology can only be adopted if it is made to appear to be beneficial to the farmers; ‘‘The government researches and simplifies technology to the lowest level so that every individual can easily understand it and adopt it; ‘‘If the technology is simple enough that an individual who does not have a Western education from primary and secondary school can use it without seeking assistance from one or two personnel, then it will definitely help’’

This findings align with Pierpaoli's 2013 study on applying TAM in adopting precision agriculture technology; the study indicates that technology usefulness and ease of use play a crucial role in adopting technology, as long as these factors do not substantially increase production costs. The study further argues that developing a tool with limited performance and only a few valuable features would more efficiently achieve a lower purchasing price. This study's findings are also consistent with what Pappa, Iliopoulos, and Massouras (2018) researched on the analysis of mobile phone usage and adoption among farmers in Sub-Sahara.

This demonstrates that perceived ease of use significantly influences their adoption of mobile phones.

Hendrawan, Trihandoyo and Saroso 2023 also argue that perceived usefulness as an essential criterion when adopting and implementing technology among smallholder farmers; this is drawn upon from their study on implementing the Technology Acceptance Model to measure ICT usage by smallholder farmers; the respondents considered the perceived usefulness of ICT to be more significant than its perceived ease of use in their daily activities.

6.4.11 Trust

This study identifies trust issues as a factor affecting the adoption of Industry 4.0 technologies among the AFSC actors in Nigeria. Trust emerges as an aggregate dimension within the survey, having technology threats and technology misconceptions and Transparency and support as 2nd order themes.

Drawing upon qualitative data extract findings presented in chapter 4, several 1st order quotes suggested that trust as element that affects industry 4.0 technology in Nigeria, such as: ‘‘This will make them frightened so they prefer to keep the old method by preserving their jobs rather than bringing in robots that will replace human labour causing them to lose their job; ‘‘When you work with maybe one or two of these people, you would have built trust with that person because he's in that community. I've seen him they know him before.’’ Based on these findings, The AFSC actors expressed that technology threat due to the apprehension that introducing technology would result in loss of livelihood and jobs in the sectors. Other emerging discourse from the study is that AFSC actors prefer to stick with different methods as most are frightened, as they express their lack of trust as been deceive by solution providers, human labour replacement, trust in the integrity of solutions providers and possibly will adopt technological solutions from reliable technology brands.

Transparency and support are also another form of expressing a lack of trust; most actors believe that they might be defrauded if they adopt and implement new technological solutions that are presented to them. The findings also show that working with people (relationship between user and technology provider) can be a social network medium where trust is built and promotes adoption. According to AFSC that express; that when you work with people, you have to build trust with that person because they are part of your community. I've seen him, and they know him before.

These results correspond to the findings of AlHogail 2018, which demonstrated that trust is a vital factor in consumers' decision to adopt IoTs. AlHogail 2018 further argues that trust helps user overcome concerns about risk and uncertainty associated with IoT and increases their willingness to accept and embrace these technologies; the study concluded by present factors level of trust, which are the products, social influence and security. Bahmanziari et al., 2003. Akinwunmi et al., 2015 also argue that trust plays a significant role in accepting and adopting technology. Therefore, it is recommended that future research on technology adoption should include an examination of this factor. Canavari et al., 2010 argue that trust is essential in the transition from traditional methods and electronic B2B relationships in the agri-food supply chain. Fischer, C., 2013 study on the impact of communication on trust in agrifood supply chain in Europe concluded that trust in supply chain partners can be substantially enhanced by good communication and positive track records of previous collaboration. Favourable prior cooperation and personal relationships in both supply chain stages boost trust by promoting effective communication. Yadav et al., 2020 supported this argument by establishing that lack of trust and government support are a significant hindrance to adopting blockchain technology in the Indian agrifood sector. Potential technology users suggested that they require assurance of the technology's reliability during usage. This is necessary to establish trust in the technology, which will reduce fear (Akinwunmi et al., 2015 also argue).

6.5 Financial investment, International Organization, role of government

The findings from this study, among many interview respondents, show that access to finance, either loans or grants, government support and international organisations are crucial in the widespread adoption and use of industry 4.0 technology in the AFSC in Nigeria.

The interview data suggested increased financial resources could increase commitment to technology adoption. The study data indicated that access to economic resources will promote widespread adoption and use. Another emerging idea from the study highlights the role of international organisations in promoting technology adoption in the AFSC in Nigeria in the form of creating awareness and access to loans and training. These findings align with Liu, Zhang and Li 2022 study, and they argue that in the surge of blockchain technology adoption in the agri-food industry, an actor needs to make financial decisions to adopt the technology and leverage the promising competitive advantage.

Adenle, Wedig and Azadi 2019 in their study on sustainable agriculture in Africa using innovative technologies, argues that international organisations can significantly contribute to implementing evidence-based policies that promote specific combinations of low- and technological solutions tailored to the local context. This study, in correspondence to the study of Shiferaw and Muricho (2011), argues that farmer organisations in sub-Saharan Africa help promote technology adoption and market access among African farmers.

6.6 Enabling elements for technology adoption

The quantitative data analysis from this study shows that performance expectancy (PE), Technology Benefits (TB), and enabling conditions correlate or have a positive impact on users' behavioural intention (BI) to use technology. It can be deduced that the AFSC actors who responded to the survey believe, based on their experience, that the performance expectancy of technology can influence the actors' behaviour in using industry 4.0 technology in the AFSC sector, this finding aligns with Venkatesh et al., 2003arguemenst that Performance expectancy influence the decision to use technology. The technology benefits presented to AFSC actors will positively impact their intention to use technology; stakeholders will have the intention to use technology if there are benefits to the farming, processes and logistics business. It can be further deduced that benefits such as waste reduction, climate change mitigation, access to credit, job creation, investment opportunities and data-driven decision-making processes are potential benefits that can create a positive intention to use technology; these findings corroborate Rogers et al., 2014 that suggested that benefits of technology influence the adoption. Enabling conditions (EC) such as infrastructure, access to technology, knowledge, skills, technology compatibility and access to help are factors that the AFSC actors suggested will influence their behaviour intention to use industry 4.0 technologies this aligns with the findings of Li et al., 2020; Ronaghi and Forouharfar 2020 that enabling conditions can help facilitate the adoption and use of technology

The quantitative data analysis also reveals that behaviour intention (BI), enabling conditions (EC), price value (PV), and technology adoption readiness correlate with or positively impact user behaviour (UB) to use technology among the AFSC actors in Nigeria, this findings is in agreements with Li st al., 2020.; Thong *2012* that investigate the impact of technology price on technology use and adoption. It can be deduced that behaviour intention to use technology has a positive impact on use behaviour to use of technology; this is because the intention to use can be a baseline for continuous interest in using the technology within the AFSC processes. Enabling conditions such as infrastructure, access to technology, knowledge, skills, technology compatibility, and access to help are factors that can influence the continuous use of technology. The price value in terms of the cost of technology, as shown in this study, impacts the actor's behaviour toward using technology; this aligns with Roger's 2005 theory of technology diffusion, which argues that the price of the technology has factors that influence the diffusion of technology.

