FRAMEWORK FOR SMART SUSTAINABLE FARMING USING THE ARTIFICIAL INTELLIGENCE OF THINGS IN SOUTH AFRICA: A CASE OF SMALL-SCALE PLANT FARMING

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DECLARATION OF WORK AND COPYRIGHT

I, Smile Manganyi, hereby declare that the research project titled "Framework for sustainable farming using the Artificial Intelligence of Things in South Africa: a case of small-scale plant farming." for the Master of Commerce in Business Information Systems at the University of Venda. This is my unique work and has not previously been submitted to this institution or any other higher educational institution. I further declare that all sources cited are indicated and acknowledged by providing a thorough list of references.

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DEDICATION

I dedicate my research to the Almighty God, who provided me with strength, determination, and courage to fulfil my goals. I also dedicate this to my late mother, Joice Mashaba, who brought me up and encouraged me to become the good person I am now and has always been there to guide and motivate me throughout to believe in the value of education, as well as my wonderful family for their unfailing support.

ABSTRACT

The 4.0 green revolution in agriculture, also known as "smart farming," combines agricultural methodologies with technology such as sensors, actuators, information, and communication technology (ICT), the Internet of Things (IoT), robotics, and drones, to achieve desired production efficiencies at controlled costs. It is considered an important factor in disseminating farming to small-scale plant farmers across the globe. Even though some large-scale farmers in South Africa have previously embraced Artificial Intelligence of Things to support their agricultural processes. Small-scale plant farmers are still unable to operate due to some circumstances, such as inappropriate skills, knowledge, and services. There is no proper framework to assist small-scale plant farmers in the Vhembe district of Limpopo to develop a quality and smart farming environment. This study focused on discovering factors that influence the implementation of Artificial Intelligence of Things (AIoT) systems towards small-scale plant farmers and its challenges. The researcher collected data from 10 participants through interviews and guided by a structured interview guide. The collected data was transcribed using Microsoft word and analysed through thematic framework analysis using ATLAS ti. The findings of this study intended to bring new insights and guidelines to small-scale plant farmers on the best method to utilise AIoT tools and skills they would require throughout. The study recommended that the government must assist the small-scale farmers with funding, maintenance and awareness towards the automation of their farms. The study found that AIoT is an essential tool for sustaining farming. The findings revealed that the effective adoption of AIoT shall improve productivity and sustainability for small-scale farmers to serve the globe without relying solely on commercial farms. Eventually, this study proposed a framework for smart sustainable farming specified at integrating farming practices, technologies and its stakeholders based on the UTAUT model.

Keywords: *Artificial Intelligence of Things, Smart farming, Artificial Intelligence (AI), Internet of Things, Small-scale plant farmers.*

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LIST OF ACRONYMS AND ABBREVIATIONS

- AIoT – Artificial Intelligence of Things
- ICT- Information Communication Technology
- AI – Artificial Intelligence
- IoT – Internet of Things
- WSN - Wireless Sensor Network
- UTAUT - Unified Theory of Acceptance and use of Technology.
- ATLAS.ti - Archive of Technology, Life world and Language for text interpretation.
- ML – Machine Learning

CHAPTER ONE: INTRODUCTION AND BACKGROUND OF THE STUDY

1.1. Introduction

Agriculture is the basis of human life, the fundament of survival, and the primary condition of all production (Dharmaraj & Vijayanand, 2018). According to Food and Agriculture Organisation (2017), Global food production must expand by 70% by 2050 to feed the world's rising population, which is estimated and expected to reach 10 billion by then. During that time, land under cultivation will only rise by 4% (Dharmaraj & Vijayanand, 2018). Although the area of arable land does not increase, soil and environmental health are under strain owing due to changes in diets, increases in water demand, climate change, and animal illnesses (Chandra & Collis, 2021). The goal to revolutionise traditional farming to smart agriculture has to be achieved to increase productivity and cater population in the world (Ayaz, Ammad-Uddin, Sharif, Mansour, & Aggoune, 2019). Smart agriculture incorporates automated technology into agricultural practices, allowing for better overall farming operations, and administration and enabled farmers to initiate more intelligent decision-making (Kamilaris, Gao, Prenafeta-Boldu, & Ali, 2016).

According to Friha, Ferrag, Shu, Maglaras, and Wang (2021), there have been four main revolutions or development in the agricultural sector, namely the age of traditional agriculture featured by humans (rated 1.0). They further demonstrated the age of mechanise farming which was featured by the rumbling sounds and rated at 2.0. Automated agriculture has shown a rapid development in farming methodologies (rated 3.0). The age of smart agriculture was rated 4.0 which the study focused on. Smart agriculture is featured by the Internet of Things (loT) and Artificial Intelligence (AI) systems.

To end severe poverty and hunger throughout South Africa and across African continent, sustainable farming techniques has to be promoted and the developed in rural regions (Mugambiwa, & Tirivangasi, 2017). According to (Sidek, 2019), When AI is integrated with IoT, things become more intelligent, and comprehensible decisions are made without human involvement. The technology has been effectively utilised in several fields, including smart cities, healthcare, and residences (Kamilaris, Gao, Prenafeta-Boldu, & Ali, 2016).

Digitising the food chain process can lead to increased efficiency, transparency, equity, and profitability. According to Chandra and Collis (2021), the majority of these improvements are aimed at high-income countries (HICs) and big commercial agricultural supplies. Shepherd (2016), demonstrated that small-scale farmers frequently produce for personal use. However, according to Ndlovu and Masuku (2021), many small-scale farmers sell their products to the informal markets solely within their own communities. They further stated that small farmers lack a regular and planned market link that ensures trades and purchases occur. Smallholder farmers are barred from many of the most profitable routes, such as direct sales to supermarkets and exports, because they lack managerial skills (Ndlovu et al., 202). To feed the growing population, support economic growth, and close food shortages, small-scale farmers must invest in their companies and embark on smart farming.

1.2. Background of the Study

Sustainable Agriculture is a key component of the global gross domestic product and a substantial global driver of economic growth (Priya & Kaur, 2021). Artificial Intelligence of Things is a mix or combination of artificial intelligence technology and internet of things infrastructure to produce more effective IT operations, increase human-machine interactions, and optimise data management (Haqiq, Zaim, Bouganssa, Salbi, & Sbihi, 2022). Both AI and IoT aid in gathering values from sensors, processing that obtained data, and recognising the relevant aspects, which eventually helps in the forecast of temperature and rainfall as well as crop production, weed control, soil management, water management, and crop diseases (Aggarwal & Singh, 2021). AI and IoT give a significant relief to farmers which automates almost the whole agriculture process (Aggarwal & Singh, 2021). Previously, agricultural society used to have more than 75% of the total labour force (Chand & Srivastava, 2014). However, as many countries began to develop, the manual labour force has been declining due to technological advances. Developed countries such as United Kingdom has high production output since the technological innovations are deployed and help in reducing the input costs and efficiency of the overall production factor (Korkmaz, 2017). According to Mbatha (2020), South Africa's agriculture industry contributes less to GDP than other sectors such as mining, manufacturing, energy, and education etc. Since 1994, the year of South Africa's first democratic elections, its agricultural percentage contributed to GDP has decreased from 3.9 percent to 2 per cent in 2018 (Sibeko & Isaacs, 2020).

Matsimbi (2020) stated that 21% of South African citizens were food insecure. Inadequate social welfare may lead South Africa to a significant risk of food insecurity (Masipa, 2017). AIoT enabled precision to small-scale farmers the potential to boost livelihoods and hasten the transition of low- and middle-income nations to self-reliance (Antony, Leith, Jolley, Lu, & Sweeney, 2020). The research intends to determine the impact of several significant factors which includes effort and performance expectations, enabling conditions, technical aspects, internet access costs, and socio-cultural issues) on the behavioural intention and actual use of AIoT or agriculture 4.0 in South Africa, Vhembe District of Limpopo Province.

1.3. Problem Statement

The rapid growth of the human population in the world has increased food demand and supplies for human survival (Bradford, 1999). Despite the successful innovation and implementation of smart agriculture in developed countries and large-scale farmers in South Africa and other countries, small-scale plant farmers face several obstacles that prevent the expansion of their agricultural activities (López, Figueroa & Corrales, 2021). According to Antony, Leith, Jolley, Lu, and Sweeney (2020), these challenges include limited access to business information, pressures on farmland from population growth, resource optimisation, climate change, lack of exposure, market exposure and prices and lack of their involvement in the initial stage of the invention process. Additional challenges include bureaucracy, poor trust and transparency, and improper use of an international and foreign language—English—in a context that is culturally specific to the area.

Sub-Saharan African countries rely heavily on rain-fed agriculture, making climate variability, climate change, and food insecurity a significant danger to their farming communities (Zheleva, Bogdanov, Zois, Xiong, Chandra & Kimball, 2017). Small-scale plant producers do not have access to the most up-to-date agricultural information, such as input or market costs and the most profitable marketplaces to sell their products (Aggarwal & Singh, 2021). Small-scale farmers lack the experience or skills to use the latest technologies, and that most find it difficult to take advantage of these systems and effectively use them to access the most up-to-date farming information (Balyan, Jangir, Tripathi, Tripathi, Jhang, & Pandey, 2024). Small-scale farmers have challenges in making appropriate decisions on agriculture and production management due to the growing number of stakeholders and available information (Gagliardi, Cosma, & Marasco, 2022).

A human-computer system that analyses heterogeneous data and gives farmers a list of recommendations to help them make decisions under various circumstances is known as a decision support system for agricultural applications (Taechatanasat & Armstrong, 2014). AIoT applications have the potential to boost production and possibly helps small-scale plant farmers with drones for plant protection, fertiliser application, crop health monitoring, greenhouse culture, smart farm equipment, weed and insect control, irrigation systems, and storage buildings (Subeesh & Mehta, 2021). According to Güven, Baz, Kocaoğlu, Toprak, Erol Barkana, and Özdemir (2023), farmers may use mobile devices and wireless networks to track their farms in order to monitor field characteristics and safeguard plants that lead to sustainable food production and the elimination of poverty.

There is, however, a paucity of studies detailing the results and difficulties of using the AIoT in small-scale farming. Thus, in order to determine what elements are necessary for developing a framework for smart farming and successfully applying AIoT to small-scale plant farming, the study used a case study of small-scale farmers in the Vhembe District of Limpopo.

1.4. Aim and Objectives

Subsection 1.4.1 and 1.4.2 gives the aim and objectives of this study respectively.

1.4.1. Research Aim

This study aims to propose a framework for smart sustainable small-scale plant farming considering the implementation of the internet of things and artificial intelligence to enhance productivity, reduce efforts on time-consumption, simulation, and improve farming practices in the Vhembe Rural District of Limpopo Province.

1.4.2. Objectives:

The objectives are as follows:

- To determine the usage of Artificial Intelligence of Things systems by small-scale plant farmers.
- To adjudicate hindrance factors in the use of AIoT by small-scale plant farmers in Vhembe District.
- To identify the perception of small-scale plant farmers towards the adoption and use of the Artificial Intelligence of Things for sustainable farming.
- To propose a framework using the Artificial Intelligence of Things that could be used by small-scale plant farmers for sustainable farming in the Vhembe Rural District.

1.5 Research Hypothesis.

The following are hypotheses of the study:

- H_1_0: Performance expectancy does not have a significant influence on behavioural intention towards AIoT technology for sustainable farming.

- H_1_1: Performance expectancy have a significant influence on the intention to use AIoT technology to sustainable farming.
- H_2_0: Effort expectancy does not have a significant influence on behavioural intention towards AIoT technology for sustainable farming.
- H_2_1: Effort Expectancy have a significant influence on the intention to use AIoT technology for sustainable farming.
- H_3_0: Facilitating conditions does not have a significant influence on the behavioural intention to use AIoT technology for sustainable farming.
- H_3_1: Facilitating conditions have a significant influence on the intention to use AIoT technology for sustainable farming.
- H_4_0 : Price value does not have a significant influence on the behavioural intention to use AIoT technology for sustainable farming.
- H_4_1 : Price Value have a significant influence on the intention to use AIoT technology for sustainable farming.
- H_5_0: Socio-cultural value does not have a significant influence on the behavioural intention to use AIoT technology for sustainable farming.

  H_5_1: Socio-cultural value have a significant influence on the intention to use AIoT technology for sustainable farming.
- H_6_0: Technical information does not have a significant influence on the behavioural intention to use AIoT technology for sustainable farming.
- H_6_1: Technical Information have a significant influence on the intention to use AIoT technology for sustainable farming.
- H_7_0: Behavioural intention towards AIoT does not have a significant influence on the Use behaviour of AIoT for sustainable farming.
- H_7_1: Behavioural intention towards AIoT have a significant influence on the Use behaviour of AIoT for sustainable farming.

1.6 Significance of the study

The study's relevance stems from its ability to promote sustainable farming and solve the issues confronting small-scale farmers in South Africa. As a result, it increases production and efficiency, allows for data-driven decision-making, and encourages the use of sophisticated agricultural technology. If the smart agriculture is successfully implemented, it can lead to the development of the economic agricultural systems in rural regions of South Africa and other countries. Smart Agriculture provides benefits such as economic competitiveness, addresses environmental challenges and improves the performance, quality and volume of production (Alreshidi, 2019). Small-scale farmers may maximise their potential while reducing costs and time by understanding all of the issues before implementing smart agriculture and employing a framework designed for sustainable farming using AIoT.

This study highlighted elements to consider when adopting smart sustainable farming and gave appropriate guidance towards an optimum solution that minimises risks while maximising the potential of agricultural digitalisation. The study targeted small-scale plant farmers in South Africa, as main participants. With the little literature published in Vhembe District of Limpopo Province, the findings of this study contribute to the knowledge base and the findings of the study can also be applied to other rural regions of South Africa.

1.7 Scope of the study

This research focused on the implications of digital technology, particularly smartphones, mobile apps, and hardware such as intelligent boards, sensors, smart agricultural vehicles, cloud computing, and drones. The target demographic for the study is small-scale plant growers in the Vhembe District of Limpopo Province. The study analysed potential advantages and difficulties to identify the region that needs to be focused on in order to maximise potential. It takes into account small-scale farmers' perceptions and sustainability of the usage of AIoT for sustainable farming.

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1.8 Limitations of the study

The sample population was limited to geographical locations that were within the researcher's financial means. Respondents may have rejected to participate or expressed dishonest opinions, resulting in mistakes. Another constraint was time since the researcher needed to finish the investigation, collect data, wait for a response, analyse the data, and deliver results within a specific time frame. As a result, the study is confined to small-scale plant farmers in South Arica, Limpopo Province, Vhembe District.

1.9 Operational definitions

Operational definition provides an obvious, specific, and communicative meaning to a concept utilised to assure thorough understanding of the idea by explaining how the notion is assessed and used in this particular research.

The following are the operational definitions:

- Small-scale plant Farmers

Muzekenyi, Zuwarimwe & Beata, (2019), defines small-scale plant farmers as all other producers who own small-scale field of land on which they produce livelihood plants and depend mostly entirely on household labour. According to Ndlovu and Masuku (2021), many small-scale farmers sell their products to the informal markets solely within their own communities. In the context of this study, small-scale farmers refer to subsistence farmers cultivating on less than 10 hectors, run by one or two households or employed less than ten workers.

- Artificial Intelligence (AI)

AI is a technology that aims to make computers do human-like reasoning. According to (Alreshidi, 2019), AI's are robots or machines deployed to monitor everyday life. In the context of the study AI's machines helps in monitoring crops and soil health without human interference.

- Internet of Things (IoT)

Defined as a network of physical devices, automobiles, appliances, and other physical items that are integrated with sensors, software, and network connectivity to gather and exchange data (Perwej, Haq, Parwej, Mumdouh, & Hassan, 2019). In this study, IoT is the sensing and monitoring of production, which includes crop development, food processing, and the use of farm resources. It also refers to a better understanding of the unique farming conditions, such as weather, environmental factors, weeds, and diseases, as well as more advanced and remote control of farm, processing, and logistics operations using actuators and robots.

- Artificial Intelligence of Things (AIoT)

Within the framework of the research, artificial intelligence (AI) and the Internet of Things (IoT) are combined to increase operational efficiency, human-machine interactions, and enhance data management and analytics.

- Sustainable farming

Alshaal and El-Ramady (2017), described sustainable farming as an interrelated solution for long-term agricultural operations and satisfying society's current food and textile demands without jeopardising the current or future generations' capacity to fulfil their own needs. In the context of this study, sustainable farming is a production of plants continuously while maintaining a good economic return.

- Smart Sustainable farming

Refers to a technique for managing farms and preserving resources by utilising advanced AIoT applications to increase productivity (Adli, Remli, Wan Salihin Wong, Ismail, Gonzalez-Briones, Corchado and Mohamad, 2023). In the context of this study, systems are deployed to monitor and manage the whole farm such as harvesting, crop management, and automatic irrigation process and water usage.

1.10 Outline of the Study

Chapter 1: Introduction

This chapter provides a brief overview to this research study, covering the background to the study, the problem statement, aim and objectives, research questions, and a proposition to structure the research report of this study.

Chapter 2: Literature Review

This chapter comprises of a review on existing knowledge in this field of study from a variety of sources which are directed by the objectives of the research study.

Chapter 3: Research Methodology

This chapter describes the research strategy and technique in depth. It determined the research methodology, data gathering processes, data collection equipment and techniques, and data analysis based on the study's objectives.

Chapter 4: Presentation of research findings

This chapter discusses and presents the analysis and outcomes of the data gathered using appropriate research instruments.

