A POLICY DESIGN FOR DEPLOYMENT AND DIFFUSION OF PRECISION FARMING IN TÜRKİYE

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ABSTRACT

A POLICY DESIGN FOR DEPLOYMENT AND DIFFUSION OF PRECISION FARMING IN TÜRKİYE

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The purpose of this thesis is to investigate the adoption and diffusion of precision farming technologies in agricultural activities in Türkiye. By identifying the current challenges and impediments, the study aims to propose policies that will eliminate these barriers and enhance the diffusion and adoption of these technologies. Initially, the concepts of Agriculture 4.0, smart farming, and precision farming, along with their scopes, are discussed. Among the existing precision farming technologies, autoguidance is taken as the main focus. The dynamics behind the diffusion and adoption of these technologies are examined using the Technological Innovation System approach.

In this thesis, the function based Hekkert Model is used, with the functions being customized and detailed according to precision farming technologies. By analysing the findings from qualitative research conducted with participants from different professional groups, the study reveals the key factors affecting the status, diffusion, and adoption of precision farming technologies in Türkiye. It also explores the interactions between these technologies and users from various sectors, their expectations, and the potential benefits of these technologies. Furthermore, the study examines the gap between Türkiye and developed countries like those in Europe and the United States in this regard. Finally, several policy recommendations are presented, with a discussion emphasizing the priority of demand-side policies during the implementation phase.

Keywords: Agriculture 4.0, Smart Farming, Precision Farming, Technological Innovation System, Autoguidance

ÖZ

TÜRKİYE'DE HASSAS TARIMIN YAYGINLAŞTIRILMASI VE UYGULANMASINA YÖNELİK POLİTİKA TASARIMI

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Bu tezin amacı, Türkiye'de tarımsal faaliyetlerde, hassas tarım teknolojilerinin kullanımı ve yayılımını araştırmak, mevcutta karşılaşılan sorunlar ve engelleri ortaya koyarak, bu engelleri ortadan kaldıracak, yayılım ve kullanımı artıracak politika önerilerinde bulunmaktır. Öncelikli olarak Tarım 4.0, akıllı tarım ve hassas tarım kavramları ve bunların kapsamları ortaya konmaya çalışılmıştır. Var olan hassas tarım teknolojilerinden, otomatik dümenleme temel olarak alınmış ve bu teknolojilerin yayılım ve kullanımının arkasındaki dinamikler, Teknolojik Yenilik Sistemi yaklaşımına göre incelenmiştir. Bu süreçte fonksiyon bazlı Hekkert Modeli temel alınmış ve fonksiyonlar hassas tarım teknolojilerine göre yeniden tasarlanmış ve detaylandırılmıştır.

Farklı meslek gruplarından katılımcılar ile yürütülen kalitatif araştırmalardan çıkan bulgular analiz edilerek, hassas tarım teknolojilerinin Türkiye'deki durumu, yayılımı ve kullanımını etkileyen temel faktörler, farklı sektörlerden kullanıcıların bu teknolojilerle olan ilişkileri, beklentileri ve bu teknolojilerin olası faydaları ortaya konmuştur. Ayrıca, Türkiye'nin bu konuda, Avrupa, Amerika gibi gelişmiş ülkelerle olan farkı da incelenmiştir. Son olarak, çeşitli politika önerileri getirilerek, bunlar arasında uygulama esnasında talep yönlü politikalara öncelik verilmesi tartışılmıştır.

Anahtar Kelimeler: Tarım 4.0, Akıllı Tarım, Hassas Tarım, Teknolojik Yenilik Sistemi, Otomatik Dümenleme

Emeği ile kazanıp, onuru ile yaşayanlara…

Nadir Tayfun Yılmaz'ın anısına…

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LIST OF ABBREVIATIONS

AI	Artificial Intelligence
ATAM	General Directorate of Plant Production and Smart Farming Research and Application Center
ÇUKOBİRLİK	Çukurova Cotton, Peanuts, and Oilseeds Agricultural Sales Cooperatives Union
EU	European Union
FAO	Food and Agriculture Organization
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
IoT	Internet of Things
İTTM	İzmir Agriculture and Technology Center
LIDAR	Light Detection and Ranging
ML	Machine Learning
MNC	Multinational Cooperation
MoAF	Ministry of Agriculture and Forestry
MoIT	Ministry of Industry and Technology
MoTF	Ministry of Treasury and Finance
MoTI	Ministry of Transport and Infrastructure
NIS	National Innovation System
PANKOBİRLİK	Sugar Beet Growers' Cooperative Union
RTK	Real Time Kinematics
SME	Small and Medium Enterprises
TAGEM	General Directorate of Agricultural Research and Policy
TARİŞ	Fig, Grape, Cotton, and Oilseeds Agricultural Sales Cooperatives Unions
TARMAKBİR	The Turkish Association of Agricultural Machinery and Equipment Manufacturers

TIS	Technological Innovation System
TIV	Total Industry Volume
TÜBİTAK	Scientific and Technological Research Council of Türkiye
TUSAGA	Turkish National Fundamental GNSS Network
TTGV	Technology Development Foundation of Türkiye
USA	United States of America
USDA	United States Department of Agriculture
VRS	Virtual Reference Station
WSAN	Wireless Sensor and Actuator Network
WSN	Wireless Sensor Network

CHAPTER 1

INTRODUCTION

Agriculture has played a crucial role in human civilization throughout history. It has shaped societies since ancient times and spurred the development and transformation of nations (Byerlee et al., 2009). The First Agricultural Revolution dates back to around 10,000 B.C., marking the transition to settled life and a period reliant on human and animal power, lasting without major changes until the 1800s. With the development of steam engines and the onset of the Industrial Revolution, we see the emergence of agricultural equipment and internal combustion engines, leading to the advent of tractors in the latter half of the 19th century, marking the Second Agricultural Revolution. In the last quarter of the 20th century, the development of computer technologies, sensors, and robots brought about the era of automation in agriculture, known as the Third Agricultural Revolution. This period also marks the beginning of discussions on sustainability. Today, with advancements in information systems, we are experiencing the Fourth Agricultural Revolution. As autonomy and efficiency in agriculture continue to grow, we are hearing the footsteps of the Fifth Agricultural Revolution.

Today, we can manage the end-to-end agricultural value chain using IoT, cloud computing, artificial intelligence and machine learning (AI/ML), big data, wireless sensor networks, decision support systems, and robotics technologies. Agriculture 4.0 impacts and enhances not only planting, cultivating, and harvesting activities in the field but also pre-field activities (such as fertilizer, seed, and pesticide technologies) and post-field processes (such as product traceability, logistics, and preservation). Agriculture 4.0 utilizes various tools to monitor, control, predict, and manage these value chain processes effectively. According to da Silveira et al., 2021, Agriculture 4.0 is characterized by the enhancement of traditional agricultural techniques and methods through the incorporation of emerging technologies and disruptive solutions, aiming to optimize the value chain in agricultural production. On the other hand, smart farming as a part of Agriculture 4.0 mainly focuses on in-field activities in agricultural value chain such as planting, cultivating, harvesting and livestock. Smart farming covers precision farming such as autoguidance, yield mapping, telematics and variable rate control, digital solutions such as farm management system, satellite imaging, agricultural robots such as drone and application robots, and IoT solutions such as weather stations and smart irrigation systems. As a summary, smart farming is a comprehensive term that encompasses precision farming, decision support systems, and communication technologies (Smart Farming Platform, 2019). And Precision farming as a subset of smart farming aims to enhance the efficiency of agricultural activities, particularly field operations, by optimizing resource use through the primary use of GPS, sensors, and remote sensing technologies.

Agriculture is more vulnerable to external factors compared to other sectors, and we see the most severe impacts here. In Sustainable Agriculture report by Technology Development Foundation of Türkiye (TTGV), it is stated that currently, there are 4.5 billion hectares of agricultural land worldwide and 24 million hectares in Turkey. However, in the past 50 years, an area equivalent to 1.5 times the size of Türkiye's agricultural land has been lost[1]. By 2050, with the population reaching 10 billion and increased calorie consumption, the demand for food is expected to rise by 70%, further highlighting the importance of agriculture.

However, climate change, water scarcity, and decreasing agricultural land exert significant pressure on this vulnerable structure.

On the other hand, traditional and conventional agriculture is a major polluter and water user. Currently, 75% of the water consumed in Türkiye is used for agricultural activities. Yet, Türkiye is a country experiencing water stress, with an annual per capita available water amount of 1,350 m^3. (According to the Falkenmark indicator,

[1] https://ttgv.org.tr/yayinlar/surdurulebilir-tarim-toprak-ve-su

water stress begins at levels below 1,700 m^3.)[2] Similarly, the use of fertilizers and pesticides, as well as planting, cultivation, and harvesting methods, degrade soil health and weaken its carbon sequestration ability. This, in turn, leads to increased carbon dioxide emissions and greenhouse gas accumulation.

The solution to all these issues can be seen in sustainable agriculture, which aims to increase productivity while being environmentally and resource conscious. In sustainable agriculture, precision farming as a sub-set of smart farming applications offers important solutions by providing autoguidance, yield mapping & monitoring, variable rate application and telematics technologies.

Türkiye still conducts agriculture based on mechanization. Although mechanization in Türkiye began in the second half of the 19th century during the Ottoman era with the production of simple hand tools, it progressed quite slowly. The first tractor was purchased from Britain in 1907 in Adana. While the total number of tractors in 1914 was only four, a rapid increase was observed after the establishment of the Republic of Türkiye (Report on the Interaction between Agriculture and the Machinery Industry, 2022). Today, although Türkiye lags behind Europe, America, and Australia in smart farming applications, significant progress has been made, especially in recent times.

My thesis, titled "A Policy Design for the Deployment and Diffusion of Precision Farming in Türkiye," seeks to uncover the dynamics driving the adoption of precision farming technologies, with a particular focus on autoguidance and yield mapping. The goal is to propose policies that can accelerate the adoption of these technologies, thereby enhancing agricultural productivity and efficiency in Türkiye. The main research questions to explore are given in below.

i. What is the state of art of precision farming, and especially of auto guidance and yield mapping in Türkiye?
ii. What are the main potential benefits of precision farming for the Turkish economy, and its agriculture in particular?

[2] https://ttgv.org.tr/yayinlar/surdurulebilir-tarim-toprak-ve-su

The research has been carried out within the framework of Technological Innovation System approach, which allows us to understand and explain how different contributors impact the rate and direction of innovation. This encompasses societal subsystems, actors, and institutions that play a role in the innovation process. And we utilized seven functions model proposed by Hekkert (2007) to analyse diffusion and adoption of precision farming, entrepreneurial ecosystem, the barriers, rate and direction of technological changes in precision farming in Türkiye. Hekkert (2007) proposes functions as

1. Entrepreneurial activities (F1)
2. Knowledge development (F2)
3. Knowledge diffusion (F3)
4. Guidance of the search (F4)
5. Market formation (F5)
6. Resource mobilization (F6)
7. Creation of legitimacy (F7)

Technological change, innovation, and their adoption and diffusion are socio-technical phenomena that reflect the interaction between people and technology. Consequently, a socio-technical analysis is performed, and a qualitative research methodology was used for data collection and analysis to address the research questions in the thesis. The method is semi-structured interview and MaxQDA Plus 2022 software was employed for analysis of interviews.

1.1. Organization of the Thesis

The remainder of the thesis is organized as follows.

In the second chapter, literature review, a comprehensive literature review is provided. The chapter starts with evolution of agricultural sector throughout the history. Different agricultural paradigms are detailed in terms of their characteristics and the technologies that they used. Afterwards Agriculture 4.0, Smart farming and Precision farming concepts and terms are explained with the relationship between each other based on different explanations in the literature. Precision farming and the technologies it encompasses, particularly autoguidance and yield mapping and monitoring, are explained and detailed in all aspects. Furthermore, the state of smart farming and precision farming is compared between Türkiye and various countries around the world. Finally, innovation system approach and technological innovation system as a theoretical framework is examined.

In the third chapter, we deepen the discussion on theoretical framework by giving research questions and Hekkert’s functional approach is explained. Each system function is discussed with details of key performance indicators. Afterwards, methodology selection is explained and rationalized. The last part of chapter provides overview on methods, data collection, sampling of profile, semi-structure interview structure and data analysis.

Fourth chapter provides discussion of findings for each Hekkert’s function. In the chapters of functions, all the sub-functions are detailed in terms of weakness, strength, current situation based on interviews outcomes. Furthermore, the chapters are enriched with secondary data, bibliometric analysis and quotes from participants when needed.

In the fifth chapter, the state of art of precision farming in Türkiye is presented based on findings and diffusion and adoption of autoguidance and yield mapping and monitoring is discussed. Furthermore, challenges and impediments for diffusion and adoption in Türkiye is elaborated. Finally, the chapter is concluded with policy suggestions for all function based on evidence and limitation of this study.

1.2. Significance of the Thesis

This thesis contributions to existing literature can classified in multiple perspectives. First, it especially depicts the relationship between Agriculture 4.0, smart farming, and precision farming, which are discussed in a scattered manner in the literature and can provide clear explanation for each concept in terms of their content and scope. Additionally, it attempts to determine Türkiye's position in the diffusion and adoption of these technologies globally, aiming to reveal their economic benefits and role in sustainable agriculture. Second, the thesis examines the diffusion and adoption of precision farming technologies, which are generally more focused on the technical and application aspects in the literature, as a socio-technical system in many dimensions, particularly autoguidance and yield mapping and monitoring. Furthermore, it reveals the main components of the system, the relationships between them, and the rules within the framework of the technological innovation system.

Third, by directly approaching users, producers, farmers, and those conducting R&D activities in precision farming, especially autoguidance and yield mapping and monitoring, semi-structured interviews have been conducted to explore the real-life applications of precision farming technologies, the factors that support and hinder their dissemination, the ecosystem formed around this topic, the interactions of elements within this ecosystem, and the factors influencing the direction and speed of the technology.

Finally, based on the findings and results obtained, policy recommendations have been provided for all functions of the technological innovation system model used to further diffusion and adaption of precision farming technologies.

CHAPTER 2

LITERATURE REVIEW

2.1. Evolution of the agricultural sector from Agriculture 1.0 to 4.0

Agriculture has always had a significant role in human civilization throughout the history. It has transformed the society from ancient time and triggered the growth and transformation of countries (Byerlee et al., 2009). The relation between agriculture and economic growth has been viewed from different perspectives, Lewis (1954) defined economic growth as the relocation of labour from agriculture to industry. Johnston and Mellor (1961) argued that agriculture facilitates industrial growth especially in the early stage of industrialization. Beyond the growth role achieved through supplying labour and capital for non-agricultural sectors, agriculture supplies foods on the demand side. If food supply cannot meet the demand, food prices rise and as a result the cost of living will increase. Consequently, the stress on the wages hinders industrial growth (Diao et al., 2007)

Kuznets (1961) identified three ways agriculture contributes to economic growth: as a product, through market interactions, and as a resource. The resource contribution can come in the form of capital, labour, or other factors.

Agriculture has been transformed from indigenous farming to precision and smart farming since 10,000 BC triggered by different industrial revolutions (Lui et al., 2021). We can divide this period into four phases as in industry. The period called *Agriculture 1.0* is the first agricultural revolution and the activities were mainly based on the man and animal power with the basic tools. The second Agricultural Revolution is called *Agriculture 2.0* and was triggered by the First Industrial Revolution that emerged in the 19^{th} century with the adoption of specific technologies such as combustion engine and steam power (Albiero et al., 2020). Agriculture 2.0 brought not only diverse types of machinery but also introduced chemicals such as fertilizers and pesticides. The black mirror of all these progresses was environmental pollutions (Beluhova – Uzunova et al., 2022)

When we come to the third agricultural revolution in the last quarter of 20th century, i.e. *Agriculture 3.0*, the development in information and communication technologies provided by 2nd and 3rd Industrial Revolutions led to agricultural robots, yield monitoring and guidance system (Lui et al., 2021). Furthermore, the sustainable agriculture was first introduced during this period (Beluhova – Uzunova et al., 2022).

Today, we are in Agriculture 4.0 era thanks to Industry 4.0 with the application of digital technologies such as Internet of Things (IoT), cloud computing, big data, Wireless Sensor Network (WSN) and AI.

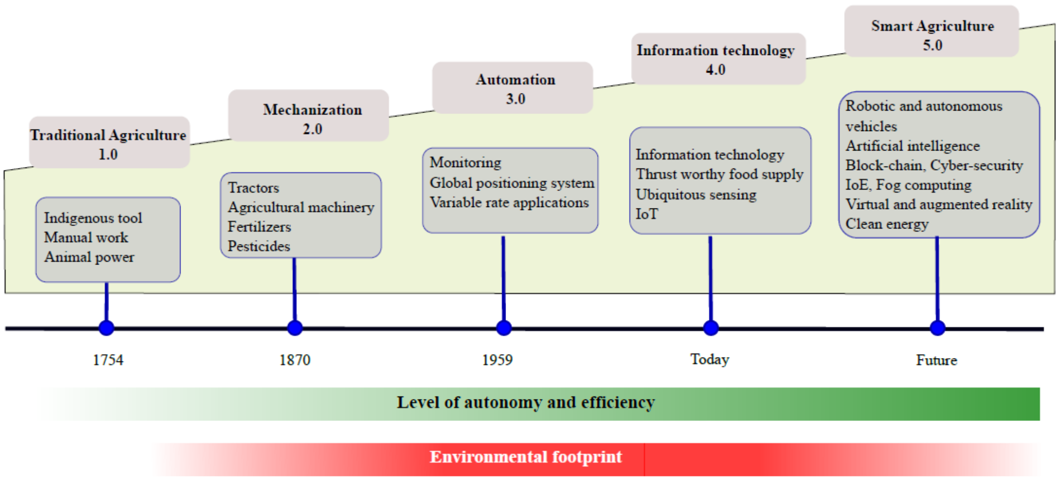

Figure 1: Agricultural revolution from 1.0 to 5.0.

Source: Ghobadpour et al., 2022

2.2. Agriculture 4.0 and Precision farming

Agriculture 4.0 is an emerging concept and the significant increase in literature can be seen from 2018 onwards (Maffezzoli et al., 2022). However, despite the rising trend in literature, the concept is still ambiguous, and a widely accepted definition is not yet available. Although expressions such as digital agriculture, precision or smart farming and Agriculture 4.0 terms are used in the literature interchangeably, available literature shows that scholars and researchers use these words with different meanings.

Klerkx et al. (2019) assert that agriculture 4.0, precision farming, digital farming and smart farming all have the same meaning and define agriculture 4.0 as the disruption of traditional agricultural techniques and methods as a result of the integration of emerging technologies with disruptive solutions to optimize the value chain in agricultural production. Fielke et al. (2020) considers agriculture 4.0 as the adoption and integration of digital technologies for the agricultural activities. Zambon et al. (2019) evaluate agriculture 4.0 as an opportunity to cover all the value chain in food and agriculture processes. There is another approach that define Agriculture 4.0 as a strategy to manage agricultural activities by adopting and integrating IoT, communication network on the one hand, and cultivation, planting and harvesting systems on the other hand (Ferrandez-Pastor et al., 2016). Moreover, the tendency is to use terms such as farming robots, smart farming, precision agriculture, digital agriculture, smart agriculture, agrifood 4.0, agri AI to describe agriculture 4.0 in the literature (Da Silveira et al., 2021). Additional definitions are given by Beluhova – Uzunova et al. (2022) in Table 1.

Despite the different views present in the literature, integration of digitalization, data analytics & intelligence and the holistic approach to value chain are the common concepts.

Agriculture 4.0 is a term that encompasses all the cutting-edge technologies used in various aspects of agriculture and throughout the whole agricultural value chain. Da Silveira et al. (2021) offer an insightful overview of these tools and technologies, which can be found in Table 2. This table categorizes agricultural activities into three main groups: pre-field, in-field, and post-field. These three categories cover all the activities and processes in an agricultural value chain and as it can be seen from the table, agriculture is not limited to field activities such as planting and harvesting. It starts from the pre-field processes and ends with the post-field activities. Pre-field activities cover the processes before planting in the field and involve aspects like seed development and genetics, with core technologies such as chemistry, genetics, and nanotechnology playing a crucial role.

Table 1: Summary of Agriculture 4.0 definitions and perspective

Authors	Definition	Perspective
Monteleone et. al. [45], p. 3	*"This concept appeared at the beginning of the 21st century, as an evolution of the PA concept through the diffusion of IoT“*	Agriculture 4.0 as a Precision Farming Evolution
Piwowar, [45], p. 170	*“Similarly to the concept of Industry 4.0, the transformation process in Agriculture 4.0, aimed at increasing competitiveness, is also implemented through the use of modern information technology”*	Links Agriculture 4.0 to Industry 4.0
Sott et.al.[53], p. 149855	*"Refers to the use of information and communication technologies such as Big Data and Analytics to explore the variability of data and use it to deal with changes in the agricultural scenario"*	Agriculture 4.0 and digital technologies
Kong et. al. [29], p. 2	*“Agriculture 4.0 also improve the agricultural system’s responsive performance with accurate decision making in response to operational uncertainties and real time data updates."*	Agriculture 4.0 and decision making
Kovács, Hust,[30], p. 38	*“It is broader and more comprehensive, as it seeks to integrate all actors in agri-food production through a technological value chain."*	Agriculture and food value chain
Huh and Kim, [24], p. 8	*“Represents the use of emerging technologies to create a value chain to integrate organizations, farmers, customers, and all stakeholders in favour of economic, social, and environmental sustainability."*	Agriculture 4.0 and its main goals

Source: Beluhova – Uzunova et al., 2022

In-field activities include planting, harvesting, and cultivation, where key technologies are geoinformatics (consisting of a set of technologies that focus on the acquisition, processing, analysis, interpretation, and visualization of geographic or spatial information), new hardware and software for machine control, and wireless network systems.

Post-field activities revolve around product distribution and processing, of which leverage technologies such as near field communication, geoinformatics, modeling, and edge computing.

As Table 2 illustrates, all these activities and technologies within these categories collectively contribute to the agricultural value chain.

In addition, *"In 4th agricultural revolution, the systems and devices are intelligent and have relative autonomy for decision making and are all connected ubiquitously (p.2)" (Albiero et al, (2020,).* And the concept of Agriculture 4.0 is not only about data collection but also processing, analyzing and decision making to improve agricultural processes (Shena et al., 2010).

> "*Sustainable and intelligent industrial agriculture would be achieved through real-time variable fine-grained collection, processing, and analyzing spatio-temporal data in all aspects of the agricultural industry, from food production, processing, distribution to consumer experience. Such an industrial agriculture ecosystem with real-time farm management, a high degree of automation, and data-driven intelligent decision-making would greatly improve productivity, agri-food supply chain efficiency, food safety, and the use of natural resources"* (Liu et al., 2021, p 4323).

Besides, Agriculture 4.0 is progressing depending on industry 4.0 and advancement in digital technologies such as IoT, AI, sensors that can find application in agricultural processes. Therefore, the fundamentals of agriculture 4.0 are IoT, big data, connectivity and cloud computing, artificial intelligence (Albiero et al., 2020).

Robotics and autonomous systems, and blockchain are the other enabling technologies examined in Liu et al. (2021). IoT, robotics, cloud computing, data analytics (big data, artificial intelligence, and machine learning), sensors (remote sensing, wireless sensors, and wireless sensors & actuator networks), decision support system are the core agriculture 4.0 technologies (Araujo et al., 2021).