Technology adoption readiness (TAR) measures how ready a sector or nation is to achieve digital transformation. TAR uses investment in technology, government support, infrastructure, technology availability, and manpower as metrics to measure the technology readiness of the AFSC actors in Nigeria. This study finds that TAR positively impacts user behaviour when using technology; this suggests that an industry's technology readiness can be evident in the behaviour of actors who continuously use the technology. These findings align with Antony, Sony, and Mcdermott's 2021 Krishnan et al. 2021 and Silva et al. 2022, which investigate certain factors to illustrate technology adoption and use readiness. Antony, Sony, and Mcdermott 2021 argue that certain Network readiness indexes, such as infrastructure, policy, government support skills and SDG contributions, are elements crucial to evaluate the readiness of a business or country to adopt and use technology.

6.7 Conclusion

This chapter presents and discusses the research findings, covering all aspects of the research questions and qualitative and quantitative data analysis. The findings first highlighted the challenges facing the AFSC in Nigeria to clearly understand the challenges within the sector and emphasise the need for sustainable processes and practices. The role of industry 4,0 technologies was examined by actors presently using and adopting them within their agrifood processes. The chapter also captures the sustainability impact of industry 4.0 technologies by AFSC actors and users and several factors influencing their use and adoption. The next chapter will cover the research's conclusions and capture how the study's objectives and aims were met. It will also highlight this study's practical contribution to actors, government, and academia. Furthermore, it will also provide recommendations for future research.

CHAPTER SEVEN (7)

7.0 RESEARCH CONTRIBUTIONS AND RECOMMENDATIONS

7.1 Introduction

This chapter comprehensively summarises the thesis. It covers how the research question was answered through the research instrument and data analysis and presents how this study contributes to practice and academics. The practical recommendations section is a critical component of the chapter, which presents actionable and feasible recommendations to improve the AFSC 4.0 journey towards sustainability in the agri-food industry in Nigeria. These recommendations are designed to be easily implementable, empowering the industry to make significant strides towards sustainability. The section also addresses the research's limitations and potential areas for future research.

7.2 Achieving Research Objectives

The central focus of this study was to examine the impacts of Industry 4.0 technology in achieving sustainability in the AFSC industry in Nigeria. This was hinged on three research questions, targeted to meet the aims and objectives of the study. This section will be of due diligence, highlighting the study admins and objectives and how the study addressed and achieved them. The research objectives are listed from 7.1.1 to 7.1.4 and discussed in detail.

7.2.1 To explore the level of knowledge and awareness of sustainability among agrifood actors in Nigeria.

The first objective of this study was to examine the level of knowledge and awareness of sustainability among the AFSC actors; this focused on checking through the interview procedure what sustainability means to them and their practices. The study records several opinions on sustainability awareness among the AFSC actors. Deducing from Chapter 4, 2nd order codes such as sustainability awareness, sustainability knowledge, environmental consciousness and sustainability solutions (technology) were recorded among the AFSC respondents, which can be concluded that the participants for the study have knowledge and awareness of sustainability are environmentally conscious of the negative impact of the AFSC on the environment and of opinion that technological solutions help in promoting sustainability within the AFSC industry in Nigeria. These findings help to investigate and establish the importance of a sustainable approach within the Nigeria AFSC industry.

7.1.2 To Identify the sustainability impacts of employing Industry 4.0 technologies by agrifood stakeholders in Nigeria.

The second objective was to identify the role of Industry 4.0 Technology in promoting sustainability in the AFSC in Nigeria among the actors currently deploying these various technologies, such as IoTs, Big Data, Precision agriculture, GPS, drones, weather forecast technology, etc. Deducing from Chapter 4, these objectives were met, and it is eye-opening that industry 4.0 technology use and adoption in the AFSC in Nigeria results in emergency agritech startups, job opportunities, youth employment, process efficiency, skill transfer, and improved livelihood. This objective was achieved by interviewing 25 participants and 158 survey participants.

7.1.3 To understand the underlying enablers and challenges responsible for using and accepting industry 4.0 technologies.

The study's third objective is to investigate the practical elements that influence the use and adoption of Industry 4,0 technology among the AFSC actors that participate in the study. This was achieved through the interview instrument and survey instrument. The interview of the participants established that factors such as community base advisory (CBA), social influence, industry influence, ease of use, profitability and technology demonstration are elements that were evidence to help the adoption of this technology among the users in Nigeria. The survey instrument using the UTUAT helps to investigate the influencing factors further, and findings established that price value (PV), Behavior intention (BI), enabling conditions (EC), and technology adoption readiness have a significant impact on user behaviour (UB) to use technology. The findings also established that performance expectancy (PE) substantially affects behaviour intention to use technology. The objectives of this study were achieved through the interview of 25 participants and 158 survey participants.

7.1.4 **Summary of AFSC challenges addressed in the study**

Chapter 4 (validating conceptual framework) shows the impact of Industry 4.0 technology and the challenges it addresses in this study. As stated in Chapter 1, the list of challenges is as follows: food waste, Natural resource degradation, Climate change, Dietary demand, Population Growth and Urbanisation, and Capital Infrastructure.

Participants in this study agree that the use of Industry 4.0 technologies in farming, food processing and logistics has helped reduce food waste. This technology allows the actors to have data that helps to drive better food handling on the farms and off-farming operations. The farmers mentioned that the CBA services that give local farmers information about weather and best agricultural practices significantly impacted mitigating and reducing food waste by providing them with sensors to monitor the temperature and humidity of agrifood products from farmers to manufacturing companies. Post-harvest loss was also reduced due to increased access to the market. Food manufacturing companies believe that IoT sensors are used to monitor the condition of the food on the go, reducing food waste on the go.

Precision agriculture and smart farming have a significant impact on reducing the adverse effects of agrifood on the climate and reducing the cost of production by lowering agricultural input usage. By employing PA and SF, agricultural inputs like fertiliser are only applied to fields based on the nutrient requirement of the farm field portion. The nutritional requirement of the field is monitored using several sensors.