Chapter 5: Summary, conclusions and recommendations.

This chapter covers the findings, conclusions, future recommendations and a framework for the sustainable farming using Artificial Intelligence of Things towards small scale farming.

1.11 Summary

In summary, this chapter provides an outline of the research that would be undertaken in this study. It included a quick rundown of the research study's history, issue description, research scope, and motivation for the inquiry, research objectives, and hypothesis. It also gave a quick overview of the research. It also highlighted how the study endeavour will contribute to the body of knowledge and help to solve societal problems. The research design is also supplied. The definitions of basic words or concepts are also provided. The next chapter contains literature reviews.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

A literature review examines additional sources of data from an existing knowledge base that are consistent with the research study to support the creation of a research topic, objectives, questions, and the importance of the study (Fischer, 2008). The review of literature is imperative as it also provides the basis for understanding the subject matter comprehensively. This chapter provides a literature review, on the adoption of Agriculture 4.0 (A_4.0) by small-scale plant farmers. The existing literature on digital technology, such as Artificial Intelligence of Things, is thoroughly studied and integrated in light of the study's objectives.

Overview of Agriculture 4.0 Evolution.

The following sub-sections briefly describes the agricultural evolution:

Agriculture 1.0

Zhai, Martínez, Beltran, Martinez and Nestor (2020) alluded to the evolution of Agriculture 1.0 to 4.0 which was characterised by evolution of advanced technologies and their applications. The 1st industrial revolution known as Agriculture 1.0 (A_1.0) was introduced 10,000 before this century. Agriculture 1.0 referred to as the traditional agricultural era, using basic tools such as sickles and shovels in agricultural tasks, which rely heavily on manpower and animal forces (Zhai et al., 2020). As a result, production remained low until the 19th century, when Agriculture 2.0 (A_2.0) was introduced.

Agriculture 2.0

According to Zhai, Martínez, Beltran, Martinez and Nestor (2020), under A_2.0, the steam engines were developed and extensively exploited to give new powers in many spheres of agriculture and other sectors of the economy. These agricultural machinery under A_2.0 were operated manually by farmers with plenty of chemicals used. Nonetheless, this era has increased the efficiency and productivity in farming (Zhai et al., 2020). Despite this significant advancement, A_2.0 resulted in negative repercussions such as chemical contamination in the field, degradation of the natural environment, excessive electrical use, and wastage of natural resources (Zhai et al., 2020).

Agriculture 3.0

Agriculture 3.0 (A_3.0) evolved during the 20th century because of the fast growth of computing and electronics. The advancement of Information Communication Technology and computer algorithms has enabled agricultural machinery to conduct activities better, effectively and intelligently (Pech, & Vrchota, 2022).

Agriculture 4.0

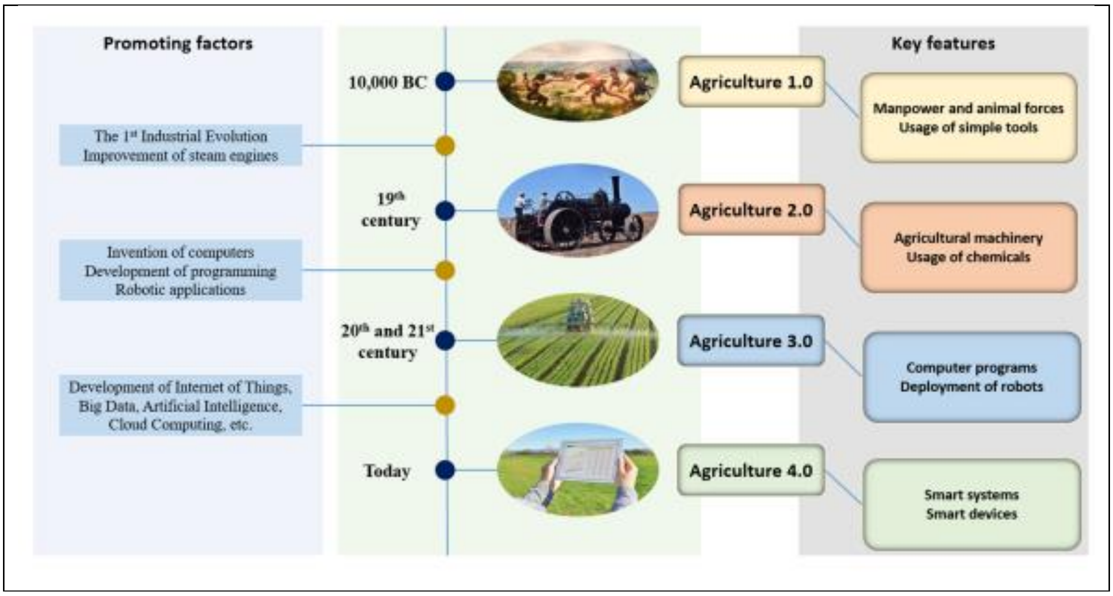

Figure 2.1 Evolution Framework of A_4.0 (Zhai, Martínez, Beltran, Martinez and Nestor, 2020).

Figure 2.1 shows the evolution of agriculture as it transformed into Agriculture 4.0, also known as Smart-Farming where smart systems and smart devices were extensively used. This involves incorporating sophisticated technology and digital solutions into agricultural processes, which have increased efficiency, sustainability and production in the farming industry (Maffezzoli, Ardolino, Bacchetti, Perona & Renga, 2022). Specifically, Agriculture 4.0 involves the use of cutting-edge technologies such as the

Internet of Things, cloud computing, big data, artificial intelligence, robotics, wireless networks, and other automated applications:

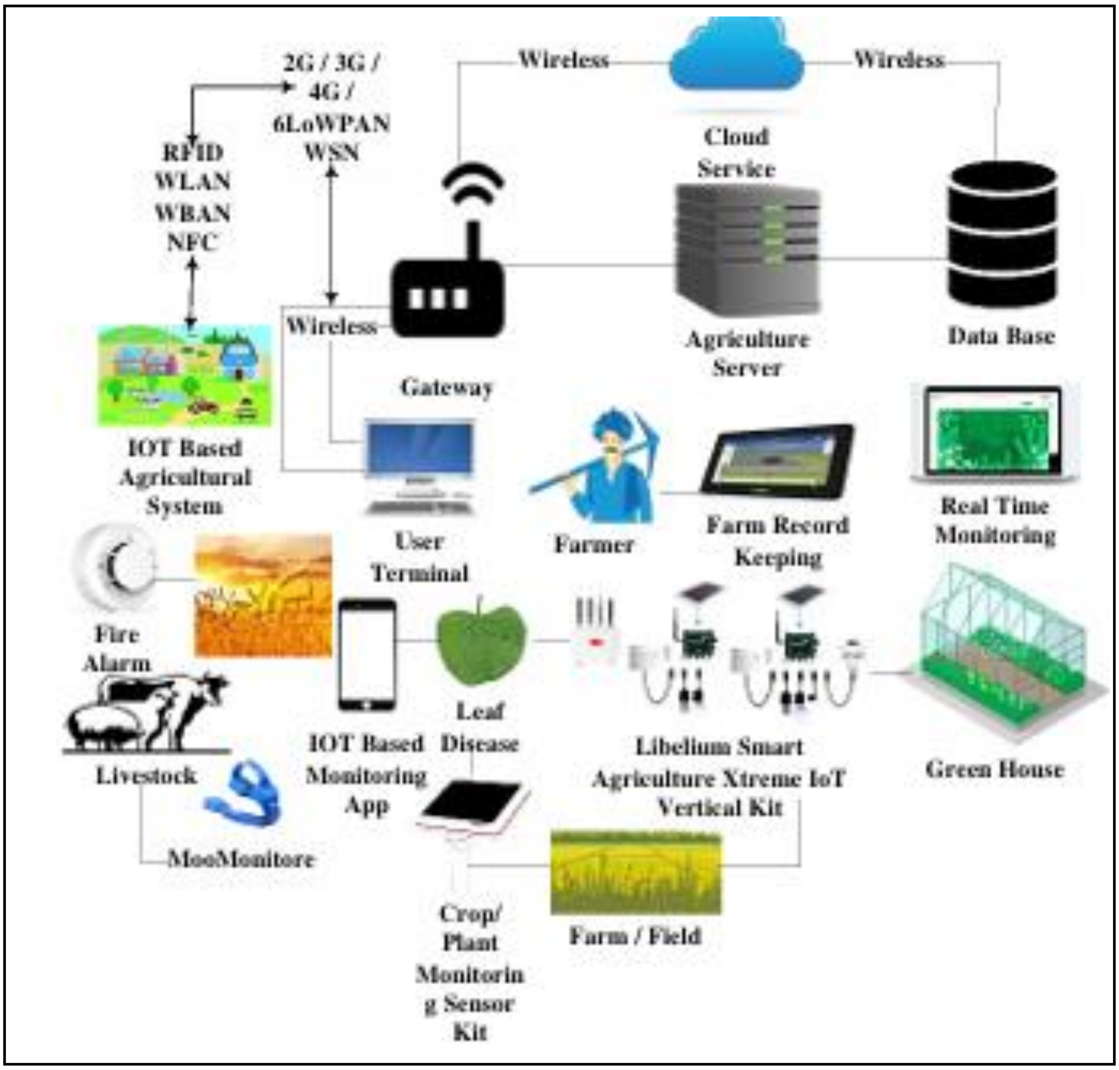

Figure 2.2 Agriculture_4.0 architecture (Farooq, Riaz, Abid, Abid, and Naeem, 2019).

2.1.1 Key components and benefits of Smart Agriculture (4.0)

Various key components and benefits of Agriculture 4.0 (see Figure 2.2) are discussed under the following sub-titles:

a. Wireless Sensor Network (WSN)

According to Farooq, Riaz, Abid, Abid, and Naeem (2019), Wireless Networks for agriculture include a variety of long and short-range communication networks. They further alluded that the communication protocol is the core of the IoT agricultural network, and that all agricultural data and information requested by AIoT apps are exchanged wirelessly over the network. In Figure 2.2, equipped sensors called Libelium IoT vertical kit were used underground to collect data and transform the information wirelessly to the agricultural servers which are interconnected with monitoring applications. With its high degree of automation, this Internet of Things kit can quickly transmit raw data to a local or distant server while conducting extensive environmental condition monitoring at the field, greenhouse, and ground level (Friha et al., n.d.).

b. Remote monitoring and control

These offer a framework for farmers to use web-based interfaces such as mobile apps, to remotely monitor and control crops across farms (Alam, Tushar, Zaman, Gonzalez, Bari & Karmaker, 2023). In Figure 2.2, The IoT based monitoring app keeps a track of farm operations, receives real-time alerts and notifications, and makes informed decisions even when they are not physically present on the farm (Farooq et.al, 2019). Using a real-time data and powerful analytics, farmers can implement accurate and precise irrigation schedules, implement integrated pest management strategies, and adopt conservation practices (da Silveira, da Silva, Machado, Barbedo & Amaral, 2023).

c. Internet of Things

IoT is one of the main or key components of Agriculture 4.0. IoT gadgets like smart sensors, drones, wireless networks, and digitally enabled weather stations are set up to gather information on crucial aspects like crop health, soil moisture, temperature, and humidity (Abbasi, Martinez & Ahmad, 2022). The data is sent wirelessly to a central hub known as cloud for analysis and processing the vast amount of data before it reaches the farmers through mobile devices (Friha, et.al, 2021). A variety of IoT-based smart agricultural applications are shown in Figure 2.3.

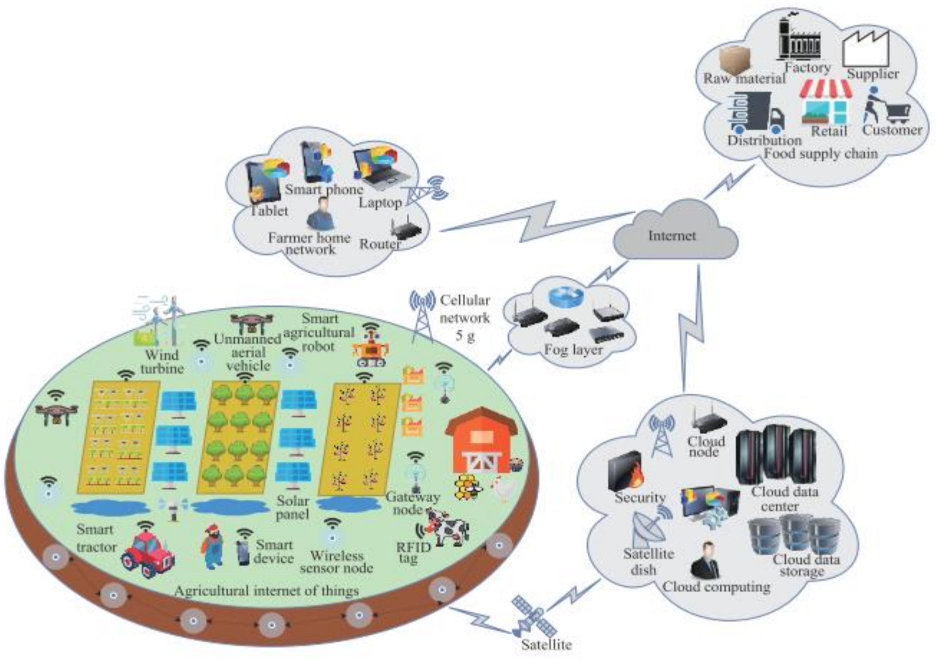

Figure 2.3 IoT-connected smart agriculture sensors (Friha, Ferrag, Shu, Maglaras and Wang, 2021).

d. Artificial Intelligence

Machine learning (ML), Deep learning and series analysis play critical roles in smart farming. For example, various soils are ideal for different crops, thus farmers must carefully choose the appropriate area depending on crop productivity. According to Akkem, Biswas, & Varanasi (2023), machine learning classification algorithms can be used to determine whether the land is suitable for a particular crop, and a machine learning regression method can determine the required or needed water resource level. In figure 2.3, Radio Frequency identification tag (RFID) was used to track the individual cattle's location using mobile devices to prevent theft in a large farm (Friha, Ferrag, Shu, Maglaras & Wang, 2021). They further used these smart-phones, tablets and laptops in Figure 2.3 to access information from the database to analyse the anticipated agricultural demand in products and services, supplies and commodity's prices from the markets.

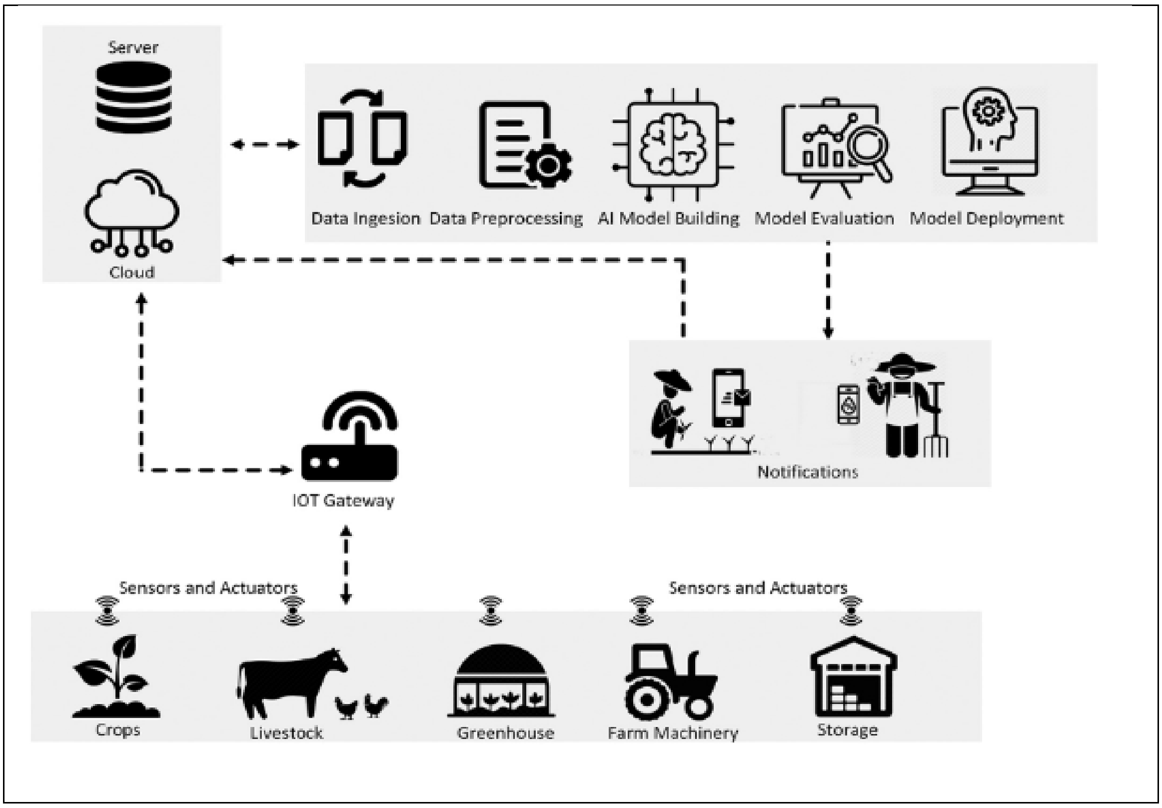

Figure 2.4 Generalised Artificial intelligence/machine learning workflow for agricultural solution (Subeesh & Mehta, 2021b).

e. Cloud Computing

According to Javaid, Haleem, Singh, and Suman (2022), the capacity of conventional database is not enough to manage the amount of data produced by Internet of Things devices. Thus, cloud-based data storage is a crucial component of smart agricultural system. In Figure 2.4, the cloud storage layer consolidates all agricultural data in the cloud, including weather, soil, fertiliser, crop, and agricultural marketing data, and distributes on-demand resources via networked infrastructure (Subeesh & Mehta, 2021b). Cloud services can also access analytics resources and web services kept in the cloud or on the internet (Figure 2.3).

f. Big Data Analytics

Big Data refers to information assets that have such a high volume, velocity, and variety that they require specialised technology and analytical methodologies for value development (Wolfert, Ge, Verdouw & Bogaardt, 2017). They further demonstrated that intelligent machines and sensors increases the amount and scope of farm data, leading to more data-driven and data-enabled operations. Big Data analytics analyses gathered data with advanced and sophisticated algorithms and machine learning methods to provide valuable insights (Javaid, Haleem, Singh & Suman, 2022). Thus, it was further hinted that data analytics is used to help with the analysis of weather conditions, animal situations, and agricultural conditions.