Table 2: Technologies of Agriculture 4.0 in the agricultural value chain

	Agriculture 4.0 Technologies		
Agricultural Activity	Chain Process	Consolidated Technologies	Emerging Technologies
Pre - Field	Genetic Development	ERP, chemistry, genetics, nanotechnology	AIoT, next-generation genomics, responsive effector systems, and novel materials, AI, synthetic protein, cellular agriculture, gene-editing technology, biometric sensing, genotype information
	Seed Development	ERP	AIoT, FMIS, ISV, sensing technologies, 3D food printing, IoUT, digital twins, USN, CNN
In - Field	Planting	Geoinformatics, new hardware, software, ERP, HDFS, LoRA	AIoT, cloud computing, mobile and autonomous robot, UAV, 5G, electrical agricultural machinery, RTK, AI, big data, blockchain, mobile apps, sensor technologies, sensing technologies, models for the individual farm, WoT, data mining, virtual reality, augmented reality, cybersecurity, intruder detection system, smart irrigation, smartphone in field crops, short message service, real-time monitoring, machine learning, cloud robotics, neural network, intelligent greenhouse, sun tracker trajectory, energy generation, decision ontologies, WSNs, IoUT, mobile sinks, USN, WCT
	Harvesting	Geoinformatics, new hardware, software, ERP, HDFS, WSNs	IoT, cloud computing, mobile and autonomous robot, UAV, 5G, electrical agricultural machinery, big data, RTK, AI, cybersecurity, mobile apps, sensor technologies, sensing technologies, models for the individual farm, intelligent software algorithms and robots, WoT, data mining, machine learning

Table 2: (continued)

Post - Field	Distribution	CT, RFID, NFC, geoinformatics, WSNs	AIoT, blockchain, cloud computing, big data, AI, IS, DLT, robotization of internal audit, traceability
	Processing	ICT, RFID, modeling, edge, computing, NFC, WSNs	AIoT, blockchain, cloud computing, big data, AI, IS, DLT, mobile and autonomous robot, cybersecurity, feed intake, data analytics algorithms, machine learning, intelligent software algorithms, and robots, mooCare, forecasting engine, hyper ledger fabric
	Consumer	ICT, RFID, NFC	AIoT, blockchain, cloud computing, big data, AI, IS, cybersecurity, 3D food printing

AIoT- Agricultural Internet of Things. **AI** - Artificial Intelligence. **CNN -** Convolutional Neural Network. **DLT -** Distributed Ledger Technologies. **ERP-** Enterprise Resource Planning. **FMIS** - Farm Management Information System. Geoinformatics - RS, GIS, and GPS. **HDFS -** Hadoop Distributed File System. **ICT** - Information and Communication Technology. **IoUT -** Internet of Underground Things. **IS -** Internet of Services. **ISV -** Improved Seed Varieties. **LoRa -** Long Range radio. **NFC -** Near FieldCommunication. **RFID -** Radio Frequency Identification. **RTK -** Real Time Kinematics. **UAV -** Unmanned Aerial Vehicle (drone). **USN -** Ubiquitous Sensor Networks.**WCT** - Wireless Communication Technology. **WoT -** Web of Things. **WSNs -** Wireless Sensor Networks.

Source: Silveira et al., 2021

2.3. Precision farming

In a nutshell, precision farming involves bringing cutting-edge digital technologies into the world of agriculture. This includes elements such as geoinformatics which is a discipline focusing on geographic information collected form geographic information system, remote sensing, global positioning system and its analysis and application, sensing and control, real-time kinematics (RTK), telematics, cloud computing. The main goal is to make farming smarter and more efficient. By using these technologies, farmers can reduce their use of resources such as fuel, fertilizer, and pesticides, while also minimizing their impact on the environment. These advancements fall under the umbrella of Agriculture 4.0. These high-tech tools are mainly put to work in the field, enhancing various agricultural operations (BTIK, 2021).

European Agricultural Machinery Association gives a more technical definition for precision farming:

> "Precision *Farming started when GPS signals were made available to the general public. Precision Farming enables vehicle guidance and site-specific monitoring and control. Combined with telematics and data management, Precision Farming improves the accuracy of operations and allows the managing of in-field (or in-herd) variations. The objective is to give each plant (or animal) exactly what it needs to grow optimally, with the aim to improve the agronomic output while reducing the input (=producing 'more with less')"* (CEMA, 2017, p.1).

In the same document, the kick off for precision farming has been dated to 1990s with automatic guidance and yield monitoring system triggered by military GPS signals availability for public use. Precision farming integrates and utilizes the guidance solution, sensing & control, telematics, and data management into the agricultural activities. In early 2010's, precision farming boosted with the progress in new technologies, especially in IoT, big data, cloud-based ICT, wireless sensor and actuator network (WSAN), high bandwidth cellular communication. Besides, after 2010's smart technologies like smart control devices, improved automation capabilities emerged. The integration of these technologies into tractors and agricultural equipment such as combine harvester, bailer and forage harvester has transformed precision farming, which is now called *Smart Farming*. Smart farming represents a more recent evolution of precision farming based on digital technologies and data management (CEMA, 2017).

Another report (Smart Farming Platform, 2019) states that smart farming is a broad term and covers precision farming as well as decision support system and communication. It tackles with all the phases of agricultural activities from planting to harvesting by utilizing precision farming, decision support system, communication technologies and internet. Therefore, precision farming can be considered as one of the components of smart farming. Figure 2 in below clarifies the relationship between smart farming and precision farming.

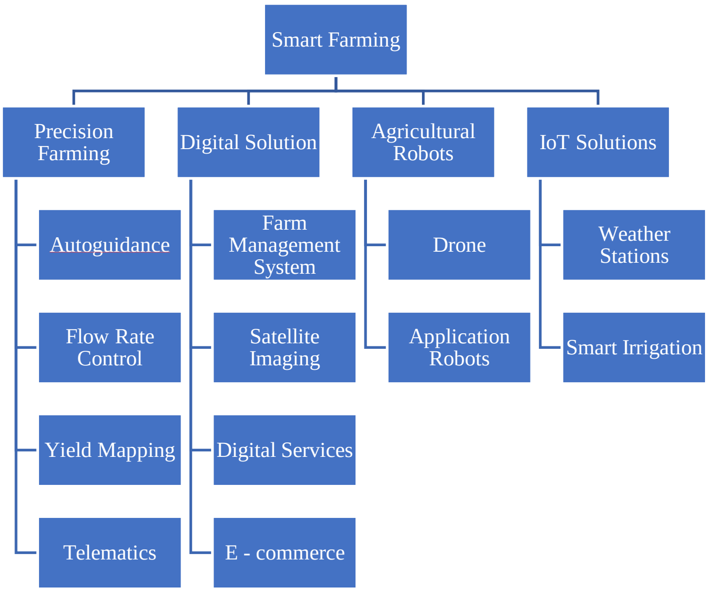

Figure 2: Smart Farming and Precision Farming

Source: TürkTraktör, (2023).

BTIK, 2021 Smart Farming report provides a comprehensive exploration of the core agricultural activities associated with smart farming and classifies them as follows:

•Autonomous tractors and agricultural equipment

Radar, Lidar (Light Detection and Ranging) which is a kind of remote sensing by using laser pulse, GPS, odometry which is a technique to estimate position of autonomous devices by using the data from motion sensors, computer control and sensors enable tractors and agricultural equipment to sense, navigate and guide autonomously without human interface. This feature allows especially precision farming operations which enhance resource efficiency.

•***Unmanned Aerial Vehicle***

Drone is the best known unmanned aerial vehicle, and the technology is utilized mainly for imaging, humidity detection, crop monitoring, yield assessment, irrigation timing decision as well as spraying and fertilizing.

•***Smart irrigation system***

Smart irrigation is based on the principle of providing each plant's roots with the right amount of water and nutrients, in measured doses, to maintain the optimal moisture levels at the root, ensuring that the plant receives what it needs, neither more nor less.

•***Smart fertilizing***

The absorption rate of fertilizer by the plant is around 20% - 40% and the rest is unused. The residual amount causes pollution on the soil and increases the operational cost. However, smart fertilizing optimizes the amount and prepares the fertilizing receipt by compiling weather conditions, soil analysis and historical yield maps and data. Consequently, the level of residual amount decreases from 60% - 80% to 35% - 54%.

•***Farm management system***

The ultimate goal of smart farming is farm management system which is a holistic approach to agricultural processes. The farm management system entails specific spraying and fertilizing receipt based on soil analysis and yield mapping, autoguidance systems, measurement of agricultural process parameters via sensors and decision-making system, traceable logistics operations.

•***Smart greenhouses***

Smart Greenhouse Systems that can adapt to changes in external weather conditions with minimal input, make decisions to save water in the plant's root, and manage plant growth, greenhouse climate, and plant nutrition within a total automation management system.

•***Livestock farming***

In smart agriculture, in livestock farming benefits from technologies application in cattle step and location tracking, milk analysis and milking systems, smart barn and forage management as well as herd, poultry and hive management and tracking system

Therefore, precision farming and smart farming have distinct meanings and key differences come from their focus, technologies, goals, and tools. While precision farming focuses on optimizing the use of resources and make the agricultural activities especially in – field operations more efficient by using GPS, sensors, and remote sensing technologies primarily, smart farming has a broader and holistic focus to bring efficiency and sustainability to the entire farming process by integrating IoT, AI, robotics, and advanced autonomous systems. Therefore, we can consider precision farming as a subset of smart farming.

The main objectives of precision farming are:

- Reduction of agricultural inputs (fertilizers, pesticides, and chemicals) in comparison with conventional usage
- Minimization of environmental impact
- High volume of decent quality product
- Effective information flow for decision support system
- Record and data integrity in agriculture.

Empirical evidence points out that automatic guidance system reduces the inputs used in agricultural activities such as fertilizers, seeds, chemicals, and fuel by enabling the driver to control the tractor, equipment path and operations precisely to eliminate overlaps and gaps in the field (Yao et al., 2005). Research shows that autoguidance systems ensure 10% reduction in total operational cost, 9% reduction in fuel consumption and 17% saving in total time (BITK -, 2021). Association of

Equipment Manufacturers states that consistent usage of precision farming provides 4% increase in crop yield, 7% increase in fertilizer efficiency, 9% reduction in herbicide and pesticide, 6% reduction in fuel usage and 4% decrease in water consumption based on a study held in USA in 2021[3]. Especially for the vegetables such as corn, cotton, sugar beet and sunflower plantation which require certain row distance between the plants, it is more effective.

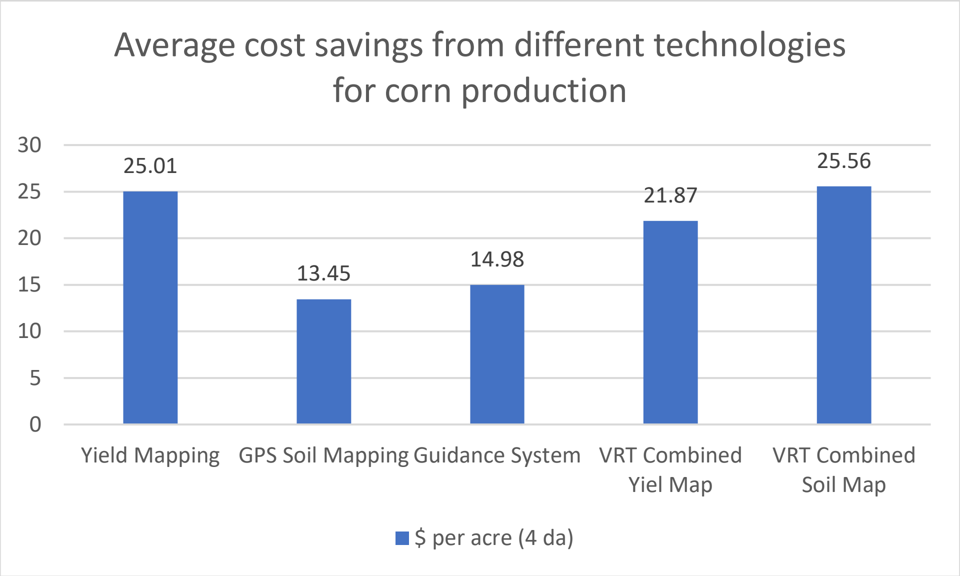

Figure 3: Corn production cost saving in USA with different precision farming technologies.

Source:[4] USDA, 2016

As a summary, despite the different positioning and definition in the literature, precision farming can be defined as a bundle of technologies which advance the accuracy of in -field operations and manage the heterogeneities in the field and in the herd. This approach prioritizes recognizing and accommodating variations instead of the one-size-fits-all mentality applied to fields and herds. Instead, precision farming fosters a realm of operational excellence that optimizes agricultural practices to a degree of finesse and effectiveness that was previously unparalleled. (CEMA, 2017).

[3] https://www.aem.org/news/the-environmental-benefits-of-precision-agriculture-quantified

[4] https://www.farm-equipment.com/blogs/6-opinions-columns/post/13649-economic-benefits-of-using-precision-farming

In this thesis, we will not consider all the dimensions of precision farming. Instead, we will focus on guidance solution, autonomous tractors and agricultural equipment. Specifically, auto guidance and yield mapping that will be explained in next section will be the focal technologies.

2.3.1. Autoguidance

Machine automation and guidance has been always a focus and attraction point for agricultural researchers and the first patent in this area was dated in the early 1920's (Reid et al., 2000). The automatic vehicle guidance or autoguidance can be defined as "*accurate automatic control of vehicle or driving implement along a predefined trajectors*" (Yao et al., 2005). Soitinaho and Oksanen (2021) defines automated guidance or autoguidance as a system which can guide and direct the vehicle automatically from one position to another one to achieve a task.

The main motivation for the autoguidance is to obtain workforce spare time to allocate it for other tasks which increase productivity. Automatic guidance systems are able to provide accuracy in centimeter level with the aid of technologies such as GPS receiver, gyroscope, accelerometer, sensors, and additional measurement devices. The key systems for automatic guidance are navigation sensors, vehicle motion model, navigation planner and steering controller (Reid et al., 2000). Although several components may differ based on the system structures such as whether it is hydraulic or electric control, a general illustration for autoguidance system with key components is given in Figure 4.

There are different technical solutions to achieve the guidance automatically. Sensors, Global Navigation Satellite Systems (GNSS) (GPS by US or GLONASS by Russia), machine vision and laser triangulation are the main methods for automatic guidance and the system entails three main parts for tractors or equipment: a sensor, a controller, and an actuator (Keicher et al., 2000). The main autoguidance solution for the commercial application today is GPS technology which is a satellite – based real - time radio positioning navigation system (Yao et al., 2005).

Figure 4: Illustration of an autoguidance system.

Source: TürkTraktör 2023.

Although the general tendency and popular solution for autoguidance is GPS, the method in terms of both software and hardware is determined by addressing the field conditions and limitations stem from crop planting and harvesting. Agricultural lands can be classified into four major groups, as shown in Figure 5 below.

a) Orchard
b) Between two rows of crop

In these two types of landscape, guidance can be provided by observing and analysing the visual elements and computerized visual system calculates the positioning as well as GNNS based positioning.

c) Open field
d) Terrace farming

Insufficient visual references in open field and terrace farming causes that camera imaging and laser ranging for positioning is challenging. Therefore, GNSS offers optimal solution for positioning (Soitinaho et al., 2023)

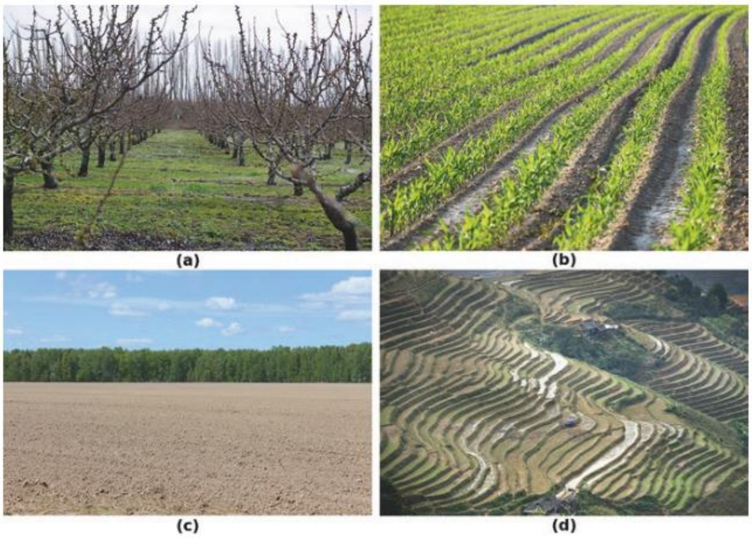

Figure 5: Different types of agricultural landscape.

Source: Soitinaho et al., 2023

Autoguidance system provides several benefits both for inputs of agricultural activities and operators by optimizing field operations, reducing downtime, improving resource management, and providing consistent, high-quality work.

First, autoguidance system can compile the navigation plan automatically and take over the steering task of the tractor. And it allows the driver to focus on monitoring the equipment performance, setting adjustment and real time decision, therefore, driving of the tractor or the equipment is enhanced with comfort and the operator fatigue and cognitive workload are reduced by eliminating monotonous steering tasks. Consequently, working hours of operators can be extended which is crucial for the seasonal activities. Moreover, the technology improves the working conditions by offering user-friendly interfaces and ergonomic controls which allows driver to operate and manage the tractor or agricultural equipment. It also creates synergy with farmer’s skills by augmenting them autoguidance via hardware and software. Therefore, the production volume rises with better quality.

2.3.2. Yield Monitoring & Mapping

Yield monitoring and mapping is one of the key applications of precision farming and represents a modern advancement in agricultural technologies, enabling farmers to assess the impact of weather conditions, soil characteristics, and their farming practices on grain yields (Shearer et al., 1999). The major input for the technique is the collection of georeferenced data on crop yield and characteristics while harvesting[5].

The application entails some specific installment on the combine harvesters to obtain soil information, remote sensor data and crop yield information. All these information can be basically acquired from several components such as grain flow sensor, grain moisture sensor, GPS receiver and finally processed by task computer with user interface (Shearer et al., 1999)

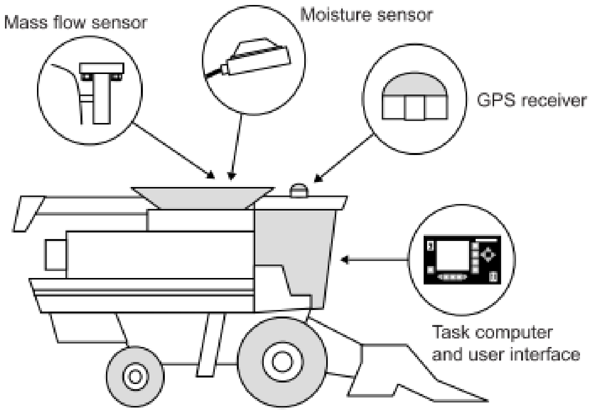

Figure 6: Illustration of yield mapping system component on a combine.

Source: Shearer et al., 1999

The system enables the farmer to gather variable data such as grain yield, soil properties, amount of grain loss within a single field in several steps (Ahmad et al., 2018).

1. Harvested grain is first loaded into the grain elevator.
2. Sensors in the elevator measure the moisture content of the grain.
3. While the grain is transported to the holding tank, more sensors track its yield.
4. The data from these sensors is sent to the driver's cabin.

[5] https://cropwatch.unl.edu/ssm/mapping

5. The information is displayed on a screen for real-time monitoring.
6. The data is also georeferenced, allowing for mapping and in-depth analysis at a later time or date.

The data allows yield calculation for each field location. And with a proper GIS (geographic information system software), it can be transferred and displayed on a map. The farmers use the yield maps to understand crop yield and interpret the related information to mitigate the potential threats and enhance possible opportunities. Furthermore, farmer can export and record the maps with source data to use for future agricultural activities such as fertilizing, planting, and spraying which requires specific equipment. Figure 7 shows an example of simple yield map which gives output per hectare. The red portion is the area of land with low yield, green areas are representing the high amount of output per hectare.

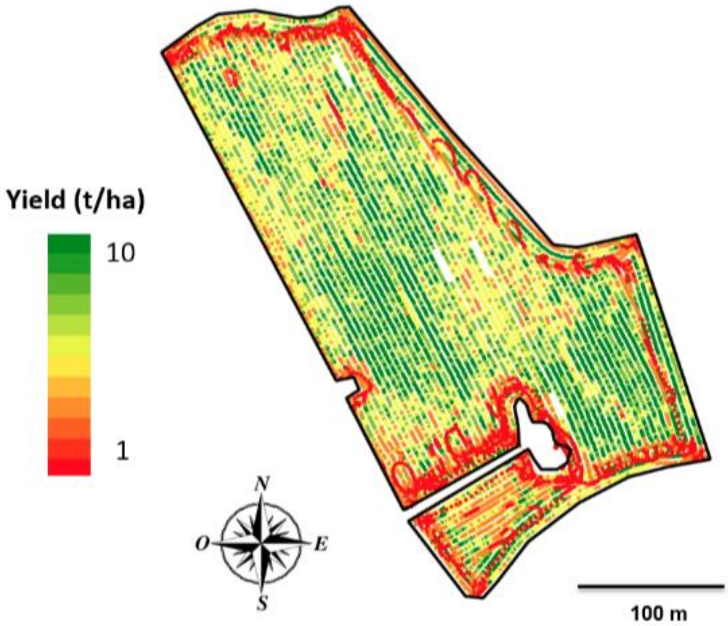

Figure 7: Illustration of a yield map.

Source: https://www.aspexit.com/yield-maps-in-precision-agriculture/

Yet, the yield mapping benefit depends on several factors (Lark et al., 2000)

a) Yield maps cannot provide the reasons for low values of yield explicitly and interpretation is crucial. In other words, low values, or anomalies in identical fields on the same yield map have different root causes.

b) The variations in yield maps for different seasons may occur due to distinct factors. Therefore, proper data analysis with proper tools should be applied on the long-term data at least five years of yield maps.[6]

If the yield variability cannot be justified and rationalized due to the field conditions such as nutrient supply, topography and past year treatment and application on the field, then site – specific field management which is the main aim of precision farming is not worth to be applied. The below flowchart proposes the strategy upon the yield map analysis.[7]

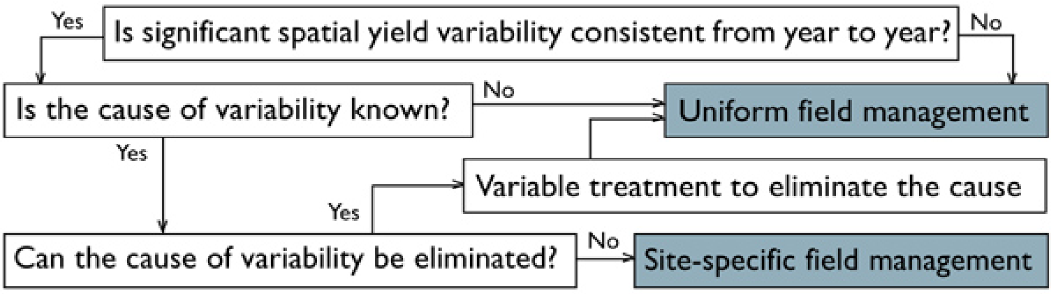

Figure 8: Decision flowchart for site – specific field management.

Source: Ahmad et al., 2018

A farmer can use this algorithm to understand whether investment on site – specific crop management brings benefit. In brief, when yield variability in different zone of field is consistent from year to year and if the cause of variability is known but cannot be avoided, then site – specific field management is appropriate solution which provides customized treatment for each zone of field.

2.4. Smart Farming in Türkiye and in the world

The diffusion and adoption of smart farming and precision farming technologies in different countries varies especially based on land size and scale of agriculture with

[6]https://cropwatch.unl.edu/ssm/mapping#:~:text=Yield%20Mapping%20Concept,developed%20for%20mapping%20crop%20yields.

[7]https://cropwatch.unl.edu/ssm/mapping#:~:text=Yield%20Mapping%20Concept,developed%20for%20mapping%20crop%20yields.

income level. In Smart Farming Report (Konya Municipality, 2024)[8], it is stated that bigger the land size and higher the income from agricultural activities, more utilization and adoption of precision farming technologies.

When we look at same report, USA, Canada, and Australia are leading countries in terms of utilization of these technologies in parallel with the land size. The average land size is 3243 ha in Australia, 582 ha in Argentina, 273 in Canada, 178 ha in USA, 45 ha in France, 40 ha in Germany and 6 ha in Türkiye. McKinsey & Company surveyed 5500 farmers in Asia, Europa, North & South America in 2022 and published a report[9]. The results tell us that around 62 % European and North American farmers are currently utilizing smart farming technologies, especially farm management system, and remote sensing, or planning to adopt in next two years. Asian farmer is the last one with only 9 % of them using or planning to use smart farming technologies mainly interested in farm automation system and agricultural robotics. The survey's result shows the farmers who own the field bigger than 2000 ha have more tendency to use smart and precision farming technologies. Another report[10] published by United States Department of Agriculture (USDA) inform that autoguidance system is mostly adopted and utilized system among precision farming technologies. In 2019, autoguidance systems were used on 40 % of all the field in US and the utilization percentage of this technology is 72.9 % for corn and 64.5 % for sorghum and cotton.

National Institute of Food and Agriculture in USA is specifically supporting research in agricultural equipment, sensor technologies and software development as well as providing upskilling and reskilling of farmers for the adoption and utilization of smart farming technologies. Israel is particular country for agricultural technologies especially on smart irrigation, biotechnology and wastewater recycling. R&D budget to support agricultural technologies is 17 % of total Israel state budget. Japan is another good example of adoption of agricultural technologies and decrease

[8] https://kosam.org/uploads/raporlar/4c8bd42b.pdf

[9] https://www.mckinsey.com/industries/agriculture/our-insights/agtech-breaking-down-the-farmer-adoption-dilemma

[10] www.ers.usda.gov/webdocs/publications/105894/eib-248.pdf

agricultural input. Therefore, Japan's agricultural exports increased by 24%, generating a revenue of 35 billion dollars in 2016[11]

When we look at smart farming and precision farming in Türkiye, although digital transformation and digital technologies implementation in agriculture is being pursued in Türkiye, Information and Communication, which is crucial for smart and precision farming - Development index (ICT)[12] still needs to be developed and Türkiye's score, 85.8, is below the EU average score (88) and high – income countries score (90).