Another challenge addressed in this study was the increased dietary demand and the growing population. The rising population in Africa (Nigeria) has significantly demanded the agrifood supply. Adopting technology results in more efficient agricultural practices, better Food 4.0 manufacturing processes, and better smart logistics. Africa's agriculture has an ageing population; however, due to the adoption of Industry 4.0 technologies, there has been an increase in emerging agrifood startups, youth employment, and increasing interest in agritech jobs among youths, expanding the workforce in the agrifood industry.

The lack of capital infrastructure is also a major challenge addressed in this study. The investigation shows that there are increasing investment opportunities within the agrifood industry, covering farming, food processing, and logistics. Government and international organisations have begun to invest in rural communities (Roads, electricity, and water), which are essential for a vibrant agricultural community to thrive and be effective.

Summary of AFSC Industry 4.0 technology sustainability: Impact of this study

The sustainability impact of this study is stated in Figure 4.7 (Validating Conceptual Framework). The studies established that the use of Industry 4.0 technologies within the Nigerian AFSC results in high-yield productivity, reduces the cost of production and increases agritech start-ups. The economic impacts of this study include youth employment, rural community development, increased investment opportunities, and improved livelihood for AFSC stakeholders.

7. 2 Research Contributions

This study significantly contributes to research, academics, methodology, and AFSC practices. This is covered in sections 7.2.1 to 7.2.3

7.2.1 Academic contribution

Having established the emerging ideas from the body of literature on AFSC sustainability in the era of industry 4.0 technology, it is necessary to examine this research within the context of Nigeria's AFSC industry. This empirical study within the Nigeria agrifood industry creates an avenue for contextual study, which draws academic contribution from examining the impact of Industry 4.0 technology in the sustainable AFSC in the context of Nigeria's agrifood industry, enables in-depth analysis of AFSC actors' experience in the use and adoption of Industry 4.0 technology without generalising concepts and ideas captured in other studies conducted in different country or agrifood contexts. This study has established that Industry 4.0 positively impacts AFSC sustainability within Nigeria's AFSC industry. However, there are a few emerging ideas on how technology is transferred.

Technological Progress and Employment Generation: It has been demonstrated that Industry 4.0 technologies are essential to creating new employment prospects in the AFSC industries. Because of these technologies, more occupations requiring new skill sets are being made, which increases the workforce's need for ongoing learning and adaptation. This change also reflects a larger trend in the industry toward more efficient and sustainable farming methods.

The study indicates a noteworthy surge in recently established technology-driven enterprises. This rise in entrepreneurship is noteworthy because it reflects a creative environment that fosters the creation and use of industry 4.0 solutions. This frontier of AFSC possibilities will probably be significant for new technologies' commercialisation and scalability, which will help the agricultural industry's economy flourish and spread technology.

According to this study, the AFSC industry in Nigeria is about to witness significant investment opportunities targeted at boosting AFSC efficiency via technology. This presents huge potential for AFSC to draw capital investment, spur economic growth, and strengthen the agricultural industry's competitive edge, making it especially pertinent to policymakers and investors. The AFSC industry has observed the successful transfer of skills and knowledge, which has empowered AFSC actors. This empowerment is crucial for the effective adoption and integration of new technologies. By providing appropriate training, the agricultural sector may improve resilience, sustainability, and productivity for farmers and other stakeholders.

It is worth noting that the findings of technological context design emerge as factors that influence the accessibility and use of technology among the AFSC actors in Nigeria. This study contributes to knowledge by viewing the technology adoption journey through the lens of the user's need and suggesting the need to create technology that meets the user's needs and solves challenges within the agribusiness context. Several actors suggested that most imported technology does not seem suitable for Nigeria, and their needs were not considered while developing it. This is, therefore, a recommendation for technology-developing companies to co-create technological solutions with the intended users of the technology.

Several studies on the role of Industry 4.0 were conducted in different parts of the world, with significant results and implications for the agri-food industry. Therefore, there is a need to examine the role of industry 4.0 technologies in the context of actors in Nigeria.

The idea of community-based advisory (CBA) as a medium that influences technology adoption emerged from the study, Several studies have suggested that Industry 4.0 technology helps in achieving sustainability within the AFSC,

The study thoroughly examines how AFSC businesses are changing due to technology adoption. By capturing the rise of new business models and creative approaches made possible by technology, this research contributes to the expanding body of literature on the digital transformation of the AFSC industry within the Nigerian context. It presents the transition from conventional practices to data-driven processes within farming, food processing, and distribution of agri-food commodities.

This study emphasises the significance of technology in improving decision-making among various AFSC actors. Using qualitative and quantitative data, it illustrates how access to and using technology has enabled farmers, food manufacturers, and distributors to make better decisions that increase overall productivity and sustainability. The results imply that technology 4.0 solutions help in mitigation and resource management; these findings provide helpful information for actors and policymakers who want to promote sustainability using technology integration within the AFSC industry in Nigeria.

This study also presents that Technology adoption readiness affects varying technology adoption rates in different nations and industries.

The study carefully analyses the levels of technology adoption readiness in Nigeria's AFSC, highlighting essential enablers and inhibitors of adoption and use, including infrastructure, skill, knowledge and access to technology. In particular, this finding contributes to knowledge by suggesting that TAR should be considered a factor in access technology adoption, as clearly seen in the case of the Nigeria AFSC industry.

This finding will serve as a strategic framework to empower different AFSC stakeholders, governmental agencies and international organisations to provide an intervention with the AFSC industry to improve the digitalisation of AFSC in Nigeria towards sustainability outcomes.

7.2.2 Contribution to Policy and Practices

The findings gathered in this study have significant policy implications. They can serve as guidelines and frameworks in the development and application of policy within the AFSC industry in Nigeria, fostering the transition into a digital-driven and sustainable agrifood system, resulting in more resilient and competitive agricultural systems. The ability of industry 4.0 technology to improve sustainability and operation sufficiency will encourage actors and agribusinesses to adopt and use technology within their operations successfully.

Policy and Practice Implications: The study provides valuable information for practitioners and policymakers by highlighting technology demonstration and community-based advisory (CBA) as important promotional aspects. These results imply that AFSC actors' technology adoption rates can be successfully increased by focused interventions that emphasise community involvement and real-world demonstrations.

This study also provides a thorough framework to direct the creation of focused policies by identifying important variables such as industrial influence, societal influence, community-based advisory (CBA), technology demonstration, technology transfer, profitability, and competitive advantage. The quantitative analysis highlights the significance of behavioural intention in the technology adoption process by providing additional insight into the function of user behaviour (UB), which is influenced by enabling factors, price value, and behaviour intention. Important policy implications of this research include:

Strategic Recommendations: The study's identification of competitive advantage and profitability as important motivators emphasises the necessity of developing strategies that highlight the financial benefits of implementing Industry 4.0 technologies. This strategic view can help stakeholders create incentive programs that balance technology innovation with the economic goals of AFSC actors.