2.2 Traditional farming vs. Modern farming.

Traditional farming is the original style of agriculture that has been practised for thousands of years and is the most ancient food-producing technique (Shakeel, 2018). Modern farming entails farming using new and sophisticated techniques and technology. This entails farming with the aid of contemporary science and technology. Within the context of technology and equipment, traditional farming relies on manual labour and basic tools such as hand tools, animal-drawn ploughs, and simple irrigation systems (Tandup, 2023). Modern farming, on the other hand, utilises advanced machinery and equipment such as tractors, combines, precision irrigation systems, and automated machinery (Seufert, Austin, Badami, Turner & Ramankutty, 2023). (Seufert, et. al, 2023) further said that Modern farming also incorporates technologies like GPS, sensors, and drones for monitoring and data collection.

In the context Vhembe District, a traditional farming is often practiced by small-scale farmers, with limited land and resources. It is typically more labour-intensive and focuses on subsistence or local markets. Modern farming, in contrast, often involves large-scale operations with mechanised processes and optimised resource utilisation (Shakeel, 2018). It aims for increased productivity and efficiency to meet the demands of a global market. Another key difference is with regard to crop selection and diversity (Neethirajan, 2020). This implies that traditional farming tends to prioritise local or indigenous crops that are well-suited to the local environment and cultural preferences. It often emphasises crop diversity and relies on traditional knowledge and practices.

Furthermore, in the context of input usage and chemicals, traditional farming methods often rely on organic fertilisers, crop rotation, and natural pest control methods while modern farming, relies on synthetic fertilisers, pesticides, and herbicides to maximise yields (Seufert et al., 2023). Traditional farming is comparable to organic farming where a farmer has a mixed farm with plants, climbers, and creepers also livestock. Traditional farming tolerated an unpredictable environment whereas, the modern farming provided predictable environment through weather forecasting (Karkhile & Ghuge, 2015).

2.3 Applications of IoT and AI in agriculture automation

Agricultural automation may be revolutionised by the use of AIoT in farming, and it is already making progress in this area. AIOT is defined as a network of physical items, or "things," that are linked together and have the capacity to exchange data, gather information, and interact with their surroundings (Matta & Pant, 2019). The AIoT helps farmers collect a range of data by monitoring and controlling the entire farm using various tracking devices and sensors, and before being stored on a media storage, the collected data is analysed in order to perform sophisticated decision-making tasks (Alreshidi, 2019). Some of these applications are discussed in the following sub-sections:

2.3.1 Irrigation systems

Within the context of precision farming, according to Araújo, Peres, Lidon, Barata and Ramalho (2023), the analysis of data from sensors, satellites, and drones to provide real-time data about soil conditions, moisture levels, and crop health. This enables farmers to adjust irrigation, fertilisation, and pesticide usage, resulting in less resource waste and higher crop yields.

Kumar (2019), suggested an irrigation system using sensors and machine learning algorithms to predict previous actions, crop rotation, water management, harvesting time, and optimal planting.

Figure 2.5 shows the effective usage of water using moisture sensors and pump monitors which are vital to optimise irrigation. The "per drop more crop" technique has been recognised as the best way to make use of the limited water supplies (Subeesh & Mehta, 2021a). Despite the fact that technical interventions for effective water management have been ongoing for some time, the emergence of IoT has significantly elevated both the operation and management of water systems:

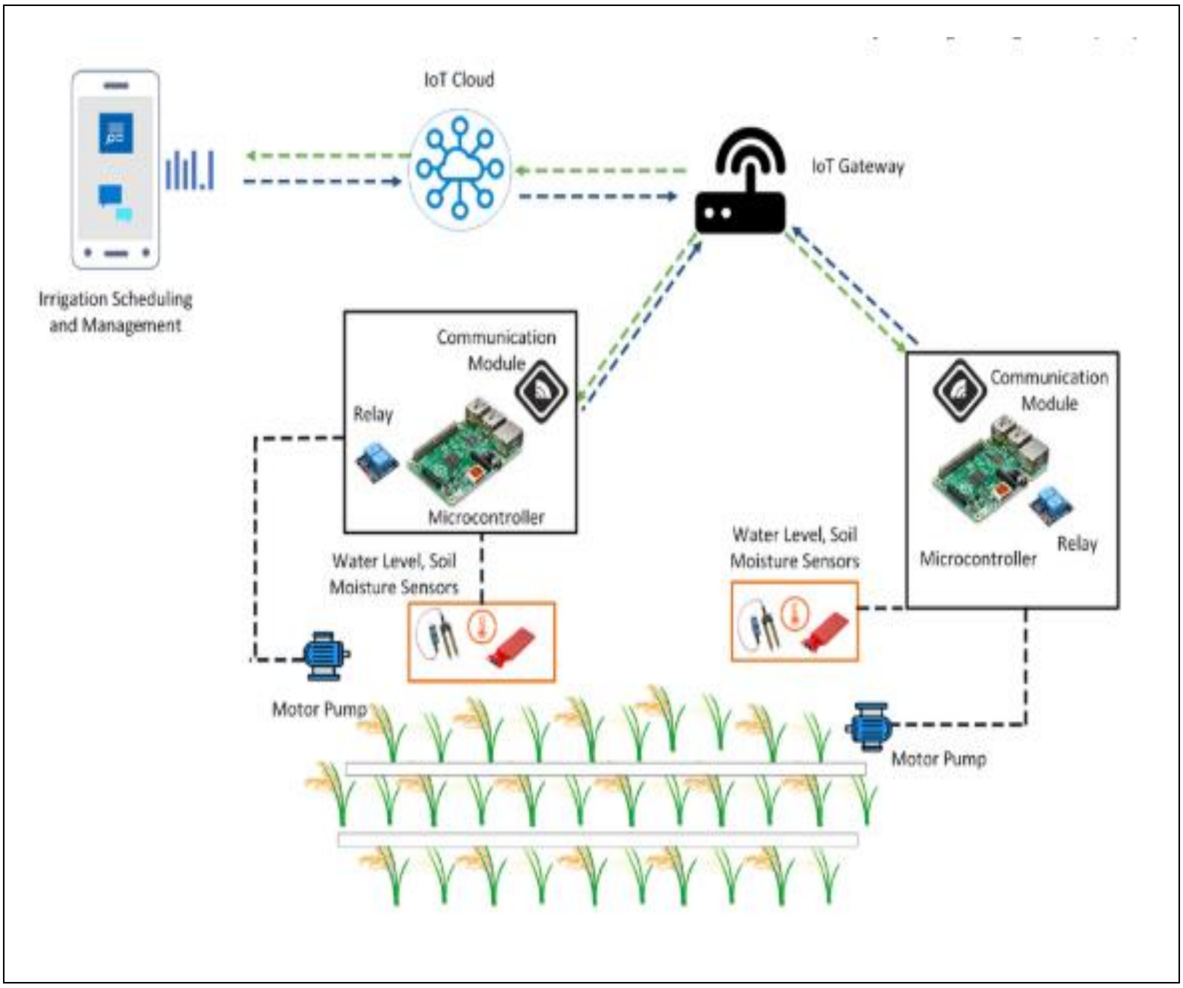

Figure 2.5 Automated Irrigation systems by (Subeesh & Mehta, 2021b)

2.3.2 Crop disease detection.

Klerkx, Jakku and Labarthe (2019) postulated that AI algorithms can analyse images of crops to identify early signs of diseases or pests. This means that by detecting these concerns at an early stage allows farmers to take focused actions, such as applying localised treatments, to prevent the spread and minimise the use of chemical interventions. This ultimately results in improved farming. “SATURAS" and Stem Water Potential (SWP) technology-based technique is introduced for water requirements in fruit cultivation. Sensors are installed on the stem rather than branches, leaves, or soil to ensure precise and exact water monitoring system (Vincent, Deepa, Elavarasan, Srinivasan, Chauhdary, & Iwendi, 2019). Additionally, farmers benefit from a low-cost approach that uses only 1-2 sensors per acre. Thus, the farmer receives a message telling him to take further action in the event that any anomalies are found on the plants.

2.3.3 Yield prediction.

Within the context of yield prediction, Rose and Chilvers (2018), indicated that AI algorithms can use historical and real-time data on weather patterns, soil conditions, and crop traits to effectively anticipate agricultural yields. The information through smartphones or monitors helps farmers plan their harvest, manage storage facilities, and estimate market supply, reducing food waste and increasing efficiency (Rose, Wheeler, Winter, Lobley & Chivers, 2021). The growth trend is detected using a machine-learning model based on data from sensors. Kumar, Chowdhary, Udutalapally, Das, & Mohanty, 2019), developed an IoLT (Internet of Leaf Things)-based crop growth monitoring system (gCrops) that captures photos of leaves with a camera and an ultrasonic sensor to track leaf development in real-time. The algorithm forecasts the age of the leaves based on their length (Kumar et al., 2019). The results revealed 98% accuracy in determining leaf development, health, and maturity, hence improving crop quality and yields.

2.3.4 Smart pest control

The AI-powered systems can monitor pest activity and create predictive models based on environmental factors and pest life cycles (Ozdogan, Gacar & Aktas, 2017). Instead than depending entirely on broad-spectrum insecticides, farmers may now use specialised treatments such as pheromone traps or beneficial insect release. Puranik, Ranjan, & Kumari (2019), proposed Internet of Things based solution for automated agriculture, with the help of Arduino UNO device that has a communication chip such as GSM module to manage water, monitor crops, control pesticides and insecticides.

2.3.5 Automated weed management

Zhai, Martinez, Beltran and Martinez (2020) postulated that AI technologies, including computer vision and machine learning, can identify and differentiate between crops and weeds. This enables autonomous or semi-autonomous robotic systems to precisely apply herbicides only where needed, reducing chemical usage, and minimising the environmental impact.

2.3.6 Efficient resource allocation

Klerkx, Jakku and Labarthe (2019), implied that AI systems can optimise the distribution of resources, such as water, electricity, and fertilisers, by considering various factors like crop type, growth stage, and local weather conditions. This means that by using resources more efficiently, farmers can reduce costs, conserve natural resources, and minimise environmental pollution.

2.3.7 Livestock monitoring

Eastwood, Edwards and Turner (2021), are of the view that AI systems equipped with sensors and computer vision can monitor livestock health, behaviour, and feeding patterns. Hence by detecting early signs of disease or distress, farmers can intervene promptly, improving animal welfare, reducing mortality rates, and optimising feed efficiency. Automated systems can gather data on the status of the cattle by enabling sensors like accelerometers, pedometers and temperature sensors and record activity duration and patterns change from normal conditions during oestrous and calving events (Subeesh & Mehta, 2021a).

According to Subeesh and Mehta (2021), smart collar system was designed for smart dairy management, as shown in Figure 2.6. Eventually, automated systems gather data on the status of the cattle by employing sensors like accelerometers, pedometers and temperature sensors. During oestrus and calving, their activity duration and patterns differ from those in normal conditions. The AI model utilises the data obtained in the cloud to examine this pattern, check for irregularities in the activity, and conclude that the cow is going through calving or oestrous (Subeesh & Mehta, 2021b).

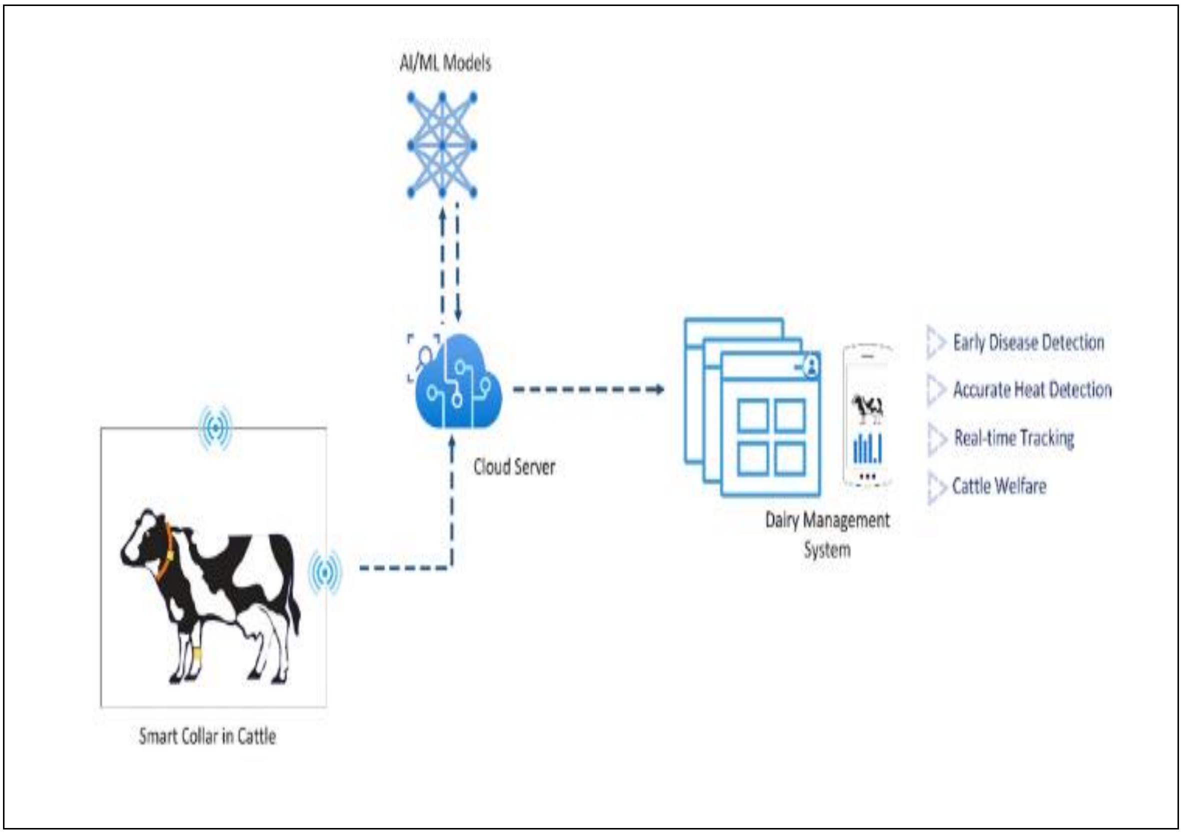

Figure 2.6 Smart collar system for smart dairy management (Subeesh & Mehta, 2021b).

2.3.8 Greenhouse monitoring

Greenhouse refers to the glasshouse technology that gives benefits for growing plants anytime and anyplace by monitoring adequate environmental conditions (Benyezza, Bouhedda, Kara & Rebouh, 2023). Numerous research on Wireless Sensor Network (WSN) usage in greenhouses has been done to monitor environmental or meteorological conditions.

