Devon Agri-Tech Accelerator (DATA) Project

Sector Research and Mapping Report

Funding Scheme: UK Government Community Renewal Fund (CRF)

Project Lead: Devon County Council

Project Partners: University of Plymouth

Duchy college

West Devon Business Information Point

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Professor Shaofeng Liu, Dr Lise Hunter and Dr Jiang Pan
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Executive Summary

Innovation and technologies have shaped the agriculture sector for centuries and will continue to play an important role in the sector. According to the UK Food Strategy published in June 2022, UK government plans to spend over £270 million across farming innovation programmes to 2029 and have bolstered funding for farmers to invest in new technology where there is scope to boost their productivity. This report focuses on emerging agriculture technologies (rather than traditional agriculture machineries) that can change the agricultural landscape in the years ahead. As one of the biggest agricultural counties in the country, Devon, has been championing programmes to support the adoption and on-farm take-up of innovation and technologies that can sustainably boost the production and profitability of farm businesses. Due to the special geographic feature and the nature of farm businesses in Devon, especially the fact that majority of farms in Devon are small businesses, it is important to understand specific gaps, barriers and challenges in adopting agricultural technologies in the County, which requires rigorous research in order to close the gaps, overcome the barriers and meet the challenges.

Devon Agri-Tech Accelerator (DATA) is a project funded by UK Government under the scheme of Community Renewal Fund. The project is led by Devon County Council. Its partners include University of Plymouth, Duchy College and West Devon Business Information Point. DATA project aims to develop a Devon Agri-Tech Alliance between stakeholders which will collaborate to grow and develop the sector in Devon by using the research to formulate a future action plan to maximise opportunities such as Shared Prosperity Fund (SPF). The project consists of four elements:

- Sector research and mapping
- Development of an Agri-Tech Alliance
- Farm Innovation Pilot in Torridge and West Devon
- Knowledge Exchange and Grant Pilot

This document reports the first element of the project, that is, sector research and mapping. The report contains in total six sections:

- Section 1: Introduction

- Section 2: Research methodology
- Section 3: Findings from desk research, including contextual review, technology review and mapping farm businesses and agri-tech businesses in Devon
- Section 4: Findings from primary research part 1 – based on a questionnaire survey on technology acceptance (usefulness, ease-of-use, potential benefits)
- Section 5: Findings from primary research part 2 – based on in-depth interviews (key barriers, challenges and opportunities)
- Section 6: Conclusions and recommendations

The research used a multi-perspective, multi-method approach. Firstly, the research undertook desk research with a contextual analysis of Devon agriculture, a comprehensive review of emerging agricultural technologies, and mapping of farm businesses and agri-tech businesses in Devon. Primary research was conducted to enhance the desk research. The primary research includes two elements: a questionnaire survey and in-depth interviews, which allowed us to obtain rich, triangulated data on technology adoption from three perspectives: farmers' perspective, agri-tech developers' perspective and farm business experts' perspective.

Main findings from the contextual review show that there are a wide range of emerging technologies readily available to farming. The technology review classified the emerging technologies into ten categories. They are: drones and robots, satellite photography, IoT-based networks, weather forecasting and tracking, automated irrigation, biotech, soilless controlled-environment farming, light and heat control, integrated sensors, and soil technology. Our research finds that the agri-tech development businesses in Devon place more focus on five categories of the technologies (IoT-based networks, biotech, light and heat control, integrated sensors and soil technology). There is currently little emphasis on developing the other five categories of technologies from agri-tech developers in Devon. In terms of the adoption of the technologies on Devon farms, all ten categories of emerging technologies are being used. The top five most widely used technologies in descending order are weather forecasting and tracking (currently used by 59.1% of farms participated in our research), biotech (36.4%), satellite technology (31.8%), soil technology (18.2%) and IoT-based networks (18.2%). The use of other five categories of technologies on farms in Devon are quite low: drones and robots are used by 13.6% of farms, automated irrigation at 9.1% and so is light and heat control. Integrated sensors and soilless controlled-environment farming are the least used, both at 4.6%.

It is clear that the top five categories of technologies receiving the most effort from agri-tech development companies in Devon do not match the five most widely used technologies by our farms. This means that farmers will use technologies not necessarily provided by local or regional developers. The agri-tech developers do not necessarily place their emphasis on the technologies that are used by local or regional farmers. Both farmers and agri-tech developers look at wider global market when it comes to deciding what technologies to use or to develop.

Main findings from the questionnaire survey show that both farmers and agri-tech developers are largely positive about the potential benefits in all three pillars (economic, environmental and social) of using emerging technologies. Economic benefits confirmed by both groups of survey respondents are that using technologies can improve farm businesses' productivity and effectiveness. Agreed environmental benefit includes reducing pollutions, however farmers are not certain that using technologies will effectively reduce energy and water consumption, even though agri-tech developers think so. Farmers agree with agri-tech developers on two types of social benefits – improving farmers' working conditions and creating new job opportunities, but the two groups of respondents do not agree on a third type of social benefit – improving nutrition, health and well-being, that is, farmers have a much less positive view and the gap between the farmers and agri-tech developers is significant.

Our research finds that there are a range of barriers to the adoption of emerging technologies on farms in Devon. The top three barriers highlighted by most of our interviewees are farm size, investment cost and access to fund. Our contextual review already reveals that most farms in Devon are small businesses, which unfortunately proves to be a barrier to adopting emerging technologies during our primary research. Farmers believe that most technologies are too expensive, and they cannot afford the money to purchase or maintain over time. They also think that most funds have gone to manufacturers (agri-tech developers) instead of farms, and that the bidding process for funds is too complex to farmers.