Context-Specific Insights: This research, situated in the Nigerian context, offers significant context-specific insights that add to the international conversation about adopting technology in agriculture. The results can guide comparable research in other developing nations, promoting a comparative perspective and possibly resulting in a wider applicability of the factors found.

Community-Based Advisory Systems: The significance of localised advisory services is shown by identifying CBA as a significant factor in adopting technology. To offer AFSC actors specialised assistance and direction, policymakers should give top priority to the creation and bolstering of CBA systems. This can be accomplished by providing local advisers with training programs that will enable them to effectively demonstrate and convey Industry 4.0 technologies.

According to the study's findings on profitability and competitive advantage as drivers of technology adoption, strong incentive structures are necessary. Policymakers should create financial support programs, tax incentives, and subsidies to enable AFSC actors to embrace Industry 4.0 technology at a reasonable cost. These rewards ought to be in line with the readiness and performance expectations found in the study.

Programs for Technology Demonstration: One of the main elements encouraging adoption is technology demonstration. Establishing demonstration farms and pilot programs highlighting the valuable advantages and applications of Industry 4.0 technology should be a priority for policymakers. Proving their benefits can increase behavioural intention to embrace these technologies.

Enabling Conditions: The study emphasises the significance of favourable regulatory settings, infrastructure, and financial accessibility. Policymakers must guarantee the availability of internet connectivity and a power supply. Developing a favourable legislative environment that makes funding choices easily accessible is essential to promoting the adoption of new technologies.

Awareness and Education Campaigns: Specific campaigns are necessary to raise awareness and educate the public due to the impact of industry and social issues. The goal of these efforts needs to be to inform AFSC participants about the advantages of Industry 4.0 technologies and how they might boost competitiveness and productivity. The effect and reach of these initiatives can be increased through cooperation with influential people and leaders in the industry.

Support for Research and Development: To continuously innovate and adapt Industry 4.0 technology to the local context, policymakers should cultivate a robust research and development environment. Fostering collaborations across academic institutions, research centres, and business sectors can propel the creation of solutions tailored to specific contexts, augmenting their significance and uptake rates in the AFSC.

Processes for Monitoring and Evaluation: Strong processes for monitoring and evaluating policies are essential to determining how they affect technology adoption. This will allow decision-makers to modify and enhance their policies based on data, guaranteeing that they continue to be efficient and adaptable to the changing requirements of the AFSC.

By concentrating on community-based advisory, incentive structures, demonstration programs, enabling conditions, awareness campaigns, R&D support, and efficient monitoring, policymakers can establish a favourable environment that encourages the widespread adoption of cutting-edge technologies, boosting productivity, profitability and competitive advantage in the industry.

7.2.3 Theoretical contribution

The study's main theoretical contribution is expanding UTAUT and providing practical insights for professionals in the field. Including Technology Adoption Readiness (TAR), Price Value, and enabling conditions in the context of Nigeria AFSC sustainability using industry 4.0 technology offers actionable strategies for technology adoption and use. By doing this, the UTAUT model was well tailored to ideas within the study context, minimising the generalisation of applications used in several studies. All the elements of UTAUT emerge as factors that influence adoption, drawing from the qualitative study.

The study used the Unified Theory of Acceptance and Use of Technology (UTAUT) to investigate the factors that influence the use of Industry 4.0 technology among the AFSC actors in Nigeria. The UTAUT was modified to include technology adoption readiness (TAR), price value (PV), and technology dividends (TD). The significance of the modified UTAUT theory was used to investigate factors that influence the adoption of technology among the

Nigerian actors who are p[recently deploying technology. This modified UTAUT framework helps to establish that technology adoption readiness is a factor that influences the adoption and use of technology. It is worthy of note that examining knowledge, skills, and infrastructure access the readiness of the agrifood industry for scale adoption. It is also worth noting that technology adoption readiness varies across sectors and countries. During the interview, one participant mentioned that agri-tech startups in Kenya are more successful than those in Nigeria. This can parallel the fact that Kenya has more technology adoption readiness than Kenya. It can be stated that technology adoption in a country impacts technology adoption and use in several industries, and TAR varies across several sectors within the same country.

Research Recommendations

Drawing upon the findings established in this study, the research presents recommendations that will benefit both agrifood supply chain practices and the world of academics. The following are the recommendations this study presents:

- Government and AFSC actors should promote sustainable awareness across the agrifood industry and foster policy and industry standards to measure sustainability growth.
- In the global fight against climate change, the AFSC in Nigeria should empower actors through collaborative research and development to pioneer initiatives that decarbonise the carbon footprint, reduce food waste, and promote industry efficiency.
- Investment in agriculture should increase capital infrastructure development and digital infrastructure creation, promoting the agrifood industry's digitalisation.
- Industry 4.0 technology can present data-driven processes for sustainable livestock health management
- The labour force working in the agri-food industry is ageing. To attract young talent into on-farm and off-farm digital jobs, the AFSC business needs to be invested in and transformed.
- A review of agricultural technology policy should be conducted to link it to achieving social, economic, and environmental sustainability goals.
- The readiness for technology adoption in the country should be taken seriously as an agenda to improve, where the digital divide can be reduced and broader participation of the Nigerian agrifood industry in the digital revolution can be created.
- Africa Can feed the world; it has 60% of arable lands. An international organisation will support the development of the AFSC industry in Africa through technology and sustainability initiatives.
- Agriculture education in Nigeria should be modified with modern knowledge and technological advancement. Undergraduate agriculture education should include

courses like agriculture sustainability, precision agriculture, smart agriculture, smart logistics, and industry 4.0 food manufacturing, with industry-year experience in skill and knowledge acquisition.

7.3 Limitations of the study

During this study, the principal researcher ensured all the study objectives were achieved and all research questions were answered with appropriate, high-quality data. However, this study faced some challenges and limitations, which is common in most research endeavours. However, Yin (2009) points out that all research studies have constraints placed on the researcher, and this work is no exception. The list of these restrictions follows: limited literature and empirical papers on the AFSC sustainability using industry 4.0 technology, most leading authors and studies conducted in this field were mainly from Asia and Europe; a comparative study was the initial approach for the study, but the researcher has limited access to AFSC industry in Europe or Asia; the study would have been a bigger context, covering Africa. The initial idea was to conduct a case study with 6 African countries and compare the scopes of the findings; access to data was also a challenge, as many participants who participated in the study declined after the researcher travelled to Nigeria to meet them.