According to Farooq, Riaz, Abid, Abid, and Naeem, (2019), Wireless Sensor Network is essential to be deployed in monitoring greenhouse conditions. Figure 2.7 shows how data acquired by sophisticated sensors and detectors was delivered to the main server for processing. Sensors and networks for reliable data transfer are critical components in physical implementation. Figure 2.7 depicts how AIoT may be used in greenhouses to reduce human resource requirements, accumulate energy, and establish a direct communication between ranchers and customers:

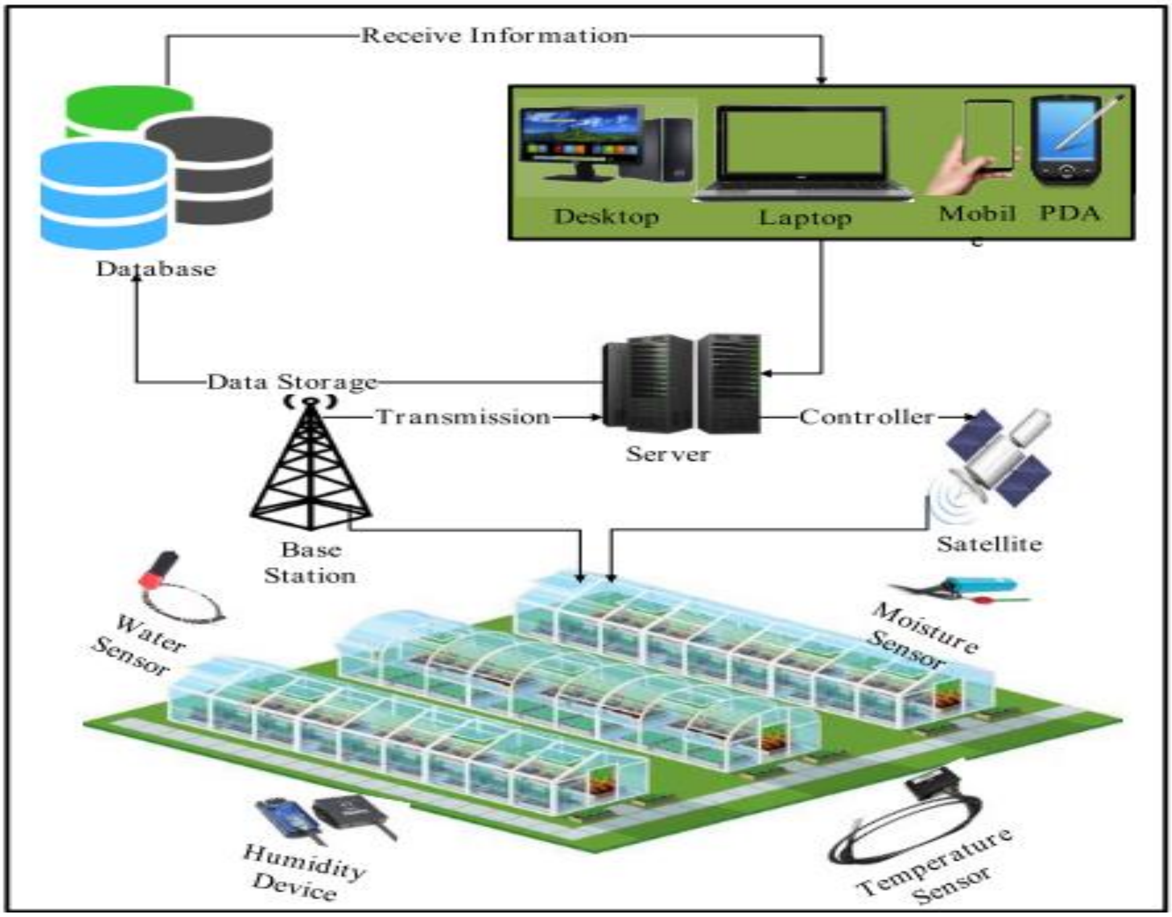

Figure 2.7 Greenhouse monitoring system (Farooq, Riaz, Abid, Abid, & Naeem, 2019).

2.3.9 Autonomous farming machinery

Alam, Tushar, Zaman, Gonzalez, Bari and Karmaker (2023) indicated that AI-enabled autonomous vehicles and machinery to execute tasks like sowing, harvesting, and crop monitoring with precision and efficiency. These technologies reduce labour requirements, lower fuel consumption, and minimise soil compaction, which results in sustainable and cost-effective farming practices. According to Subeesh & Mahta (2021), autonomous vehicle often uses sensors like radars and lasers to detect impediments and respond to them intelligently and use Global Navigation and Satellite System (GNSS) to pinpoint and locate the position of the animals and move to an area autonomously.

2.3.10 Climate and weather forecasting

Kovacs and Husti, (2018) elucidated that AI models can process large volumes of historical climate and weather data to generate accurate forecasts. These projections assist cultivator to make knowledgeable decisions about planting schedules, crop selection, and irrigation plans, mitigating the impact of adverse weather conditions and optimising resource management.

2.3.11 Supply chain optimisation.

Cariou, Moiroux-Arvis, Pinet and Chanet (2023) stated that AI systems can analyse data across the entire agricultural supply chain, from farm to market, to identify inefficiencies and optimise logistics. This leads to reduced food waste, improved traceability, and better coordination among stakeholders, fostering sustainable and transparent practices.

2.3.12 Biodiversity conservation

With regards to biodiversity conservation, Aldhyani and Alkahtani (2023) indicated that AI can aid in monitoring and managing biodiversity on farmland by analysing data on species distribution and habitat conditions. They added that this information helps farmers implement conservation practices, such as creating wildlife corridors or preserving natural habitats, to support pollinators and beneficial organisms.

2.3.13 Decision support systems

Marin-Garcia, Torres-Marin and Chaverra-Lasso (2023) acknowledged that AI-powered decision support systems can integrate various data sources, including weather data, market trends, and historical yield data, to provide personalised recommendations and insights to farmers. This help them in making intelligent decisions about crop and soil selection, resource management, and risk mitigation, ultimately improving productivity and sustainability.

2.4 Perception towards the adoption and the use of AIoT in smart farming.

Perception is how something is understood, perceived, or interpreted. The perception of AIoT by small-scale plant farmers falls under the research objectives. Despite that AIoT has recently been implemented in several agricultural projects. Saiz-Rubio, & Rovira-Más (2020), assert that the AIoT has been less implemented in developing nations, it has been effectively embraced in industrialised nations. In the context of South Africa, commercial farms help to improve the production and storage processes in South Africa, which helps to better control of plant and animal illnesses (Broekman & Steyn, 2021).

Agtag and One-soil mobile applications are mostly used by small-scale farmers to access day-to-day or updated information and predictions on farming practices (Mathivha, 2022). She further stated that some small-scale farmers rely on their Televisions and Radio channels to get the information of weather, fertilizers and seeds treatment. According to Taheri, Zanjirani and Zackery (2020), low levels of literacy and lack of experience to software interfaces may hinder rural farmers in developing nations, making the AIoT designs inappropriate for them. The application of AIoT is mostly limited to scholarly studies whereas the adoption by small-scale plant farmers has not yet received enough attention (Taheri et al., 2020). There is a considerable difference in the perception of AIoT between Large and small-scale plant farmers, this study aims to identify and close the gap between the different levels of perception which prevents the implementation of smart farming to its full potential.

2.5 Benefits of using the Artificial Intelligence of Things in the agricultural industries.

There are many benefits from the implementation and adoption of Artificial Intelligence of Things in the agricultural sector such as efficiency of input, cost reduction, profitability, sustainability, food safety and environmental protection (Alreshidi, 2019). The AIoT applications maximises production efficiency by lowering environmental effects and resource utilisation, such as water and electricity. Data gathered by AIoT systems help to save expenses, boost agricultural revenue, and lessen adverse environmental effects (Jawad, Nordin, Gharghan, Jawad, & Ismail, 2017). AIoT enhance the precision of operations by providing each plant or animal precisely what it needs to grow in the best possible way, to optimise overall performance and reduce waste, inputs, and pollution (Friha, Ferrag, Shu, Maglaras & Wang, (2021).

According to Subeesh and Mehta (2021), the potential applications of AIoT increase productivity and possibly help small-scale plant farmers with smart farm machinery, weed and pest control, irrigation systems, greenhouse cultivation, storage structures, drones for plant protection, fertiliser application and crop health monitoring. Most importantly, helps farmers to utilise inputs such as seeds and fertilisers more effectively, use tillage equipment more effectively, enhance crop and field evaluations, and make the best management decisions at the correct time and place (Taheri, Zanjirani and Zackery, 2020). Small-scale farmers in the Vhembe District of Limpopo Province of Limpopo utilize their smartphones to research on the type of soil and amount of water needed for crops, which helps them grow more sweet potatoes (Mathivha, 2022).

2.6 Hindrance factors in the adoption of AIoT by small-scale farmers

While AIoT has the potential to revolutionise various industries and improve efficiency, there are certain hindrance factors that can affect its adoption and implementation by small-scale businesses. According to Silveira, Lermen & Amaral, (2021), one of the main factors which affect small-scale farmers is the cost of implementations. The cost of AIoT technology can be prohibitive for small-scale farmers with limited budgets. The AIoT systems may require significant investments in terms of hardware, software, and infrastructure. As a result, small-scale firms may find it difficult to devote the necessary funding for adopting AIoT solutions, which might prevent adoption in rural communications.

The technical expertise is another factor that could hinder the adoption of AIoT in rural communities. These systems require specialised technical knowledge and skills for development, deployment, and maintenance purposes (Kansal, Bhushan & Sharma, 2022). They further alluded that small-scale businesses may lack the in-house expertise or resources to effectively handle AIoT technologies, making it difficult for them to fully leverage their benefits. Additionally, small-scale businesses often have limited resources and infrastructure, which can hinder the scalability of AIoT solutions (Nozari, Szmelter-Jarosz, & Ghahremani-Nahr, 2022). As the number of connected devices and data increases, it may become challenging for small-scale businesses to manage and process the data effectively (Nozari et al., 2022).

Furthermore, data privacy and security is another concern for small-scale farmers because AIoT involves the collection and analysis of vast amounts of data from connected devices (Washizu & Nakano, 2022). Any data breaches or vulnerabilities can have severe consequences, figure 2.3 showed initial implantation of security measures to ensure data privacy and security. As a result, small businesses may lack the resources or knowledge to implement robust security measures, making them vulnerable to cyber threats. AIoT technologies are subject to various legal and regulatory requirements related to data protection, privacy, and compliance.

According Pivoto, Waquil, Talamini, Finocchio, Dalla-Corte, and de Vargas-Mores, (2018), small-scale businesses may face challenges in understanding and adhering to these frameworks, which can hinder their adoption of AIoT solutions. In the Vhembe District of Limpopo, traditional farming practices are deeply ingrained, and small-scale farmers are resistance to adopting new technologies (Mathivha, 2022). The lack of resources and training materials in local languages can limit understanding and adoption (Nozari et al., 2022).

2.7 Challenges faced by farmers when adopting Artificial Intelligence of Things.

Despite the benefits and potential for technology to change the agriculture industry, the major challenge is that small-scale plant farmers lack technical knowledge of the ecosystem (Subeesh & Mehta, 2021). The interface in the digital products are offered in advanced language rather than regional languages, thus making it harder for small-scale farmers to understand (Caputo, Greco, Fera & Macchiaroli, 2019). The quality and cost of the devices and sensors are major concerns for small-scale plant farmers, to adopt the advanced technology (Subeesh & Mehta, 2021). The reliability of the systems plays vital role in the sector. They also highlighted that adopting AIoT has a direct influence on agricultural methods, thus any risks to component functioning or failure would result in dependability difficulties.

According to Mathivha (2022), the majority of small-scale farmers in Vhembe District are unable to use cell phones or ICT applications, and network coverage varies outside of townships. Villa-Henriksen, Edwards, Pesonen, Green (2020), demostrated that AIoT devices are diverse, interoperability is essential, and appropriate synchronisation is required for improved operation. Antony, Leith, Jolley, Lu, & Sweeney (2020), alluded to certain major challenges in the adoption of AIoT by small-scale plant farmers such as measurement devices (i.e. Access to components, device design, and sensor calibration, poor connectivity, transmission cost, data storage and smartphone penetration, IoT revenue generation, complexity in ecosystem, project structure, IoT business model and short funding timelines). Furthermore, the lack of relevant and sufficient agricultural information by small-scale plant farmers is one of the key factors constraining efforts to improve agriculture (Mgbenka, Mbah, & Ezeano, 2016).

2.8 AI/IOT framework, layers, and structured applications to the agricultural sector.

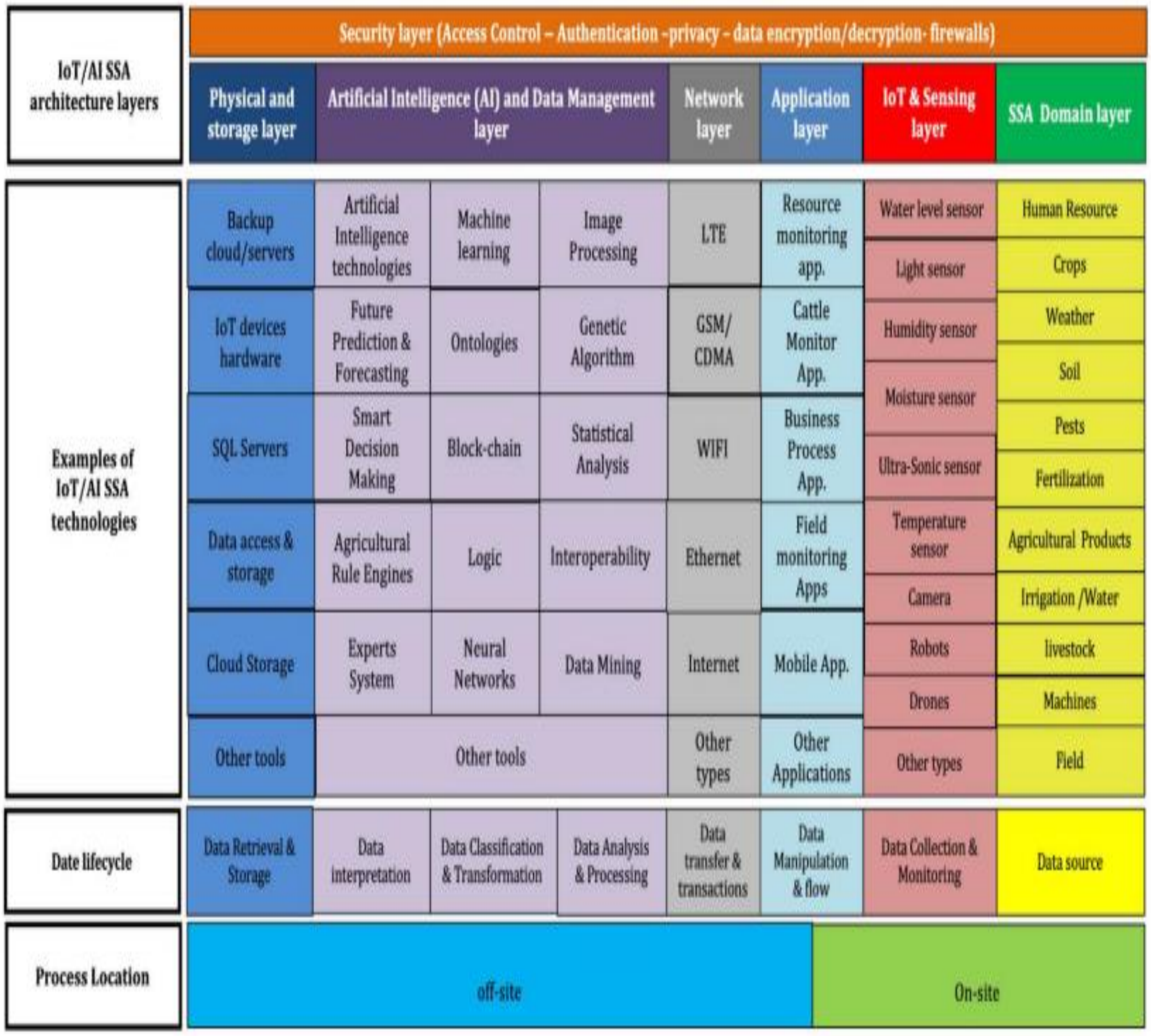

Figure 2.8 AIoT Architectural Layers (Alreshidi, 2019).

According to (Alreshidi, 2019), a successful adoption of AIoT for sustainable farming necessitates a thorough understanding of the layers that describe proper architectures and interconnections between farm devices, network and end users (see figure 2.8). The base layered architecture is composed of five layers: physical and storage, Artificial Intelligence and Data Management Layer, networking, security, and application. These layers are discussed in the following sub-sections:

a) Physical Layer and storage layer

The physical layer consists of different types of technology such as sensors, wireless sensor networks (WSN), actuators, driverless tractors, radio frequency identification (RFID), and unmanned aerial vehicles (UAVs) to perform sensing, agricultural robots and control actions (Khatoon & Ahmed, 2021). In figure 2.8, batteries are used to power devices, and these batteries can be recharged using renewable energy sources like solar panels and wind turbines (Friha, Ferrag, Shu, Maglaras & Wang, 2021). The data processed in this layer passes the networking layer to the application. In the context of this study, self-driving tractor technology has the potential to address the rising worry about labour shortages by boosting performance and efficiency without the need for a person.

b) Artificial Intelligence and Data Management Layer

This layer is responsible for managing processes and controlling business logic, which consists of three activities in figure 2.8 (Alreshidi, 2019). The first stage involves analysing and processing the produced data using data mining and intelligence statistical analysis. Second, this stage classifies and transforms examined data using ontologies and machine learning, before interpreting and representing the modified data as knowledge to make machines smarter.

c) Network Layer

The processed data from the physical layer is received and passed to the higher layer, which transmits control commands from the application layer to the perception layer (Balakrishna & Moparthi, 2021). The network layer is made up of field gateways that use Ethernet or mobile networks like 2G/3G/4G/5G). Bluetooth and near field communication (NFC), or Wi-Fi (Friha, Ferrag, Shu, Maglaras & Wang, 2021). The network layer is responsible of ensuring that data is available and accessible across all other layers and it controls the flow of data among all layers (Alreshidi, 2019). In Figure 2.3, the 5G network (with a high bandwidth, low latency and massive connection) was used to better manages their resources quickly and reduce waste.

d) Security Layer

According to Kour and Arora (2020), this layer encompasses the hardware and software complexity such as service security, portability, discovery, scalability and interoperability. It's also responsible for ensuring data security is transferred throughout different layers and tackles any security concerns and vulnerabilities within all other AIoT framework layers such as malware, spyware and viruses (Alreshidi, 2019). Some of the core applications applied in security later are privacy, authentication, data encryption or decryption and firewall (see, Figure 2.8). A firewall is a network security solution that protects your network from unauthorised traffic. Firewalls block incoming viruses based on a set of pre-programmed restrictions. (Gundu, and Maronga, 2019). One of the game changers is cyber security, it utilises cutting-edge security technologies and AI algorithms to prevent any threats to the platform. According to Jun, Craig, Shafik, & Sharif (2021), cyber security protects intruders from disrupting farming production and endangering people's lives, food production networks, and food industry business networks are at risk.

e) Application layer

This layer contains a collection of apps related to intelligent, sustainable agriculture. Alreshidi (2019), asserts that the application layer grants full or partial authority over data movement, transactions, and access to an authorised institution. Its main emphasis is on managing data migration and flow at all levels. Jayaraj, Aneesh, Sooraj, Lekshmi & Deenath, (2020), stated some of the IoT-based messaging protocols used in the application layer such as advanced message queuing protocol (AMQP), message queue telemetry transport (MQTT), extensible messaging and presence protocol (XMPP). The application layer uses these protocols to carry out a variety of agricultural tasks with the least amount of human intervention.