Ministry of Agriculture and Forestry (MoAF) launched Digital Transformation in Agriculture in 2020 [13]. The program generally put the digitalization of services such as e-farmer portal, agricultural land management portal, digital marketplace for agriculture as vision. Nevertheless, fostering utilization of satellite technologies and development of electric tractor is in the program. MoAF led establishment of Smart Farming Platform[14] by involving agricultural equipment sector representatives, and academicians to develop strategies for smart and precision farming in Türkiye in 2016. Furthermore, General Directorate of Agricultural Research and Policy (TAGEM) under MoAF initiated the development of autoguidance system for tractors. Today, market size of autoguidance system as total industry volume (TIV) which represents total amount of specific goods sold over a specific period is given below by comparing with tractor total industry volume in Türkiye.

This graph provides useful information and insight that autoguidance market size which represents the total number of sold units in Türkiye has been increasing year over year. When we compared with tractor market size, the ratio of autoguidance unit per tractor has increased from 0.9% in 2020 to 5% in 2023. We can conclude that

[11] https://tarmakbir.org/wp-content/uploads/2022/07/akillitarimrapor01.pdf

[12] https://www.itu.int/hub/publication/D-IND-ICT_MDD-2023-2/

[13]https://manisa.tarimorman.gov.tr/Belgeler/Tar%C4%B1mda%20Dijital%20D%C3%B6n%C3%BC%C5%9F%C3%BCm%20Hamlesi/Tar%C4%B1mda%20Dijital%20D%C3%B6n%C3%BC%C5%9F%C3%BCm.pdf

[14] https://tarmakbir.org/wp-content/uploads/2022/07/akillitarimrapor01.pdf

autoguidance market is expanding, however it is still low compared to tractor market size.

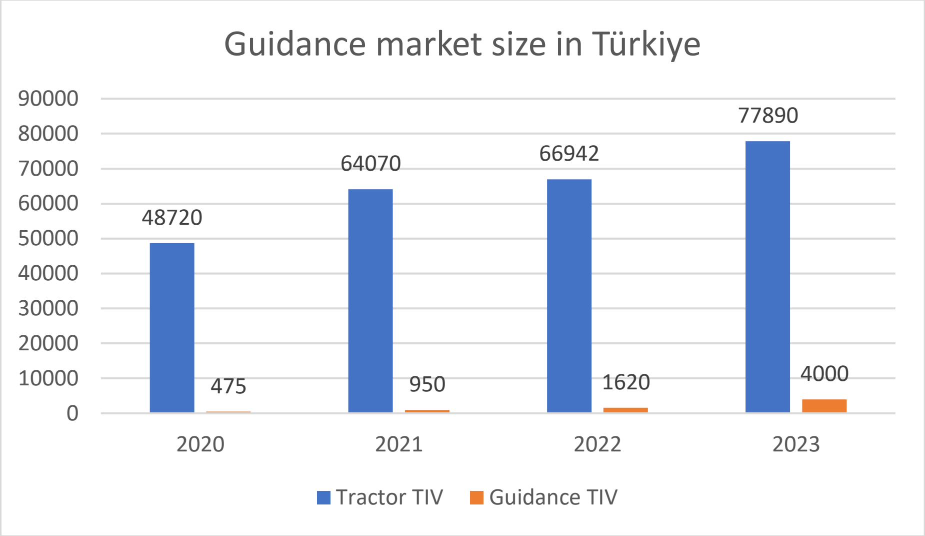

Figure 9: Guidance market size in Türkiye (Number tractor and number of guidance system).

Source: Türk Traktör, - 2024

2.5. Innovation System Approach

In this section, I will discuss the progress and details of the innovation systems approach that I used in my thesis. In fact, research on innovation systems has a history of approximately 37 years and it started with the research of Christopher Freeman on Japanese national innovation system in 1987 and Richard R. Nelson's preface to a chapter with the title "National Innovation System" in 1988 (Klein et al., 2016). Then research on regional, sectoral, and technological innovation system followed.

A system can be defined as a group of interconnected elements that collaborate to achieve a shared goal. If a feedback mechanism is present, the system is dynamic otherwise, it turns out to a static system. And innovation systems examine the development of new technologies through intricate interactions among various actors. (Klein et al., 2016)

Edquist (2005) stated that innovations and technological change are the main triggers of economic growth and social welfare, and system of innovation provides a comprehensive framework to study the innovations in the economy. However, innovation is not an isolated process and cannot be obtained individually. It is affected by many distinct factors such as interaction between the organizations, exchange of various kind of information and knowledge, constructive interaction among the organizations (suppliers, customers, competitors, universities, research institutes, government). Technological change and innovation both exist and diffuse in an innovation system (Carlsson et al., 2002). The system of innovation approach let us to overcome this complexity and to describe and understand the innovation process with all the major factors affecting it.

Innovation process is an evolutionary process, therefore, the models and frameworks which are based on evolutionary approach are able to explain the mechanism more realistically than the models based on neoclassical economics (Nelson, 1981). Apart from Nelson, Carlsson and Stankiewicz, Rosenberg and Lundvall support the idea that innovation and technological change are evolutionary (Edquist, 2005).

Innovation system can be national, regional, sectoral level or technological and as stated above, they all serve as a framework for creation, diffusion, and usage of knowledge (Carlsson et al.,2002). Any innovation system is composed of three components, the actors, networks, and institutions and there is no specific orchestration among the components. The actors may have different aims which can insert the tensions and the conflict into innovation system. Yet, these are essential for the innovation system dynamics (Bergek et al., 2008)

National innovation system proposes a framework covering industries and organizations related with science and technology and policies for innovation in a country. All the analysis are pursued in national level by considering all the components. However, as the boundary contains many linkages among components and involves different actors, the system is quite complex (Carlsson et al.,2002). Even Lundvall (1998, p.415) stated that *"the concept National Systems of Innovation can be regarded as a tool for analysing economic development and economic growth."*

On the other hand, regional innovation system concentrates on relationship between innovation and economic development and performance of particular region. (Doloreux, 2005)

Sectoral innovation system has smaller boundary than national innovation system and mainly focuses on an industry or a sector. The basic idea of sectoral innovation system is that each sector or industry has different technological regime which covers unique knowledge base, linkages among actors and different opportunities (Carlsson et al, 2002)

2.5.1. Technological Innovation System (TIS)

Since I used technological innovation system approach as the innovation system in my thesis, this section is entirely dedicated to the TIS approach. TIS is not a new concept, and it was originated from the framework proposed by Carlsson and Stankiewicz (1991) focusing on technologies and product and the foundational idea behind the concept is that a country's economic growth depends on the technological systems in which various economic actors are involved. During 1990s, there were various contributions to enrich the framework (Markard et al., 2015)

Bergek et al. (2015, p.2) define technological innovation system as follows:

> "*The specific variant of technological innovation system (TIS) focuses on understanding how the innovation system around a particular technology function. The focus can be on mature technological fields or on the emergence and diffusion of new and radical innovations*".

TIS boundary can be beyond national or sectoral innovation system, and it can intersect them. Hekkert et al. (2007) proposes a schematic view of relationship between different types of innovation systems. To sum up, the boundary of TIS can be defined in accordance with the needs and requirement of analysis.

TIS complexity is relatively lower than NSI due to small number of system component, actors, network, and institutions (Hekkert et al., 2007). And TIS analysis in general focuses on a selected technology in a selected country. (Markard et al., 2015). TIS focuses on the development, diffusion, and adoption of a specific technology.

Any technological innovation system is affected by two types of broad interaction, external links, and structural couplings. External links are the factors which can affect TIS but cannot be affected by TIS itself. Structural couplings are the components of TIS (Bergek et al., 2015)

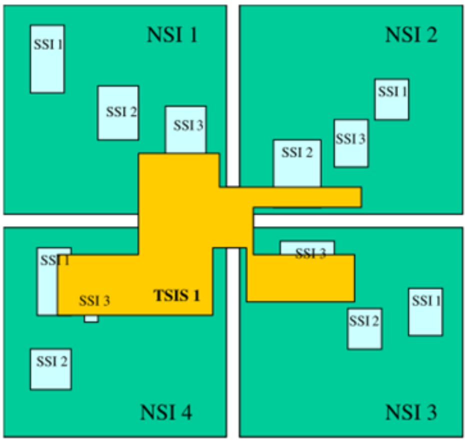

Figure 10: Boundary relations between National, Sectoral and Technological Innovation Systems

Source: Hekkert et al., 2007

CHAPTER 3

THEORETICAL BACKGROUND AND METHODOLOGY

This chapter overviews the research question and introduces the theoretical framework of innovation system, in other words, technological innovation system will be further discussed in terms of its functions based on Hekkert's model at first. Second, the models will be elaborated in accordance with the research question and conceptual framework and each function will be explained in this scope and linked with the research topic. Third, the methodology section compiles data acquisition, interview process, questions which is specifically designed in the scope of Hekkert's model by considering the type of interviewee, and finally data analysis tools and methods will be discussed.

3.1. Framework discussion and Functional Analysis

Precision farming as a product of Agriculture 4.0 is not a new technology. It has been applied and utilized for a long time especially in developed countries as discussed in literature survey. However, its introduction and exploration in Türkiye is comparatively new and Fig. 11 illustrates the state of art of mechanization and digitalization in agriculture across Türkiye, EU, USA and Australia. The chart shows that precision farming technologies diffusion is slower in Türkiye when compared with developed countries such as EU, USA and Australia. My thesis, "A policy design for deployment and diffusion of precision farming in Türkiye" aims to find the mechanisms and dynamics behind diffusion specifically for autoguidance & yield mapping technologies and propose a policy to expedite adoption which may enhance efficiency in agricultural productivity in Türkiye. And the research questions provided below will be investigated as well.

Research questions unveil diffusion and adoption levels of precision farming technologies, especially for autoguidance and yield mapping and monitoring systems in Türkiye, the gap between different countries, main factors that affect diffusion and adoption, knowledge development in Türkiye with rate and direction, potential economic benefits. Three research questions being analysed are given below.

i. What is the state of art of precision farming, and especially of auto guidance and yield mapping in Türkiye?
ii. What are the main potential benefits of precision farming for the Turkish economy, and its agriculture in particular?

The research has been conducted in Technological Innovation System framework to elucidate structures and processes which establish and shape the precision farming technologies such as autoguidance and yield mapping as it provides insight in the dynamics of innovation system to understand development, adoption, and diffusion of a new technology. The innovation system approach helps us to understand and explain how various contributors influence the rate and direction of innovation. This includes societal subsystems, actors, and institutions involved in the production of innovation (Hekkert et al., 2007)

Jacobsson and Bergek (2004) describes TIS as a growth model which is driven by cumulative causation based on notion of instability. It means that a social process does not move towards to an equilibrium state, since a change promotes and supports the changes which evoke and prompt the system. Consequently, there is always movement and transformation process in the system. And TIS enframes the process by defining key activities or system functions which interacts with each other (Suurs, 2009, pp.26). Bergek et al. (2008) call all the processes which promote the development, diffusion, and adoption of innovations as system functions or key activities.

> *"There are two main reasons for adopting the Functions of Innovation Systems Approach. The most fundamental reason is that an analysis in terms of system functions allows for a focus on dynamics. The second reason for adopting a functional perspective is that it points to a notion of performance that incorporates variables other than diffusion rates.*" (Suurs, 2009, p.51)

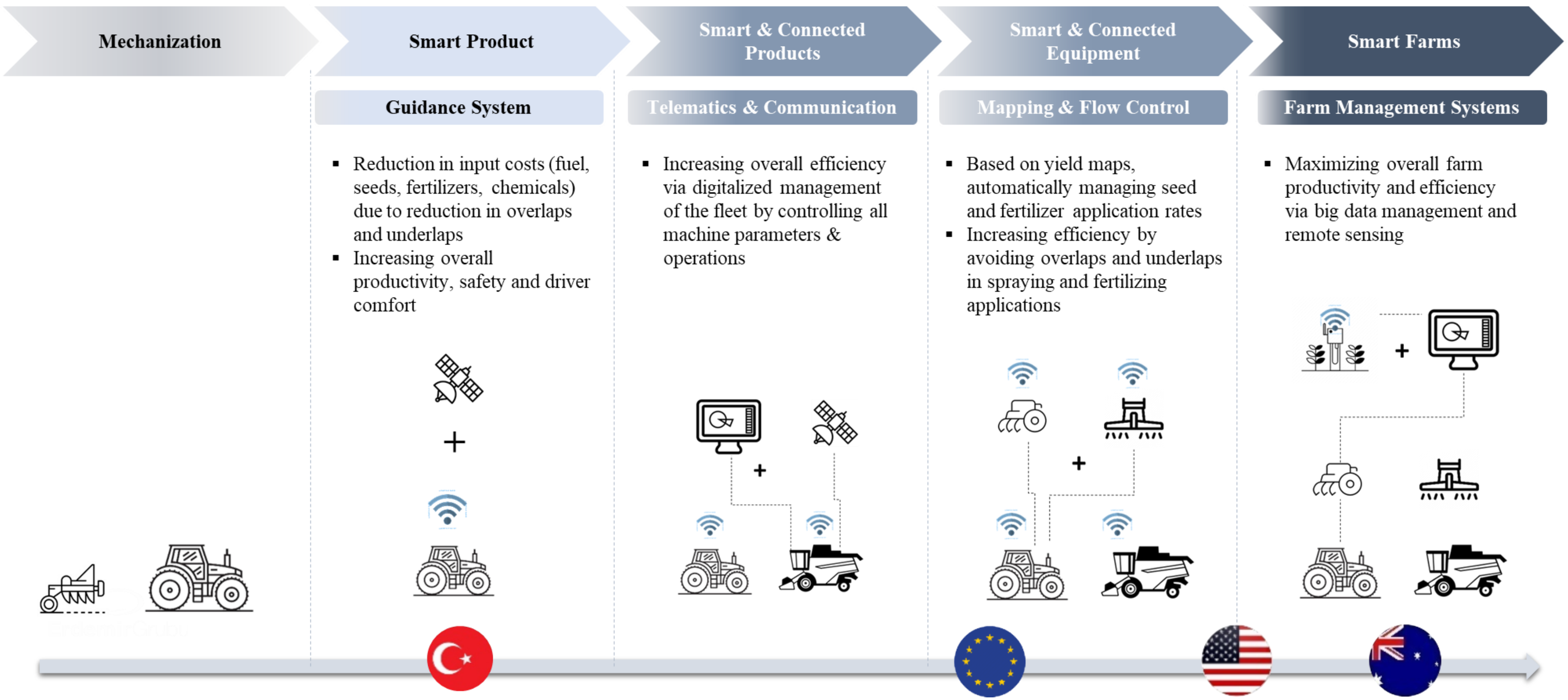

Figure 11: The state of art of mechanization and digitalization in agriculture across Türkiye, EU, USA and Australia

Source: TürkTraktör technical report, 2023

Hekkert et al. (2007) gives three good reasons to consider the functions approach. First, it allows us to compare how well innovation systems perform, even when they have different institutional setups. This makes it easier to see which systems are doing better.

Second, the functions perspective gives us a more organized way to map out the factors that drive innovation. This helps us analyse innovation systems more effectively.

And third, the functions perspective has the potential to provide clear goals for policies and the tools needed to achieve these goals. By evaluating system performance based on the functionality of a particular innovation system, we can set specific targets and use the right instruments to reach them.

Under the light of above arguments, despite different function approaches such as Bergek et al. (2005), Edquist and Chaminade (2005) which are summarized by Markard et al. (2008), we will utilize the seven functions defined by Hekkert (2007) as his model provides more inclusive and up-to-date model for technological innovation system analysis (Parlak, 2023)

The main system functions considered in Hekkert (2007) are.

1. Entrepreneurial activities (F1)
2. Knowledge development (F2)
3. Knowledge diffusion (F3)
4. Guidance of the search (F4)
5. Market formation (F5)
6. Resource mobilization (F6)
7. Creation of legitimacy (F7)

The detail explanation of each function will be provided and the main activities as well as key performance indicators will be customized and described based on research scope.

3.1.1. Entrepreneurial activities (F1)

The driver of an innovation system is the presence of active entrepreneurs who determine the system performance with support of other six functions. Solow defines entrepreneurial activities as the triggers for the economic growth (Baykal, 2021, p.31). Entrepreneurs progressively make trial and tests to cope with the uncertainties and to understand market behaviour. Entrepreneur can perform either by creating a new start up with the vision of business opportunities in a new market or by broadening and diversify the existing business by using the emerging technologies and new developments. (Hekkert et al., 2007)

The main key performance indicators of entrepreneurial function are number of new entrants, new start up, the number of experiments with the new development and technologies, the number of diversifications from existing business, which creates ecosystem for entrepreneurs.

In the context of this thesis, F1 function helps to assess the precision farming and specifically autoguidance and yield mapping technologies ecosystems in terms of strength and weakness involving both local and foreign players and the technology generators in the market, and entrepreneurial activities in Türkiye for precision farming. During research, we will take into the consideration of both technology provider and technology users' perspectives.

3.1.2. Knowledge development (F2)

Learning and knowledge development are crucial for innovation process and knowledge development is achieved in two ways, learning by searching and learning by doing according to Hekkert (2007). Learning by searching in this context represents the research activities in universities and institutes, while learning by doing covers R&D activities, product development programs and projects and it takes place mainly in companies and firm, training center, cooperative and collaborative projects, R&D center, manufacturing plants. Furthermore, knowledge is a fundamental resource for today economies and the fact brings the notion of knowledge economy.

The basic performance indicator for F2 function is R&D projects, number and content of the patents and investments in R&D.

The research will analyse patents in precision farming in Türkiye by doing a basic patent search in Türk Patent website, articles in scientific journals by making bibliometric analysis and investigate R&D projects both in private and governmental sectors by interviewing with participants from industry and searching in news, website in the scope of knowledge development function. The aim is to unveil the direction of technology research in Türkiye and to establish a correlation between applications in the field and research and development.

3.1.3. Knowledge diffusion through networks (F3)

As well as knowledge development, knowledge diffusion has a vital role in exchange of information for the network. Hekkert (2007) discusses two type of knowledge diffusion. First, learning by interacting created by the interaction among the components of network such as government, precision farming companies, startups, research institutes to transfer and transform the knowledge to create synergy. Second, learning by doing which exist through the interactions between users such as farmers and producers such as precision farming companies and startups. It mainly covers application and utilization of precision farming technologies such as autoguidance and yield mapping by farmers in the agricultural activities.

The number of workshops, conferences, summits, and audio – visual media as well as network size and intensity are the main performance indicators of F3 function aiming to disseminate and transfer the knowledge created and developed as described in F2 function within market and among the farmers.

I intend to conduct an examination encompassing workshops and publications originating from associations, public institutions, and the private sector. Additionally, I will scrutinize awareness events, communication channels, and network size, all within the confines of my thesis scope.

3.1.4. Guidance of the search (F4)

Guidance of the search function is regarded as the process of selection within the technological variety that is created by knowledge development function (F2). And this selection based on the preferences of society can impact on the direction of technological change. Furthermore, there is a reciprocal relationship between direction of technological change and user demand which means that each of them affects the other one.

This function can be examined by charting the specific goals outlined by governments or industries for a particular technology. Additionally, we can gauge the level of anticipation for new technological advancements by mapping the articles in academic journals.

I will scrutinize the policies and targets for precisions farming through a trend analysis for new technologies (bibliometric analysis), customer demands and manufacturer vision and the goals in the scope of F4 function.

3.1.5. Market formation (F5)

When a new technology emerges, the diffusion can be slow since at the early stage, the technology is not matured and cannot be adopted properly. (Hekkert et al., 2007) The farmers expectations about the benefits of autoguidance and yield mapping, communication infrastructure availability, price of these technologies, skills needed for utilization of technologies, delaying decision to see what other farmers do, lack of incentives, lack of regulation are primary factors affecting the adoption therefore the users may not get the full benefit and advantage. Under these circumstances, the market needs to be formed by applying different approaches and policies both in supply side and demand side with instruments such as thematic funding to foster precision farming R&D activities and industry in order to create ecosystem, public procurement especially for governmental farms like TİGEM premises, subsidies through public bank to farmers for buying precision farming system, especially autoguidance and yield mapping, regulation to make yield mapping system mandatory for combine harvester, regulation to upskill farmers.

The performance can be assessed by observing and considering the market size, specific tax regime and new standards.

I have investigated the government support especially from Ziraat Bank and its financial incentives, precision farming product demand and volume evolutions over the years and investment on infrastructure in the scope of market formation function.

3.1.6. Resource mobilization (F6)

Resource mobilization function is representing the allocation of necessary resources in terms of financial and human capital to generate the knowledge. Therefore, resource mobilization functions can be considered as an important element and input for knowledge development function (F2) (Hekkert et al., 2007). As the resource requirement may change in terms of quantity (number of researchers and engineers involved in R&D activities, number of grants, subsidies or investment to support innovation processes), quality (the level of expertise and competence of human resources in precision farming technology development), and variety (types, sources, or origins of the funds, or the backgrounds or disciplines of the researchers, engineers or farmers) in time it is difficult to find an appropriate performance indicator over time.

Nevertheless, I will try to measure the performance by assessing financial resources such as funds for precision farming technology development and human capital for R&D activities both for development and adoption of the technology.

3.1.7. Creation of legitimacy (F7)

Any new technology faces with the roadblocks and forces exerted by the different power groups due to their interest during its diffusion and adaptation. In order to overcome, there needs legitimacy for new technological trajectory that can be supplied by an advocacy coalition. Legitimacy acts as a catalyst by providing resources, favourable tax and incentives regime and market formation. The legitimacy and power of new technological trajectory depend on the size and influence of this advocacy coalition. (Hekkert et al., 2007)

Creation of legitimacy can be mapped by assessing the related interest groups, their size and level of influence and impact.

I will analyse the laws, regulation, policies, and existence of specific institutions in Türkiye for the function 7.

3.2. Methodology

3.2.1. Research strategy and methodology selection

Technological change, innovation, its adoption, and diffusion are socio-technical phenomena which represents the interaction between people and technology. Byrman (2012) states about qualitative research that

> "*In contrast to the adoption of a natural scientific model in quantitative research, the stress is on the understanding of the social world through an examination of the interpretation of that world by its participants"* (p.380).

Therefore, a socio – technical analysis was conducted, and I employed qualitative research methodology for data collection and analysis to answer the research questions.

Furthermore, quantitative elements such as precision farming market size and its evolution, financial tools and incentives were added to enrich the analysis and support the arguments as secondary data. The rationale behind the choice of methodology is based on the investigation of interrelatedness of social and technical aspects in the society and unveiling the status of precision farming technology, its diffusion and adoption rate and direction, barriers, ecosystem, and further needs and demands.

3.2.2. Method and data acquisition

Different research methods associated with qualitative methodology are available, such as ethnography/participant observation, interviews, focus group, discourse, and conversation analysis. The best fit method for our research is conducting interviews to understand the precision farming technology users, producers, and authorities from the industry as it provides more flexibility to seek out the views of participants and provides insight. Furthermore, interviews are more suitable for the heterogenous interviewee profiles encountered in our research. The semi -structured interview tool was employed with the list of questions given below in table 3.

Besides, different methods and tools such as bibliometric analysis, market analysis patents search, and more were used for each of Hekkert function based on needs. Summary table of methods and tools for each function is given in table 4.

Table 3: Semi – structured questions and related function in Hekkert TIS model

Related Function	Questions
N/A	Can you introduce yourself
N/A	How long have you been working in the field of precision farming / with precision farming?
N/A	Can you describe your agricultural activities? Can you tell us about your job description?
F3- F5	How did you decide to use precision farming in your operation?
F3- F4- F5	Which kind of technology and which brand do you use?
F3	Did you join any public briefings or workshop organized by any institutions?
F3	How did you learn the usage of technology, did you have any knowledge before?
F4	What do you further demand on top of current features of precision farming?
F5	Do you use any incentive or fund from government, Ziraat Bank, Tarım Kredi Koop. Or any other means for buying precision farming equipment?
F5	What is your assessment on infrastructure (ICT etc) and supports for precision farming?
F1- F2- F6	What do you think about R&D activities related with precision farming in Türkiye?
F1- F2- F6	Have you ever met (aware) any start up related with precision farming originated from Türkiye?
F7	How do you evaluate the policies, laws and regulation related with precision farming in Türkiye?
F1- F4 -F5	What is your general assessment on precision farming in Türkiye?