Another limitation of this study arises from the sampling methods used in the study; the study employed the use of purposeful sampling methods to select AFSC actors based on the criteria that they are using industry 4.0 technologies within the agrifood industry This ensure that AFSC actors participating in the research as a direct link to the study base on their experience and their wealth of industry experience will contributes to the study inquiry(Palinkas et al., 2015). However, this form of sampling method creates a selection balance, limited representativeness, and the sufficiency of the sample, and the rigor of the selection processes is questionable. The study's primary investigator understood the limitations of this sampling selection process but believed that purposeful sampling is the best sampling choice for the study because the study participants should be AFSC using Industry 4.0 technologies within the agrifood industry in Nigeria.

7.4 Future Research

This study has unearthed several areas of research and analysis within the AFSC in which other interested researchers can delve deeper. The recommendations for additional study are Industry-led research on technological demonstration for technology adoption in the AFSC. Survey of business model modifications for AFSC actors in the era of industry 4.0 technology; decarbonisation of AFSC in Nigeria, potential strategy towards sustainability; sustainable livestock management using industry 4.0 technology study on readiness of Africa agri-tech startups for digitisation of agrifood industry; study on commodity trade within the AFSC industry with application of technology and stakeholders interactions. This research work has brought up a lot of areas that could be of interest to researchers who want to explore issues relating to the public sector in Nigeria further.

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APPENDIX

Appendix 1- Interview Schedule Protocol

Opening

A. (Establish Rapport) [shake hands] My name is Kehinde Olafare, I am a PhD student at Nottingham Trent University; I will be interviewing you for a research study.

B. (Purpose) I want to ask you questions about the role of digital technology (like IoTs, Big data, and precision Farming) in achieving a sustainable agri-food supply chain in (developing)Nigeria or a developed country(UK). I would like to know the current state of the use of technology, potential, and challenges of digital solutions.

C. (Motivation) I hope to use this information to help improve the practices and adoption of digital technology in the agri-food supply chain.

D. Ethical Consideration) This interview follows ethical practice, and all information, including the recording and transcript, will be handled in confidence and anonymity. If you take part in this research study, the data collected will be kept by authorised persons from the Nottingham Trent University and will not be attributed to you either by name, your position or company

E. (Timeline) The interview should take about 45 minutes. Are you available to respond to some questions at this time? The interview will cover the following topics: agri-food sustainability, supply chain performance, adoption, technology application, and Readiness index.

F. (Option) This interview can either be recorded or note-taking, based on your preferences.

Transition: Before we start this interview, can I ask you to take a couple of minutes to reflect on your experience in the agri-food supply chain(farming, processing, distribution and retail). What are the challenges, how can the SFC be sustainable, what role will Digital solutions play in achieving Sustainability, and how can we promote the adoption and use of technologies?

1. Agri-food supply chain performance

A. The Agri-food industry is a significant part of Africa's economy. Can you describe what you do in this industry?

B. What are the significant challenges you are facing in this practice?

C. Talk me through your cost of production. As it increases over the year? What are the major causes, and how do you ensure profitability?

2. SUSTAINABILITY (Prompt)

a. Are you familiar with the term Sustainability?

b. Can you explain what Sustainability means to you?

c. What are the methods you are employing to promote agri-food sustainability?

Resource management	
Increase food production	
Reduction of food waste	
Reduction of agriculture footprint (GHG emission)	
Increase access to the market	
Increase profitability	
Agriculture and food employment	
Increase livelihood of farmers and stakeholders	
No child labour	
Zero-emission of freight transport	

Use of renewable energy	

Economic impact

1. What do you think is a possible way to increase income and promote the good livelihood of workers and stakeholders?
2. What are the ways you can expand your business?
3. Tell me the plan for financial investment (in machinery, technology, etc.).
4. What are your opinions on loans and grants for agribusiness? Are there available credits for agribusiness?

Environmental Impact

1. Food waste is the major challenge of the agri-food industry. Talk me through the ways you are reducing food waste.
2. At which point of the supply chain do you generate the most waste?
3. What are the ways you think technology can help reduce waste?

Social Impact

1. How do you contribute to the employment of young people in your local area?
2. What infrastructure (electricity, road, equipment and technology) do you need to do your work effectively?
3. Do you or other stakeholders make a decent living from this business?

d. In your opinion, do you think technology can help promote Sustainability

3. Technology: 4th industrial revolution (Big Data, IoT, Drone, Precision Farming)

A. Do you use technology? Can you describe the kind of technology you use?

B. In your opinion, do you think technology (data-driven process) can help promote Sustainability?

C. What are the means of data generation you use in your process?

Big Data	IoT	Precision farming	Smart farming	Smart Logistics	Artificial intelligent	Drones, GPS GIS	

i. Which of the above digital technologies and tools are you deploying?

ii. Do you have plans to adopt digital technology and implement a data process?

iii. Who is responsible for making decisions for digital adoption in your company?

4. Adoption of technology

A. What are your thoughts on adopting a new method or technology?

B. Will technological demonstration (In terms of usage and application) promote technology adoption?

C. How is an investment in infrastructure affect the adoption of technology?

D. Do you think technology will enhance the performance of your production?

E. What advantage do you think this technology will offer your Agrifood supply chain?

F. What do you think will be a significant challenge of technology adoption?

Finance & Investment	Infrastructure	Lack of skill	Perceive usefulness

G. What are your preferred means of digital and knowledge transfer?

Incubation networks	Training and workshop	Through research institutions	Promote by the ministry of agriculture & food	Through networks

5 Readiness (Network readiness)

A. How do you plan to acquire the necessary skills?

B. What is the necessary infrastructure to promote digitalization and Sustainability?

C. Do you have the necessary workforce to frontier this agricultural revolution?

D. What do you think is the role of government and international bodies in promoting technology adoption?

Appendix 2- Interview Transcript (Participant 1)

Interview Schedule Protocol

Kehinde: I am Kehinde from Nottingham Trent University. I am a PhD student. My research topic is the role of technology in developing a sustainable food supply chain in Africa, using Nigeria as a case study.

Kehinde

(Purpose) The PhD research is around the role of technology in developing a sustainable food supply chain system in Africa and in Nigeria.

(Motivation) The motivation for this research is to improve the practice and adoption of digital technologies in our global supply chain and to increase sustainability.