Key challenges faced by farm businesses when adopting new technologies are mostly related to employees' skills, knowledge and access to training. Farm businesses with only a small number of employees cannot afford the time or money to receive full-time training. The research findings lead us to ask the question whether on-the-job, on-the-site training can be provided for farmers with hands-on experience in using the technologies that are applicable to their farming operations (i.e. "learning by doing").

Here is the summary of our main conclusions:

(1) Supporting the adoption of agricultural technologies and on-farm take-up of new innovations is extremely important, because both farm businesses and Agri-Tech developers see potential benefits (economic, environment and social) in adopting the technologies. This is clearly supported by the evidence from research findings detailed in Section 4.5, Section 4.6 and Section 4.7.

(2) A wide range of emerging agricultural technologies are readily available (Section 3.2 technology review). In addition, there are a great number of Agri-Tech companies in Devon which are delivering technologies with a high level of readiness (evidence in Section 4.1.2). Our research findings show that the technologies from agri-tech developers in Devon are concentrated on five out of the ten categories of technologies as reviewed in Section 3.2. There is a clear gap in the technology categories that currently needs to be filled by Agri- Tech development from outside Devon. This can be seen as an opportunity for future innovations in the region.

(3) Perceived usefulness of agricultural technologies differs between farmers and agri-tech developers (evidence in Section 4.3). Research findings show that agri-tech developers are positive about the technologies' usefulness, however a significant percentage of farmers have reservations. This gap between the agri-tech developers and farmers needs to be closed in order for emerging agricultural technologies to be adopted on farms.

(4) Perceived ease-of-use is another significant gap between the farmers' and tech developers' views (evidence in Section 4.4). However, this gap can be bridged by various programmes such as knowledge sharing, technology demonstration, on-the-farm training, and peer learning.

(5) The main barriers to adopting technologies are numerous, but the top three based on research are farm size, investment cost and access to funding (evidence in Section 5.1.1, Section 5.2.1, Section 5.3.1). Farm businesses in Devon are predominantly SMEs (evidence in Section 4.1.1). Most of them cannot afford expensive new innovations and technologies without funding support from appropriate sources.

(6) Key challenges highlighted by all three types of participants in our primary research are mostly related to farm business employees' skills, knowledge, and access to training (evidence in Section 51.2, Section 5.2.2, Section 5.3.2, Section 5.4.1). Farm businesses with only a small number of employees cannot afford the time or money to receive training full-time. In addition, farmers may not prefer to learn from classroom or laboratory-based lectures, but can learn well from peers (i.e., other farmers) in the farming community. What type of approach to training is appropriate to equipping farmers with the right skills and knowledge to adopt new technologies?

(7) Despite all the gaps, barriers and challenges, our research participants see a range of opportunities by adopting new technologies on farms, such as in sustainable farming, attracting young farmers, land management and biodiversity, and organic farming (evidence in Section 5.1.3, Section 5.2.3, Section 5.3.3, Section 5.4.2).

Contents

1. Introduction

This section provides some background information about the DATA project, defines the aim and objectives of the sector research and mapping element of the project, and outlines the content of the report.

1.1 Background of DATA project

Devon Agri-Tech Accelerator (DATA) project is funded by the UK government under The Community Renewal Fund scheme. The project is led by Devon County Council (DCC). Partners of the project are University of Plymouth (UoP), Duchy College (DC) and West Devon Business Information Point (BIP). The project started in January 2022.

One of the outcomes of Brexit is the discontinuation of EU Structural Funds by 2023 to be replaced by the new UK Shared Prosperity Fund. The UK Shared Prosperity Fund is designed to support people and places across the UK, focusing on domestic priorities to grow the local economy and help communities. To get started on this ambitious programme, the Community Renewal Fund was set up to help support local areas to pilot imaginative new approaches and programmes that unleash their potential, install pride, and prepare them to take full advantage of the UK Shared Prosperity Fund when it launches in 2022 (UK Government, 2021). It is against this background that DATA project is positioned with its focus on improving productivity in the farming sector.

The farming sector has been facing serious challenges over the past two decades. Technology acceptance and adoption in farm businesses has been slow due to many factors such as high investment cost, ageing population of farmers and rising inputs cost. Brexit has deprived the sector of its most reliable labour mainly from Europe. Cheaper food imports have strained operating margins, making it harder for farmers to invest in best practices. More recent events such as energy costs and the rise of inflation are forcing a re-think among agri-tech stakeholders, particularly in Devon, and bring an urgency to the need to design innovative approaches to unleash the potential of Devon farming. The DATA project proposed under the Community Renewal Fund, is to pilot support to the agri-tech sector whilst at the same time map the opportunities and current activities in Devon and build a Partnership that will act in the sector's interest -The Devon Agri-Tech Alliance. The University of Plymouth is one of the four proponents. This report is based on the sector research and mapping exercise led by Plymouth Business School in collaboration with Sustainable Earth Institute at University of Plymouth.

1.2 Aim and objectives

Innovation and technologies have shaped the agriculture sector for centuries and will continue to play an important role in the sector. UK government plans to spend over £270 million across farming innovation programmes to 2029 and have bolstered funding for farmers to invest in new technology where there is scope to boost their productivity (UK Food Strategy, 2022). As one of the biggest agricultural counties in the country, Devon, has been championing programmes to support the adoption and on-farm take-up of innovation and technologies that can sustainably boost the production and profitability of farm businesses. For clarity, this research focuses on emerging agriculture technologies (rather than traditional agriculture machineries) that can change the agricultural landscape in the years ahead.