Table 3: (continued)

F1- F2- F3- F4- F5	What is your opinion about future of precision farming in Türkiye?
F4- F7	Dou think that policy mechanism is supporting the diffusion and adoption of precision farming technology?
F7	Do you know any chamber or institution about precision farming (or smart farming)?
F1- F3- F4- F5 -F6	What is your next step in precision farming?
F1- F2- F3 -F5- F6- F7	What are the impediments in Türkiye about diffusion of precision farming technologies?
F5	What is your comment on the price and investment level for autoguidance and/or yield mapping, is it affordable?
F5- F3- F4	Can you find and access service dealer point to fix any issue related to precision farming when needed?
F3- F5	Can you fix or maintain by yourself without getting help when any failure or issue occur on precision farming equipment?

Source: Author

Table 4: Summary table of tools and methods for each Hekkert function

Function	Methods and Tools
Entrepreneurial activities (F1)	Interview, Market analysis
Knowledge development (F2)	Interview, Startup search, Patent Search, Bibliometric analysis, Analysis of initiatives
Knowledge diffusion through network (F3)	Interview
Guidance of the search (F4)	Interview
Market formation (F5)	Interview, Market analysis, Analysis of regulations
Resource Mobilization (F6)	Interview, Analysis of incentives
Creation of Legitimacy (F7)	Interview, Analysis of laws & regulations

Source: Author

3.2.3. Sampling of profiles

The participants' profiles were selected based on their relevance to the research questions. This method is called purposive sampling, and the number of participants is defined to ensure accessing to a wide range of individuals to cover the scope of thesis. However, the sample size and number of participants is always debatable, and Bryman (2012) discusses sample size comprehensively based on different authors and researchers. There are different approaches, one of which proposes between twenty and thirty as a minimum number of interviews, another one blesses the small size of sampling like smaller than twenty. Onwuegbuzie and Collins (2007) stated that.

> "*In general, sample sizes in qualitative research should not be so small as to make it difficult to achieve data saturation, theoretical saturation, or informational redundancy. At the same time, the sample should not be so large that it is difficult to undertake a deep, case-oriented analysis* (p.289)."

Data saturation occurs when new data does not yield or provide new information. Theoretical saturation represents that additional data no longer contributes to emerging theory and informational redundancy is similar to data saturation and refers that additional data does not provide new information or insight.

The critical point is saturation, whenever a number of participants secure it, the sample size can be defined accordingly.

In the thesis, I reached saturation around 10^{th} interview, nevertheless, conducted one more interview with a farmer to validate the saturation. The profiles of interviewees are given in Table 5.

Table 5: Interviewees list and profiles

Interviewee No	Code	Title
Farmer 1	FR1	Large scale farmer
Farmer 2	FR2	Large scale farmer
Farmer 3	FR3	Large scale farmer
Farmer 4	FR4	Small scale farmer
Farmer 5	FR5	Small scale farmer
Farmer 6	FR6	Large scale farmer
Industry 1	ID1	Marketing director
Industry 2	ID2	Precision farming department manager
Industry 3	ID3	Business development manager
Manufacturer 1	PF1	Precision farming product manufacturer
Manufacturer 2	PF2	Precision farming product manufacturer

Source: Author

3.2.4. Semi–structured interview structure

The interviews have been organized as primarily face-to-face however due to agricultural season and accessibility, several interviews with farmers have been held online.

11 interviews were conducted in different cities, Ankara, Konya, Aydın, Osmaniye from a variety of proficiency, farmers, precision farming marketing, business development and R&D functions in industry, employees from precision farming companies. Duration of the meeting was around 45 minutes.

3.2.5. Data analysis

Bryman (2012,) argues that qualitative research cannot provide definitive set of rules compared to quantitative research and it is generally ambiguous. Furthermore, the codified analytical procedures are not sufficient in qualitative research and the researcher usually face with excessive data which is difficult to handle. Bingham (2023) mentioned two strategies for qualitative research, deductive and inductive approach. Although Bryman (2012) states that inductive approach is predominant in qualitative methodology, deductive approach can also be employed to analyse the data with predetermined codes and categories based on a theoretical framework. Besides, researchers can develop and create deductive codes to define and describe what they anticipate or expect from data (Bingham, 2023). Gale et al. (2013) said that in the deductive approach, themes and codes are chosen in advance, informed by existing literature, established theories, or the particular focus of the research question.

On the other hand, in inductive approach, codes and categories are not predetermined. As Bingham (2023) stated that they are constructed based on data and inductive analysis involves reviewing the data and uncovering codes, categories, patterns, and themes as they naturally arise from the information.

Therefore, I employed deductive approach by using Hekkert framework. Data was collected as described in section 3.2.4. After transcribing the interviews, the data has been coded in alignment with Hekkert's functions and key performance indicators. This will ensure that the data analysis is both efficient and effective.

I used MaxQDA Plus 2022 software to code and analyse the interviews which were transcribed in advance as input into the software. The program mainly provides clustering and comparison of comments and ideas based on Hekkert functions. Therefore, coding is crucial step to obtain accurate analysis.

The list of codes is given in table 6.

Table 6: Coding System

Coding System
Policy recommendation
supply side policies
Agricultural planning
awareness focus
association and network establishment
regulation for precision farming
regulation for import of precision farming equipment
regulation for herbicides and pesticides
regular field and soil assessment & analysis
supporting and deploying R&D
Agricultural policies (product pattern, unification etc)
Cooperation between Start Up's and SME, MNC etc
infrastructure
grant
incentives
upskilling
Experience (years in precision farming)
20<
10<x<20
<10
Industry
farmer
supplier and technology provide
R&D
marketing
Entrepreneurial activities (F1)
Diversification of incumbent actors' activities

Table 6: (continued)

Ecosystem for entrepreneurship
Number of new entrants
Knowledge development (F2)
effectiveness of start up
high
moderate
low
number of start up
R&D project
intention and plan only
solid program ongoing
no visible program
scholar articles in precision farming
patents in precision farming
Knowledge diffusion through networks (F3)
on the job training
level of awareness
high
medium
low
channels
social media
resellers/dealers
Fair
contractor
word of mouth
startup meeting
internet
awareness event
workshop and publications from assoc., inst., and sector
Guidance of the search (F4)
customer demand
agricultural robots
data analysis
visual recognition and image processing
smart fertilizing
Fleet management
Telematics
smart seed
smart spraying
subscription base usage
ISOBUS equipment

autonomous tractor
smart irrigation
farm management
drone
autogudaince
yield mapping
variable rate application
trends for new technologies in precision farming
policies and targets for precision farming
not available
available but not sufficient
available and sufficient
Market formation (F5)
land size
service and aftermarket support
investment on infrastructure
soil analysis support
GPS
sufficient
insufficient
volume evolution in precision farming year over year
precision farming product price and demand
tax regime and incentives
government support
Resource mobilization (F6)
human capital for R&D activities
financial resource, funds etc
Creation of legitimacy (F7)
specific institutions existence
laws, regulations, and policies
aftermarket regulation
import regulation

Source: Author

CHAPTER 4

FINDINGS & DISCUSSION

The outcome of semi – structured interviews was compiled to obtain meaningful data. 11 interviews have been conducted and average duration of sessions which were held via online or face-to-face took around 45 minutes. Data was analysed by using MAXQDA software with the coding which has been given in section 3.2.5 based on Hekkert's model.

In this chapter, I present the findings and insights for each Hekkert function under the light of data analysis and discuss the situation in Türkiye which will be supported by secondary data from different sources to form a frame for conclusion and policy recommendations.

This thesis question intends to research the yield mapping and monitoring as well as automatic / manual guidance, the mature data for yield mapping and monitoring could not be pursued for Türkiye. In Türkiye, due to the infeasibility of purchasing a combine harvester for farmers, the harvest process is generally carried out by contractors who own combine harvesters. For these contractors, it is not pertinent to equip their machines with yield mapping and monitoring systems. Since the number of individual owners of combine harvester is quite low, the data remains very limited. Although the government has occasionally introduced projects such as installing a yield mapping system on every combine harvester, these have not been long-lasting.

Figure 12 shows that the participants have enough experience on autoguidance system to comment on this technology. Especially, four interviewees have been using this technology more than 10 years and they can be classified as early adaptors.

The general information for 11 participants is given below.

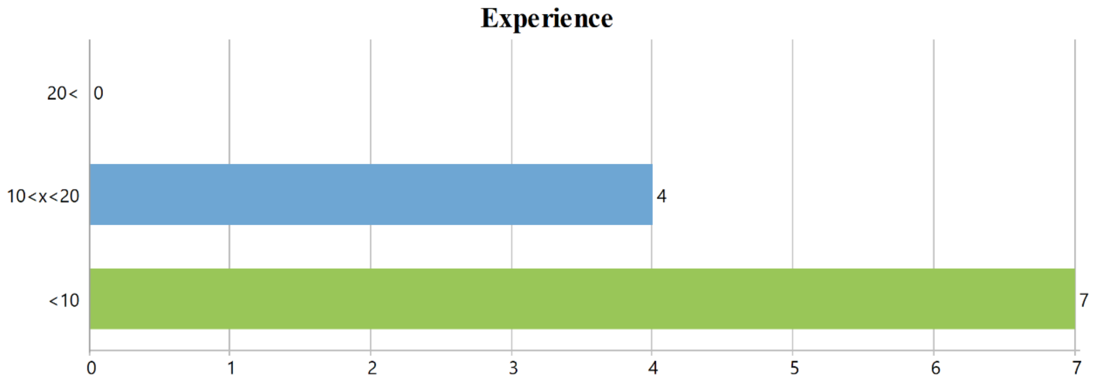

Figure 12: Number of participants with experience on precision farming (y axis shows the years)

Source: Author

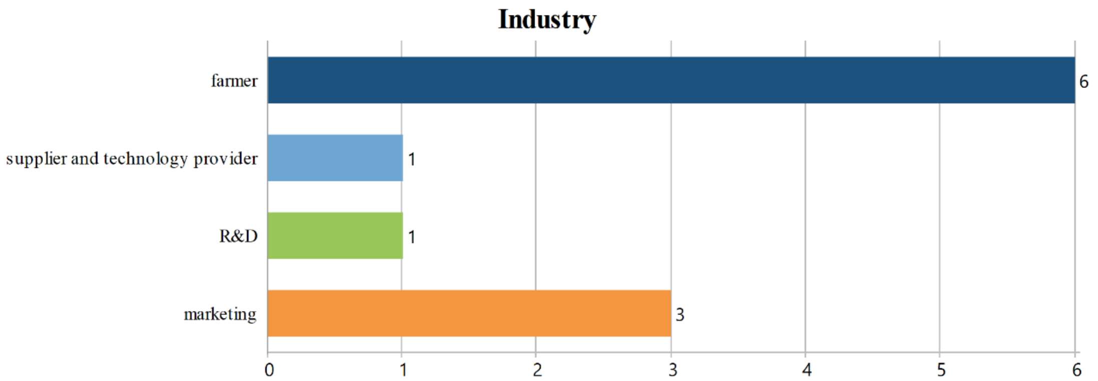

Figure 13: Participants' background and their business.

Source: Author

The majority of participants are farmer who are effectively adopting and using autoguidance. Four of them are large scale farmer and they can comment on the benefits coming from autoguidance system more comprehensively. None of them has yield mapping and monitoring system.

Three participants are marketing professional from tractor business, one participant from precision farming technology foreign supplier and one is from local research and development company on autoguidance. All of them have provided enough data to obtain theoretical saturation.

4.1. Entrepreneurial activities (F1)

Entrepreneurial activities function helps to assess weakness and strength of ecosystem for precision farming and specifically autoguidance and yield mapping technologies and deals with number of new entrants, new startup, the number of experiments with the new development and technologies, the number of diversifications from existing business.

Interview output analysis shows that participants from all business, precision farming companies, farmer, and industry, mentioned some aspects of entrepreneurial activities. The below graphs provide a summary of sub – functions for different dimensions of F1 function. We would like to point out that participants can provide feedback on more than one sub-function.

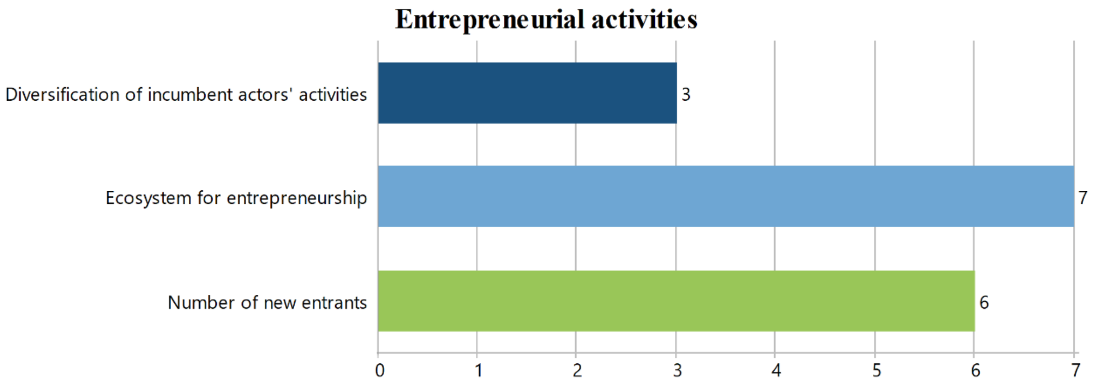

Figure 14: Number of comments on sub-functions.

Source: Author

When we look at the diversification of incumbent actors, the results shows that all incumbent actors in Türkiye are foreign based and none of the participants mentioned any significantly active local technology provider name. PF2 told that western-origin products have targeted high-end farmers for a long time. This is still valid. He also said that with the entry of the Chinese into the market, prices have dropped, making these autoguidance systems accessible to lower-budget farmers as well. Western-origin product prices are still high compared to Chinese product. PF2 provided information as below.

For many years, Trimble and Topcon remained prominent global players in the market. However, there is an important distinction to be made here. As the pioneers and long-term innovators of these systems, these two companies have maintained a focus on the premium segment. In contrast, Chinese companies have entered the market with more budget-friendly and affordable solutions, emphasizing primarily steering functions and offering a low-cost correction method by utilizing only the VRS system for connectivity. In this segment, companies like Trimble and Topcon are notably absent. These key players have consistently developed products for the premium, or at least the upper-middle segment, and the reason for this is quite clear: the manufacturers in question have been working as OEMs with large producers. Consequently, there are not many firms providing products to the lower segment, small farmers, or those seeking more affordable solutions.

On the other hand, research findings and secondary data show similar results. We cannot clearly identify the differences among existing players in the field of automatic guidance in terms of product features and modus operandi. First of all, the players in the market are generally foreign origin and their activities were established on trade and sales specifically. The list of players that was consolidated during Konya Agricultural Fair 2024 which is the biggest fair in Türkiye is below, Table 7. The actors are mainly Chinese origin, although, reputed ones, Trimble is from USA and Topcon is from Japan. The entry of Chinese suppliers into the market has changed the current situation and autoguidance system became consumer goods with the lower prices. The price level for different brands in the market is varying between roughly 5.000 – 11.000 $.

All farmers interviewees mentioned that all the brands are able to provide the core features of guidance system with the expected accuracy level. The differences among the products from different suppliers come from aftermarket support, correction signal which is needed to obtain accuracy in position for agricultural operations as standard GPS provides an approximate position and extra features such as automatic turning at field row end, signal buffering and reverse motion. All shows that diversification from existing business among actors is low and they have dealing with similar products by implementing similar business operations.

When we look at Turkish startups or companies, which are dealing with the autoguidance technologies by mainly doing research and development as well as production, and ecosystem for entrepreneurship, my observation based on interviews and secondary data indicates that there are not any solid initiatives from government and institutions, although a couple of initiatives have been launched.

On 5th of November 2019, the workshop has been held by Food and Agriculture Organization of United Nations (FAO), General Directorate of Agricultural Research and Policy (TAGEM) and Ministry of Agriculture and Forestry (MoAaF) to support national e-agriculture strategy development and released a final declaration document[15].

However, we cannot see any emphasize on autogudiance system explicitly within this document. Besides, on 5th of October 2020, a protocol[16] has been mutually signed by Gebze Technical University and General Directorate of Plant Production and Smart Farming Research and Application Center (ATAM)[17] has been established on 16th of May 2023 based on the protocol mentioned above to foster the cooperation among different parties such as local and foreign companies and institutes, to pursue the research and development on smart farming and to support the scientist and researchers. The center does not conduct R&D activities itself, instead, its mission is to create ecosystem for researchers, provide consultancy, cooperation with local and foreign institutes and related parties, and encouraging publications.

These initiatives have not brought enough action yet and the participants that I interviewed did not feel the impact from all these initiatives. Besides, the startups are generally engaged with software development rather than product development for precision farming technologies.

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15 https://www.tarimorman.gov.tr/TAGEM/Belgeler/yayin/T%C3%9CRK%C3%87E_ULUSAL%20E-TARIM%20STRATEJ%C4%B0S%C4%B0%20HAZIRLIK%20%C3%87ALI%C5%9ETAYI_RAPORU.pdf

16 https://www.tarimorman.gov.tr/BUGEM/Haber/579/Akilli-Tarim-Egitimi-Ve-Isbirligi-Protokolu-Imzalandi#

17 https://gtuatam.gtu.edu.tr/kurulus-tarihce.html

Table 7: Autoguidance system sellers in Türkiye

Seller Companies	**Geomate**	**Future – CHC Nav NX - 510**	**CHC Nav**	**Sveaverken**	**AGV**	**NARAS**	**Trimble**	**E – Survey**	**FJ Fynamics**	**Traxnav**	**Imo**	**Topcon**
Correction Signal*	RTK Radio & RTK VRS	RTK Radio & RTK VRS	RTK Radio & RTK VRS	RTK Radio & RTK VRS & Atlas RTK	RTK Radio & RTK VRS	RTK Radio & RTK VRS	RTX CenterPoint & RTK & RTK VRS	RTK Radio & RTK VRS	RTK Radio & RTK VRS	RTK Radio & RTK VRS & Atlas RTK	RTK Radio & RTK VRS	RTK Radio & RTK VRS
Accuracy	±2.5 cm	±2.5 cm	±2.5 cm	±2.5 cm	±2.5 cm	±2.5 cm	±2.5 cm	±2.5 cm	±2.5 cm	±2.5 cm	±2.5 cm	±2 cm
Origin	China	China	China	China	China	China	USA	China	China	China	China	Japan

Source: TürkTraktör (2024).

* Standard GPS provides an approximate position. In order to obtain accuracy in position for agricultural operations, correction signal is needed, and it is supplied by fixed reference station.

Regarding this, participant PF1 stated that:

> *We don't have a known ecosystem that we see or know of. That's where the ecosystem aspect comes into play. We've also made agreements with 1-2 companies that support our R&D efforts, so we're not just using our own resources. So, we've started to build an ecosystem of R&D precision farming around us as well.*

Moreover, the Directorate General of Agricultural Research and Policy (TAGEM) has subsidized National Autoguidance System development project (Yerli Otomatik Dümenleme ve Kontrol Sistemi – OTAK) that was undertaken by ASELSAN in 2015[18] [19]. Although Pakdemirli et al. (2021) mention that the project has been concluded and finalized, there is not any commercialized product in the market. Another initiative is the AgroTod project, a private sector effort to develop autoguidance system supported by TÜBİTAK 1507. It has been launched as the first local autoguidance system[20]. Apart from these examples, there are different news in media on local and national autoguidance development project[21]. Understanding the content of development programs and contributions of companies is challenging as participant PF1 stated that focus of research and development in precision farming is not the hardware as it is commodity mainly being procured from China, the real challenge is software development which requires know – how. Participant PF2 said on the same topic.

> *There are very few ready manufacturers of automatic steering systems in Türkiye, however, research and development and then manufacturing is a long and expensive process. Patience about research and development is often lacking among local manufacturers, contributing to the problem. The devices we use today result from long-term innovation, trial and error, and market maturity, not quick invention. I'm sceptical that R&D efforts by local companies will yield substantial results quickly. It would be more appropriate to start with companies that are strong both technically and financially. Notably, a few companies in Konya are conducting modest trials in precision farming equipment development, but nothing significant in terms of R&D.*

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[18] https://arastirma.tarimorman.gov.tr/koyunculuk/Menu/76/Tarim-4-0

[19] https://www.aa.com.tr/tr/bilim-teknoloji/aselsan-insansiz-sistemler-alanindaki-calismalari-tarim-alaninda-cigir-acacak/320995

[20] https://www.girisimhaber.com/post/2024/03/09/Ilk-ve-Tek-Yerli-Otomatik-Dumenleme-Sistemi-AgroTOD.aspx

[21] https://www.youtube.com/watch?v=eOq46XSKiLQ

As a result, the interviews and secondary data does not point to any mature and established ecosystem for entrepreneurial activities for autoguidance technologies despite several initiatives and attempts. The number of startups and the number of experiments with the new development and technologies is low and did not provide any solid result yet. In addition, the main actors are foreign companies, and their precision farming products, especially autoguidance system, are becoming more widely adopted. Therefore, since Türkiye is latecomer in entrepreneurship, especially in the field of autoguidance, it should create differentiation in support and the product in terms of features, correction signal and accuracy, price in this area if it wants to create an ecosystem.

4.2. Knowledge development (F2)

Hekkert F2 function focuses on learning and knowledge development which are crucial for innovation process and knowledge development. Knowledge development can be achieved in two ways, learning by searching and learning by doing. I have analysed Knowledge Development function in five dimensions: productivity level of startup which is called as effectiveness, number of startup, R&D projects, scholarly articles in precision farming and patents in precision farming. The numbers in Figure 15 represents number of participants who commented related sub – functions, i.e. four interviewees gave feedback on effectiveness of startup, two interviewees on number of startup and so on. None of the participants commented on scholarly articles in precision farming.

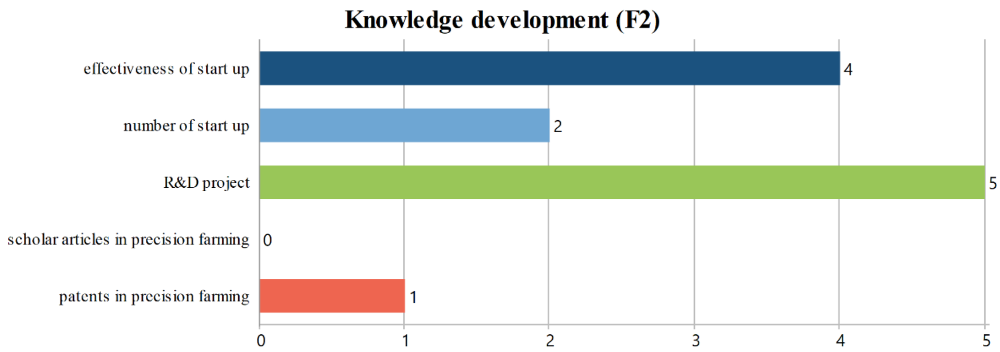

Figure 15: Number of participants who commented on sub-functions.

Source: Author

A small number of participants provided feedback about startups for smart farming in terms of competency, their focus area and effectiveness but none of them can give any solid information about startup specifically focusing on autoguidance system. ID3 gave below information related with startups.

> *We have likely engaged with close to 50 startups and may continue to do so. However, the proportion of startups that accurately define the farmer's problem and offer a suitable solution may be only 20% to 30%. Beyond this, there are startups that tend to exaggerate the problem or base their solutions on broader assumptions.*

Based on participants' comments and my observations in agricultural fair of Konya, Bursa and Adana, startups are recently working more on data analysis & intelligence, agricultural robot, and mobile applications.

Türkiye Technohub organization database classifies 39 startups and scaleups in agritech business[22]. Registered startups in the database are generally providing AI based AgTech solutions, software as a service (SaaS), intelligent agricultural control system which supports autoguidance system but not directly conducts R&D on autoguidance system itself. Therefore, except the examples given in entrepreneurial activities section, their focus is not on autoguidance or yield mapping and monitoring system and productivity in this area is not at desired level.

Existence of R&D projects by asking questions about R&D activities and awareness of any startup related with precision farming in Türkiye has been monitored and followed in three different levels, intention and plan only, solid program ongoing and no visible program. Interviewees from industry and precision farming companies commented on this topic. Majority of participants stated that there is not any specific program that they know, or they are not aware of to develop autoguidance system. ID2 said that:

> *Honestly, when you first sent the set of questions and I saw the question, I paused to think. Is there a specific R&D study that immediately comes to*

[22] https://app.turkiyetechnohub.org/companies.startups/f/all_slug_locations/anyof_turkey/company_status/not_closed/company_type/not_service%20provider_government%20nonprofit/data_type/anyof_Verified/growth_stages/not_mature/industries/anyof_food/sub_industries/anyof_agritech

mind on this topic? Nothing came to me instantly. I researched and checked, but normally, if a piece of information or data is widely known and common, as you know, Google usually presents you with three to five prominent examples right away. However, in this case, none appeared before me.