(Ethical Consideration) This interview follows ethical practice, and all information, including the recording and transcript, will be handled in confidence and anonymity. This means that your identity is not going to be shared with anyone. We only just record, transcribe, decode and analyse the transcription. If you take part in this research study, the data collected will be kept by authorised persons from the Nottingham Trent University and will not be attributed to you either by name, your position or company.

(Timeline) The timeline for this research is between 40 and 45 minutes.

Kehinde

The interview has five (5) sections.

1. Agri-food supply chain performance
2. Sustainability
3. Technology: 4th industrial revolution (Big Data, IoT, Drone, Precision Farming)
4. . Adoption of technology
5. Readiness (Network readiness)

Agri-food supply chain performance

Kehinde : The Agri-food industry which you are part of, is a significant part of Africa's economy. Can you describe what you do in this industry generally?

Participant 1: I operate in the agricultural technology space in, in the industry. I am the founder of XXXX XXX Precision Ltd. Lagos Nigeria. We do is provide drone technology and data solutions to farmers as related to distribution of data, and also use of robotics, like aerial drones to offer solutions to farmers and also help them to monitor their crops digitally.

With drone data, we help farmers make smart decision and make farm management easier. As regards our spraying drones, we offer crop protection services to farmers autonomously, and also broadcasting operation, broadcasting of fertilizer seeds etc. Right now, we are also dealing with the manufacturing part of things and assembling our sprayer drones. I am also a farmer and run a farm alongside the technology service provision.

Kenny

What are the significant challenges you are facing in this practice?

Participant 1: The challenges we have faced include regulations because we use a highly regulated technology in agriculture. Another one is infrastructure, which also leads to a level of awareness. As we are pushing the technology, we are also doing our best to increase the awareness among farmers and demonstrating to them the benefits of the technology.

Funding has also been a major challenge. Funding is critical because we operate in the technology industry, and technology is relatively capital-intensive. However, it has benefits which is far greater, but it is capital intensive.

Another challenge is skill level and capacity, which affects adoption. These are the challenges that we are presently facing to various degrees.

Kehinde: Talk me through your cost of production. What are the major costs of production? Based on the increase in production cost, how do you ensure that you're making a profit?

Participant 1: Our company has just started less than a year ago. From the farmer's perspective, the cost of production is increasing due to inflation and global challenges such as the Ukraine and fertilizer costs for farmers, as a farmer myself. But as a service provider who is into drone technology, the costs of logistics are increasing, trying to serve across the country, logistics from one point to another, because of the increase in price and availability of fuel. The increase in the dollar rate is also a challenge because we depend on forex. We want to get more aircraft in and spare parts. Prices have increased this year.

How do we ensure profitability? We just have to cut costs in terms of operational costs. Addressing issues like whether to send we need to send two people down for a job or manage to do one? I mean, that reduces the cost of operation.

The same applies to the farming business. We might have to reduce the amount of land we cover so that we can reduce the amount of input if we are buying a particular fertiliser for a particular price unit.

We are maintaining profitability and also trying to optimise our market.

Kehinde: How do you couple your drones?

Participant 1: We assemble drones. More than 80% of what we use in the production is brought into the country. So Forex will definitely affect us. We then assemble, put them together, make them a whole and a working machine.

Sustainability

Kehinde: The second section talks about sustainability. Are you familiar with the term sustainability? Can you explain what sustainability means to you? When we talk about sustainability, we talk about resource management and risk reduction, reduction of waste, reduction of ecological footprint etc. So what does sustainability mean to you?

Participant 1: For me, as a farmer, sustainability means activities or lifestyle that promotes judicious use of resources while we do not hamper or affect the environment and our ecosystem in general. We are actually having the end in view while we are in the present. Sustainability will also ensure continuity.

Kehinde: What are the methods you are employing to promote agri-food sustainability?

Participant 1: We are contributing to sustainability through our technology. With our technology, we ensure zero net emissions because that's a critical part of sustainability. In terms of energy sustainability, we are not totally dependent on fossil. We have a low footprint in terms of our machines because they are electricity-driven. We take steps to assemble our drones to reduce the cost of production and labour costs. We create job opportunities. Because we reduce the cost of production, we are able to put money in other areas of the business so that we can have a ripple effect.

Economic impact

Kehinde: What do you think is a possible way to increase income and promote the good livelihood of workers and stakeholders?

Participant 1: I think the question is, how do we increase our revenue while we also keep our workers happy?

We are mindful of humanity because our workers and stakeholders serve as the blood that drives the profitability of the revenue by the end of the day. So giving them the right motivation is important. While we can also look to another factor of the production, and see if we can optimise that, while we do not hamper their motivation and personal income, aside from the company's revenue.

Kehinde: What are the ways you can expand your business from the production level and service level?

Participant 1: What we have to do is one, get more funding, increase skills so that we can increase scale? While we are trying to do that, we also need to ensure that there is enough manpower to manage the capital, liquid or capital assets. We are also looking at expanding our business on the other side; we have to work on our market so that we can explore and maximise the demand in the market.

Kehinde: Tell me the plan for financial investment (in machinery, technology, etc.).

Participant 1: We are pushing for investment, equity grant funding and impact investment because we are actually making a real impact in the food chain. So that is our plan. Also, our biggest line is in our revenue.

Kehinde: What are your opinions on loans and grants for agribusiness? Are there available credits for Agribusiness? Is there available credit for Agri-agribusiness in Nigeria? Are they accessible?

Participant 1: Yes, there are accessible loans, but I haven't assessed one. Well, not because they are not available, but sometimes you just have to consider if it is the right option for you at that moment. Perhaps because of the risks. As for grants, we are pushing for grants.

Environmental Impact

Kehinde: Food waste is the major challenge of the agri-food industry. Talk me through the ways you are reducing food waste.

Participant 1: From the technology service that we provide, it is said that 25 to 40% of food is lost to the actions of pests and disease in Africa, amounting to about 200 billion annually. So, imagine the percentage of food lost on the field. That is 1/3 to ¼ of the total production that we should get. This has hampered our potential, you're already on the field. Not to talk of what is left when we stay along the value chain.

We are providing farmers with insight to manage their fields rightly, detect pests early and take crop protection actions like spraying with herbicides and spraying insecticides against pests, weeds and diseases.

Kehinde: Are there information and solutions that can help you detect pests in the field?

Participant 1: With drone technology, we fly the drone; we also have satellite imagery of what we're doing and capture it by monitoring. Through vegetation indices, we are able to understand what is going on with the crops in the field. As a result, we can make an informed guess.

Kehinde: At which point do you generate the most waste in the supply chain?

Participant 1: Mostly on the field.

Kehinde: What are the ways you think technology can help reduce waste?

Participant 1: I think I answered that already

Social Impact

Kehinde: How do you contribute to the employment of young people in your local area?