This "sector research and mapping" element of DATA project aims to understand the current landscape, identify stakeholders, spread of businesses, current activities and future opportunities for collaboration and markets. The research will inform future agri-tech development and the adoption of the agricultural technologies on farms in Devon.

Four specific objectives were defined in order to achieve the overall aim:

1) Review technologies applicable to farm business and the level of activities in Devon;
2) Assess the gaps in technology adoption among Devon farmers;
3) Examine the challenges to technology adoption by Devon farmers;
4) Discuss future opportunities and make recommendations for collaboration and markets.

1.3 Outline of the Report

The next section of this report presents the methodology taken in this research.

The desk research includes contextual analysis and technology review. The contextual analysis contributed to the achievement of the first objective, providing an understanding of the landscape and the current farming activities, resulting in the mapping of agricultural technologies and farm businesses in Devon. Desk research findings are presented in Section 3.

To address objective Two, we present the results of a questionnaire survey conducted with farm and agri-tech businesses, which provides some preliminary findings into gapping.

Finally, objectives Three and 4 Four are met by drawing insights via in-depth interviews with three types of stakeholders: farm businesses, farm tech businesses and also farm business experts. Findings from the analysis of interview data helped to identify challenges and articulate opportunities to formulate some recommendations for collaboration and markets.

The following Figure 1-1 illustrates the structure of the report with the key elements in each section and the logical flow between the sections.

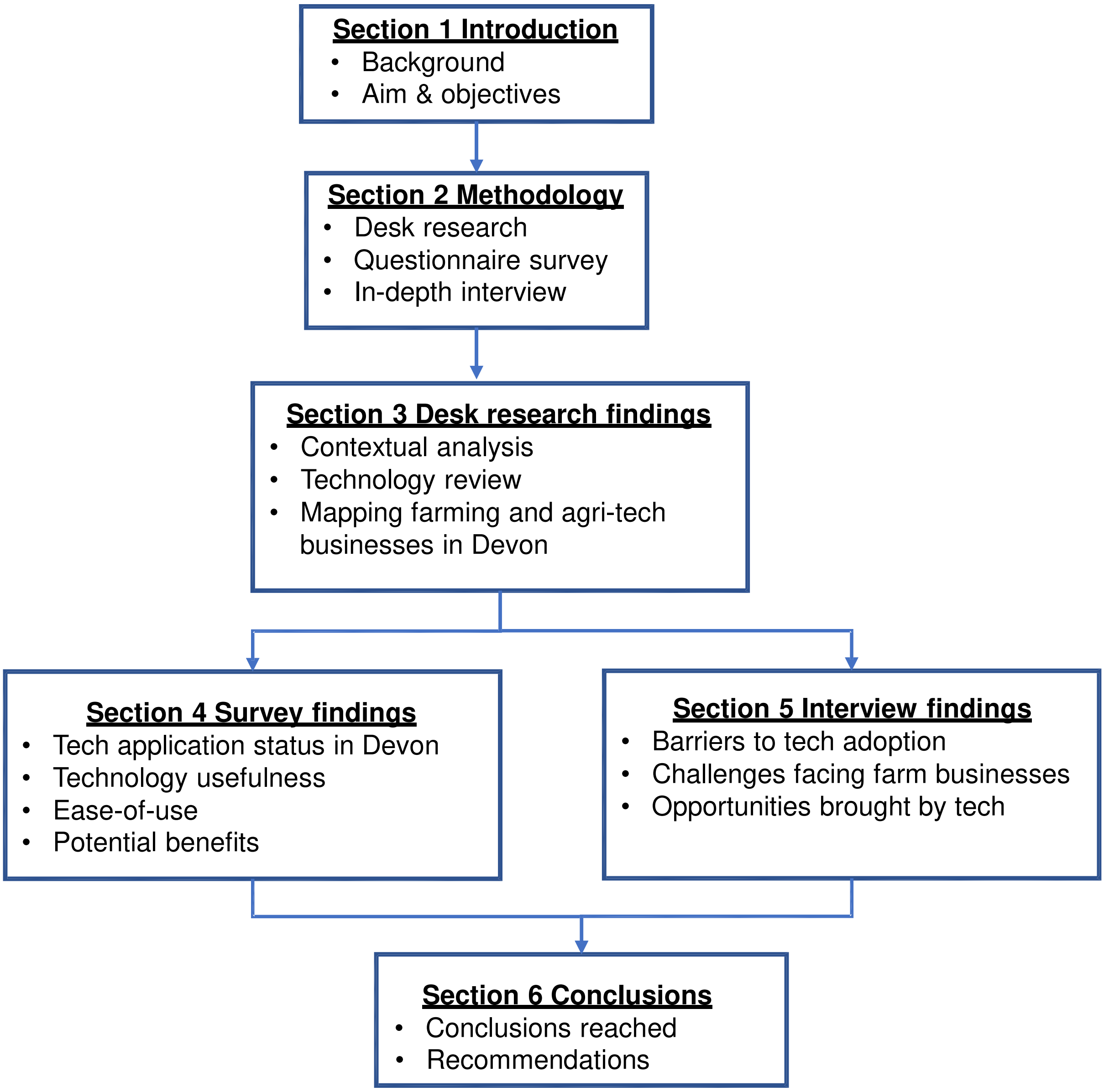

Figure 1-1 The report structure with logical flow between sections

2. Methodology

We adopted a multi-perspective, multi-method approach to undertake this research. The research used a combination of desk research and primary research. The primary research used a mixed methods for data collection and analysis, consisting of a questionnaire survey for quantitative research and in-depth interviews for qualitative research. The primary research takes three perspectives: farmers' perspective, agri-tech developers' perspective and farm business experts' perspective. The three groups of stakeholders provided us with complementary opinions. Using a combination of desk research and primary research ensured rich data for triangulation, subsequently helped to draw evidence-based conclusions. The methodology includes four phases. They are:

- Phase 1: Desk research - comprehensive review of emerging agricultural technologies currently available in global market.
- Phase 2: Desk research - contextual analysis of Devon farming sector, and mapping farm businesses and agri-tech businesses in the County.
- Phase 3: Primary research using questionnaire survey to assess the technology acceptance situation in Devon (current application status, technology usefulness, ease-of-use, potential benefits), and
- Phase 4: Primary research using in-depth interview to identify barriers, articulate challenges and opportunities for Devon agri-tech development and adoption of the technologies on farms.