Hypertext Transfer Protocol (HTTP) is the backbone and standard foundation of data exchange or communication for the World Wide Web (WWW). When creating web applications, this application layer protocol is most frequently employed because of its usefulness in providing hypermedia resources that meet the most basic online requirements (Friha, Ferrag, Shu, Maglaras, & Wang, 2021).

2.9 Theoretical underpinning

This section provides the theoretical underpinning that guides this study thus the Unified Theory of Acceptance and Use of Technology (UTAUT).

2.10.1. Unified Theory of Acceptance and use of Technology (UTAUT)

Unified theory of acceptance and use of technology (UTAUT) model consists of four key constructs (that is., performance expectancy, effort expectancy, social influence, and facilitating conditions) that influence behavioural intention to use technology, while behavioural intention and facilitating conditions determine the technology use (Venkatesh, 2022). UTAUT acts as a reference model and has been applied in both organisational and non-organisational settings to the study of several technologies (Kagoya & Mbamba, 2021). According to Odelami, Folorunso, and Igbinovia (2023), UTAUT was developed to modify the TAM model and to provoke some of the limitations of using multiple models posed by researchers.

Performance expectancy is defined as the extent to whereby a person thinks that utilising the system will enable him or her achieve work performance improvements (Venkatesh, 2022). The performance expectancy construct includes *Perceived usefulness, extrinsic motivation, job fit, relative advantage and outcome expectation.*

Effort expectancy is defined as the level of convenience related with the utilisation of the system (Odelami, Folorunso, & Igbinovia, 2023). Three effort expectancy constructs include *perceived ease of use, complexity and ease of use.*

Facilitating conditions is defined as the level whereby a user perceives that there is organisational and technological infrastructure to enable the use of the system (Venkatesh et al, 2003). Three facilitating conditions include perceived behavioural control, facilitating condition and compatibility.

Social influence is defined as the extent to wherein an individual feels essential that others believe he or she should use the new system or technology (Odelami, Folorunso, & Igbinovia, 2023). Facilitating conditions is defined as the level whereby a user perceives that there is organisational and technological infrastructure to enable the use of the system (Odelami, Folorunso, & Igbinovia, 2023). The price value is positive if the benefits of using innovation are higher than the monetary cost and such price value has a positive effect on the intention (Odelami, Folorunso, & Igbinovia, 2023). Hence the researcher is of the view that the Unified theory of acceptance and use of technology (UTAUT) is applicable within the context of the subject matter.

2.10 Conceptual framework

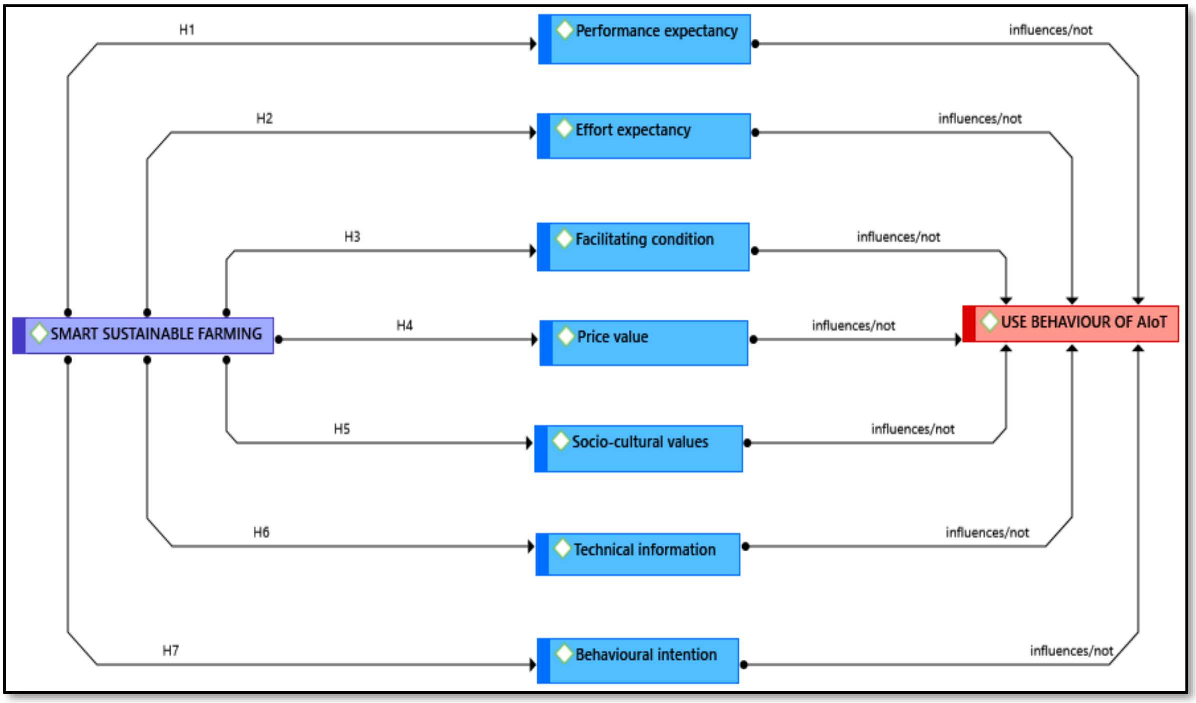

Figure 2.9: Conceptual Framework

Source: Researcher's own construct

The conceptual framework in Figure 2.9 shows that there are 7 variables grounding the hypothesis or proposition, thus Performance expectancy (H1), Effort expectancy (H2), Facilitating condition (H3), Price value (H4), socio-cultural values (H5), Technical information (H6) and Behavioural intention (H7) have or do not have an influence on the use behaviour of AIoT.

These hypothesis or propositions informs the development of the conceptual framework:

H1 is grounded on the premise that performance expectancy have a significant influence on the intention to use AIoT technology to sustain farming. Significantly impacts farmers' intentions to employ AIoT technology in farming by increasing efficiency, sustainability and productivity, driving them to adopt such innovations to better their agricultural outputs.

H2 alludes that effort expectancy has a significant influence on the intention to use AIoT technology for sustainable farming. H2 has a big impact on the intention to utilize AIoT technology in sustainable farming by making the technology more user-friendly and accessible, encouraging farmers to use it to improve their agricultural operations.

H3 positing that facilitating conditions have a significant influence on the intention to use AIoT technology for sustainable farming. H3 has a major impact on farmers' intentions to utilize IoT technology for sustainable farming by providing them with the necessary infrastructure, knowledge, and help, hence increasing their confidence and competence to embrace and effectively execute IoT solutions.

The H4 is grounded on the notion that price value has a significant influence on the intention to use AIoT technology for sustainable farming. These have a substantial impact on intention by evaluating whether the anticipated financial rewards and increases in agricultural efficiency justify the expenditure, hence influencing farmers' desire to embrace such technology.

H5 indicating that socio-cultural value have a significant influence on the intention to use AIoT technology for sustainable farming. Significantly impacts farmers' intentions to employ IoT technology for sustainable farming by altering their views and acceptance of technical developments that are aligned with traditional practices and community support.

Also, H6 is based on the premise that technical information has a significant influence on the intention to use AIoT technology for sustainable farming. These includes detailed knowledge and overview about the use and benefits of AIoT technology. Additionally, H6 improve farmers' understanding, reduce uncertainty, and increase confidence in the technology's effectiveness and application.

Lastly, H7 alludes that behavioural intention towards AIoT does has a significant influence on the use behaviour of AIoT for sustainable farming. H7 has an impact on the usage of AIoT for sustainable farming by directly pushing farmer's decision and actions to embrace and integrate AIoT technology into their agricultural methods.

2.11 Chapter summary

This chapter has provided an exposition of the views of past studies regarding the Agriculture 4.0 adoption amongst the small-scale farmers as well as their perceptions thereof. The factors affecting the adoption of AIoT were also elucidated upon within the small-scale farmer's context. The quality and cost of the devices and sensors are major concerns for small scale farmers in to adopting the advanced technology. The reliability of the system also has paramount importance in AIoT solutions.

CHAPTER THREE: RESEARCH METHODOLOGY

3.1. Introduction

A research approach adds credibility to the study and yields scientifically solid results. It also has a defined strategy that helps researchers keep on track, making the procedure seamless, manageable and effective (Patel & Patel, 2019). Research methodology helps the reader understand the plan and steps used to get the results. The research design, methodology, data collecting, data analysis, ethical issues, validity, and instrument dependability are the main topics of this part. A case study technique has been used as the research approach for this investigation (Dzwigol, 2022).

3.2 Research paradigm

Constructivism is a paradigm in the study of qualitative data that aims to comprehend how people construct and interpret their own realities as a result of interactions between their experiences, ideas, and the social context in which they are positioned (Pilarska, 2021). The constructivism paradigm highlights that knowledge is a socially constructed understanding that is impacted by an individual's experiences, beliefs, and interactions with others rather than an absolute reality that has yet to be discovered (Kamal, 2019).

The constructivism paradigm was adopted in this study because constructivism acknowledges that people have diverse worldviews and interpretations depending on their experiences, worldviews, and cultural backgrounds (Primecz, 2020). Constructivism paradigm provides the premise for highlighting the value of thoroughly examining the setting and participant experiences (Kumala & Sukmono, 2023). In line with the assertion of Mijanović (2023), the paradigm also enables the understanding of the fundamental mechanisms by which people interpret and engage with their environment.

3.3 Research approach

A qualitative research approach was adopted for the purpose of this study. Islam and Aldaihani (2022) alluded that acquiring and analysing non-numerical data is a necessary part of qualitative research in order to better understand ideas, views, or experiences. According to Khoa, Hung and Hejsalem-Brahmi (2023), the qualitative research approach can be utilised to uncover intricate details about a situation or to spark fresh study concepts. The researcher adopted the qualitative research approach to provide the premise for comprehensively understanding the subject matter in an in-depth manner. The qualitative research approach enabled the researcher to have a thorough grasp of the obstacles that farmers confront while adopting the systems, thus providing a solution for the challenges identified.

3.4 Research Design

Gieg (2023) posited that a research design is the conceptual structure within which research is conducted. Additionally, Kratochwill, Horner, Levin, Machalicek, Ferron and Johnson (2023) are of the view that a research design is primarily concerned with the aims, purposes, intents, and plans within the practical constraints of place, time, money, and the researcher's availability. In this study ethnography research design was adopted. Ethnography is a qualitative research design that involves in-depth and prolonged engagement with a specific social group or culture in its natural setting (Lassiter, 2022). The ethnographic technique was were employed to gain a deep understanding of the group's beliefs, practices, values, behaviours, and social interactions by immersing the researcher within the context being studied. This approach was adopted as it provided the premise for direct interaction with individuals enabling the examination of the world from the participants' perspective (Seo, Moon, Choi & Do, 2022). Shavit (2023) alluded that this design also aims to minimise the researcher's bias and makes sure that the conclusions drawn are based on the perceptions and experiences of the subjects being investigated.

3.4.1 Target population

To explore the adoption of AioT for sustainable farming in South Africa, Limpopo Province, Vhembe district, it is critical to collect data from the farmers who have already embraced AIoT in their farms. Barghouth (2023), stated that a target population is a well-defined collection of participants which have common thread characteristics. In this research, the target population was small-scale plant farmers from areas in the Vhembe Rural District in Limpopo Province. This means all the small-scale farmers within the Vhembe District comprised the population of the study.

3.4.2 Sampling technique

Sampling denotes the procedure by which researchers select a specific number of observations from a larger population (Sarker & AL-Muaalemi, 2022). This study followed the convenience sampling approach. Convenience sampling was adopted, and it is a non-random sampling technique where individuals are chosen for the sample based on their accessibility, desire and willingness to participate (Fowler & Lapp, 2019). The convenience sampling approach enabled the researcher to reach the participants that will be accessible and meet the sample criteria. Thus, the participants comprised of small-scale plant farmers of interest with more than 1-year experience in farming and with exposure and experience in using any form of AIoT in their farming activities. The participants were chosen from areas around Thohoyandou, Malamulele, and Makhado within the Vhembe District of Limpopo.

3.4.3 Sampling Size

White (2022) stated that a sample is a subset of a population, whereas sampling is a process of selecting a sample from a population. Norouzian (2020) alluded that the sample size is an essential aspect of every research aimed at making population conclusions from a sample. Berndt (2020) is of the view that selecting a high-quality sample frame that is appropriate for both the population being studied and to the data collecting method as an important key stage in the research. However, determining a sample size is not always straightforward because it is dependent on what kind of study being conducted. It is not easy to estimate the total population of small-scale farmers in a particular area. Thus, the study population was deemed concealed because there is no defined or clear figure of the population on small-scale plant farmers. The sample size of this study comprised a minimum of 10 small scale farmers until data saturation. Hence the final number of the participants was determined by the level of data saturation. The minimum of ten small-scale farmers were sampled due to the limited geographical locations that fell within the researcher's budget. The researcher has also looked at past studies such as Magubane (2017) and Mangoma and Wilson-Prangley (2019) who collected data from 10 participants respectively. This means that the number of participants in this study also aligns with past studies.

3.5 Research instrument

A researcher employed a structured interview guide to collect data. When conducting interviews for research, assessments, or evaluations, interviewees are given a structured interview guide, which is a systematic and standardised set of questions and prompts (Bearman, 2019). Rocha-Neto, Moreira, Hosken, Langfus, Cavalcanti, Youngstrom and Telles-Correia (2023), indicated that structured interview guide aids in ensuring that the same set of questions are asked of each participant in the same order, minimising any bias and boosting the dependability of the data gathered. The structured interview guide was adopted as the structured interview guide's questions are specifically designed to elicit replies that are consistent with the study's goals or evaluation standards (Doringer, 2021).

Additionally, as posited by Roberts (2020), structured interviews guarantee that each participant is questioned with the same set of questions, removing any possibility of interviewer-to-interviewer variation in questioning. The comparable data produced by this method of asking makes it simpler to examine and come to informed conclusions (McGrath, Palmgren & Liljedahl, 2019). De la Croix, Barrett and Stenfors (2018) are of the view that comparing responses provided by participants and spotting patterns or trends among them gives researchers or assessors confidence. The interview guide was used among small-scale plant farmers from the Vhembe District to understand how AIoT can be used for sustainable farming.

The sections of the interview guide are shown in Table 3.1.

Table 3.1: Interview guide structure

SECTION	SECTION FOCUS
A	Demographics of participants
B	The use of AIoT by small scale farmers for sustainable farming.
C	Hindrance factors in the use of AIoT by small-scale plant farmers.
D	Perception of small-scale plant farmers towards the adoption and use of the Artificial Intelligence of Things.
E	AIoT adoption recommendations

3.6 Data collection

Mazhar, Anjum, Anwar and Khan (2021) defined data collection as a process by which the researcher gathers the information required to answer the research questions or problems. Qualitative data was collected by the researcher using face-to-face structured interviews with the participants. The data was collected in English, Tshivenda and Xitsonga which are the prominent languages in the area of study. The researcher utilised an audio recorder to record the data from the participants.

3.7 Data analysis

The collected data was transcribed using Microsoft Word. The transcriptions were analysed adopting a thematic framework analysis using Advanced Technology for Large-scale Analysis and Synthesis (ATLAS.ti) version 8.4, a qualitative data analysis computer-based software. The researcher used open coding and list coding when analysing the data. This procedure identified and labelled major concepts, patterns, and themes in the data. Codes helped organize data into meaningful units. The researcher further performed constant comparison on the codes and generated code groups or families. Lastly, network diagrams were generated to summarise the codes.

3.8 Trustworthiness

The trustworthiness, rigour, and validity of the research findings are key considerations while conducting qualitative research (Kyngas, Kaariainen & Elo, 2020). Amin, Norgaard, Cavaco, Witry, Hillman, Cernasev and Desselle (2020) had overview that since qualitative research involves the subjective interpretation and comprehension of human experiences, establishing trustworthiness is crucial to determining the quality and reliability of the research. Trustworthiness entails ensuring that credibility, dependability, transferability, and conformability are attained (Stahl & King, 2020). Credibility relates to one's belief in the truthfulness and the accuracy of research findings (Peels & Bouter, 2023). To guarantee credibility, full and extensive explanations of the study setting, methodology, and findings will be provided so that readers may evaluate the validity of interpretations (Stahl & King, 2020). Transferability refers to the degree to which discoveries may be used or translated to different contexts or settings (Jonas, Kerwer, Chasiotis & Rosman, 2023).

Furthermore, dependability refers to the steadiness and stability of results throughout time and under varied conditions (Adler, 2022). The audit trail was used by the researcher to keep a detailed record of research decisions, data collection, and analysis steps to ensure transparency and replication. Also, Atutornu, Milne, Costa, Patch and Middleton (2022) posited that conformability involves ensuring that the results are based on the data and not influenced by the researchers' biases or preconceived notions. To ensure conformability, the researcher adopted a peer debriefing to seek feedback from other researchers or experts to validate the interpretations and findings.