Participant 1: What we are doing is actually the sexiest and most attractive technology that we are bringing into agriculture. We are increasing the capacity of the youth in terms them closer to technology, creating awareness and demonstration. Basically, from awareness to how they can be experts.

We hope that as we grow, we can employ them in more commercial parts. As for now, we are doing our best to increase their capacity. Technology us attractive and they are coming to us.

Kehinde: What infrastructure (electricity, road, equipment and technology) do you need to do your work effectively?

Participant 1: We definitely need logistics and good roads. Electricity is needed to power our aircraft. Safety equipment and, of course, an internet connection to share and process data.

Kehinde: In your opinion, do you think technology can help promote Sustainability?

Participant 1: We cannot do without technology when it comes to sustainability. Although there's an argument that technology, if misused, might hamper sustainability. But a good use of technology will definitely promote sustainability.

Technology: 4th industrial revolution (Big Data, IoT, Drone, Precision Farming)

Kehinde: Do you use technology? Can you describe the kind of technology you use?

Participant 1: We play in the field of precision agriculture and majorly around drone technology. Our business name is Integrated Aerial Precision, so what we are doing is that we're actually leveraging drone technology and the power of data to generate drone technology, satellite imagery, to be able to empower farmers with aerial intelligence, insights and actions that make smart agriculture possible.

Kehinde: In your opinion, do you think technology (data-driven process) can help promote Sustainability?

Participant 1: Yes, data is key. But in the factor of production that were taught in elementary school, were told there are four (4) factors which are land, capital, entrepreneur and labor. I believe data should be the fifth factor because you cannot get information without data. Data is very key in optimizing resources. Also, the manager cannot do well with all of the rest of the resources if there is no information.

Kehinde: What are the means of data generation you use in your process?

Participant 1: we major use drones, satellite imagery, GIS, or GPS technologies.

Yes, we are all about that, from our name integrated. We want to integrate everything into a system that helps farmers and make their lives easier. I mean if the sensor is communicating with the drone up there and the sensor is communicating with the irrigation, you know, we can have data. We are basically focused on drone right now. We will also be integrating satellite imagery in order to make our work more robust. So, we are we are starting off with that already.

Adoption of technology

Kehinde: Who makes the decision to adopt a new technology in your company?

Participant 1: The management. Although the members of staff can also influence this, depending on their insight and capacity. The point is, do we see value in this technology, and can it deliver?

Kehinde: What are your thoughts on adopting new technology?

Participant 1: It depends on how we bring technology to people, how they see it and how it is presented to them. For example, let us GMOs as a case study. GMOS are actually one of the greatest inventions, but people's perception of how it came into existence and how digital technology is communicated and presented influences the perception and adoption of technology.

Kehinde: Will technological demonstration (In terms of usage and application) promote technology adoption?

Participant 1: I believe so. That has actually happened many times because we have to do a demonstration to farmers before they can say they have adopted it. I think demonstration is a critical part. They can see our digital products on the screen or even by spraying to show how it works.

Kehinde: Do you think an investment in infrastructure affects the adoption of technology?

Participant 1: If there is something more, you get to see it often. The more you see it, the quicker you form opinions, and you get familiar with it. That is what investment does. Without investment, the adoption process will be slow.

Kehinde: Do you think technology will enhance the performance of your production?

Participant 1: Yes

Kenny: Do you think technology will compete with human skills, farmers and supply chain stakeholders?

Participant 1: All we want as farmers is to ensure efficiency on the field. The fact is that we have a labour deficit already in the agricultural sector.

Kehinde: What do you think will be a significant challenge of technology adoption?

- Finance & Investment?
- Infrastructure?
- Lack of skill?
- Perceive usefulness?

Participant 1: All of them, but I think it starts with a positive perception already that creates demand that forces every other element to succumb because the market is king and the customer is king. It doesn't matter where the investment has been made and the infrastructure put in place. Even with the skills and capacities, when there's no market, it all falls apart.

Kehinde: Can we refer to this as passive usefulness?

Participant 1: Yes, the market is king. I will give priority to the market.

Kenny: What are your preferred means of digital and knowledge transfer to a new group of people?

Participant 1: Seeing is believing.

Kenny: How about through websites, institutions and partnerships with universities?

Participant 1: Yes, partnership with relevant organizations enhances early adoption. They can give more validation to users.

Readiness (Network readiness)

Kehinde: How do you plan to acquire the necessary skills if you want to take a new lens of technology in your business? What is your method and plan for acquiring skills?

Participant 1: Learning never stops. For us to improve our value proposition and delivery, we have to keep building capacity and learning. Communication and technical skills are important.

Relating with farmers, we can see how best we can serve them, and that improves our skills. Creation of workshops and conferences is also very important to us.

Kehinde: Do you think Nigeria or Africa have the necessary workforce to pioneer this agricultural revolution?

Participant 1: The working population is available, but there is a skill gap.

Kehinde: What do you think is the role of government and international bodies in promoting technology adoption?

Participant 1: Government can play a role by creating an enabling environment in terms of regulation policies, adoption rate and access to technology. It might also affect skill development. But when there is no good economic policy, how do we then have the funds to pay or to acquire value.

Kehinde: What about the roles of international bodies?

Participant 1: I think they serve as an enabler in the sense that they have the power to bring resources together. They have the power to come down to the grassroots and promote the adoption of technology. They also have the power to increase capacity because they have the expertise and the understanding of the grassroots. They can create programs, structures and influence government policy.

Kehinde: We have come to the end of this interview. Thank you for your time.

Survey Questionnaire & Response

Construct for the driver of sustainability

Questions: What are the drivers of sustainability?

Scale	Climate Change	Food waste	Natural resources degradation	Overpopulation
Strongly Disagree	10.75% participants	17% participants	13.3% participants	12% participants

Disagree	9.5% Participants	31.6% participants	21.5% participants	25.3% participants
Neither Agree nor Disagree	9.5% Participants	13.3% participants	9.5% participants	8.2% participants
Agree	43.6% participants	22.7% participants	33.5% participants	30.4% participants
Strongly Agree	26.5% participants	13.3% participants	21.5% participants	23.4% participants
Total Response	158	158	158	158

Construct for Technology Dividends

Questions: What is the role of technology?