Yet, a couple of participants from industry gave specific examples for ongoing programs. Participant ID1 said that:

We have a joint project where manual steering was implemented in the second half of last year (2022). We aim to introduce autoguidance mid-2024. The R&D here focuses more on software, while the hardware is sourced from the Far East, from mainboards to antennas, and possibly even cabling. Many key components come from the Far East, but the R&D work done here is more about software, with a focus on user-friendly Turkish interfaces. We even have a multimedia screen that meets the demands of Turkish farmers, experiencing fewer signal interruptions compared to Far Eastern kits, Trimble, and European kits.

Apart from this, we recently saw a company's domestic software release, claiming to be the first and only domestically produced automatic steering system called ... However, upon inspection, we found that its infrastructure and even its software are of Far Eastern origin. Additionally, there are startups working on precision agriculture, focusing on variable rate applications which enables agricultural equipment to apply inputs in varying rates and yield maps monitored from satellites. We also see activities in drone-based spraying in Türkiye, indicating local initiatives in this field.

Participant PF1 from the precision farming company which is recently developing manual and autoguidance system mentioned that:

We consider hardware to be of secondary importance, but we develop and write all the source code for the software ourselves. We now want to produce new electric motors in Türkiye and even compete with China. We believe there is an opportunity to break the advantage that China has by reducing costs here.

There is not enough comment for patents on precision farming form participants. Only one participant spoke about it, however, it did not give any substantial information. Instead, I have made a patent analysis by using Türk Patent database to elaborate applications on autoguidance system. The main keywords used are.

- Precision farming
- Smart farming

- Automatic guidance
- Autoguidance
- Precision guidance
- Manual guidance

The outcome of search with details is given in below table.

Table 8: Patents related with precision and smart farming in Türkiye.

Category	Application No	Classification	Status
Precision farming	2021/021521	Patent	Pending
Smart farming	2024/001305	Patent	Pending
Smart farming	2023/011641	Patent	Pending
Smart farming	2023/009428	Utility model	Pending
Smart farming	2022/019987	Utility model	Pending
Smart farming	2022/010041	Utility model	Pending
Smart farming	2022/003213	Utility model	Pending
Smart farming	2022/000351	Utility model	Registered
Smart farming	2021/001933	Patent	Pending
Smart farming	2019/18318	Patent	Registered
Smart farming	2019/06270	Patent	Registered
Smart farming	2014/14445	Patent	Registered
Automatic Guidance	2018/01519	Patent	Registered

Source: Türk Patent Database[23]

Although there are a number of registered or pending patents, only one of them is related to autoguidance system which offers automatic steering system with image processing and visual recognition to provide low-cost solution. The solution proposed by patent is different than autoguidance system using GPS.

The rest is interested in smart irrigation, farm management systems, drone, and other smart farming components.

As there is not any comments or input from the participants on scholarly articles which was expected because of their interests and proficiencies, I have deepened by

[23] https://www.turkpatent.gov.tr/arastirma-yap?form=patent&params=%257B%2522title%2522%253A%2522hassas%2520tar%25C4%25B1m%2522%257D&run=true

conducting a bibliometric analysis both for Türkiye and rest of the world to understand our position. The analysis was executed on Biblioshiny and Vosviewer software by extracting data from Web of Science with the keywords of precision farming, smart farming, automatic guidance, automatic steering, yield mapping, agriculture 4.0 and agricultural robots for mainly last 20 years since 2004. The outcome is summarized in the following.

In the world: The total number of articles in the world for last the 20 years period is 2918 and publication years are given in Figure 16. The first relevant article “Stimulation of an automatic steering system for a hydrostatic vehicle” had been published in 1971 by Parish and Goering.

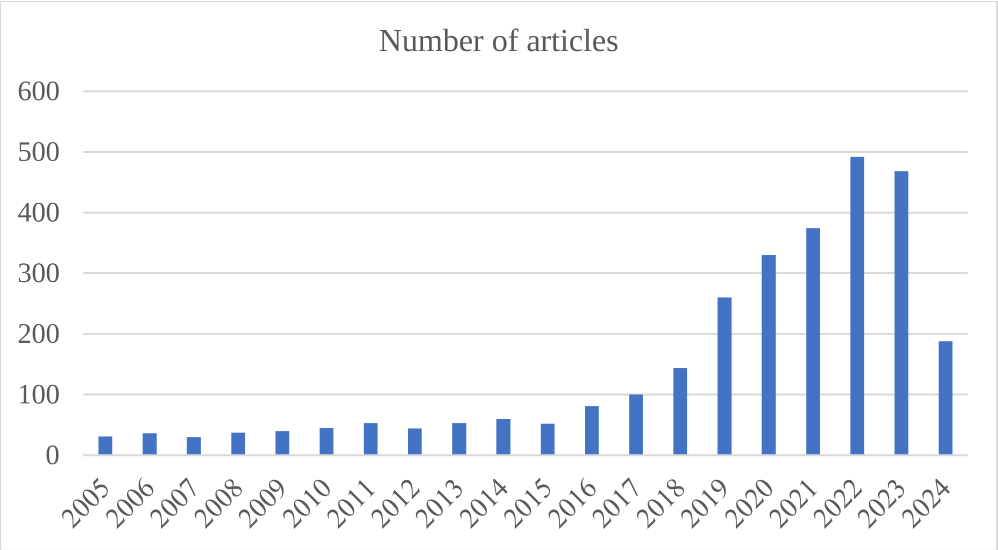

Figure 16: Number of articles related with the keywords of precision farming, smart farming, automatic guidance, automatic steering, yield mapping, agriculture 4.0 and agricultural robots in the world based on publication year.

Source: Web of Science

The number of scientific articles in China, USA, India, Germany, and Italy is highest compared to other countries in this area, Figure 18 provides more information on other countries and yearly publication numbers.

When I analysed the Web of Science data by using bibliometric tool, Biblioshiny, the most frequently mentioned words in the articles were "precision farming," "smart farming," and "internet of things," in that order. While making the analysis, some words have been clustered such as precision farming and precision agriculture under precision farming, internet of things and IoT under internet of things as they are representing same meaning. Although there is no direct emphasis on autoguidance, related terms such as remote sensing, precision farming, precision agriculture, and sensors may encompass it. Details can be found in Figure 19.

Based on the trend analysis I conducted using Biblioshiny with data from the Web of Science, Figure 20 illustrates the yearly changes in topics discussed in scientific articles. Automatic guidance including autonomous vehicle, automatic steering, GPS was more popular between the year 2010 – 2020. However, the recent popular subjects are aquaculture, smart farming, deep learning, and machine learning in general today. The last two topics, deep and machine learning are in line with data hype.

In Türkiye: When we examine the result based on the keyword of precision farming, smart farming, automatic guidance, automatic steering, yield mapping, agriculture 4.0 and agricultural robots for Türkiye, the total number is 54 scientific articles for the same period and yearly distribution can be seen in Figure 17 and the most productive years are between 2020 – 2024.

When we make a bibliometric analysis to understand mostly used keywords in scientific articles on precision farming in Türkiye, Figure 21 shows that the results are similar pattern with the world and top three are precision farming, smart farming, and internet of things respectively.

Cluster analysis for the articles published from Türkiye made by using Vosviewer based on data from Web of Science shows relationship among precision farming, smart farming and precision agriculture and common focal points in Figure 22. In fact, the terms are used interchangeably in scientific articles. In the thesis, precision farming and precision agriculture have same meaning, however as discussed in previous chapter smart farming is broader term covering precision farming and precision agriculture as well. The research topics are mainly concentrated on soil analysis, internet of things, yield mapping, data analysis and spatial variability.

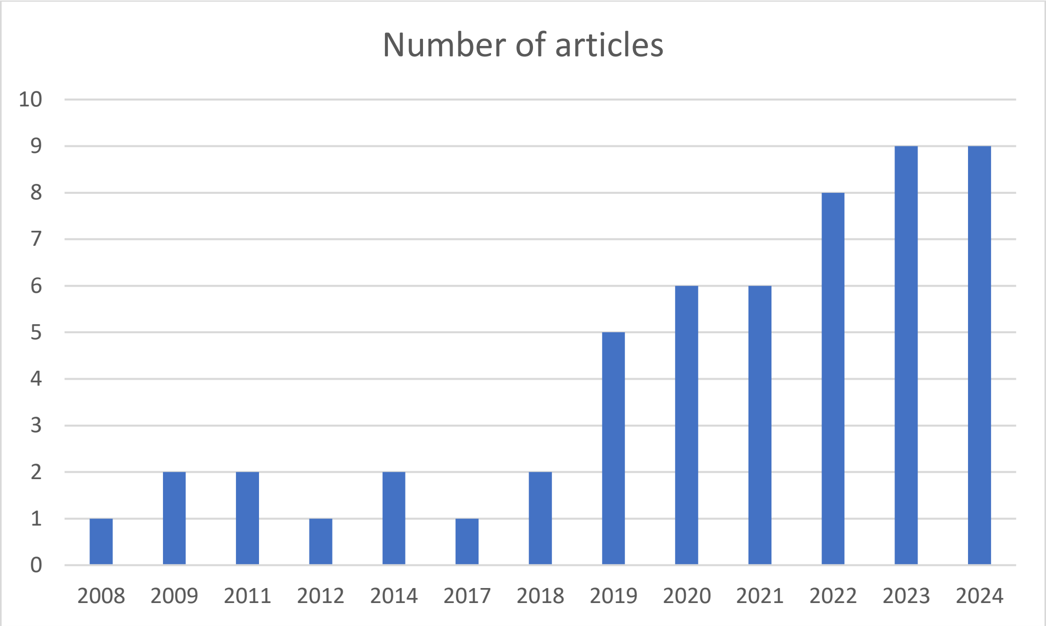

Figure 17: Number of articles related with the keywords of precision farming, smart farming, automatic guidance, automatic steering, yield mapping, agriculture 4.0 and agricultural robots in the world based on publication year in Türkiye.

Source: Web of Science

On the other hand, based on the trend analysis I conducted using Biblioshiny with data from the Web of Science, figure 23 illustrates the yearly changes in topics discussed in scientific articles in Türkiye. Figure 23 shows that scholars speak about blockchain in agriculture, variable rate application and machine development unlike the world. Furthermore, it may be interpreted as the focus has changed from precision farming, automatic steering, and precision agriculture since 2019. In figure 22, second trend topic is variable rate. In fact, majority of farmer interviewees have emphasized on these variable rate applications especially for spraying and fertilizing operations. The farmers that I interviewed consider variable rate technology as a significant method for reducing agricultural inputs by using a site-specific approach. I expect that its adoption will increase as input prices rise and technological advancements in tractors and agricultural equipment, which enable variable rate applications, continue in Türkiye.

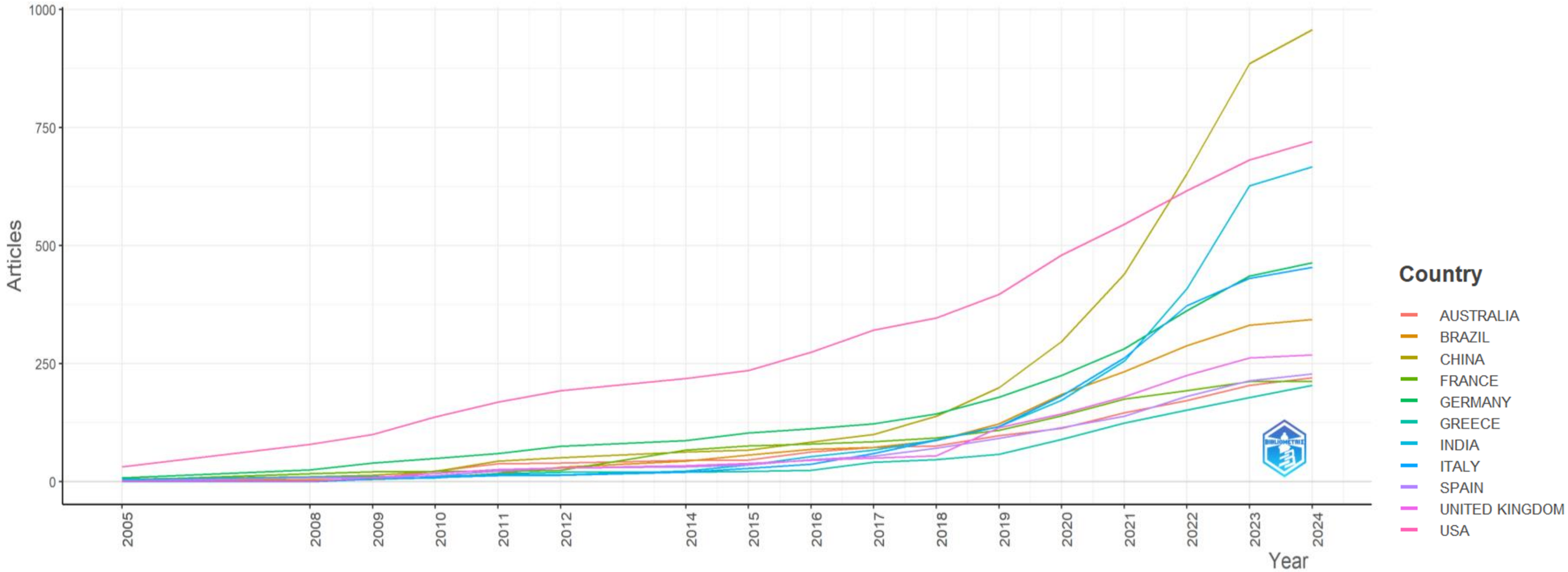

Figure 18: Number of scientific articles on precision farming over 20 years in different countries.

Source: Web of Science & Biblioshiny

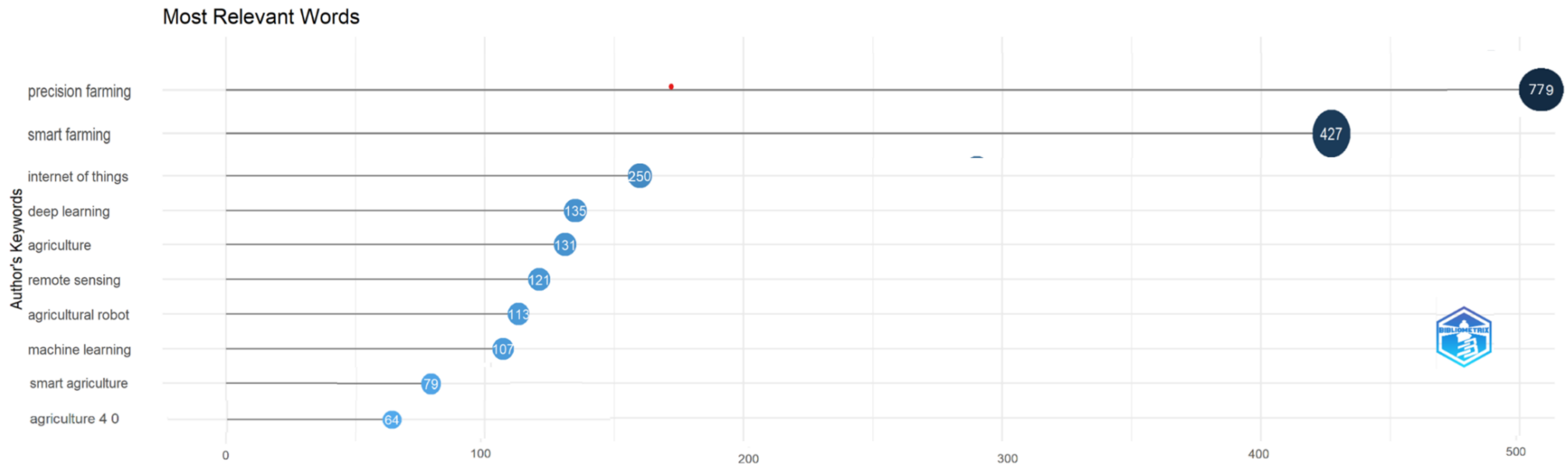

Figure 19: The most frequently mentioned words in the articles published in the world.

Source: Web of Science & Biblioshiny

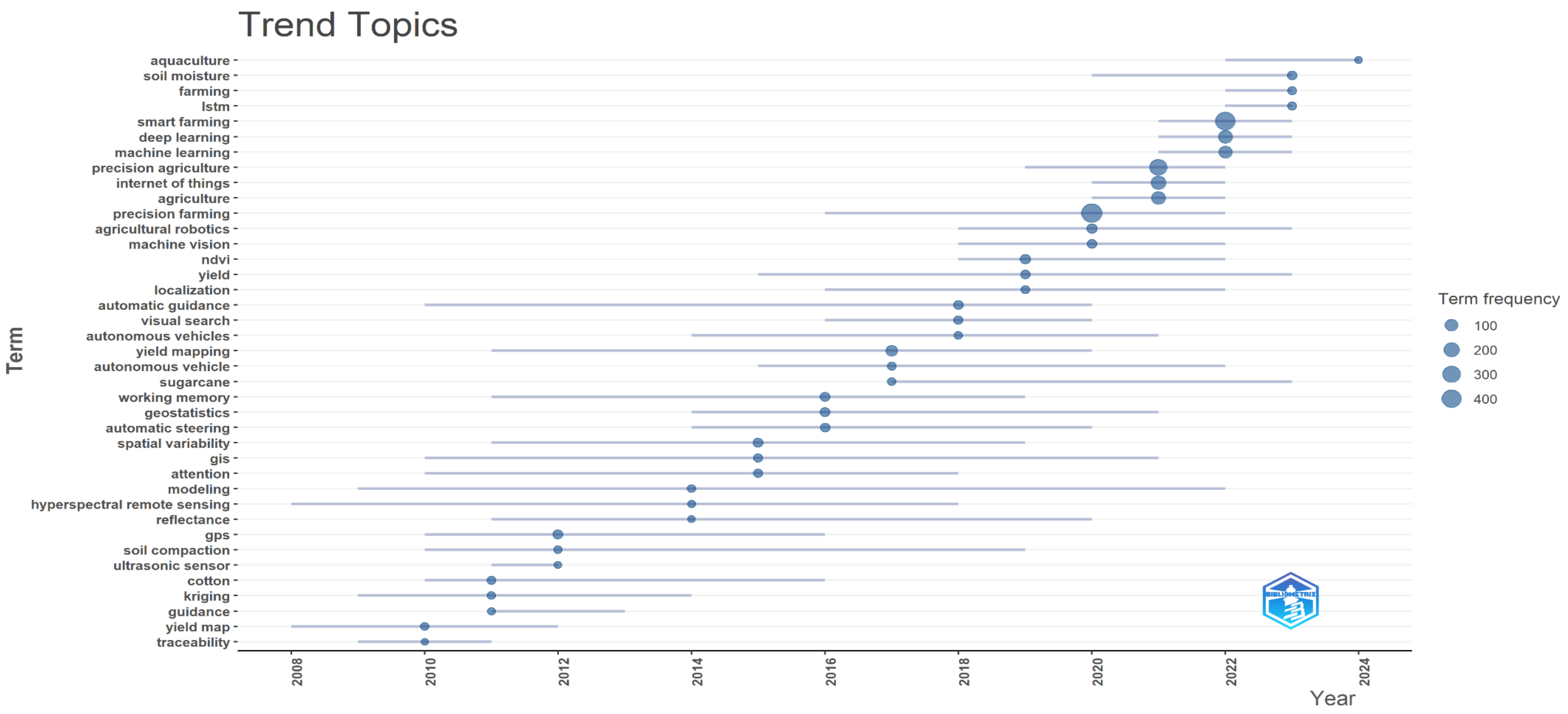

Figure 20: Trend topics in the world.

Source: Web of Science & Biblioshiny

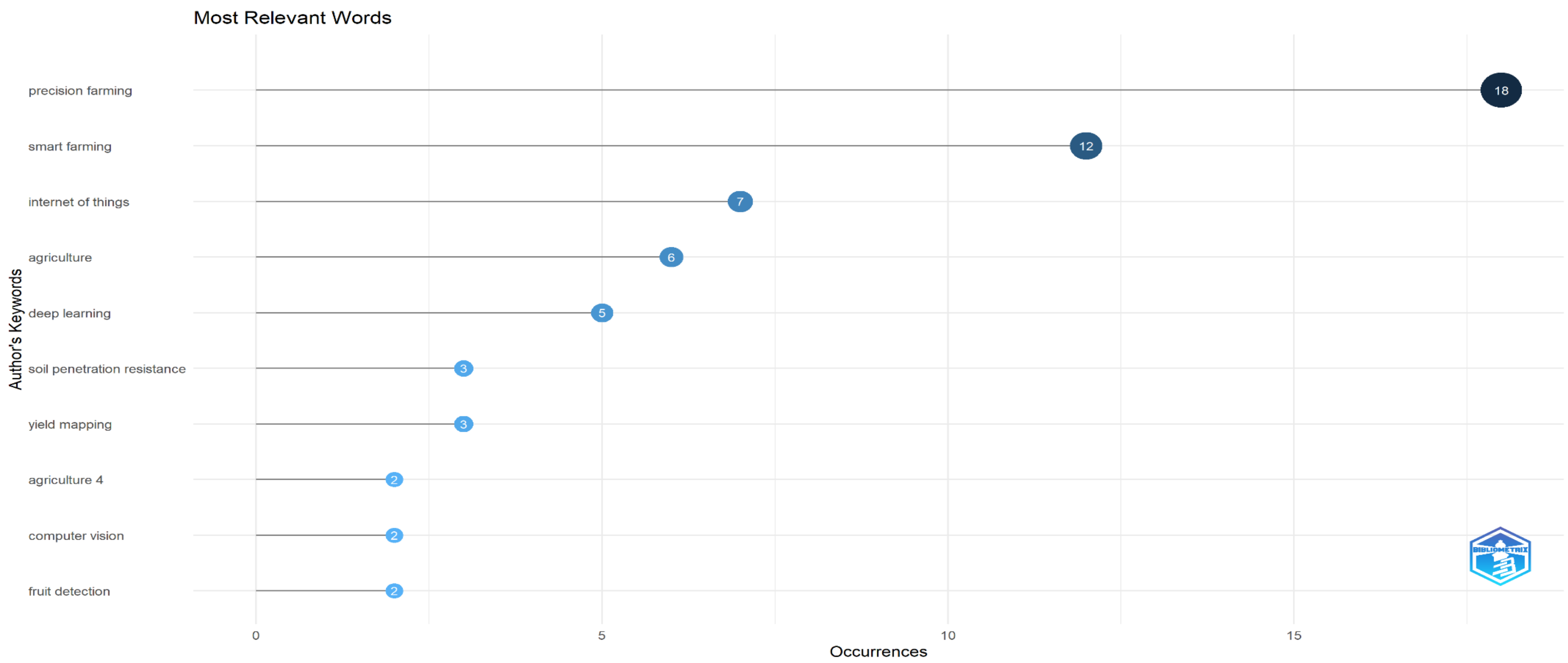

Figure 21: The most frequently mentioned words in the articles published in Türkiye.

Source: Web of Science & Biblioshiny

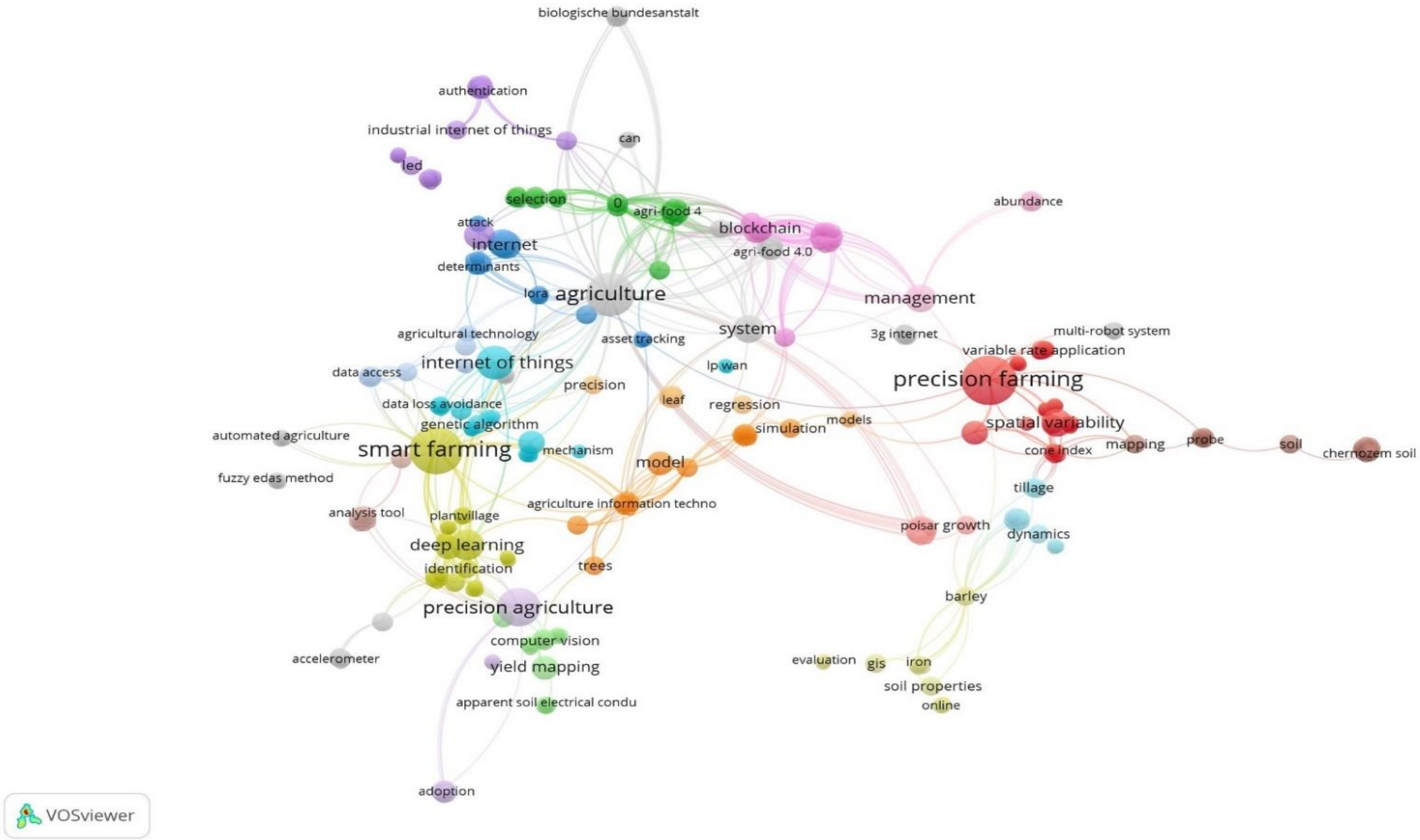

Figure 22: Networks among main research areas in Türkiye.