The key activities of the four phases and main inputs and outputs of each of the phases are illustrated in Figure 2-1.

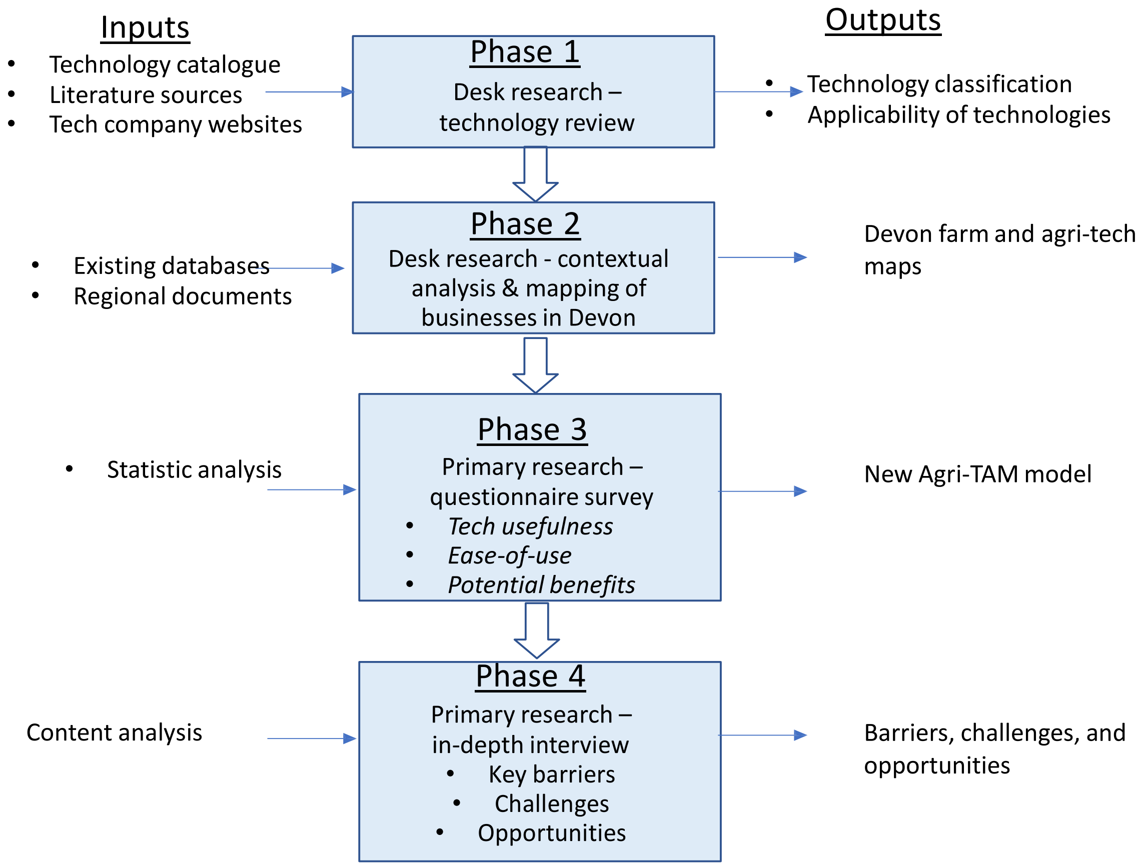

Figure 2-1 Research methodology framework

2.1 Phase 1: Desk research – review emerging agricultural technologies

This phase is to establish a solid understanding of currently available agricultural technologies including the analysis of their advantages and disadvantages, as well as their maturity level and application status. During Phase 1, our review resulted in the classification of emerging agricultural technologies into ten categories applicable to farming worldwide, particularly to countries similar to the UK in agricultural context. The details of the agri-tech categorisation are documented in Appendix A which can be used by farming community to help them make informed decisions on adopting relevant technologies.

2.2 Phase 2: Desk research - contextual analysis and mapping farm businesses and agri-tech development in Devon

This phase is to obtain an understanding of the farm activities and agri-tech development in Devon**.** In Phase 2, we drew on sector reports with particular focus on the South West and Devon. Official databases from various sources including *South West AgriTech, AGRI-TECH CENTRES, Agri-EPI Centre, AGRITECH UK*, assisted in identifying farm businesses and respective types of activities in Devon. These combined activities resulted in the mapping of farms and agri-tech businesses established in Devon. The detailed outputs from this phase are provided in Section 3, contextual analysis.

2.3 Phase 3: Primary data collection with questionnaire survey to assess technology acceptance

To address the gaps identified from Phase 1 and Phase 2, we took various steps in Phase 3 to comprehensively assess the agri-tech adoption. First, we adopted the original Technology Acceptance Model (TAM) that has been widely recognised as the measure for technology usefulness and ease-of-use by practitioners (Davis, 1986). This initial TAM can provide a basic structure of a research instrument to guide data collection in general sense. To contextualise TAM in Devon agriculture sector, we extended the initial TAM by adding two new dimensions:

(1) Potential barriers and challenges, such as technology maturity level to ascertain whether low- or non- adoption could be the result of less-known, poorly tested or very nascent technologies.