3.9 Ethical considerations

The upholding of ethical norms is critical while doing research, particularly research involving human participation, and specifically interviews. This study met the ethical requirements as established by the University of Venda Research Ethics Committee, which are as follows:

i. Respondents were informed that the survey is anonymous and voluntary, and all collected information will be kept secret.
ii. Respondents were advised they may withdraw from the research at any time without consequences or penalty.
iii. Information obtained was considered as group data, and no individual details would be released or reported on.
iv. The study followed University of Venda research norms and standards. The researcher agreed not to utilise his position for personal gain or advantage.
v. The researcher reassured respondents that the research would not affect them or their businesses.

3.10 Chapter summary

This chapter provided the methodological aspects of the study. It is imperative to note that the research approach, research strategy and sampling techniques were also outlined. The research instrument and the data collection and analysis dictates were also established. The trustworthiness aspects were also outlined as well as the ethical considerations. This chapter is critical as it provides the roadmap regarding how the objectives of the study were concluded. Methodology is a crucial stage of the overall study since a poor research design might result in inaccurate or erroneous findings and conclusions. Hence, the methodological aspects were explored and discoursed. The next chapter provides a data analysis and interpretation of the results.

CHAPTER FOUR: DATA ANALYSIS AND INTERPRETATION

4.1. Introduction

This chapter presents the results found based on the analysis of the data collected from small-scale farmers. Data analysis is the technique of finding the correct data to answer a study purpose, comprehending the procedures underpinning the data, determining the relevant patterns in the data, and then expressing the results with the maximum potential impact (Maxwell, Delaney & Kelley, 2017). The analysis was conducted using ATLAS.ti through performing various open coding, list coding and constant comparisons. The results that originated from the analysis are provided in this chapter. The information acquired in this study is given in the form of frequency tables and graphical representations or diagrams.

4.2. Participants Demographic Profiles

This section contains and thoroughly presents demographic information about the participants in this research. This includes the level of education, gender, age group and years in farming respectively.

Table 4.1: Participants Demographic Information

Participant	Level of Education	Gender	Age	Years in farming.
1	Bachelors	Male	29	6
2	Bachelors	Female	22	4
3	Bachelors	Female	35	7
4	Grade 12	Female	24	5
5	Grade 12	Male	31	12
6	Bachelors	Female	36	10
7	Diploma	Male	45	12
8	Bachelors	Female	27	7
9	Bachelors	Female	28	6
10	Bachelors	Female	20	3

Table 4.1 displays the participants' demographic information, which is covered in the following sub-sections:

4.2.1 Level of Education

With regards to the level of education, 7 of the participants had bachelor's degrees with 2 having Grade 12 as the highest qualification and only 1 had a diploma. This means that most of the sample that participated in this study have degrees implying that they are educated small-scale farmers.

4.2.2 Gender of Participants

With regards to the gender of the participants, 7 of the participants were female and 3 being male. This means that a larger sample that participated in this study were female indicating a higher participation of women in entrepreneurship.

4.2.3 Age of Participants

With regards to the age of the 10 participants, 3 of the participants were aged between 20 to 25 years, 3 other participants were aged 26 to 30 years, the other 2 were aged 31 to 35 years and the remaining 2 participants being 36 years and 45 years respectively. This indicates a mature sample participated in this study.

4.2.4 Years in Farming

With regards to years in farming, 3 of the participants have been in farming between 3 to 5 years and with those in farming between 6 to 10 years being 5. Those who were in business between 11 to 15 years were 2. This means that the majority of the small-scale farmers have been in business for relatively more years.

4.3. Qualitative Data Analysis

Data analysis is the technique of finding correct data to answer a study purpose, comprehending the mechanisms behind the data, determining the relevant patterns in the data, and finally expressing the results with the maximum effect (Maxwell, Delaney & Kelley, 2017). Data was analysed using ATLAS.ti through performing various open coding, list coding and constant comparisons. The results that originated from the analysis are provided in this chapter.

Firstly, the researcher imported qualitative data into ATLAS.ti which included the transcribed Microsoft Word documents. This process was followed by the coding procedure where the researcher created codes to represent themes, concepts, or patterns in the data. This resulted in the creation of codes or sub themes. This then was followed by coding the families, thus grouping related codes into code families to organise and hierarchically structure the codes. This helped in creating a more structured and meaningful representation of the data. Meaningful codes or themes were created by adopting the constant comparison technique. The researcher then created group families or major themes that comprised of the codes or sub-themes that arose during the analysis. The last step was creating network views to visualise relationships and connections between codes.

4.4. Results

This section provides the results that emanated from the analysis of data for sub-sections 4.2.1, 4.2.2, 4.2.3 & 4.2.4.

4.4.1 Small-scale farmers' usage of AIoT systems

This study focused on determining the usage of Artificial Intelligence of Things systems by small-scale plant farmers in Vhembe District. The sub themes that emerged from the analysis are recording and monitoring, automated irrigation and temperature controlling which are explained in the following subsections:

a. Recording and monitoring

This study found that the small-scale farmers are using AIoT systems for recording and monitoring their farming initiatives. This emerged from the expressions of Participants 1, 2, 4 and 9 shown in the following extracts:

> *"Obviously, whatever that we do in the farm or green-house we have to record and if the system is implemented to its full potential we can connect to our laptops and monitor everything that is happening like humidity and temperature and also moisture inside the green-house. We do have infrastructure."* ***(P1)***

> *"This system assists us to grow more and more crops and monitors the whole farm without rooming around the farm."* ***(P2)***

> *"Okay. We use this system to gather information about weather conditions, soil quality, temperature, humidity and... Okay."* ***(P4)***

"The temperature sensors heart rate monitors and accelerometer can be attached to animals to track their vital signs and detect signs of illness or stress. Cameras equipped with computer version technology can monitor the livestock behaviour, detect any abnormalities, and also provide visual confirmation of health and wellbeing." ***(P9)***

The participants indicated that they use AIOT systems for monitoring the humidity and moisture in the greenhouses where they grow their plants. The participants also indicated that the systems allow them to monitor the whole farm whilst on a single location and without necessarily physically moving around the farm. The participants further alluded that AIoT systems are also used in livestock farming where temperature and heart rate sensors are used to monitor or track the vital signs of the livestock and detect signs of illnesses or stress. This implies that the AIoT systems are being used by small-scale farmers in recording and monitoring the farming activities and the livestock which is critical towards enhancing sustainable farming. These findings corroborate with Alzuhair and Alghaihab (2023) who alluded that acoustic and ambient sensing AIoT platforms for agricultural applications provide the basis for recording and monitoring in farms.

b. Automated irrigation

The results also showed that small-scale farmers are using the AIoT systems for automated irrigation. This was based on the views of Participants 1, 2 and 4 shown in the following excerpts:

"We can also use other acoustic emission sensors in a smart irrigation system that also detects when there is a shortage of water in the crop." ***(P1)***

"Yes, we have used it. We have automatic irrigation system. Basically, we get water from the creeks, then we use a deep irrigation system that automatically drops water at or near the root of the plant." ***(P2)***

"It can help to optimise irrigation schedules, providing insight into soil moisture, levels and prediction, water requirement, also reducing water wastage." ***(P4)***

Based on the above evidence, the participants uses the AIoT systems in advancing their automation of their irrigation efforts. The participants further indicated that the AIoT assists them in optimising irrigation schedules and providing them with real-time data pertaining a soil moisture, levels and prediction of water requirements which contributes towards the efficient use of water. Aligning with the findings of Rout, Das, Saxena and Ghosh (2023) this study found that this automation of irrigation systems by the small-scale farmers is crucial towards advancing their farming efforts.

c. Temperature controlling

Temperature controller is another indicator of the usage of AIoT systems by small-scale farmers. With regards to temperature controlling the sentiments shared by Participants 1 and 3 are shown in the following quotations.

"The way we use artificial intelligence in farming, we use it in mostly in green-house to control the temperature so that we do not have a person using a manual thermometer to check the temperature. We have it controlling the temperature." ***(P1)***

"In our poultry farm we have NodeMCU for updating farm information to the owners. Gas sensor MQ2 to detect the presence of ammonia. Temperature sensor to detect the temperature and humidity of the farm. Infrared sensor (IR) to detect the temperature and humidity of the farm. IR sensor to prevent the wick, the help of transmitted and received IR radiation. And fire sensor to detect the presence of fire accident with the help of smoke. Lastly, we have the Integrated Servo Motor application which helps in automatic food and water feeding." ***(P3)***

The participants indicated that they use the AIoT systems to control the temperatures in the greenhouses which avoids manual controlling. The participants further alluded that in the poultry farming context, they use AIoT systems to detect the temperature and humidity of the farm. In line with Chou, Chang, Zhong, Guo, Hsieh, Peng, Tai, Chung, Wang and Jiang (2023) this study found that temperature controlling in such type of farming is crucial hence the AIoT are enabling the small-scale farmers to effectively and efficiently monitor and control the temperatures towards enabling a proper yield.

A summary of the use of AIoT systems by small-scale farmers is provided in Figure 4.1:

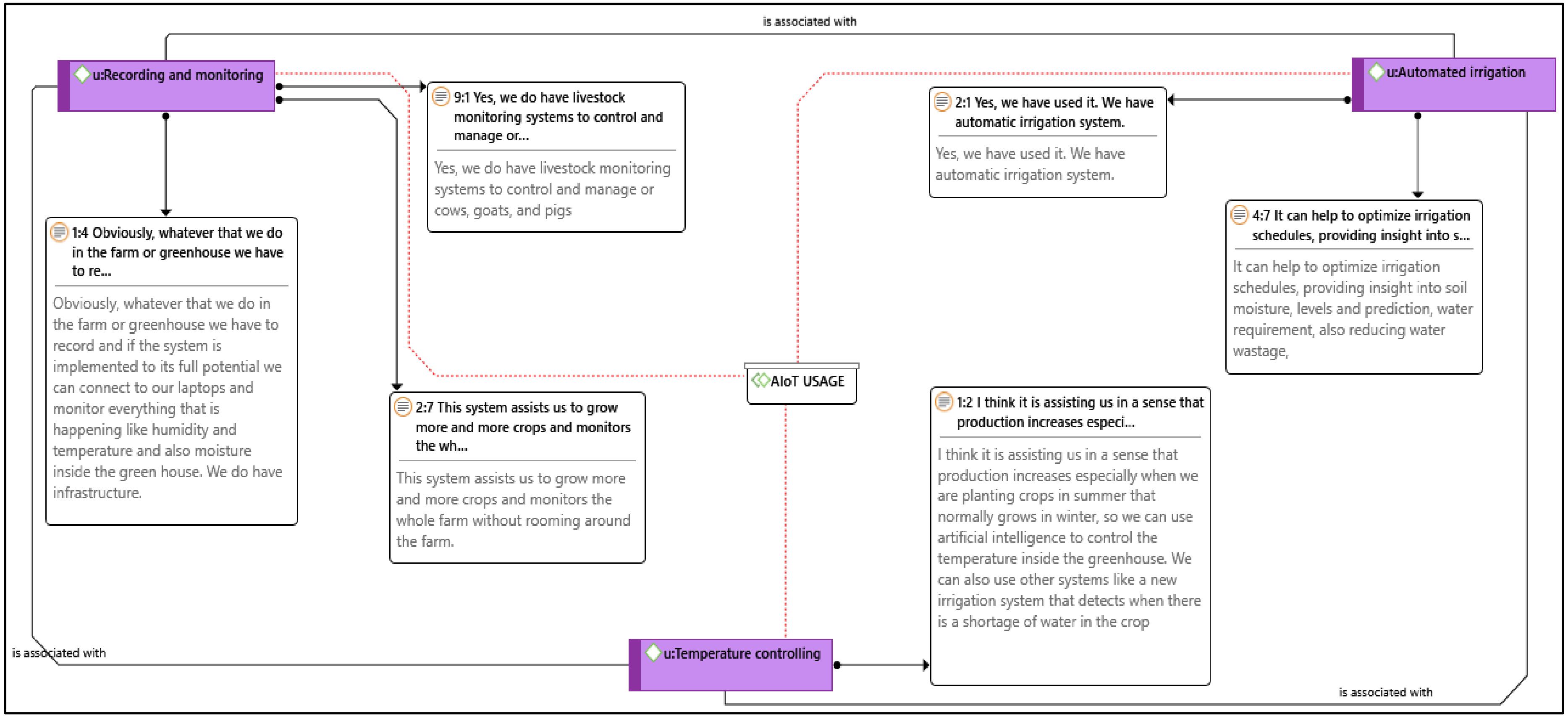

Figure 4.1: Small scale farmers' usage of AIoT systems network

Source: Researcher's own construct

4.4.2 Factors hindering the use of AIoT by small scale farmers

This study focused on identifying the factors hindering the use of AIoT by small-scale plant farmers in Vhembe District. The sub themes that emerged from the analysis are load shedding, costs associated with AIoT systems, unawareness of AIoT policies and network connectivity and these are explored in this section.

a. Load-shedding

Load-shedding has been noted to be one of the factors hindering the use of AIoT by small scale farmers. This was based on the views of Participants 1, 2, 4, 6 and 9 shown in the following excerpts:

> *"When we have a problem of load-shedding we need to refill diesel for standby generators. Since we are a large institution, when there is a breakdown, we need someone on standby."* ***(P1)***

> *"When there is no electricity our irrigation system to apply water cannot be functional. All the sensing devices stop working. The diesel is South Africa is expensive to run backup generator during load-shedding."* ***(P2)***

> *"When there is no electricity, our yield prediction system connectivity with sensors cannot function well and the fuel in South Africa is very expensive to run a backup generator during road shedding."* ***(P4)***

> *"In South Africa, we have load-shedding, this can be a crisis on farming system."* ***(P6)***

> *"When there is no electricity, the system requires the back-up generator or the solar systems in place of which the fuel prices have increased in South Africa."* ***(P9)***

The participants indicated that when there is load-shedding their automated irrigation systems is not functional due to electricity crises. This is not only true to irrigation systems but to all the systems that are being adopted by the farmers as they are heavily dependent on electricity. This means that the absence or unavailability of electricity has a detrimental impact on their functionality. Hence load-shedding is considered as a factor that hinders the effective adoption and use of AIoT systems by small scale farmers which also aligns with Phuong, Swaans, Struik and Stomph (2023) who argued that load-shedding adversely impact the implementation and effectiveness of AIoT in agriculture.

b. Costs associated with AIoT systems

The results showed that costs associated with AIoT systems is another factor that has a detrimental impact on the usage of AIoT systems. This was evidenced by the expressions of Participants 2, 4, 5, 6 and 9 shown in the following extracts:

> *"Ok, artificial intelligence systems are costly and also operation requires an experts. Maintenance it requires external companies to maintain the hardware and software. Things like maintenance, load-shedding and also the increase of fuel price to back generators."* ***(P2)***

> *"So, as well as the maintenance, it requires external companies or vendors to maintain the hardware and software."* ***(P4)***

> *"Since I don't use this system, I read about this system on articles. Some of these systems are expensive. Thus government funding and training can enable us to implement AIoT our farms as we are knowledgeable about systems. We are just lacking funds."* ***(P5)***

> *"The maintenance as it requires external companies to maintain the hardware and software."* ***(P6)***

> *"When there is no electricity, the system requires the back-up generator or the solar systems in place of which the fuel prices have increased in South Africa."* ***(P9)***

Considering the above evidence, the participants in this study indicated that the AIoT systems are expensive to acquire which has an adverse impact on their adoption and use by small scale farmers. Additionally, the maintenance of these systems is also costly which the small-scale farmers do not afford. Aligning with Matin, Islam, Wang, Huo and Xu (2023) alluded that the costs associated with AIoT systems thus purchasing and maintaining them adversely affect the adoption and use of these systems by small scale farmers.

c. Unawareness on AIoT policies

Unawareness of the AIoT policies was noted to be another factor that hinders the adoption of AIoT systems by small scale farmers.

> *"Unfortunately, no I do know any policies." **(P2)***

> *"As I have mentioned above, we don't have this type of a system. I don't have idea." **(P5)***

Participants stated they are unaware of the AIoT policies that control how these technologies are used. The lack of awareness of these policies may also be linked to lack of awareness of these systems. The lack of awareness thereof may hinder the adoption of these systems. This study corroborates with Adli, Remli, Wan Salihin Wong, Ismail, Gonzalez-Briones, Corchado and Mohamad (2023) who indicated that the lack of awareness of AIoT negatively affecting its adoption in agriculture.

d. Network connectivity

Network connectivity was noted to be another factor that hinders the adoption of AIoT systems. This was based on the views of Participant 9 shown in the following extract:

> *"The challenges is be the limited internet connectivity since we are located in rural areas. Network congestion can occur leading to delays and data transmission issues." **(P9)***

With regards to network connectivity the participant indicated that there is limited internet connectivity in the rural areas and this has a negative effect on the use of AIoT systems. This is based on the notion that most of the AIoT systems are heavily depended on the availability of network or internet connectivity. Hence connectivity challenges adversely affect the use of these systems. Da Silveira, da Silva, Machado, Barbedo and Amaral (2023) indicated that network challenges is a barrier to the implementation of sustainable agricultural practises.