Source: Web of Science & Vosviewer

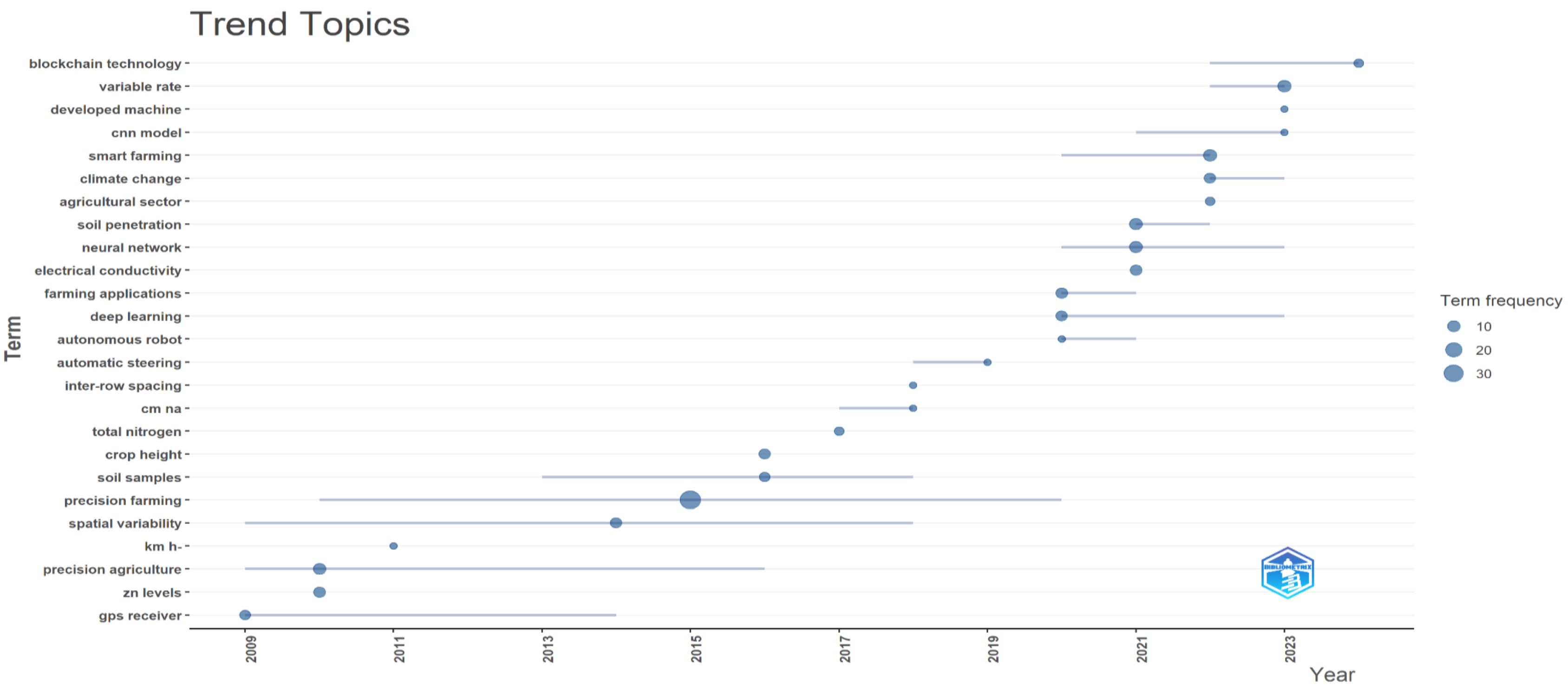

Figure 23: Trend topics in Türkiye.

Source: Web of Science & Biblioshiny

4.3. Knowledge diffusion through network (F3)

We have investigated the third Hekkert function which frames knowledge diffusion via “Learning by interacting” created by the interaction among the components of network and "Learning by doing" occurs through interactions between users. The analyses have been made based on five sub-functions of knowledge diffusion function which are diffusion channels, on the job training, level of awareness among different stakeholders, such as farmers, precision farming technology suppliers, industry and workshop organization and publications. The elements of F3 and the quantification of participants' comments are detailed below.

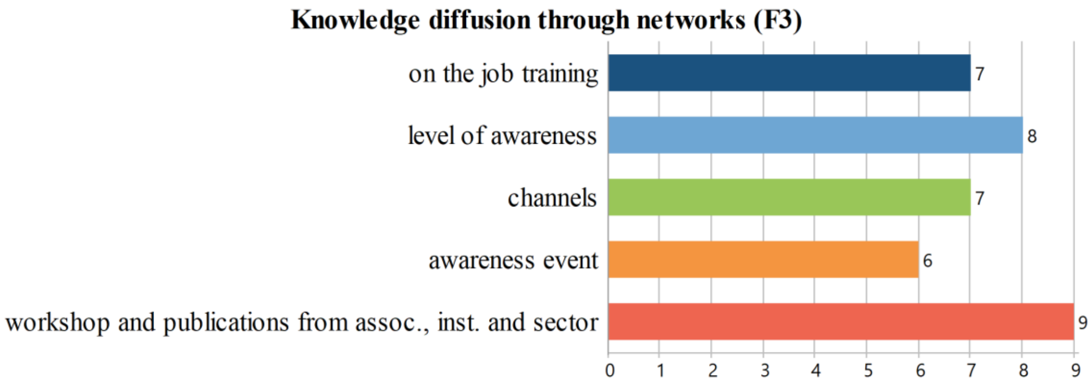

Figure 24: Distribution of participants’ comments on Knowledge diffusion & channels.

Source: Author

In this section, it is found that the interviewees perceived and assessed the level of public awareness on precision farming, specifically autoguidance and yield mapping as low – medium level. Farmers consider awareness level as medium, and they believe that awareness about autoguidance technology will automatically increase as sales of it increase. However, the participants from industry and precision farming companies are evaluating the subject in a multidimensional way and currently, their view is towards a lower public awareness level. Participant ID1 evaluates several countries’ awareness level on a five-point scale and according to his opinion, Türkiye is between two – three points in autoguidance system and one in yield mapping technology while France, Germany, Australia, and USA, especially California region is between four – five points.

Interview data analysis revealed that knowledge requirement from farmers, industry and precision farming technology supplier is different. Farmers needs installation and usage of technology and dissemination of knowledge among farmers is through reseller/dealer of precision farming equipment, fairs, contractor, and word of mouth. Farmers mentioned that majority of them did not get specific training beforehand and they learned usage of the technology on the job training just after purchasing.

Participant FR3 said that:

> *In general, yes, there is financial support, but have we seen any agricultural provincial or district directorates gathering farmers to provide training on precision farming or technologies?*

And participant FR4 said that:

> *No meetings, launches, or seminars have been organized—neither by any district agricultural offices, chambers of commerce, nor trade exchanges—regarding these topics.*

On the other side, the industry is focusing more on the adaptation of technology to products, and they use startups, fairs, and internet as main sources of knowledge.

Interview data analysis shows that awareness events and workshops by governments, institutes, nonprofit organizations, and universities are insufficient and not well organized, although a couple of organizations and seminars were held by TARMAKBİR, Ankara University, Konya Food & Agriculture University and Konya Karatay University, Tekirdağ Namık Kemal University, TAGEM and several initiatives were actualized such as Vodafone Smart Village[24], İzmir Agriculture and Technology Center[25], Eyüp Sultan Municipality Center for Implementing and Researching Agriculture 4.0 Policies[26], Gebze Technical University Smart Farming Research and Application Center (ATAM)[27]. Farmers expect direct interaction with

[24] http://www.vodafoneakillikoy.com/hakkinda.php

[25] https://ittm.itb.org.tr/

[26] https://www.istka.org.tr/haberler/istka-destegiyle-kurulan-tarim-4-0-merkezi-faaliyete-gecti/

[27] https://gtuatam.gtu.edu.tr/index.html#

local governmental agencies such as Agriculture and Forestry Provincial and District Directorates, Türkiye's Chamber of Agriculture and they request these agencies to organize workshops and demonstrations, to provide training on how precision farming provides benefits and how the technologies can be implemented. However, farmers expectations have not been met adequately, and precision farming technology and equipment sellers have taken this role in the field.

ID1 summarized that:

> *Unfortunately, as we discussed before, progress here also depends on the efforts of producers and farmers being able to see these technologies in their own close environment. Sadly, access to information, especially accurate information, remains a barrier, preventing farmers from making these kinds of investments.*

Additionally, the data suggest that while policy efforts are being made to promote the widespread adoption of precision agricultural technology, there appears to be a lack of implementation at the user level.

4.4. Guidance of the search (F4)

In this section, we analyse guidance of the search which is regarded as the process of selection within the technological variety that is created by knowledge development function (F2) by deep diving into three sub-functions, customer demand, trends for new technologies in precision farming and policies and targets for precision farming. Stratification of participants' comments is given in figure 25.

The participants from industry and precision farming companies classify the trends for new technologies in precision farming in Türkiye into the several categories. It would still be beneficial to mention that these technologies are new for Türkiye but have been in use worldwide for some time.

- Participants mentioned that while autoguidance technology deploys, yield mapping, agricultural robots, variable flow rate control and drone for spraying and fertilizing will find more areas for application.

- Analysis and intelligence of agricultural data, image processing of field and vegetation are other growth area.
- Field management will find more application opportunities.
- Finally, one of the participants stated that farmers will tend to use subscription base services, especially for equipment rental.

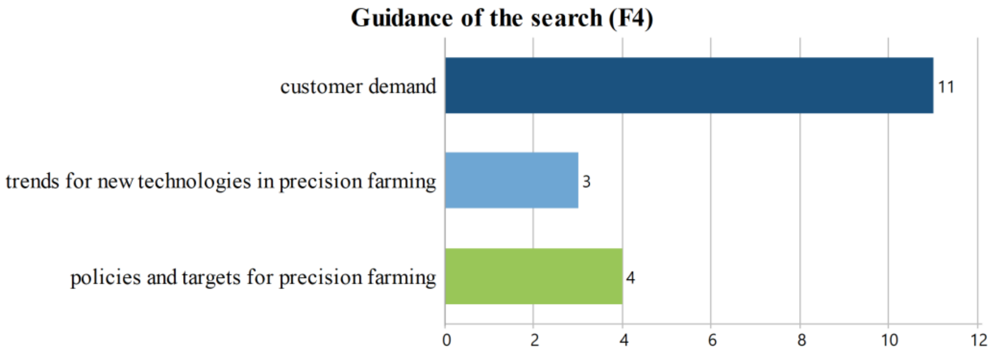

Figure 25: Distribution of participants' comments on Guidance of the search sub – functions.

Source: Author

When examining the requirements and anticipations of farmers, they align with the aforementioned trends in general. Nevertheless, they want to see more applications of autonomous and adaptive technologies such as autonomous tractors, soil and crop sensors and agricultural robots, ISOBUS compatible agricultural equipment, smart irrigation systems, drone application for spraying and fertilizing, yield mapping, utilization of autoguidance with full features, variable flow rate control system, telematics for fleet management and monitoring tractor or equipment parameters, smart spraying, and smart fertilizing in their agricultural activities.

PF2 mentioned that:

> *There is a noticeable increase in equipment sold with ISOBUS right now. Expecting it to be used to its full potential at this stage might be unrealistic, but I believe once people realize what an ISOBUS-equipped machine is capable of and how it can be used, they will quickly reach that level.*

And FR1 said that:

> *We are trying to introduce agricultural technologies into our lives that reduce the need for human involvement.*

When we look at the policies which affect rate and direction of technology in precision farming and targets in Türkiye, the participants said that they are not aware of explicit policy not only for precision farming but also for autoguidance itself to foster the rate and direction. On the other hand, they mentioned that despite the lack of comprehensive policy, the government provides temporary incentives and subsidies through Ziraat Bank. Participant ID2 noted that the Ministry of Agriculture and Forestry and the Ministry of Industry and Technology are working to transfer EU incentives to the agriculture sector in Türkiye. Participant ID1 recommended policies in three areas: land unification which is process of combining and consolidation of fragmented land parcels to increase agricultural efficiency as land unifications, by allowing the formation of larger plots, will especially encourage investments in precision farming technologies, planning which crops to be planted based on agricultural price forecasts, and improving access to financial instruments.

We can conclude that there is not any solid policy either in demand or supply side to affect rate and direction of technology although there were a couple of initiatives and workshop mentioned in previous sections. Farmers expectations are being shaped by technology provider in general.

4.5. Market formation (F5)

The section is related with market formation of precision farming and specifically for autoguidance systems. Market formation is directly linked with diffusion and adoption of technology which can be slow. Therefore, market needs to be stimulated by applying different approaches and policies. We have analysed market formation in different dimensions. First of all, volume evolution year over year from the point of participant view. Second, product price and demand, tax regime and incentives, government support. Third, investment on infrastructure and lastly, the effect of land size and aftermarket support and service. The participants answer classification is given in below figure 26.

All the participants commented that interest to autoguidance system has been increasing for last couple of years and they all agree that the trend will continue in upcoming years triggered by diffusion of low-cost products from China and rise in agricultural input prices. Furthermore, they expect that autoguidance system integration on small horsepower tractor will increase.

FR4 told about increase in the utilization of autoguidance systems.

> *My conclusion is that there is currently an increase in the use of autoguidance systems. In our region, for example, previously there might have been three to five systems across three to five villages, but now, if a village has ten tractors, five to six of them are equipped with autguidance systems.*

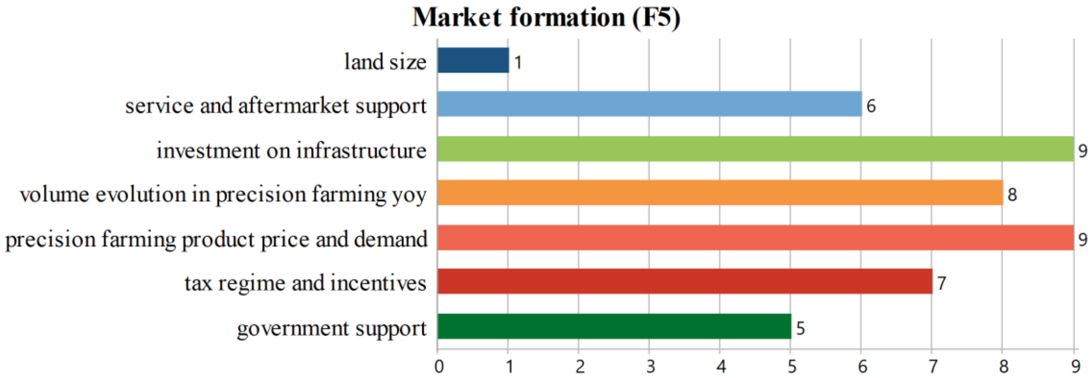

Figure 26: Market formation sub – functions emphasized by the participants.

Source: Author

The price level is varying between 5.000 – 10.000 USD roughly and all the price segments can find market among the farmers. China originated products use the technology which get correction signal from virtual reference station (VRS). Although level of accuracy is lower than western origin product, small scale farmers prefer it due to low product cost and low payment for correction signal which is paid to service provider who owns communication infrastructure and transmits the signals. Western origin product provides more accuracy, against this, the price is high, and they ask subscription fee for correction signal as they provide it from their satellite or ask farmer to buy a base station which supply correction signals. The big scale farmers who perform planting, soil preparation, and precision planting prefer them.

Government incentivizes autoguidance system via Ziraat Bank by subsidizing based on its origin whether local or foreign. However, it is interpreted based on farmer interviewees' statements that farmers either find government support insufficient or do not use while purchasing due to difficult application process or a lot of paperwork. Fleet customers who are generally big scale farmers prefer the incentives.

FR2 said that:

> *There aren't really many incentives, to be honest. There are incentives provided by the government, but many issues arise with them. For one, you need to go through a consultant, and the fee the consultant charges is fixed. Even though the government covers some of that cost, the paperwork burden is much greater.*

One of the vital elements for diffusion of autoguidance technology is communication infrastructure. Poor quality signals or interruption in transmission oblige farmers to give up or not to utilize autoguidance. This is a specific issue especially for southeast border of Türkiye due to jammer system deployed by the army.

FR4 mentioned that:

> *In our region, there are quite a few jammers because there's a police station in the industrial zone and a large military unit near us. As a result, some of our fields don't get a signal because when they activate the jammer, it cuts off communication. Sometimes we go to the district governor's office and submit a petition, requesting them not to activate the jammer during the hours we want to work in the fields.*

The participants have different opinions about the communication infrastructure. Farmers assess the infrastructure as sufficient in general except ones who suffer from jammers. Interviewees from industry and precision farming companies said that the communication network is adequate and operative. And they mentioned that TUSAGA[28] (Türkiye Ulusal Temel GNSS Ağı) network established by General Directorate of Mapping and General Directorate of Land Registry and Cadastre is a substantial service provider for correction signal all over Türkiye. Moreover,

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[28] https://www.tusaga-aktif.gov.tr/

regional RTK (Real time kinematics) base station network established by precision farming companies are another signal provider. Nevertheless, all the participants have a common opinion on necessity of further improvement of communication network and signal quality.

ID1 said that:

> *In RTK systems, we have an advantage compared to other European countries thanks to the TUSAGA network. Farmers can access it for a small fee, which is truly a system without an equivalent in Europe.*

Second element that affects diffusion of autoguidance substantially is land size on which farmers perform their agricultural activities. And small land size cannot justify the investment in autoguidance system. However, if they still want to make this investment, they tend to turn to Chinese products.

At this point, when we consider whether autoguidance systems could be treated as a common pool resource, which were discussed in the article by Kadirbeyoğlu and Özertan (2015) for different subject, for small-scale farmers, the following evaluations can be made.

- Autoguidance systems need to be installed on tractors, and physically transferring them between different tractors will not be very easy. Additionally, some calibrations need to be made according to the tractor being used.
- Due to the climate conditions in the same region, tractors generally start working at similar times, making it difficult to plan the shared use of autoguidance systems among them.
- Moreover, in Türkiye, the culture of sharing not only precision farming equipment but also tractors or other agricultural machinery is not very widespread. Even cooperatives are not very successful in this regard. Although such ideas and intentions occasionally arise from government bodies, they often do not materialize.

- Furthermore, especially with the introduction of Chinese kits into the market, this technology, which was previously accessible to farmers with large land areas and relatively high-income levels, has now become affordable for farmers with more moderate incomes.

Therefore, it may not be practical to apply common pool resource management for autogudiance system.

The last factor affecting the diffusion that the participant mentioned during interviews is aftersales service availability. All the participants agree that the service level is sufficient and available whenever needed in Türkiye. The high-end users which buy western origin product are generally more sensitive on this availability and technology suppliers has their own service network. Far East origin products suppliers prefer exchanging the products if any issue or failure occurs instead of establishing a service network.

As a conclusion, diffusion of autoguidance technology, and in general precision farming technologies, in Türkiye can be fostered by more government incentive and investing on communication infrastructure. Although diffusion is sensitive to aftersales service support, it is in good shape in Türkiye recently. Finally, land unification is on the government's[29,30] agenda despite low implementation rate. In fact, land unification in Türkiye started in 1961 in Çumra/Konya. The governments released 230 laws and regulations since then. Although unification process accelerated after 2018 and as of 2022-year end, total consolidated field is around 6.8 million hectares, the target is 8.5 million hectares (Greening Türkiye's Economy report, 2023)

4.6. Resource Mobilization (F6)

The resource mobilization function involves allocating the required financial and human resources to generate knowledge. It was difficult to find out data during the

[29] https://www.resmigazete.gov.tr/eskiler/2019/02/20190207-5.htm

[30] https://www.resmigazete.gov.tr/eskiler/2021/01/20210129-1.htm

interviews and only four participants in total commented on sub – functions of resource mobilization, human capital for R&D activities and financial resources.

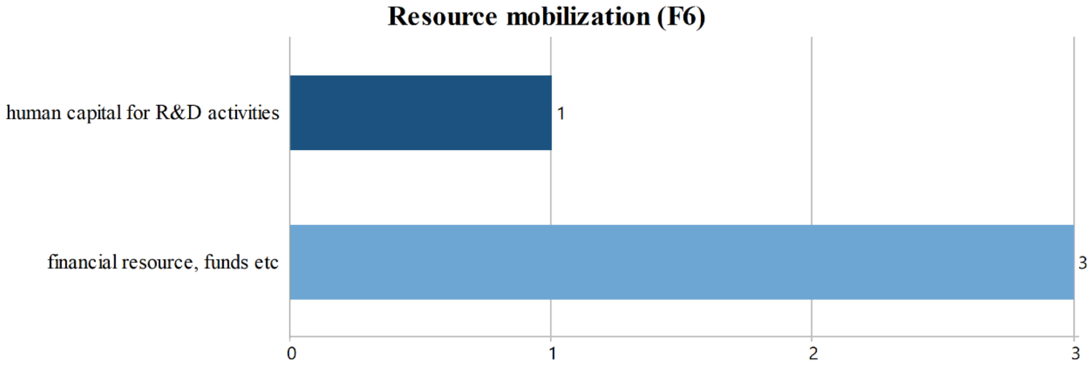

Figure 27: Resource mobilization sub – functions emphasized by the *participants.*

Source: Author

We can interpret that qualified human resources for R&D activities of autoguidance and precision farming both for software and system development and integration of these system to tractor and agricultural equipment in general is not matured yet in Türkiye. Nonetheless, startups are promising in this regard.

ID3 said that:

> *When evaluating the human resources and competencies within …, we realize that we lack experience in precision farming. So, at this point, we ask ourselves, can we collaborate with a startup or scale-up company in this field?*

Interviews data shows that financial resource and funds are limited to support from private banks to startups and incentives by TÜBİTAK, TTGV and Ministry of Agriculture and Forestry. They occasionally open a call for agriculture and precision farming. Nevertheless, the participants from industry stated that startups can find financial resources especially from private banks who are more interested in agriculture recently. And they propose that Ministry of Agriculture and Forestry and Ministry of Industry and Technology should realize their vision and put a solid plan to support precision farming technology development.

4.7. Creation of Legitimacy (F7)

Legitimacy which is needed to overcome forces exerted by different power group and roadblocks for diffusion and adoption is crucial for startups to survive and grow, especially in emerging fields like autoguidance and precision farming. In this section, we will discuss the legitimacy in Türkiye on two aspects, specific institutions existence and law, regulation, and policies which are facilitating, based on the interviews with the key actors and the secondary data sources.