(2) Potential benefits to adopt a new agri-tech. To add relevance to the purpose of this study, a number of measurements of sustainability indicating economic, environmental and social benefits that could derive from new technologies being adopted on farms. The new added dimensions can aid farmers' decision- making in complex situations where conflicting demands compete, such as the need to create employment and protect the environment.

The new technology acceptance model for agri-business (i.e., Agri-TAM) developed from DATA project is shown in Figure 2-2.

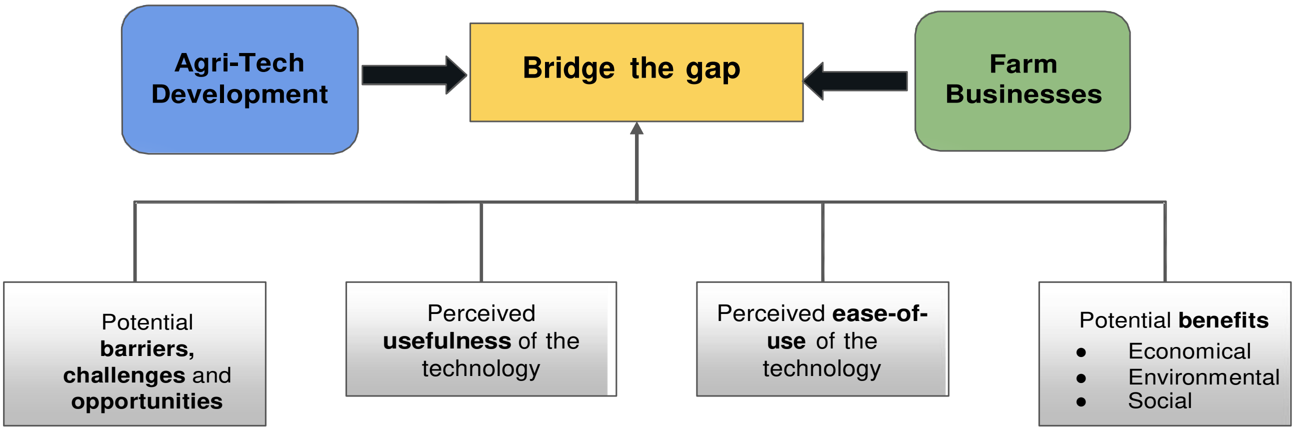

Figure 2-2 Agri-TAM developed from DATA project

The Agri-TAM has been used to guide our empirical research, in particular to fine-tune the design of survey questionnaire and interview template. The questionnaire was piloted with farmers and agri-tech developers and refined before the formal launch of questionnaire survey. Using existing databases and contextual review findings from Phases 2, we purposively targeted at 208 farm businesses and 70 agri-tech development companies in Devon for primary data collection. For the data collected via survey, we completed a statistical analysis to identify the key factors affecting the adoption of Agri-Techs, including the usefulness, ease-of-use and key benefits of adopting relevant technologies from two perspectives: agri-tech developers' and farmers'.

2.4 Phase 4: Primary research using in-depth interviews to identify barriers, challenges, and opportunities

Qualitative data such as stakeholders' opinion and attitude on emerging agricultural technologies were collected via in-depth interviews. Even though interviews are more time-consuming, they provided us with rich data that questionnaire survey cannot achieve. In order to gain insights into the adoption of agricultural technologies in Devon, especially the key barriers, challenges and opportunities, we included three groups of stakeholders, that is, besides farmers and agri-tech developers, an additional group of participants, farm business experts, are included in the interview stage. Compared with farm businesses (as agri-tech end users) and agri-tech businesses (as agri-tech developers), farm business experts (such as consultants) have more neutral standings in terms of adopting agricultural technologies, hence can provide opinions from a third perspective.

In Phase 4, we used content analysis method to make sense of the data recorded in interviews. All interviews are transcribed word for word for accuracy. This triangulation approach provided much richer qualitative data to understand the barriers and challenges of adopting technologies on farms in Devon; and the opportunities that farmers and agri-tech developers can be looking forward to.

3. Desk Research Findings: Contextual Analysis, Technology Review and Mapping Farming and Agri-tech Businesses in Devon

This section presents the main findings from desk research. First, Section 3.1 provides an overview of Devon farming and agri-tech businesses, followed by Section 3.2 on technology review, that is, the classification of emerging agricultural technologies currently available in global market. Finally, Section 3.3 presents the mapping outcomes of farm businesses and agri-tech business in Devon. Relevant gaps can be identified based on the technology review and the mapping exercise done for Devon.

3.1 Contextual analysis of Devon farming and agri-tech businesses

The South West holds special importance in the UK national farming landscape, comprising 20% of the farmed area (Defra, 2022). In 2016, the total farmed area in the South West was just under 1.8 million hectares, with 49% of it under permanent pasture and 12% under temporary grass (Defra, 2022). The region has a huge variety of agricultural landscape from fertile arable and dairy lowlands to the remote uplands of Dartmoor and Exmoor.