A summary of the factors hindering the use of AIoT by small-scale plant farmers in Vhembe District is shown in Figure 4.2:

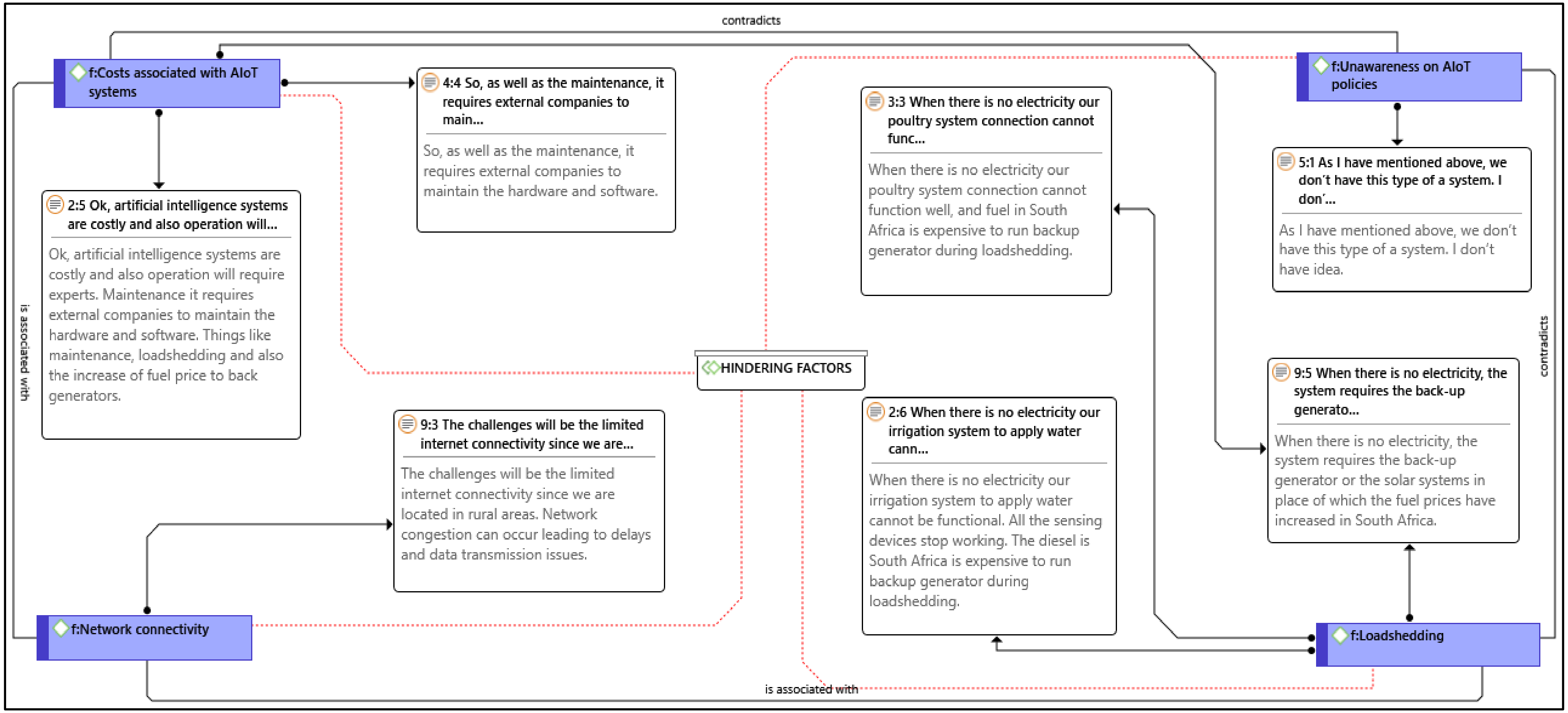

Figure 4.2: Factors hindering AIoT usage by small-scale farmers' network.

Source: Researchers' own construct.

4.4.3 AIoT adoption perception among small-scale farmers

This study also focused on evaluating small-scale plant farmer's perception towards the adoption and use of the Artificial Intelligence of Things for sustainable farming. The sub-themes that emerged from the analysis are increased production and efficiency promotion and these are explored in this section.

a. Increased production

Increased production marks the perception of small-scale farmers towards the use and adoption of AIoT for sustainable farming. This is based on the views of Participants 1, 2, 3, 4 and 10 shown in the following extracts:

> *"I think it is assisting us in a sense that production increases especially when we are planting crops in summer that normally grow in winter, so we can use artificial intelligence to control the temperature inside the greenhouse. We can also use other systems like a new irrigation system that detects when there is a shortage of water in the crop."* ***(P1)***

> *"This system assists us to grow more and more crops and monitors the whole farm without roaming around the farm."* ***(P2)***

> *"It can reduce manpower and increases production of healthy chickens."* ***(P3)***

> *"Prediction system contributes significantly to sustainable farming by promoting efficient resources use, reducing environmental impact, and also enhancing overall agricultural productivity."* ***(P4)***

> *"Technology makes things faster and if things are quick which means we can produce more and lead to more profit."* ***(P10)***

The participants indicated that with the use of AIoT production increases especially when planting seasonal crops in different seasons through greenhouses. AIoT was also noted to be enabling the small-scale farmers to grow more crops as it enables the monitoring of the whole farm. It also contributes to sustainable farming through efficient resource use, reducing environmental impact, and enhancing overall agricultural productivity. The adoption and usage of AIoT signifies the use of technology in farming, which offers farmers with sustainability advantages by ensuring that farmers are functioning efficiently and effectively, resulting in increased productivity. Thus, AIoT adoption and use contribute towards increased production as well as profits. In line with this study's findings, Phuong, Swaans, Struik and Stomph (2023) indicated that AIoT provides the basis for enhancing the production of vegetables.

b. Efficiency promotion

Efficiency promotion is another perception of small-scale farmers towards the adoption and use of the Artificial Intelligence of Things for sustainable farming. This is evidenced by the expressions of Participants 2, 4, 6 and 9 shown in the following quotations:

> *"It reduces labour and also it is efficient water usage. It irrigates only plants. It is also convenient and time-saving."* ***(P2)***

> *"Okay, it assists us to plan and allocate resources such as water, fertilisers, and pesticides more efficiently."* ***(P4)***

> *"Mmm, it can assist us to plan and allocate resources such as water, fertilisers and pesticides to work more efficiently and effectively."* ***(P6)***

> *"The RFID tags and GPS scholars enable real-time tracking of livestock which help to prevent theft and locate missing animals. Also, optimise grazing patterns and also assists in efficient management."* ***(P9)***

In terms of efficiency promotion, the participants indicated that the adoption and use of AIoT systems provide the basis for efficiently allocating the resources within the farm. The use of AIoT was also perceived to be assisting in the efficient management of the farmer's efforts. It also contributes to efficient water use. According to Rout et al. (2023), this study found that the efficiency promotion that is associated with the adoption and use of AIoT systems by small scale farmers denotes the contributions of such systems of sustainable farming.

A summary of the small-scale plant farmer's perception towards the adoption and use of the Artificial Intelligence of Things for sustainable farming is shown in Figure 4.3.

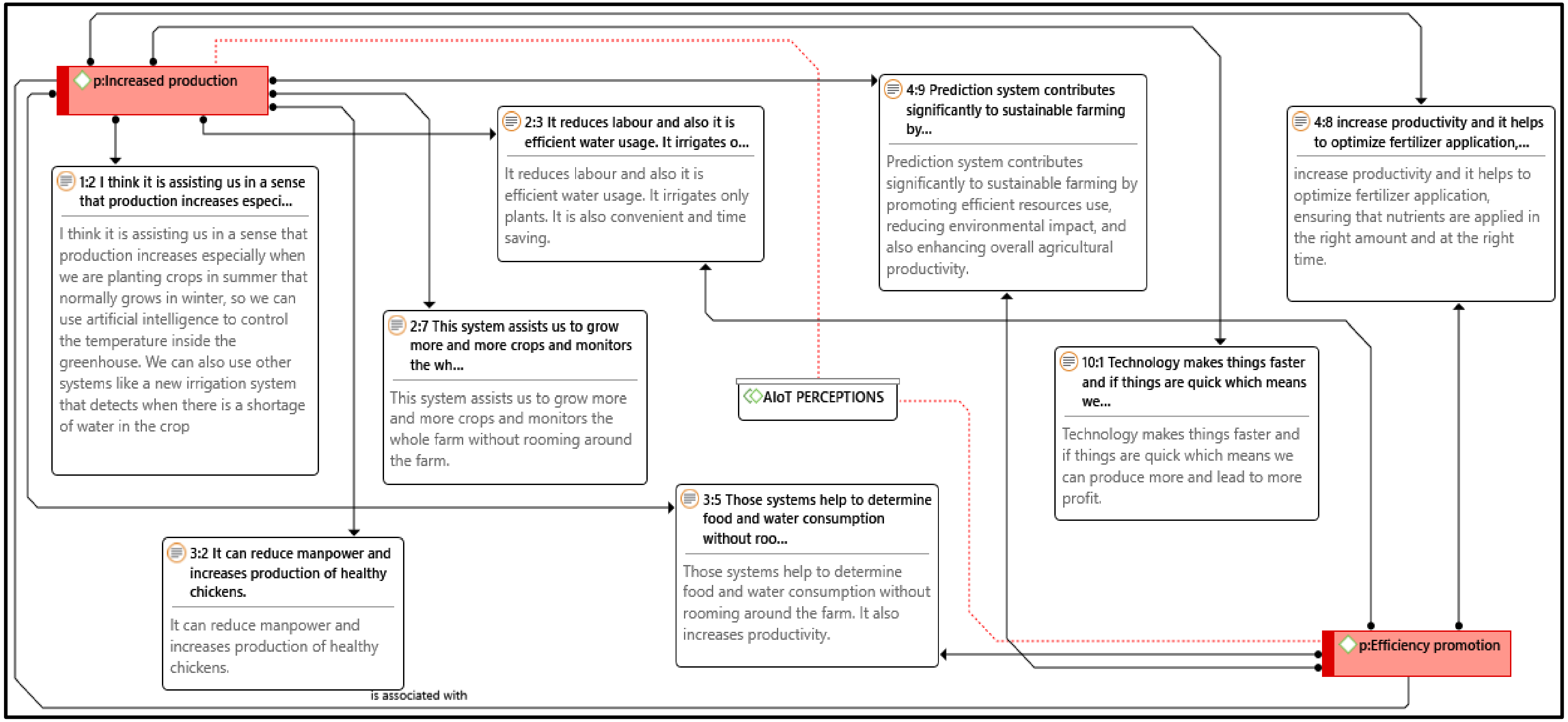

Figure 4.3: Perception of AIoT adoption among small-scale farmer's networks.

Source: Researchers' own construct

4.5 Hypothesis Testing

4.5.1 Hypotheses 1

H_1_1: Performance expectancy had a significant influence on the intention to use AIoT technology to sustainable farming. The results revealed that the use of AIoT increases production especially when planting seasonal crops in different seasons through greenhouses. AIoT was also noted to be enabling the small-scale farmers to grow more crops as it enables the monitoring of the whole farm. It also contributes to sustainable farming through efficient resource use, reducing environmental impact, and enhancing overall agricultural productivity. The finding is in line with Alreshidi (2019) which indicated that Smart Agriculture provides benefits such as economic competitiveness, addresses environmental challenges and improves the performance, quality and volume of production.

4.5.2 Hypotheses 2

H_2_1: Effort Expectancy had a significant influence on behavioural intention to use AIoT technology for sustainable farming. The participants indicated that the adoption and use of AIoT systems provide the basis for efficiently allocating the resources within the farm. The use of AIoT was also perceived to be assisting in the efficient management of the farmer's efforts. It also contributes to efficient water use. The results are in line with Rout, Das, Saxena and Ghosh (2023), which demonstrated that the efficiency promotion that is associated with the adoption and use of AIoT systems by small scale farmers denotes the contributions of such systems of sustainable farming.

4.5.3 Hypotheses 3

H_3_1: Facilitating conditions had a significant influence on behavioural intention to use AIoT technology for sustainable farming. The results revealed that government funding could enable farmers to implement AIoT in their farms as they are knowledgeable about systems. The results are in line with Muzekenyi (2020), which stated that government need to fund small scale farmers and provide necessary on AIoT application.

4.5.4 **Hypotheses 4**

H_4_1 : Price value have a significant influence on behavioural intention to use AIoT technology for sustainable farming. Most of the respondents has access to AIoT applications. The finding is in line with Sennuga, Conway, and Sennuga, M. A. (2020), which demonstrated that most of the respondents had access to Television and Radios to access the last farming methodologies.

4.5.5 **Hypotheses 5**

H_5_1: Socio-cultural value have a significant influence on the intention to use AIoT technology for sustainable farming. The findings demonstrated that Mobile phone is the only source they use to get the latest information related to farming procedure.

4.5.6 **Hypotheses 6**

H_6_1: Technical Information have a significant influence on the intention to use AIoT technology for sustainable farming. The finding corroborate with Friha, Ferrag, Shu, Maglaras and Wang (2021) that stated that smart-phones, tablets and laptops are used to access the latest agricultural information, analyse the anticipated agricultural demand in products and services, supplies and commodity's prices from the markets.

4.5.7 **Hypotheses 7**

H_7_1: Behavioural intention towards AIoT have a significant influence on the Use behaviour of AIoT for sustainable farming. The results indicated that they use the AIoT systems to control the temperatures in the greenhouses which avoids manual controlling. The results further revealed that they use AIoT systems in their poultry yards to detect the temperature and humidity of the farm. Additionally, results demonstrated that AIoT assists them in optimising irrigation schedules and providing them with real-time data pertaining a soil moisture, levels and prediction of water requirements which contributes towards the efficient use of water.

4.6 Summary

This chapter has unravelled usage of AIoT systems by small-scale plant farmers, factors hindering the use of AIoT and the small-scale plant farmer's perception towards the adoption and use of the AIoT for sustainable farming. The next chapter provides the discussion of the findings.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

In Chapter 4 the results that emerged from the analysis of data in line with the study objectives were presented. This chapter focuses on providing conclusions and recommendations towards the sustainability of the small-scale farmers. The first section of this chapter presents the overall conclusion drawn from the study while the second part addresses the recommendations to the problem identified in chapter 1. The recommendations in this chapter were informed by the participant's face-to-face structured interviews that were done and transcribed.

Ultimately the objectives of the study were as follows:

Objective 1: To determine the usage of Artificial Intelligence of Things systems by small-scale plant farmers in the Vhembe District.

Objective 2: To adjudicate hindrance factors in the use of AIoT by small-scale plant farmers in the Vhembe District.

Objective 3: To identify the perception of small-scale plant farmers towards the adoption and use of the Artificial Intelligence of Things for sustainable farming.

Objective 4: To propose a framework using the Artificial Intelligence of Things that could be used by small-scale plant farmers for sustainable farming in the Vhembe Rural District.

It is imperative to note that addressing the study objectives is pivotal towards reaching the findings & conclusion of the research. Hence the findings of the above research objectives is provided in the next section.

5.2 Findings on research objectives

The findings of the research objectives of the study is provided in this section.

5.2.1 Findings on small scale farmers usage of AIoT systems

In terms of objective 1, to determine the usage of Artificial Intelligence of Things systems by small-scale plant farmers in Vhembe District, this study found that the usage is evidenced by recording and monitoring, automated irrigation and temperature controlling. This study found that small-scale plant farmers are using AIoT systems to monitor the whole farm on a fixed location. In addition, in the context of recording and monitoring, this study also revealed that small-scale plant farmers use AIoT systems in livestock farming where temperature and heart rate sensors are used to monitor or track the vital signs of the livestock and detect signs of illnesses or stress. This shows that AIoT is adopted by small-scale farmers in recording and monitoring the pivotal farming activities that are conducted by the farmers.

In addition, this research revealed that small-scale farmers are using AIoT through automated irrigation. In the context of automated irrigation, small-scale farmers use AIoT to assist them in optimising irrigation schedules and providing them with real-time data pertaining soil moisture, levels and prediction of water requirements which contributes towards the efficient use of water. This means that small-scale farmers are capitalising on the use of AIoT and providing the basis for efficiently and effectively irrigating their crops as it provides them with a need for analysis data prior to irrigation such as soil moisture which provides the basis for a comprehensive understanding of the water requirements. This irrigation automation is crucial not only in irrigation optimisation but also provides the basis for the conversation of water which is also a scarce resource in the Vhembe District.

Furthermore, small-scale farmers are also using the AIoT platforms in the context of temperature control. This study has found that the AIoT adopted by small-scale farmers enables them to automate temperature control in greenhouses. Additionally, the AIoT enables small-scale farmers to detect the temperature and humidity of the farm. This implies that the AIoT is playing a crucial role in ensuring that the temperature is controlled and enabling the farmers to farm sustainably. Hence this study has managed to establish the usage of Artificial Intelligence of Things systems by small-scale plant farmers in the Vhembe District, which is marked by recording and monitoring, automated irrigation, and temperature controlling.

5.2.2 Factors hindering the use of AIoT by small-scale farmers.

With regards to objective 2, to adjudicate hindrance factors in the use of AIoT by small-scale plant farmers in Vhembe District, this study established that these factors are load shedding, costs associated with AIoT systems, unawareness of AIoT policies and network connectivity. Load-shedding has been found to be one of the factors that is hindering the use of AIoT amongst small-scale farmers. It is crucial to note that load-shedding defeats the purpose of automation in small-scale farms as the adoption of AIoT heavily relies on the availability of electricity. South Africa as a whole is grappling with load-shedding, and Vhembe District is not an exception to this, and this has a direct effect of their farming efforts. This means that the small-scale farmer's usage or adoption of AIoT is negatively affected by load-shedding.