First of all, the quantification of participants comments and answer on these two aspects is given in below graph,

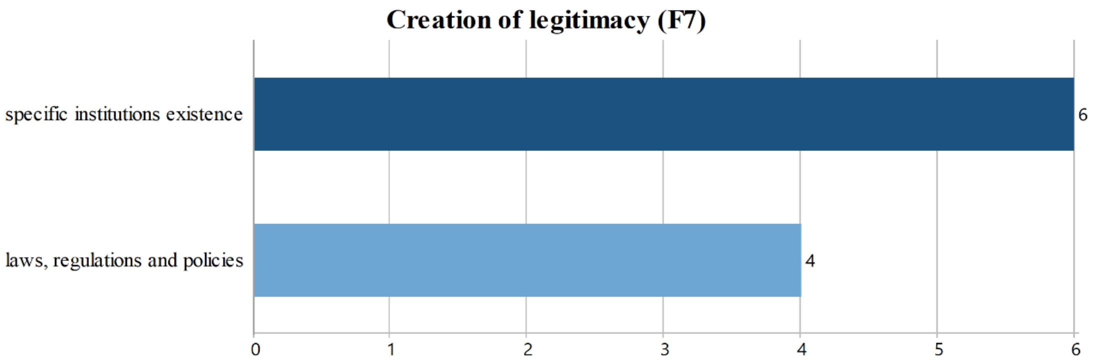

Figure 28: Creation of legitimacy sub – functions emphasized by the participants.

Source: Author

Six participants commented on specific institutions existence and all of them agree that there is not any institution to foster diffusion and adoption of precision farming technologies either as rules or dedicated structure, chamber, or organizations. Agricultural organizations and cooperatives such as PANKOBİRLİK (Sugar Beet Growers' Cooperative Union) which is the largest civil organization in Türkiye agricultural sector, ÇUKOBİRLİK (Çukurova Cotton, Peanuts, and Oilseeds Agricultural Sales Cooperatives Union) and TARİŞ (Tariş Fig, Grape, Cotton, and Oilseeds Agricultural Sales Cooperatives Unions) have no interest or vision regarding autoguidance or precision farming. As participant ID1 said, all training, promotion and awareness activities are carried out by precision farming or agricultural equipment companies with commercial concern. On the other hand, as mentioned above, there are several organizations such as Gebze Technical University, General Directorate of Plant Production and Smart Farming Research and Application Center (ATAM) and İzmir Agriculture and Technology Center (İTTM) has vision on autoguidance and yield mapping vision in the scope of smart farming.

ID3 commented that:

> *As far as I know, there is a Reform Directorate within the Ministry of Agriculture, and there is also TAGEM. TAGEM tests new technologies, and projects can be carried out there, but other than that, I don't believe there is an independent institution that directly develops agricultural policy outside of the Ministry of Agriculture.*

Laws, regulations, and policies has been analysed and participants commented on aftermarket regulation which arrange and organize warranty and service operations, service conditions and support in case of any breakdown or issue on precision farming equipment and import regulation as well. The data shows that there is not any regulation or laws specific to autoguidance. Nevertheless, regulation for communication infrastructure, signals and satellites which are crucial for autogudiance and yield mapping system is effective. And there is need to release regulation for aftermarket operation and importation for such system.

ID1 said that:

> *The lack of regulations regarding the sale, the number of authorized service centers, and the definition of an authorized service is noticeable. I'm not sure if TSE has a standard like 12047 or 12046 for precision farming, but as far as I know, there isn't one.*

Nevertheless, TAGEM (General Directorate of Agricultural Research and Policy) has stressed smart farming in its 2021 – 2025 master plan[31] and it may provide a framework and policies for autoguidance, precision farming and other components of smart farming.

[31] https://www.tarimorman.gov.tr/TAGEM/Belgeler/yayin/YonergeveMasterPlan.rar

CHAPTER 5

CONCLUSION AND POLICY RECOMMENDATIONS

In this chapter, I will conclude the research and recommend policies for precision farming in Türkiye. There will be three sections, in the first section, I will shed light on the current situation of precision farming in Türkiye and review the level of diffusion. The second section will present the main challenges and impediments which hinder more diffusion and adoption of precision farming technologies, especially autoguidance and yield mapping. And lastly, policy recommendation will be advanced in order to foster utilization of them based on Hekkert functions.

5.1 Precision farming in Türkiye

As discussed in the previous chapters, precision farming is a set of technologies that enable farmers to manage their fields more efficiently and effectively. Precision farming can reduce input costs, increase yields, improve environmental quality, and enhance farm profitability. Say et al. (2017) summarizes these precision farming technologies below in Table 9.

Table 9: Precision farming technologies

Data Collection Technologies	Data Process & Decision-Making Technologies	Application Technologies
Soil sampling and mapping	Geographical info systems (GIS)	Variable rate application
Yield monitoring and mapping	Agricultural mapping software	Section control
Global satellite positioning (GNSS)	Economic analysis	GNSS-based guidance
Remote sensing	Geostatistics	Agricultural robots
Field / crop scouting	Modelling	

Source: Say et al. (2017)

In the thesis, although we focused on autoguidance (GNSS – based guidance), we understand that most of the factors, which affect diffusion and adoption of autogudiance and yield mapping & monitoring and Hekkert's TIS functions, are valid for other precision farming technologies.

Findings that we discussed in previous chapter show that diffusion and adoption of precision farming technologies are being affected by many factors such as size of land, product price, skill set, telecommunication infrastructure and signal quality, subsidies and financial support and legitimization. Say et al. (2017) provide similar factors that may impact on diffusion and adoption in their article and on top of my findings, they mention features of farm, family structure of farmer, complexity, and compatibility of technologies.

Findings and analysis show that precision farming technologies diffusion and adoption in Türkiye is not at the same level as in developed countries such as US, Australia, and EU countries. Autoguidance technology is the most popular one in Türkiye in parallel with rest of the world, despite this fact, its adoption and deployment of technology is not at the desired level and even yield mapping and monitoring technology utilization is at low levels in Türkiye.

Table 10: Precision farming adoption level in Türkiye

Türkiye	About 500 combine harvesters (about 3% countrywide) are equipped with yield monitoring systems	Keskin & Sekerli (2016)
Türkiye	About 310 combine harvesters are equipped with yield monitors. About 110 automatic steering systems and 25 steering assistance systems were sold to the farmers. Number of variable rate applicators is less than 20.	Akdemir (2016)
Türkiye / Adana province	About 110 farmers use GNSS-based auto guidance systems in Adana province.	Keskin et al. (2017)
Türkiye	About 60 cotton harvesters (about 6% countrywide) are equipped with yield monitoring systems.	Erzurumlu (2017)

Source: Say et al. (2017)

On the other hand, we can observe an increasing trend on the diffusion and adoption rate of autoguidance system in Türkiye in 2000's as well as other precision farming technologies such as variable rate control, soil sampling and monitoring, remote sensing, drone applications. Howeve, yield mapping and monitoring does not show similar trend in its diffusion.

5.2. Challenges and impediments in Türkiye

Analysis of interview data and research shows that there are several factors and challenges which cause low diffusion and adoption levels of autoguidance and yield mapping & monitoring technologies. In fact, these factors are valid for other precision farming technologies as well.

1. The telecommunication infrastructure is not enough to obtain efficient signal transmission. The border zones, especially southeast area is suffering from jammers which are used for military purposes.
2. The cost of equipment is still high although Chinese suppliers provide low-cost level products.
3. The average land size in Türkiye is quite small and it does not justify the wide adoption and utilization of autoguidance and yield mapping & monitoring technologies.
4. Farmers' skills in some applications are not sufficient to use and they find them complex and difficult to operate. Furthermore, they have a mindset more focused on traditional applications in agriculture.
5. Although there are several institutional initiatives and programs to deploy precision farming technologies in Türkiye, the stakeholders, such as farmers, startups, and industry does not observe any holistic approach and are not aware of the programs and supports initiated by government or institutions.
6. Financial tools and subsidies are limited and insufficient to promote the diffusion of precision farming technologies.
7. Research and development in industry and academia in precision farming in Türkiye is not diverse and it is at the beginner level. Moreover, the direction of precision farming technology is not definitive, i.e. there is not any solid vision and target defined. Therefore, current policies are not effective and have limited effects on the rate and direction of precision farming

technologies. As a result, these policies cannot trigger innovations and they are not effective.

8. Training and awareness activities for farmer and precision farming technology users are not comprehensive and purpose oriented. They are generally pursued by private precision farming companies with commercial concerns.
9. These technologies require a certain level of technological infrastructure on tractor and agricultural equipment, such as electronic engine, ISOBUS, CAN bus. Therefore, significant portion of these equipment in Türkiye may not be compatible with autoguidance and yield mapping and monitoring.
10. Precision farming technologies uses and generate different kind of data including personal data such as location, user preferences, crop to be planted and yield. However, there is not adequate legal and regulatory framework to secure data ownership, privacy, and liability.

5.3. Policy proposals for Türkiye

Table 11: Policy proposals

Hekkert Function	Issue / Concern	Policy Instrument	Aim	Responsible	Category
Entrepreneurial activites	Undefined ecosystem for precision farming entrepreneurs	Solid strategy development by defining all stakeholders	Providing clear direction to entrepreneurs and signalling	MoAF & MoIT	Political
		Incentive package specifically for software development	Subsidizing the new entrants' research and developments expenses and provide incubation	MoAF & MoIT	Economic
	Low number of startups	Establishment of cluster with startups	Cooperation before competition and allow knowledge transfer among startups to avoid duplication of expenses on research and development	MoIT	Economic
	Lack of coordination and unknown roles & responsibilities	National Smart Farming Institute establishment under Ministry of Agriculture and Forestry	Definition of responsible and owner of vision and strategy, coordinating all stakeholder, agricultural policy recommendation to Ministry of Agriculture and Forestry	MoAF	Social

Table 11. (continued)

Knowledge development	Insufficient academic research	Dedicated academic program for precision farming	Creation of awareness among researcher and attracting students	Council of Higher Education	Technolog ical
		Specific funds for research in precision farming		TÜBİTAK	Economic
		Organization of international conferences by inviting reputed academicians and institutes	Establishment of ecosystem for knowledge transfer and signalling	Universities & TÜBİTAK	Social
	Low number of R&D programs in private companies	Public procurement of best performance precision farming technology	Fostering and subsidizing R&D programs conducted by private companies	MoAF & MoIT	Economic
	Low number of applicable patents				
Knowledge diffusion through network	Weak awareness among farmers	Support for precision farming specific fair, workshop, and event	Introducing new agricultural technologies to farmer and improve awareness	MoAF & MoIT	Social
		Launching of digital platform to promote precision farming technologies		MoIT	Technolo-gical
	unqualified skills of farmer for adoption of precision farming technologies	Extensive training program for farmers by regional agricultural authorities	Upskilling the farmers for utilization and adoption of precision farming equipment	MoAF	Social
	unqualified digital skills of farmer	Advanced training program for data analysis and intelligence	Upskilling the farmers to get the full benefit from data	MoAF	Social
Guidance of the search	Inadequate support provided to farmers for selecting precision farming technology	Assignment of expert who provide free of charge service to farmers	Facilitation of farmers' decision-making process on selection of applicable technologies	MoAF	Social
	Lack of regional analysis on needs and demand for precision farming technologies	Progressive and continuous analysis mechanism establishment	Providing input for current and future actions for affecting diffusion and adoption of precision farming technologies	MoAF	Economic
	Insufficient demonstration of precision farming technologies application to farmers	Establishment of training and demonstration center for application of different precision farming technologies	Improving the vision of farmers and introducing novel technologies	MoAF	Social
	Lack of standardization among agricultural equipment for precision farming equipment	Regulation for integration of precision farming technologies to tractors and agricultural equipment	Allowing more application of autonomous and adaptive technologies and preventing incompatibility between tractors and equipment	MoIT	Technolo-gical

Table 11. (continued)

Market formation	Small land size	Review and reinforcement of effective regulation	Accelerating of land unification which justify and materialize the investment on precision farming technologies	MoAF	Economic
		Agricultural land unification		MoAF	Economic
	Lack of specific aftersales regulation for precision farming	Regulation for service and aftermarket support	Improve the effectiveness and level of service quality provided by aftersales of precision farming companies	MoIT	Technolo-gical
	Low signal quality	Further investment on telecommunication infrastructure	Improving the signal quality especially in rural areas	MoTI	Technolo-gical
		Special regulation and resolution at southeast border	Elimination of jammer disturbance on signal transmission	MoTI	Technolo-gical
	Low affordability of precision farming equipment	Decreasing tax, especially VAT on these equipment	Subsidizing the farmers and expanding precision farming technology market	MoTF	Economic
Resource mobilization	Immature qualified human resource for R&D activities in Türkiye and insufficient financial resource	Amendment on R&D center regulation to subsidize research and development activities on precision farming technologies	Improving and increasing R&D level in quantity and quality wise	MoIT	Technolo-gical
		Opening special call for international project		TÜBİTAK	Technolo-gical
		Subsidizing precision farming technologies locally developed		MoIT	Economic
Creation of legitimacy	Lack of specific institute and organization that pursues and orchestrates activities for precision farming technologies	Establishment of an organization under ministry of Agriculture and Forestry or revision of TAGEM mission	Creation of structural approach for precision farming technologies development, diffusion and adoption	MoAF	Social
	Insufficient interest of agricultural organization and cooperatives	Task force consolidation from these organization to seek opportunities for adoption of precision farming technologies	Rising the interest and awareness in non-governmental organizations	MoAF	Social

Source: Author

Above policies based on Hekkert's framework are recommended to overcome challenges and to eliminate impediments described in the previous section. Although each policy instrument targets a primary barrier, it indirectly impacts other areas as well. Therefore, the implementation of policies for each Hekkert function will provide a holistic approach, and the interaction will lead to faster results.

Nevertheless, recommended policies can be prioritized, and I propose to start with demand side policies based on interview results immediately after implementation of policy instrument "solid strategy development by defining all stakeholders" which will serve as a framework for all the players including farmers, startups, institutes, industry, and governmental bodies. The rationales behind prioritization of demand side policies are.

- Farmers are more oriented towards conventional methods in agriculture and demonstration of precision farming technologies with their benefits will encourage them to use these technologies in agricultural activities.
- Farmers' skills to effectively use these precision farming technologies and their awareness is not at desired level. Improvement in skills and awareness will support knowledge diffusion which may bring more adoption of the technologies.
- Unification of land is crucial as the farmer who owns small land size tends to avoid adoption of precision farming technologies as it may not be feasible. The secondary data also shows that the bigger land size, the more diffusion in precision farming such as Australia and USA. Therefore, unification allows farmers to make investments on these technologies and equipment.
- Specific incentives, financial subsidies and public procurement should be provided to stimulate precision farming equipment market.
- Investment in telecommunication infrastructure is vital to adopt these technologies and to use efficiently.

Supply side policies, such as establishment of clusters among startups, national smart farming institute nomination or opening call for research can follow.

5.4. Limitation of the Study

Precision farming is a broad concept and covers many different technologies. Furthermore, functional analysis of precision farming in technological innovation system requires extensive research and study. In order to keep the study manageable, specific technologies, autoguidance and yield mapping and monitoring technologies have been selected for research and this brings several limitations.

First, technologies that thesis focused on are limited and there is always interrelatedness among technologies. Therefore, other precision farming technologies such as variable rate control, telematic even smart farming technologies digital solutions, agricultural robots and IoT solutions covered in literature review chapter should be taken into account in future studies for a more comprehensive picture.

Second, qualitative study is based on only participants from agriculture, industry and R&D and a couple of Hekkert functions could not be fully elaborated. If future studies include universities, participant from government and related bodies, agricultural branch of banks which provide financial support for precision farming technologies and related institutes, the results will be more detailed and saturated.

This study investigated agriculture in different perspectives by focusing on precision farming technologies diffusion and adoption. Future research can shed light on whole agricultural value chain and investigate it by applying different functional models in different innovation system framework.

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APPENDICES

A. APPROVAL OF THE METU HUMAN SUBJECTS ETHICS COMMITTEE

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29 KASIM 2023

Konu: Değerlendirme Sonucu

Gönderen: ODTÜ İnsan Araştırmaları Etik Kurulu (İAEK)

İlgi: İnsan Araştırmaları Etik Kurulu Başvurusu

Sayın Prof.Dr.M.Teoman Pamukçu

Danışmanlığını yürüttüğünüz Cem Tüfekçi'nin ***"Türkiye'de akıllı tarımın yayılımı ve difüzyonu için politika tasarımı"*** başlıklı araştırmanız İnsan Araştırmaları Etik Kurulu tarafından uygun görülerek 0466-ODTUİAEK-2023 protokol numarası ile onaylanmıştır.

Bilgilerinize saygılarımla sunarım.

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B. TECHNICAL TERMS and DEFINITION

Real Time Kinematics	A highly accurate technique to define receiver's location based on signals from satellite-based positioning system
Telematics	It is combination of words, telecommunications and informatics and represents communication with a machine or between the machines by transmitting or receiving information
Flow rate control	A control system used for variable rate application
ISOBUS	A standard communication protocols that allow exchange of data and information between agricultural equipment and tractors
CAN Bus	A controller network (CAN) is a serial network technology used in automotive to enable communication between electronic control units of vehicles
Variable rate control	A system which is used in agricultural operations, and it enables the agricultural equipment to apply inputs such as fertilizer, pesticides in varying rates
Correction signal	Standard GPS provides an approximate position. In order to obtain accuracy in position for agricultural operations, correction signal is needed, and it is supplied by fixed reference station
Automatic turning	End-of-raw automatic turning technology allow autoguidance system to calculate the optimal path to turn tractors with high accuracy
Reverse motion	Reverse motion option allows farmers to use autoguidance system when using tractors in reverse direction
Signal buffering	A technology to provide seamless signal by buffering and computing to high accuracy position when signal interrupts
Machine development	Product development process covering design and manufacturing of agricultural equipment
Virtual reference station	A system of reference GPS stations connected via data links and provide highly accurate real-time correction signals
LSTM	Long Short-Term Memory networks to improve various agricultural processes such as crop yield prediction, soil moisture and irrigation prediction, precision farming by analysing temporal data, such as weather patterns, crop growth, soil conditions, and market trends

NDVI	Normalized Difference Vegetation Index. A metric to measure vegetation health and density
CM-NA	Convolutional Neural Network – Attention. The model is used to manage and analyse visual and spatial data more effectively in agricultural processes.
KM-H	Knowledge Management in Horticulture/Agriculture. A process of collecting and analysing agricultural knowledge to improve decision-making process in agricultural operations.
Zn Levels	Measurement of zinc concentration in soils, plants and fertilizers as this element is vital for plant growth and overall productivity in yield.

C. TURKISH SUMMARY / TÜRKÇE ÖZET

TÜRKİYE'DE HASSAS TARIMIN YAYGINLAŞTIRILMASI VE UYGULANMASINA YÖNELİK POLİTİKA TASARIMI

Tarım, uygarlık tarihi boyunca büyük bir öneme sahip olmuş ve kritik bir rol oynamıştır. İlk Tarım Devrimi, M.Ö. 10.000 yıllarına kadar uzanır ve yerleşik yaşama geçişi işaret eder. Bu dönem, insan ve hayvan gücüne dayalı olarak büyük değişiklikler olmaksızın 1800'lü yıllara kadar sürmüştür. Buhar makinelerinin gelişmesi ve Sanayi Devrimi'nin başlamasıyla tarım ekipmanları ve içten yanmalı motorlar ortaya çıkmış, 19. yüzyılın ikinci yarısında traktörler devreye girerek İkinci Tarım Devrimi'ni başlatmıştır. 20. yüzyılın son çeyreğinde bilgisayar teknolojileri, sensörler ve robotların gelişmesiyle tarımda otomasyon dönemi başlamış ve bu da Üçüncü Tarım Devrimi olarak adlandırılmıştır. Bu dönemde aynı zamanda sürdürülebilirlik tartışmaları da gündeme gelmiştir. Günümüzde, bilgi sistemlerindeki ilerlemelerle birlikte Dördüncü Tarım Devrimi'ni yaşıyoruz.

Bugün, IoT, bulut bilişim, yapay zeka ve makine öğrenmesi (AI/ML), büyük veri, kablosuz sensör ağları, karar destek sistemleri ve robotik teknolojiler kullanarak tarımsal değer zincirini uçtan uca yönetebiliyoruz. Tarım 4.0, yalnızca sahadaki ekim, dikim, yetiştirme ve hasat faaliyetlerini değil, aynı zamanda ekim öncesi (gübre, tohum ve pestisit teknolojileri gibi) ve hasat sonrası süreçleri de (ürün izlenebilirliği, lojistik ve koruma gibi) kapsamaktadır. Tarım 4.0, bu değer zinciri süreçlerini etkili bir şekilde izlemek, kontrol etmek, tahmin etmek ve yönetmek için çeşitli araçlar kullanmaktadır. Da Silveira ve diğerlerine göre (2021), Tarım 4.0, geleneksel tarımsal teknik ve yöntemlerin, gelişmekte olan teknolojiler ve yıkıcı çözümlerle birleştirilerek tarımsal üretim değer zincirini optimize etmeyi hedeflemektedir. Öte yandan, akıllı tarım, Tarım 4.0'ın bir parçası olarak daha çok ekim, yetiştirme, hasat ve hayvancılık gibi sahadaki faaliyetlere odaklanmaktadır. Akıllı tarım; otomatik yönlendirme, verim haritalama, telematik ve değişken oranlı kontrol gibi hassas tarım uygulamalarını, dijital çözümleri (çiftlik yönetim sistemleri, uydu görüntüleme, tarımsal robotlar ve uygulama robotları) ve IoT çözümleri (hava istasyonları, akıllı sulama sistemleri gibi) kapsamaktadır. Özetle, akıllı tarım, hassas tarımı, karar destek sistemlerini ve iletişim teknolojilerini kapsayan geniş bir terimdir. Hassas tarım ise, GPS, sensörler ve uzaktan algılama teknolojilerinin birincil kullanımıyla tarımsal faaliyetlerin, özellikle saha operasyonlarının, verimliliğini artırmayı amaçlamaktadır.

Tarım, diğer sektörlere göre dış faktörlere daha duyarlıdır ve en şiddetli etkilerin görüldüğü alanlardan biridir. Tüm bu etkilerin yarattığı sorunların çözümü, üretkenliği artırırken çevreye ve kaynaklara duyarlı olmayı amaçlayan sürdürülebilir tarımda görülebilir. Sürdürülebilir tarımda, akıllı tarım uygulamalarının bir alt kümesi olan hassas tarım, otomatik dümenleme, verim haritalama ve izleme, değişken oranlı uygulama ve telematik teknolojileriyle önemli çözümler sunmaktadır.

"Türkiye'de Hassas Tarımın Yaygınlaştırılması ve Uygulanmasına Yönelik Politika Tasarımı" başlıklı tez çalışmam, özellikle otomatik dümenleme ve verim haritalama teknolojilerine odaklanarak hassas tarım teknolojilerinin benimsenmesini sağlayan dinamikleri ortaya çıkarmayı amaçlamaktadır. Amacım, bu teknolojilerin benimsenmesini hızlandıracak politikalar önermek ve böylece Türkiye'de tarımsal üretkenlik ve verimliliği artırmaktır. Tezde ele alınacak temel araştırma soruları şunlardır:

i. Türkiye'de hassas tarımın, özellikle de otomatik dümenleme ve verim haritalamanın durumu nedir?
ii. Hassas tarımın Türkiye ekonomisine ve özellikle tarımına potansiyel faydaları nelerdir?
iii. Türkiye ile ABD, AB ülkeleri ve Avustralya gibi gelişmiş ülkeler arasındaki fark –varsa– neden kaynaklanmaktadır? Bu farkı yaratan ana faktörler nelerdir?

Araştırmada, teknolojik yenilik sistemi yaklaşımı kullanılmıştır. Bu yaklaşım, yenilik sürecinde katkı sağlayanların, yeniliğin hızı ve yönü üzerindeki etkilerini anlamamıza ve açıklamamıza olanak tanır. Tezde, Hekkert (2007) tarafından önerilen fonksiyon temelli model kullanılarak Türkiye'de hassas tarımın benimsenmesi ve yaygınlaşması analiz edilmiştir. Akıllı tarım başlığı altında düşünebileceğimiz hassas tarım uygulamaları, özellikle tarımsal girdilerin azaltılırken, çıktıların azami oranda artırılmasını hedeflemektedir. Bu durum çiftçiye ekonomik fayda sağlarken, çevre açısında da sürdürebilirliğe katkı vermektedir.

Hassas tarım uygulamalarına baktığımızda, otomatik dümenleme, değişken oranlı uygulamalar, verim haritalama ve telematik ana teknolojilerdir. Bu araştırmada özellikle otomatik dümenleme ve verim haritalama üzerine odaklanılması planlamış, fakat özellikle verim haritalama uygulamalarının kısıtlı kalması nedeniyle, ana olarak otomatik dümenleme teknolojisi eksen alınmıştır.