Devon as the largest county in the South West has 513,683 hectares of farmed land, which was 29% of the South West and 6% of the England total in 2016. In terms of usage, 11% of this farmed land grows cereals (55,361 hectares), 5% arable crops (25,799 hectares), 0.4% fruit and vegetables (2,469 hectares) and 77% is grassland (394,717 hectares) (Stewart, 2022). Therefore, the county is preeminent in the UK for its dairy and meat production. In 2016, it had 577,379 cattle (11% of the England and 33% of the South West total) and had 1,403,847 sheep (11% of the England and 44% of the South West total) (Stewart, 2022). Devon also has a highly diversified range of produce including cider brandy, cheeses and chilies, plus the UK's leading organic veg-box scheme (South West AgriTech, 2022). Its total agricultural labour in 2016 was 19,650, accounting for 7% of the England and 31% of the South West total (Stewart, 2022). In recent years significant farm diversification has taken place in the South West, including forestry, vineyards, flowers, organic vegetables, and biofuel crops.

Total farming income in this county increased by 5% between 2013 and 2017 to £616 million. Devon has over 8,000 agricultural holdings, accounting for 33% of the total South West, whose agricultural output is greater than Wales and Scotland Combined (Stewart, 2022).

Even though Devon is playing an important role in both South West and England's agriculture sector, its average farm business income (FBI) for all types of farms was only £34,100 in 2019/20, which was 26% lower than the average England's FBI of £46,000. The SW Rural Productivity Commission (2017) highlighted a number of key characteristics of rural economies that could be potential barriers to income and productivity growth, including:

- Fewer large employers, and therefore a higher dependency on self-employment for career development, but fewer businesses seeking to 'scale up'.
- A more dispersed labour force.
- Lower levels of business ambition and fewer higher skills jobs.
- Limited transport and digital infrastructure accentuating the peripherality of many rural areas.
- Issues of housing affordability and planning, and workspace/employment land availability.

In addition to these above-mentioned internal characteristics or barriers, Devon farm businesses are also facing many external and global challenges, including:

- 70% more food is needed by 2050 to meet the needs of over 9 billion population worldwide, under current industry practices, this results in 65% increase in irrigation water, 67% increase in land, and 87% increase in greenhouse gas emissions (FAO, 2018).
- 1.3 billion tonnes of food get lost or wasted globally each year, which is enough to feed 2 billion people (FAO, 2011).
- Due to the impacts of Brexit, UK farms face up to 70,000 seasonal worker shortages from the EU (Financial Times, 2022), and 20% estimated shortage of lorry drivers required for UK supermarkets (BBC, 2021).

- Rural areas have been amongst the hardest hit economically by COVID-19 through their high reliance on labour-intensive sectors that were impacted heavily during lockdown.
- Energy and fertiliser crisis caused by Russia-Ukraine War. The two countries are major suppliers of energy, food and fertilizers. Farms run on fuel and fertilisers. As prices of both have risen sharply, farmers' profit margins have been squeezed. If farms are forced to cut back on fertilisers because it is too expensive, or unavailable, their yields will fall even more.

In response, the UK government called for new approaches to respond to the issues and challenges of rural areas, stating that many conventional approaches are just not appropriate in rural areas. Therefore, the use of advanced technologies in farms has been promoted and is growing rapidly. New innovations in science and technology from robotics to sensors to big data are rapidly changing the way farmers will farm in the future and have brought both economic and environmental benefits to agriculture industry. The economic benefits include better productivity, reduced operation costs, and improved sustainability of agriculture, horticulture, aquaculture and forestry. The environmental benefits range from reduced consumption of water, nutrients, and fertiliser, reduced negative impact on the surrounding ecosystem, improved animal health/welfare, reduced chemical runoff into local groundwater and rivers, etc.

At present, agri-tech underpins agriculture in rural areas across the entire UK through different production systems with livestock in Northern Ireland, Wales, West and South West, arable in the North East and East, and aquaculture in Dorset and Scotland (Agritech UK, 2022). According to South West AgriTech (2022), the South West has over 200 innovative agri-tech companies, working with academics and R&D institutions. They cover the areas including Internet of Things (IoT), robotics, sensors, data intelligence, vertical farming, precision farming, biotech, low-carbon, soil health, and regenerative and restorative agriculture. The agri-tech industry is forecasted to grow over 25% by 2026 in this region.

Agri-tech is an incredibly diverse sector from any technological or science-based innovation or practice utilised to improve the productivity and sustainability of agriculture, horticulture, aquaculture and forestry. Next section will present a comprehensive review on current agricultural technologies that have been developed and widely applied around the world.

3.2 A comprehensive review of emerging agricultural technologies and their categorisation

Agricultural technologies have existed for centuries. This section reviews emerging agricultural technologies that can change the agricultural landscape in the years ahead. For clarity, the reviewed technologies will be classified into 10 main categories. A brief overview of the ten categories of the technologies is provided in Table 3-1. More details of each category of the technologies, such as key advantages and disadvantages as well as their applicability in farming, can be found in **Appendix A.** Information about successful commercial examples of all ten categories of the technologies is also provided in the Appendix.