Scale	Digital solutions can promote agri-food sustainability.	Technology can provide Realtime monitoring of environmental conditions.	Adoption of technology can improve the social and economic status of local communities.	Adoption of technology can promote youth employment in the agri-food sector.
Strongly Disagree	3.7% participants	3.7% participants	4.4% participants	3.1% participants
Disagree	3.7% participants	3.7% participants	2.5% participants	3.1% participants
Neither Agree nor Disagree	3.7% participants	4.4% participants	8.2% participants	4.4% participants

Agree	37.9% participants	41.1% participants	40.5% participants	34.1% participants
Strongly Agree	50.6% participants	46.8% participants	44.3% participants	55.1% participants
Total Response	158	158	158	158

Construct for Behavioural Intention

Scale	I intend to use or will continue using technology (IoT, Big Data, and precision Agriculture technologies) in the future.	I always try to use technology(IoT, Big Data, and Precision Agriculture technologies) in every activity across the agri-food supply chain.	I plan to use or continue using Technologies more frequently in the future.	I am going to suggest to the other AFSC actors that they use technology (IoT, Big Data, and Precision Agriculture technologies).
Strongly Disagree	4.4% participants	4.4% participants	2.5% participants	3.2% participants
Disagree	3.7% participants	6.9% participants	1.3% participants	1.3% participants
Neither Agree	10.1%	22.1%	12.6%	6.9% participants
nor Disagree	participants	participants	participants	
Agree	42.4% participants	44.3% participants	44.3% participants	46.2% participants
Strongly Agree	39.2% participants	22.1% participants	39.2% participants	42.4% participants
Total Response	158	158	158	158

Construct for Performance Expectancy

Questions: What are your performance expectations?

Scale	Using the IoT and Big Data technologies will increase my chances of achieving higher production and crop productivity.	If I use IoT and Big Data technologies, I will increase my chances of increasing my income.	Using IoT and Big Data will give me real-time information on the state of my AFSC processes.	Using IoTs and Big Data will make me more efficient and help me make better decisions.
Strongly Disagree	2.5% participants	1.8% participants	2.5% participants	3.1% participants
Disagree	1.2% participants	2.5% participants	2.5% participants	3.7% participants
Neither Agree nor Disagree	6.3% participants	5.6% participants	8.2% participants	8.2% participants
Agree	46.8% participants	50% participants	47.4% participants	42.4% participants
Strongly Agree	43% participants	39.8%	36.7%	42.4%
		participants	participants	participants
Total Response	158	158	158	158

Construct for Effort Expectancy

Scale	My first impression of IoT and Big Data technologies was clear, favourable, and comprehensible.	Learning to use the IoTs and Big Data technologies is easy.	I found the IoT technologies easy to use	Acquiring skills needed for IoT and Big Data technology in the agri-food supply chain is easy.
Strongly Disagree	4.4% participants	3.1% participants	3.7% participants	4.4% participants
Disagree	12% participants	18.3% participants	10.7% participants	11.3% participants
Neither Agree nor Disagree	22.7% participants	23.4% participants	28.4% participants	18.3% participants
Agree	48.7% participants	44.9% participants	46.8% participants	44.3% participants
Strongly Agree	12% participants	10.1% participants	10.1% participants	21.5% participants
Total Response	158	158	158	158

Social Influence Construct

Scale	People who are important to me think that I should use technologies	The people who have influenced my behaviour think that I should use	The people whose opinions are valuable to me prefer to use IoT	The leading agribusiness in the agrifood supply chain is using IoT
	(IoT, Big Data, Precision)	technologies(IoT, Big Data, Precision)	technologies.	technologies.

Strongly Disagree	3.7% participants	3.7% participants	3.7% participants	3.2% participants
Disagree	10.1% participants	10.1% participants	6.9% participants	6.3% participants
Neither Agree nor Disagree	22.7% participants	25.9% participants	25.3% participants	22.7% participants
Agree	46.2% participants	43.6% participants	44.9% participants	44.9% participants
Strongly Agree	17% participants	16.4% participants	18.9% participants	21.5% participants
Total Response	158	158	158	158

Construct User Behaviour (UB)

Scale	I have a clear idea of how to use IoT and Big Data systems in farming, Food Processing, and logistics.	I will use IoT and Big Data technologies in farming/Food Processing/Logistics.	I use all the relevant IoT and Big Data related applications.
Strongly Disagree	8.2% participants	5% participants	5.6% participants
Disagree	27.8% participants	5.6% participants	19.6% participants
Neither nor Agree Disagree	15.8% participants	10.7% participants	22.1% participants
Strongly Agree	37.9% participants	58.8% participants	40.5% participants

Strongly Agree	10.1% participants	19.6% participants	12% participants
Total Response	158	158	158

Enabling conditions construct :

What are the enabling conditions for using technology?

Scale	I have the facilities necessary to use IoT and Big Data technologies relevant to the agrifood supply chain.	I know how to use IoT and Big Data Technologies.	I have the skills required to use IoT and Big Data Technologies.	IoT and Big Data technologies are generally compatible with the other technologies that I use currently.
Strongly Disagree	10.7% participants	6.9% participants	5.6% participants	6.3% participants
Disagree	23.4% participants	17.7% participants	17.7% participants	15.1% participants
Neither Agree nor Disagree	20.8% participants	16.4% participants	18.8% participants	24.6% participants
Strongly Agree	35.4% participants	48.1% participants	48.1% participants	38.6% participants
Strongly Agree	9.4%	10.7%	9.4%	15.1%
	participants	participants	participants	participants
Total Response	158	158	158	158

Technology Cost construct

Questions: Does the cost of technology affect adoption and usage?

Scale	The pr of technology is significant concern usage. for	IoTs, Big Data, and precision technologies are very costly.	I can make financial investments toward technology adoption.
Strongly Disagree	1.8% participants	1.8% participants	2.5% participants
Disagree	3.7% participants	8.8% participants	9.4% participants
Neither Agree or Disagree	3.7% participants	10.7% participants	22.1% participants
Agree	48.7% participants	41.1% participants	46.8% participants
Strongly Agree	41.7% participants	37.3% participants	18.9% participants
Total Response	158	158	158

Drivers of Digitalization construct

Questions: What are the things needed to drive the digitalisation of the Agrifood supply chain?

Scale	investment	Infrastructure	Knowledge	Skill	Access to technology
Strongly Disagree	0.6% participant	1.8% participants	1.2% participants	0.6% participant	1.2% participants

Disagree	3.1% participants	1.8% participants	1.2% participants	0.6% participant	0.6% participant
Neither Agree or Disagree	1.2% participants	3.7% participants	1.2% participants	1.8% participants	3.1% participants
Agree	54.4% participants	55% participants	53.1% participants	54.4% participants	50.6% participant
Strongly Agree	40.5% participants	37.3% participants	43% participants	42.4% participants	41.7%participants
Total Response	158	158	158	158	158