Akıllı tarım ve hassas tarım teknolojilerinin farklı ülkelerde, özellikle tarımsal arazilerin büyüklüklerine ve yapılan tarımın ölçeğine bağlı olarak farklı yayılım ve uygulama seviyelerinde olduğu görülmektedir. Özellikle Amerika, Kanada ve Avustralya bu teknolojilerin kullanılmasında başı çekmektedir. Bu ülkeleri diğer gelişmiş ülkeler izlemektedir. Türkiye'ye baktığımızda, tüm dünyada olduğu gibi en yaygın teknoloji otomatik dümenlemedir. Fakat, genel olarak akıllı tarım ve hassas tarım teknolojilerinin Türkiye'de yayılımı kısıtlı kalmaktadır. Tarımda dijital dönüşüm ve dijital teknolojilerin kullanılmasına dönük insiyatif olsa da, bu teknolojiler için hayati önem taşıyan bilgi ve iletişim altyapısında önemli gelişim ihtiyacı bulunmaktadır. Bugün Türkiye'nin bu alandaki bilgi ve iletişim gelişmişlik indeksi (ICT) 85,8 değeriyle Avrupa ve yüksek gelir seviyesindeki ülkelerin indeksinden geridedir.

Tarım ve Ormancılık Bakanlığı, 2020 yılında Tarımda Dijital Dönüşüm programını başlatmıştır. Fakat, bu program daha çok dijital servisler, e-tarım portalı, tarımsal arazi yönetim portal, dijital pazaryeri gibi uygulamaları vizyon olarak koymuştur. Programda otomatik dümenleme veya diğer hassas tarım teknolojilerine dönük açık bir hedef izlenmemektedir. Ayrıca yine bakanlık 2016 yılında da akıllı ve hassas tarım teknolojilerinin geliştirilmesine dönük, içinde akademisyenler ve tarımsal ekipman üreticilerinin de olduğu bir platformun kurulmasına liderlik etmiştir.

Tüm bunların ışığında, Türkiye’deki otomatik dümenleme pazarının 2020 yılında traktör başına otomatik dümenleme ünite sayısı değeri olan %0,9’dan 2023 yılında %5 değerine yükseldiği görülmektedir. Bu da yavaş da olsa pazarda bir büyümenin olduğunu işaret etmektedir.

Türkiye’de bir hassas tarım teknolojisi olan otomatik dümenlemenin yayılımı ve uygulanmasına dönük politika geliştirilmesi amaçlayan bu çalışmada Hekkert (2007) modelindeki teknolojik inovasyon sistemi için önerdiği yedi fonksiyonu analiz edebilmek için, kalitatif araştırma metodolojisi takip edilmiştir. Yarı yapılandırılmış soru seti farklı profillerdeki katılımcılara çoğunluğu yüzyüze olan görüşmelerde sorulmuş, bu görüşmeler yaklaşık 45 dakika sürmüş ve görüşmeler katılımcıların izinleri ile kayıt altına alınmıştır. Katılımcılar, çiftçiler, tarımsal ekipman üretici firmada çalışan pazarlama, iş geliştirme, hassas tarım yetkilileri ve hassas tarım teknoljisi geliştiren ve üreten firma yetkilileri olmak üzere toplam 11 kişi olarak belirlenmiştir. Bu sayı ihtiyaç duyulan veri doygunluğuna ulaşılması için yeterli olmuştur. Görüşme tutanakları transcript haline getirilerek, MAXQDA programında kodlanmış ve analiz edilmiştir.

Birinci fonksiyon olan girişimcilik faaliyetleri kapsamındaki bulgulara baktığımızda, otomatik dümenleme teknolojisine dönük pazardaki tüm oyuncuların yabancı menşeili olduğu görülmektedir. Batı kaynaklı ürünler uzun bir süredir pazarda yer alırken, özellikle yüksek gelir gurubundaki kullanıcılara hitap etmektedir. Fakat son dönemlerde daha ucuz fiyatla Çin menşeili ürünler de pazara girerek daha düşük bütçeli kullanıcılar için önemli bir alternatif sunmuşlardır. Görüşmeye katılanlar, hem batı hem de Çin kaynaklı otomatik dümenleme ürünlerinin benzer özellikle ve hassasiyet seviyesinde olduğunu dile getirmekte ve bunlar arasında farkların daha çok satış sonrası desteği, düzeltme sinyalleri ve sundukları diğer ek özelliklerden kaynaklandığını belirtmektedirler. Çeşitli bakanlık ve kurumlar tarafından bazı girişimlerde bulunulsa da, yerli teknolojilerin geliştirilmesine dönük gerçekçi bir insiyatif gözlenememiş ve buna bağlı olarak da olgun bir ekosistemden bahsedilememektedir.

İkinci fonksiyon olan bilginin üretilmesinde, katılımcıların özellikle bu alanda bulunan bulunan girişimler ile ilgili bilgi aktardığı fakat patent ve yapılan bilimsel çalışmalar konusunda kısıtlı bilgi verebildikleri görülmüştür. Bu alanda çalışan girişimler, otomatik dümenleme veya verim haritalamadan çok tarımsal verinin toplanması ve işlenmesi, tarımsal robotlar, mobil uygulamalar, akıllı tarımsal kontrol Sistemleri ve tarımsal teknoloji çözümleri gibi alanlara odaklanmaktadırlar. Katılımcıların büyük kısmı, Türkiye'de hassas tarım teknolojilerine dönük araştırma ve geliştirme faaliyetlerin ya farkında olmadıklarını ya da bu tür programların olmadığını dile getirmiştir. Patent konusunda, Türkiye Patent Enstitüsü veritabanında yapılan araştırmada, Türkiye'de akıllı tarım, hassas tarım ve otomatik dümenleme konularda 13 adet patent ve faydalı model alınmış veya başvurusu yapılmıştır. Bunlardan sadece bir adedi görüntü işleme ve görsel tanıma çözümü ile çalışan otomatik dümenleme önermektedir. Hassas tarım, akıllı tarım, otomatik dümenleme, verim haritalama, tarım 4.0 ve tarımsal robot konularındaki bilimsel araştırmaların durumunu anlamak için hem Türkiye hem de Dünya için bibliometrik analiz yapılmıştır. Dünyada son 20 yılda bu alanlarda 2918 adet yayın yapılmış, otomatik dümenleme ve otonom araçlar 2010-2020 yılları arasında daha popülerken, son dönemde akuakültür, akıllı tarım, derin öğrenme ve makine öğrenmesi gibi konular daha fazla ilgi görmektedir. Türkiye'de ise son 20 yıldaki bilimsel yayın sayısı oldukça düşük bir seviyede ve 54 adettir. 2019 yılına kadar hassas tarım ve otomatik dümenleme konuları başı çekerken, son dönemde tarımda blok zincir uygulamaları, değişken oranlı uygulamalar ve tarımsal makine geliştirilmesi üzerine çalışmalar yoğunlaşmıştır.

Üretilen bilginin, üçüncü fonksiyon olan bu bilginin yayılımına baktığımızda ise hassas tarım teknolojilerine dönük, toplumdaki bilinç ve farkındalığın seviyesi ile ilgili katılımcıların farklı görüşleri bulunmaktadır. Çiftçiler, bu bilinç ve farkındalığı orta seviyede değerlendirmekte ve zaman için bu teknolojilerin kullanılması ile artacağını düşünmekteler. Buna karşın diğer katılımcılar, farklı açılardan değerlendirme yaparak düşük seviyede olduğunu düşünmekteler. Ayrıca, çiftçilerin ihtiyaç duyduğu bilgiler genelde bu teknolojilerin kullanımı ve uygulamasına dönük olurken ve bu bilgileri, fuarlar, müteahhitler, teknoloji sağlayıcıları ve çevrelerindeki diğer kullanıcılardan öğrenirken, diğer katılımcıların bilgiye olan ihtiyaçları daha çok bu teknolojilerin adaptasyonuna dönük olmaktadır. Bilgiye erişim kanalları da girişimciler, fuarlar ve internet olmaktadır. Özellikle çiftçiler, ilgili devlet organlarından ve kuruluşlardan, hassas tarım teknolojilerine ve bunların uygulamalarına dönük bilgilendirme eğitimleri ve çalıştayları beklemektedirler. Maalesef, bugün teknoloji ve ünite satıcıları bu rolü üstlenmiş gözükmektedir.

Dördüncü fonksiyon, üretilen bilgi ışığında geliştirilen teknolojilerin seçimi ve izlediği yol ile ilgilenmektedir. Endüstri ve hassas tarım teknolojisi üreten firmalardan gelen katılımcılar:

- Otomatik dümenler teknolojisi kullanımı artarken, verim haritalama, tarım robotları, değişken oranlı uygulamalar ve ilaçlama ile gübreleme için dronların daha fazla uygulama alanı bulacağını
- Tarımsal verilerin analizi, tarla ve bitki örtüsünün görüntü işlemesi gibi alanların diğer büyüme alanları olacağını
- Tarla ve çiftlik yönetiminin daha fazla uygulama alanı bulacağını
- Son olarak, katılımcılardan biri, çiftçilerin özellikle ekipman kiralama için abonelik tabanlı hizmetleri kullanmaya yöneleceğini öngörmektedir.

Çiftçi katılımcılar, genel olarak yukarıdaki düşüncelere katılmakla birlikte, tarımsal robotlar, otonom araçlar, toprak ve bitki sensörlerinin kullanımı gibi otonom ve uyarlanabilir teknolojilerin, ISOBUS özellikle tarımsal ekipmanların, akıllı sulama sistemlerinin, dron ile ilaçlama ve gübrelemenin, verim haritalamanın, telematik uygulamlarının ve değişken oranlı uygulamaların daha fazla yaygınlaşacağı ve ihtiyaç duyulacağını düşünmektedirler. Fakat, görüşmelerden çıkan veriler, bu teknolojilerin hızı ve yönünü etkileyecek politikaların eksikliğine işaret etmektedir. Çiftçilerin ve kullanıcıların beklentileri daha çok bu teknolojileri üreten ve satanlar tarafından belirlenmektedir.

Market oluşumunu içeren beşinci fonksiyona yönelik, katılımcılar özellikle son yıllarda Çin menşeili ucuz ürünlerin girmesi ile pazarın büyüdüğünü ve bu trendin de devam edeceğini belirtmekteler. Her ne kadar Çin menşeili bu ürünlerin sağladığı hassasiyet, batı menşeili ürünler kadar olmasa da, küçük ölçekli çiftçiler tarafından daha çok tercih edilmektedir. Bununla birlikte, şu anda yoğun olarak yüksek beygir gücüne sahip traktörlerde kullanılan otomatik dümenleme sistemlerinin daha düşük beygir güçlerine de yaygınlaşması ile bu pazarın daha da büyüyeceği beklentisi bulunmaktadır. Öte taraftan pazarın oluşumuna katkısı olan teşvik ve destekler, genel olarak Ziraat bankası tarafından verilmele birlikte, özellikle çiftçi katılımcılar, bu desteklerin ya yetersiz olduğunu ya da erişimin çok zor olduğunu dile getirmişlerdir. Bunun dışında, otomatik dümenleme sistemleri için hayati önem taşıyan uydu sinyallerinin kalitesinin geliştirilmesi gerektiği, ve özellikle güneydoğu sınır bölgelerinde askeri amaçlı kullanılan sinyal karıştırıcılar nedeniyle, sıklıkla kesintiler yaşandığı katılımcılar tarafında belirtmişlerdir. Pazar oluşumunun önündeki diğer önemli bir engel de Türkiye'deki küçük arazi boyutları olmaktadır. Bu tür küçük araziler, hassas tarım teknolojilerine yapılan yatırımın fizibilitesini zorlaştırmaktadır. Bunun dışında katılımcılar, gerek batı gerekse Çin menşeili olsun, bu ürünler için verilen satış sonrası desteği yeterli bulmaktadırlar.

Altıncı fonksiyon olan kaynakların varlığı ve kullanımına baktığımızda, hassas tarım teknolojilerine dönük ArGe faaliyetlerini yürütecek teknik ve mühendislik kaynağının kısıtlı olduğunu görüyoruz. Bilgi birikiminin sağlanması da geliştirilmesi gereken alan olarak karşımıza çıkmaktadır. Yine aynı şekilde teşvikler ve destekler de sınırlı ve yetersiz kalmaktadır. Özellikle girişimciler, devletin ilgili kurumlarında daha net bir vizyon ve bu vizyona uygun daha şeffaf bir plan ve destek beklemektedirler.

Son fonksiyon olan hassas tarım teknolojilerinin ve özelde otomatik dümenleme teknolojisine meşruiyet kazandırılması aşamasında, Türkiye'de bu konuda ilgili yasa, politika ve düzenemlemelerle birlikte ilgili kurumların varlığı incelenmiştir. Katılımcıların büyük çoğunluğu, bu konuda herhangi bir kurumun olmadığını belirtmişlerdir. Türkiye'in en büyük çiftçi yapılanmalarından olan ÇUKOBİRLİK, TARİŞ ve PANKOBİRLİK'te hassas tarım teknolojilerinin kullanımı ve yaygınlaştırılmasına dönük net bir vizyon görülmemiştir. Yine aynı şekilde katılımcılar, hassas tarım teknolojilerine dönük herhangi bir politika veya düzenlemeden haberleri olmadığın belirtmişlerdir. Yine de TAGEM tarafından yayınlanan 2021-2025 ana planda akıllı tarım teknolojilerine yer ayrılmış ve vurgu yapılmıştır. Bu plan teknolojilerin yaygınlaşması için bir çerçeve sunabilir. Özetin bu son kısmında, araştırmanın sonuçlarını paylaşılarak, Türkiye'de hassas tarım teknolojilerinin yaygınlaştırılması ve uygulanması için politika önerilerinde bulunulacaktır. Öncelikli olarak Türkiye'deki hassas tarımın mevcut durumuna ışık tutacak yayılım seviyesini gözden geçirdiğimizde aşağıdaki gibi bir tablo ile karşılaşmaktayız. Önceki bölümlerde tartışıldığı gibi, hassas tarım, çiftçilerin tarlalarını daha verimli ve etkili bir şekilde yönetmelerini sağlayan birçok teknolojiyi bünyesinde barındırmaktadır. Hassas tarım, girdi maliyetlerini azaltırken, çıktıyı ve verimi artırmakta, tarımın çevre üzerinde oluşturduğu olumsuz etkileri azaltmakta ve sürdürülebilirliğe katkı sağlamaktadır. Araştırmada, her ne kadar otomatik dümenleme üzerine odaklanmış olsak da, otomatik dümenleme ile verim haritalama teknolojilerinin yayılımı ve uygulanmasını etkileyen faktörlerin ve Hekkert'in TIS fonksiyonlarının, diğer hassas tarım teknolojileri için de geçerli olduğunu anlıyoruz.

Önceki bölümde tartıştığımız bulgular, hassas tarım teknolojilerinin yayılımını ve uygulanmasını, arazi büyüklüğü, ürün fiyatı, çitçilerin dijital teknolojilere yönelik beceri seti, telekomünikasyon altyapısı ve sinyal kalitesi, sübvansiyonlar ve finansal destek ile bu teknolojilere dönük politika ile ilgili kurumları varlığı gibi birçok faktörün etkilediğini göstermektedir. Say ve diğerleri (2017) makalelerinde bu bulgulara ek olarak olarak çiftlik özellikleri, çiftçinin aile yapısı, kullanılan teknolojilerin karmaşıklığı ve uyumluluğundan da bahsetmektedirler.

Bulgular ve analizler, Türkiye'de hassas tarım teknolojilerinin yayılımı ve uygulanmasının, ABD, Avustralya ve AB ülkeleri gibi gelişmiş ülkelerle aynı seviyede olmadığını göstermektedir. Otomatik dümenleme teknolojisi, dünyada olduğu gibi Türkiye'de de en popüler hassas tarım teknolojisidir, ancak bu gerçeğe rağmen, teknolojinin benimsenmesi ve uygulanması istenilen seviyede değildir. Ayrıca Türkiye'de verim haritalama teknolojisinin kullanımı da oldukça düşük seviyededir. Diğer yandan, 2000'li yıllarda Türkiye'de otomatik dümenleme sisteminin yanında, değişken oranlı uygulamalar, toprak analizi ve izleme, uzaktan algılama, drone uygulamaları gibi diğer hassas tarım teknolojilerinin yayılım ve benimsenme oranlarında artan bir trend gözlemlenmektedir. Ne yazık ki, verim aritalama ve izleme teknolojisinin yayılımında benzer bir artış trendi görülmemektedir. Hassas tarım teknolojilerinin, özellikle otomatik dümenleme ve verim haritalama teknolojilerinin, daha fazla yayılmasını ve uygulanmasını engelleyen ana zorluklar ve engellere baktığımızda, görüşme verilerinin ve araştırmanın analizi, otomatik yönlendirme ile verim haritalama teknolojilerinin düşük yayılım ve benimsenme seviyelerine neden olan çeşitli faktörler ve zorluklar olduğunu göstermektedir. Aslında, bu faktörler diğer hassas tarım teknolojileri için de geçerlidir.

1. Telekomünikasyon altyapısı, bugün için etkili sinyal iletimi sağlamak için yeterli değildir. Sınır bölgeleri, özellikle güneydoğu bölgesi, askeri amaçlar için kullanılan sinyal bozuculardan olumsuz etkilenmektedir.
2. Çinli tedarikçiler düşük maliyetli ürünler sağlasa da ekipman maliyetleri hâlâ yüksek kalmaktadır.
3. Türkiye'deki ortalama arazi büyüklüğü gelişimiş ülkeler ile karşılaştırıldığında oldukça küçüktür ve bu durum, otomatik dümenleme ile verim haritalama teknolojilerinin geniş çapta yayılmasını ve kullanılmasına dönük fizibiliteleri olumsu yönde etkilemektedir.
4. Çiftçilerin bazı uygulamalar konusundaki becerileri yetersizdir ve bu teknolojileri kullanmayı karmaşık ve zor bulmaktadırlar. Ayrıca, tarımda daha çok geleneksel uygulamalara odaklanmış bir yaklaşım olduğu görülmektedir.
5. Türkiye'de hassas tarım teknolojilerinin uygulanmasına yönelik çeşitli kurumsal girişimler ve programlar olmasına rağmen, çiftçiler, girişimciler ve sanayi gibi paydaşlar bütüncül bir yaklaşım gözlemlememekte ve hükümet veya kurumlar tarafından başlatılan programlar ve desteklerden haberdar olmamaktadırlar.
6. Finansal araçlar, teşvikler ve sübvansiyonlar, hassas tarım teknolojilerinin yayılımını teşvik etmek için sınırlı ve yetersizdir.
7. Türkiye’de sanayi ve akademide hassas tarım teknolojileri konusunda yapılan araştırma ve geliştirme çalışmaları çeşitlilik göstermemekte ve başlangıç seviyesindedir. Ayrıca, hassas tarım teknolojisinin yönü belirsizdir, yani somut bir vizyon ve hedef tanımlanmamıştır. Bu nedenle, mevcut politikalar etkili olamamakta ve hassas tarım teknolojilerinin yayılım hızı ve yönü üzerinde sınırlı bir etki yaratmaktadırlar. Sonuç olarak, bu politikalar yenilikleri tetikleyememekte ve etkili olamamaktadır.

8. Çiftçiler ve hassas tarım teknolojisi kullanıcıları için düzenlenen eğitim ve farkındalık faaliyetleri kapsamlı ve amaca yönelik değildir. Genellikle ticari kaygılarla özellikle hassas tarım firmaları tarafından yürütülmektedir.
9. Bu teknolojiler, traktör ve tarım ekipmanlarında belirli bir düzeyde teknolojik altyapı gerektirmektedir, örneğin elektronik motor, ISOBUS, CAN BUS gibi. Bu nedenle, Türkiye'deki bu ekipmanların önemli bir kısmı otomatik dümenleme ve verim haritalama teknolojileriyle uyumlu olmayabilir.
10. Hassas tarım teknolojileri, konum, kullanıcı tercihleri, ekilecek ürün ve verim gibi kişisel verileri de içeren farklı türde veriler kullanır ve üretir. Ancak, veri sahipliğini, gizliliğini ve sorumluluğu güvence altına almak için yeterli yasal ve düzenleyici çerçeve bulunmamaktadır.

Araştırma içerisinde, Hekkert fonksiyonlarına dayalı olarak bu teknolojilerin kullanımını teşvik etmek amacıyla politika önerileri sunulmuştur. Hekkert'in çerçevesine dayanan önerilen bu politikalar, yukarıda tanımlanan zorlukların üstesinden gelmek ve engelleri ortadan kaldırmak için önerilmektedir. Her politika aracı birincil bir engeli hedef almasına rağmen, dolaylı olarak diğer alanları da etkiler. Bu nedenle, her Hekkert fonksiyonu için politika uygulaması bütüncül bir yaklaşım sağlayacak ve etkileşim daha hızlı sonuçlara yol açacaktır.

Bununla birlikte, önerilen politikalar önceliklendirilebilir ve mülakat sonuçlarına dayanarak, tüm paydaşların için (çiftçiler, girişimciler, enstitüler, sanayi ve devlet kurumları dahil) bir çerçeve oluşturacak olan "tüm paydaşları belirleyerek gerçekçi ve uygulanabilir bir strateji geliştirilmesi" politika aracının devreye alınmasından hemen sonra talep taraflı politikalar ile başlamak, hassas tarım teknolojilerinin yayılımı ve uygulamasını hızlandırabilecektir. Talep taraflı politikalarının önceliklendirilmesinin gerekçeleri ise aşağıda açıklanmaya çalışılmıştır.

- Çiftçilerin hassas tarım teknolojilerini etkili bir şekilde kullanma becerileri ve farkındalıkları istenilen seviyede değildir. Beceri ve farkındalığın artırılması, bilgi yayılımını destekleyecek ve bu da teknolojilerin daha fazla benimsenmesini sağlayacaktır.

- Arazi toplulaştırması çok önemli bir politika aracı olarak karşımıza çıkmaktadır. Çünkü küçük araziye sahip olan çiftçiler, bu teknolojilerin satin alınması ve uygulanmasından kaçınma eğilimindedir, İkincil veriler de göstermektedir ki, arazi büyüklüğü arttıkça, Avustralya ve ABD gibi gelişimiş ülkelerde olduğu şekilde, hassas tarımın yayılımı da artmaktadır. Bu nedenle, toplulaştırma çiftçilerin bu teknolojilere ve ekipmanlara yatırım yapmalarını sağlayacaktır.
- Hassas tarım ekipmanları pazarını teşvik etmek için belirli teşvikler, finansal sübvansiyonlar ve kamu alımları sağlanması faydalı olacaktı.
- Bu teknolojilerin benimsenmesi ve verimli bir şekilde kullanılması için telekomünikasyon altyapısına yatırım yapılması önem kazanmaktadır.
- Girişimciler arasında kümelenmelerin oluşturulması, ulusal akıllı tarım enstitüsü kurulması veya hassas tarım teknolojilerine dönük araştırma çağrılarının açılması gibi arz tarafı politikaları bunu takip edebilir.

Son olarak, bu çalışmanın ötesinde gelecekte yapılabilecek araştırmalarla ilgili konular ve olası alanlarla ilgili olarak değerlendirmeler şu şekildedir. Hassas tarım geniş bir kavramdır ve birçok farklı teknolojiyi kapsar. Ayrıca, hassas tarımın teknolojik yenilik sistemindeki işlevsel analizi, geniş çaplı araştırma ve inceleme gerektirir. Çalışmanın yönetilebilirliğini sağlamak amacıyla, araştırma için spesifik olarak otomatik dümenleme teknolojisi seçilmiş olup, bu durum birkaç sınırlamayı da beraberinde getirmiştir.

İlk olarak, bu tezin odaklandığı teknolojiler sınırlıdır ve teknolojiler arasında her zaman karşılıklı bir ilişki bulunmaktadır. Bu nedenle, literatür incelemesi bölümünde ele alınan değişken oranlı uygulamalar, telematik, dijital çözümler, tarım robotları ve IoT çözümleri gibi diğer hassas tarım teknolojileri ile birlikte hatta bunların da ötesinde akıllı tarım teknolojileri, gelecekteki çalışmalar için daha kapsamlı bir çerçeve sunmak adına dikkate alınmalıdır. İkinci olarak, nitel çalışma sadece tarım, sanayi ve Ar-Ge’den katılımcılarla sınırlıdır ve birkaç Hekkert fonksiyonu tam anlamıyla ayrıntılandırılamamıştır. Eğer gelecekteki çalışmalar üniversiteleri, devlet organları ve ilgili kurumların katılımcılarını, hassas tarım teknolojileri için finansal destek sağlayan bankaların tarım şubelerini ve ilgili enstitüleri kapsarsa, sonuçlar daha ayrıntılı ve doygun olabilecektir.

Bu çalışma, hassas tarım teknolojilerinin yayılımı ve benimsenmesine odaklanarak tarımı farklı açılardan incelemiştir. Gelecekteki araştırmalar, tüm tarımsal değer zincirine ışık tutabilir ve farklı yenilik sistemi çerçevelerinde farklı işlevsel modeller uygulayarak tarım 4.0'ın odaklandığı bu tarımsal değer zincirini inceleyebilir.

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