Table 3-1 A brief overview of technologies successfully applied in agriculture

Order	Technology category	Main application areas
1.	Drones and Robots	Drones are used for crop assessment, counting cattle, monitoring for disease and pesticide, water watch, mechanical pollinators; Robots have been successfully applied for harvesting, weeding, spraying, feeding, milking, transplanting and as autonomous driverless tractors.
2.	Satellite photography	One of the most used means in agriculture is to perform remote sensing. Allows to monitor crops remotely. Provides important data for objective estimations of crop conditions and yields.
3.	IoT-based networks	IoT devices are used to gather information such as soil content, moisture, chemical application, pest infestation,

		dam levels and livestock health as well as monitor fences, vehicles, and weather.
4.	Weather forecasting and tracking	Used to help plan for many day-to-day decisions, including crop irrigation, time to fertilize, and what days are suitable for working in the field.
5.	Automated irrigation	Water delivery systems like drip, surface, or sprinklers can all be automated.
6.	Agricultural Biotech	Biofuel, minichromosomal technology, cellular agriculture, antibiotics, vaccines, plant and animal breeding, pest resistant crops, pesticide-resistant crops, nutrients supplement, abiotic stress resistance, industrial strength fibers.
7.	Soilless controlled-environment farming	Indoor vertical farming, container farming, rooftop farming, hydro/aero/aquaponic greenhouse.
8.	Light and heat control	Use LEDs to produce precise wavelength in order to control crops' size, shape, growth speed, etc. without being restricted to natural seasons.
9.	Agriculture sensors	Location sensors, optical sensors, electro-chemical sensors, mechanical sensors, dielectric soil moisture sensors, air flow sensors, animal sensors.
10.	Soil technology	Soil health, and regenerative and restorative agriculture: boosting yields; regenerating lands that no longer produce food (e.g., reforestation, peatland restoration, riparian buffer zones); building functional biodiversity without relying on synthetic inputs (herbicides, pesticides, and chemical fertilizers).

3.3 Mapping farming and agri-tech businesses in Devon

In order to identify agri-tech developers and farm businesses in Devon, various official databases have been used in this research, including *South West AgriTech*, *Agri-Tech Centres*, *Agri-EPI Centre*, *Agritech UK*, *GOV.UK*, and Kompass.

From these databases, we have identified 70 agri-tech businesses in Devon. They have been classified into 11 main categories, including farm and equine vet (16), agri-tech equipment suppliers (15), farm machinery providers (13), research institutions (7), livestock feeds providers (5), organic-based chemicals and fertiliser manufacturers (4), livestock breeding (4), farm and livestock management software developers (2), circular farming service providers (2), weather forecast and tracking service provider (1), and soil and grassland health advisor (1).

The geographic locations and categories of these agri-tech businesses have been mapped out with different colours as shown in Figure 3-1. Based on this mapping results, the distribution of the businesses in Devon is hugely uneven. We can clearly see where the agri-tech businesses are concentrated, namely east, north and centre part of the county. However, in some parts of Devon, there are relatively few agri-tech businesses, especially in west and south west parts of the county. This could have an impact on the technology adoption on local farms. Also, can be observed from the mapping result, there are quite a lot of equipment/ machinery providers (in bright red and orange colours in Figure 3-1) in Devon. Comparatively, some other types of tech providers are few.

Figure 3-1 Mapping the types of agri-tech companies with locations

Regarding farm businesses in Devon, in total 208 have been identified. These farming businesses can be classified into five main categories, including 87 mixed farming businesses, 60 Livestock businesses, 29 crop and plant producers, 25 silviculture and forestry businesses, and 7 fruit and nut producers. The geographic locations of the farm businesses and the categories of these farm businesses belong to have been mapped out across Devon with different icons, as shown in Figure 3-2. This map clearly indicates where our fam businesses are concentrated, and what types of farming businesses are the main focus in which area.