Furthermore, this study found that financial costs associated with AIoT is another factor hindering the use of AIoT amongst small-scale farmers. This study established that the affordability of AIoT systems is a matter of concern amongst the small-scale farmers as they are deemed expensive to purchase and their maintenance thereof. This means that the costs associated with AIoT systems have an adverse effect on the adoption and usage thereof of these systems. This study has revealed that unawareness on AIoT policies is another factor that is also negatively affecting the usage of AIoT amongst small scale farmers. The small-scale farmers are not aware of the policies that regulate the usage of AIoT also adversely affects the usage of these systems. The lack of awareness of the policies that regulate these systems is also linked to the lack of awareness of these systems amongst these farmers. This means the lack of awareness of policies regulating the AIoT systems hinders their adoption amongst small-scale farmers.

Moreover, the findings of this study have shown that network connectivity is another hindering factor in the context of AIoT adoption amongst small-scale farmers. The effective usage of the AIoT systems is dependent of the availability of network and internet connectivity. The lack of network and internet connectivity thereof adversely affects the use of these systems amongst small scale farmers. It is imperative to submit that the glitches in network and internet connectivity are also exacerbated by load-shedding. Hence this study has unraveled that the small scale farmers in Vhembe District are hindered from using the AIoT due to a plethora of factors which are load shedding, costs associated with AIoT systems, unawareness of AIoT policies and network connectivity.

5.2.3 Findings on AIoT adoption perception among small-scale farmers

In terms of objective 3, to identify the perception of small-scale plant farmers towards the adoption and use of the Artificial Intelligence of Things for sustainable farming, the perception is marked by increased production and efficiency promotion. This study found that AIoT adoption is perceived in the context of increased production as it enables small-scale farmers to effectively and efficiently utilise the greenhouses to grow crops even outside the season which enhances the production. The use of AIoT also enables small-scale farmers to monitor all their farming activities which enhances sustainable farming. Additionally, in the context of increased production AIoT is perceived by small-scale farmers to be contributing towards sustainable farming through efficient resource use, reducing environmental impact, and enhancing overall agricultural productivity.

Moreover, this study has established that AIoT adoption is also perceived among small-scale farmers in the context of efficiency promotion. This is so because AIoT is perceived to be providing the basis for efficiently allocating the resources within the farm and assisting in efficient management of the farmer's efforts. Additionally, the usage of AIoT also contributes to the efficient water use in the farms. This means that AIoT adoption is perceived as a contributor towards efficiency promotion. Thus, this study has managed to establish the perceptions of small-scale plant farmers towards the adoption and use of the Artificial Intelligence of Things for sustainable farming which are increased production and efficiency promotion.

5.2.4 Findings on AIoT framework for sustainable farming

In terms of objective 4, to propose a framework using the Artificial Intelligence of Things that could be used by small-scale plant farmers for sustainable farming in the Vhembe Rural District, the study proposed and developed the AIoT framework for sustainable farming shown in Figure 5.1.

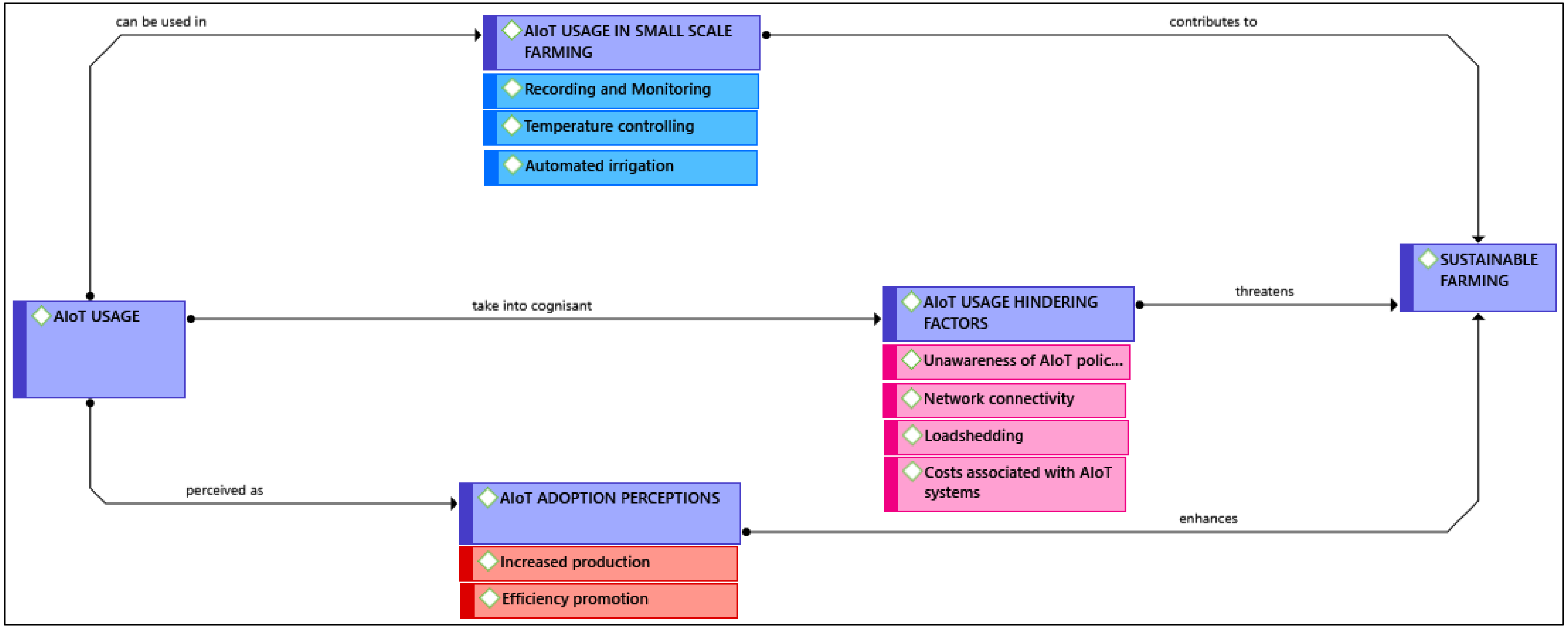

Figure 5.1: AIoT framework for sustainable farming

Source: Researcher's own construct

The AIoT framework for sustainable farming denotes that AIoT can be used by small-scale farmers in recording and monitoring, temperature controlling and automated irrigation. There can be other usages of the AIoT but in this study, these were the several usages that were established. The usage of AIoT contributes to sustainable farming amongst small-scale farmers. In addition, AIoT usage is also perceived as increased production and efficiency promotion. This perception provides the premise for enhancing sustainable farming. The framework also demonstrates that there are several barriers to AIoT implementation among small-scale plant farmers and these includes unawareness of AIoT policies, network connectivity, load-shedding and costs associated with AIoT systems. These hindering factors threaten sustainable farming and must be taken into cognisance by the farmers. This framework provides the premise for sustainable farming as it aids in guiding the implementation of AIoT systems in farming.

5.3 Contributions of the study to the body of knowledge

This study has established the usage of Artificial Intelligence of Things systems by small-scale plant farmers in Vhembe District which is evidenced by recording and monitoring, automated irrigation and temperature controlling. Additionally, the hindrance factors in the use of AIoT by small-scale plant farmers in Vhembe District were also revealed which are load-shedding, costs associated with AIoT systems, unawareness of AIoT policies and network connectivity. The perception of small-scale plant farmers towards the adoption and use of Artificial Intelligence of Things for sustainable farming was also identified as increased production and efficiency promotion. This study has also established the AIoT framework for sustainable farming which is imperative in the journey of the small-scale farmers. These findings add immensely to the body of knowledge as they provide a richer understanding of the AIoT adoption dictates amongst small scale farmers towards sustainable farming. This makes it possible to comprehend the topic matter properly and opens the door for future research by both current and potential researchers.

5.4 Recommendations

This study recommends the following:

a. There is a need for AIoT awareness in the context of sustainable farming amongst small scale farmers in the Vhembe District which can be achieved through conducting awareness workshops where the benefits of these systems are clarified as well as the policies associated with such.
b. Accelerate the adoption of AIoT, both formal and informal institutions to provide knowledge, and transfer skills by offering training and conducting thorough monitoring of their adoption progress.
a. AIoT must be regarded as a tool towards sustainable farming not as a burden amongst small scale farmers.
b. The government must assist the small scale farmers with funding towards automation of their farms by capacitating them not only with the purchasing power but also maintenance as well.

5.5 Limitations

This study was conducted along the qualitative dictates and could not reach a wider sample which can be enabled through quantitative research. This study was conducted in Vhembe District and the findings may not be generalised in other contexts. The study also faced financial constraints as all costs were being covered by the researcher.

5.6 Directions for Future Research

A similar study may be conducted adopting a quantitative or mixed methods approach towards a broader understanding of the subject matter. The perceptions and adoption of AIoT may also be investigated among commercial farmers. A similar study may also be done but in a different area towards understanding the differences or similarities that exist.

5.7 Conclusion

In summation, this chapter provided the conclusion on the usage of Artificial Intelligence of Things systems by small-scale plant farmers as well as hindrance factors in the use of AIoT. The perception of small-scale plant farmers towards the adoption and use of the Artificial Intelligence of Things for sustainable farming was also identified. A framework using the Artificial Intelligence of Things that could be used by small-scale plant farmers for sustainable farming was also provided. The chapter also included the study's contribution to the body of knowledge, along with suggestions, limitations, and future research directions.

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Appendix 1: Participant Letter

Dear Participant,

My name is **Smile Manganyi**, I am a student (Master of Commerce in Business Information Systems) at the University of Venda. In order to complete my project, I am inviting you to participate in the research titled: "*framework for smart sustainable farming using the artificial intelligence of things in South Africa: A case of small-scale plant farming.*"

The research objectives formulated for the study are:

i. To determine the usage of Artificial Intelligence of Things systems by small-scale plant farmers in Vhembe District.
ii. To adjudicate hindrance factors in the use of AIoT by small-scale plant farmers in Vhembe District.
iii. To identify the perception of small-scale plant farmers towards the adoption and use of the Artificial Intelligence of Things for sustainable farming.

iv. To propose a framework using the Artificial Intelligence of Things that could be used by small-scale plant farmers for sustainable farming in the Vhembe Rural District.

Also, note that your participation in this study is voluntary and valuable to its successful completion. Please note that this is academic research and that there are no financial rewards for participation. Should you feel that you are unable to continue for some reasons, you may withdraw at any time. The data being collected is anonymous and will be treated with a high degree of confidentiality.

Thank you for taking the time to participate.

Yours sincerely,

Smile Manganyi
smilemanganyi@gmail.com
Cell phone number: +27 78 880 0109

Appendix 2: Consent Letter

Statement of Agreement to Participate in the Research Study:

I…………………………………………………hereby confirm that I have been Informed by the researcher, Smile Manganyi, about the nature, conduct, Benefits, and risks of this study - Research Ethics Clearance Number: FMCL/23/BIS/02/2404 I have also received, read, and understood the above written information (Participant Letter of Information) regarding the study. I am aware that the results of the study, including personal details regarding my gender, age and level of education will be anonymously processed in the dissertation. In view of the requirements of research, I agree that the data collected during this study can be processed in a computerized system by the researcher. At any time, without prejudice, I may withdraw my permission and participation in the study. Having had enough time to ask questions, I hereby voluntarily declare myself ready to participate in the study. I understand that significant new findings developed during this research which may relate to my participation will be made available to me on request.

Full name of researcher..................................**Date**........................

Signature......................

Full Name of Witness (if applicable) ....**Data**...........................

Signature...............

Full Name of Legal guardian (if applicable) ....**Date**........................

Signature.....................

Appendix 3: Interview Guide

University of Venda

INTERVIEW GUIDE

For the

Research Project entitled:

FRAMEWORK FOR SMART SUSTAINABLE FARMING USING THE ARTIFICIAL INTELLIGENCE OF THINGS IN SOUTH AFRICA: A CASE OF SMALL-SCALE PLANT FARMING

COMPILED BY: Smile Manganyi

A: DEMOGRAPHICS

Please fill in the relevant details below:

What is your level of Education and training?	
What is your Gender?	
What is your Age?	
How many years did you spend in the farming business?	

B: use of Artificial Intelligence of Things (AIoT) by small scale farmers for sustainable farming.

1. What is your understanding of the artificial intelligence of things?
2. Have you used AIoT in your farming? Please elaborate your answer.
3. Please comment on how you use or plan to use AIoT in your farming efforts.
4. To what extent do you think AIoT is assisting you or could assist you in your business?
5. Are you aware of any policies or practices regarding AIoT? Please elaborate your answer.
6. Comment on the effect of these policies or practices on your or possible adoption of AIoT.
7. To what extent are these policies or practices affecting or might affect your farming efforts?

C: hindrance factors in the use of AIoT by small-scale plant farmers.

8. Have you used AIoT in your farming? (YES or No).
9. If YES above, have you faced any hindrances in the use of AIoT?
10. If NO above, what hindrances do you think you might face by using AIoT?
11. What are the factors that are or that could hinder the use of AIoT in your business efforts?
12. To what extent do you think the factors identified above is affecting or could affect your acceptance of the use of AIoT?

D: perception of small-scale plant farmers towards the adoption and use of the Artificial Intelligence of Things.

13. Please comment on the available and user friendly ICT (if any) infrastructure to support and initiate the adoption of AIoT in your farm.
14. How do you think you can benefit from the use of Artificial Intelligence in supporting sustainable farming?
15. How do you think artificial intelligence is contributing towards sustainable farming?

E: AIoT adoption recommendations

16. What do you think can be done towards addressing the challenges associated with the use of artificial intelligence?
17. What do you think could be done to increase the adoption of AIoT amongst small scale farmers to boost sustainable farming??

THANK YOU FOR YOUR PARTICIPATION!!!

Appendix 4: Ethical Clearance

ETHICS APPROVAL CERTIFICATE

RESEARCH AND INNOVATION
OFFICE OF THE DIRECTOR

NAME OF RESEARCHER/INVESTIGATOR:
Mr S Manganyi

STUDENT NO:
17010599

PROJECT TITLE: **Framework for Smart Sustainable Farming Using the Artificial Intelligence of Things in South Africa: A Case Of Small-Scale Plant Farming.**

ETHICAL CLEARENCE NO: **FMCL/23/BIS/02/2404**

SUPERVISORS/ CO-RESEARCHERS/ CO-INVESTIGATORS

NAME	INSTITUTION & DEPARTMENT	ROLE
Prof A. Kadyamatimba	UNIVEN, Business Information Systems	Supervisor
Mrs N. Patala	UNIVEN, Business Information Systems	Co - Supervisor
Mr S Manganyi	UNIVEN, Business Information Systems	Investigator – Student

Type: **Master's Research**
Risk: **Minimal risk to humans, animals, or environment (Category 2)**
Approval Period: **April 2023 – April 2024**

The Research Ethics Social Sciences Committee (RESSC) hereby approves your project as indicated above.

General Conditions

While this ethics approval is subject to all declarations, undertakings and agreements incorporated and signed in the application form, please note the following.

- The project leader (principal investigator) must report in the prescribed format to the REC:
  - Annually (or as otherwise requested) on the progress of the project, and upon completion of the project
  - Within 48hrs in case of any adverse event (or any matter that interrupts sound ethical principles) during the course of the project.
  - Annually a number of projects may be randomly selected for an external audit.
- The approval applies strictly to the protocol as stipulated in the application form. Would any changes to the protocol be deemed necessary during the course of the project, the project leader must apply for approval of these changes at the REC. Would there be deviated from the project protocol without the necessary approval of such changes, the ethics approval is immediately and automatically forfeited.
- The date of approval indicates the first date that the project may be started. Would the project have to continue after the expiry date; a new application must be made to the REC and new approval received before or on the expiry date.
- In the interest of ethical responsibility, the REC retains the right to:
  - Request access to any information or data at any time during the course or after completion of the project,
  - To ask further questions; Seek additional information; Require further modification or monitor the conduct of your research or the informed consent process.
  - withdraw or postpone approval if:
  - Any unethical principles or practices of the project are revealed or suspected.
  - It becomes apparent that any relevant information was withheld from the REC or that information has been false or misrepresented.
  - The required annual report and reporting of adverse events was not done timely and accurately,
  - New institutional rules, national legislation or international conventions deem it necessary.

ISSUED BY:
UNIVERSITY OF VENDA, RESEARCH ETHICS COMMITTEE
Date Considered: April 2023

Name of the RESSC Chairperson of the Committee: Prof Takalani Mashau

Signature:

UNIVERSITY OF VENDA
OFFICE OF THE DIRECTOR
RESEARCH AND INNOVATION
2023 -04- 25
Private Bag X5050
Thohoyandou 0950

"A quality driven financially sustainable, rural-based Comprehensive University"

Appendix 5: Editor's letter

23 April 2024

Manganyi Smile **Student ID: 17010599**

Faculty of Management and Law

Subject : Editing Services for Master's Dissertation - Masters of Commerce in Business Information Systems titled " FRAMEWORK FOR SMART SUSTAINABLE FARMING USING THE ARTIFICIAL INTELLIGENCE OF THINGS IN SOUTH AFRICA: A CASE OF SMALL-SCALE PLANT FARMING."

I, Dr Thulani Tshabalala, hereby confirm by provision for editing services for the master's dissertation authored by Smile Manganyi.

My credentials include a PHD in environmental Science from the University of KwaZulu-Natal South Africa. I possess extensive experience as a topic editor for three academic journals and have served as reviewer for several others.

The editing services conducted on the aforementioned thesis encompassed comprehensive manuscript enhancement. This involved language refinement, proofreading for grammar and spelling errors, formatting of references, and providing feedback on the content.

Sincerely,

Dr. Thulani Tshabalala

ORCID ID: 0000-0003-1735-3761