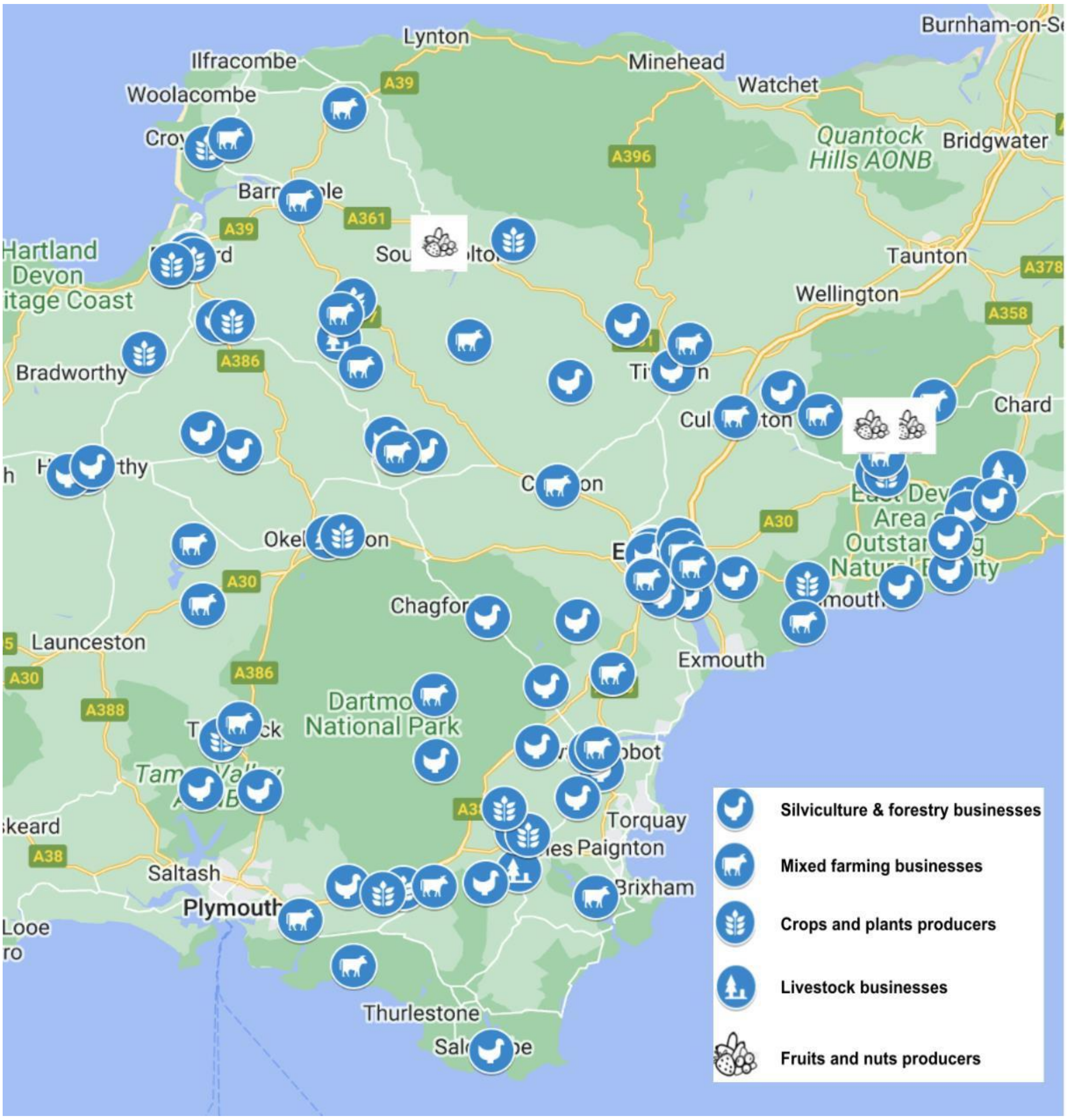

Figure 3-2: Mapping farm businesses and their categories in Devon

The contextual analysis, technology review and mapping exercise described in this section provide us sufficient knowledge and directions to move ahead to primary data collection (via a questionnaire survey and in-depth interviews). The findings from primary data collection will be presented in two sections: Section 4 reports main findings from the questionnaire survey (quantitative), and Section 5 reports main findings from in-depth interviews (qualitative).

4. Main Findings from Questionnaire Survey – Factors Affecting Agri-Tech Acceptance (Usefulness, Ease-of-Use, Potential Benefits)

This section presents the first part of our main findings based on our empirical research, that is, primary data collected via a questionnaire survey. The survey data have been collected from farm businesses (i.e., agri-tech end users) and agri-tech companies (i.e., tech developers) in Devon, following the contextual analysis, technology review and mapping exercise in Section 3. The survey enabled us to establish an understanding of both technology end users (farmers) and agri-tech developers' views on the ten categories of emerging agricultural technologies, in terms of their perceived usefulness of the technologies, ease-of-use, and potential benefits of using the technologies (economic benefits, environmental benefits and social benefits).

The second part of the main findings from empirical research will be presented in Section 5, including the main findings from in-depth interviews around key barriers to agri-tech adoption, key challenges farm businesses face, and potential opportunities for Devon farming communities.

Section 4.1 will present the profile statistics of the farm businesses and agri-tech companies which have participated in our questionnaire survey. Then Section 4.2 will detail the findings from the survey regarding current application status of agricultural technologies and respondents' attitude towards adopting the new technologies, Section 4.3 on perceived usefulness of technologies, Section 4.4 on the ease-of-use, section 4.5 on potential economic benefits of using the technologies, Section 4.6 on environmental benefits, and finally, Section 4.7 on potential social benefits of adopting agricultural technologies. To help identify the gaps between the agri-tech developers' view and farmers', the findings are visualised and compared where possible.

4.1 Profile statistics of the farm businesses and agri-tech businesses participated in the survey

Among the two types of survey participants, 73% are farmers and 27% are agri-tech developers. This section will present the profile information of farm businesses and agri-tech businesses, respectively.

4.1.1 Profile Information of farm businesses

The profile information of farm businesses participated in our survey is analysed according to four aspects: farm size according to the number of people working on the farm, farm size according to the land hectares, the types of farming (involving animals or crops), and the types of animals they raise and the types of crops the farms grow.

(1) Farm business size according to number of people working on the farm

The finding of the farm size regarding the number of people working on the farm is shown in Figure 4-1. Based on the survey data, 86.4% of the farm businesses are operated by less than 5 people, 9.1% are operated by between 6 and 10 people, and only 4.5% are run by more than 11 employees. The finding shows that farms in Devon are dominantly small businesses.

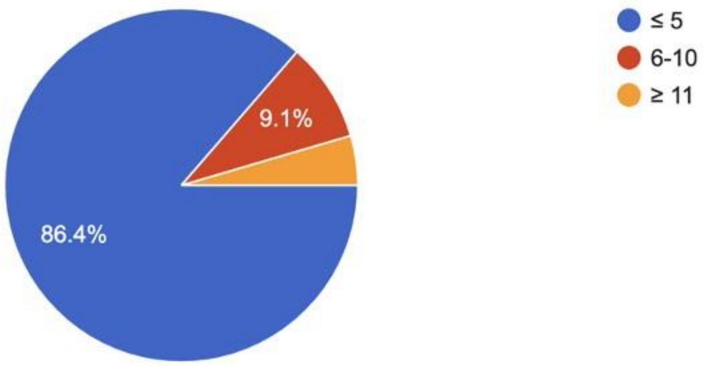

Figure 4-1: Farm size according to number of people working on the farm

(2) Farm business size according to the land hectares

Figure 4-2 illustrates the different sizes of farms according to the land they own or operate. As can be seen from the finding, 40.9% of the farms participated in our survey own less than 20 hectares which are defined as small farms by EU Standards (Eurostate, 2018), while 18.2% own between 20 and 100 hectares, that is, medium-sized by EU Standards, and 31.8% are farm contractors who do not own any farmland. Only 9.1% own more than 100 hectares (large farms by EU standards). These findings confirm that farms in Devon are predominantly SMEs.

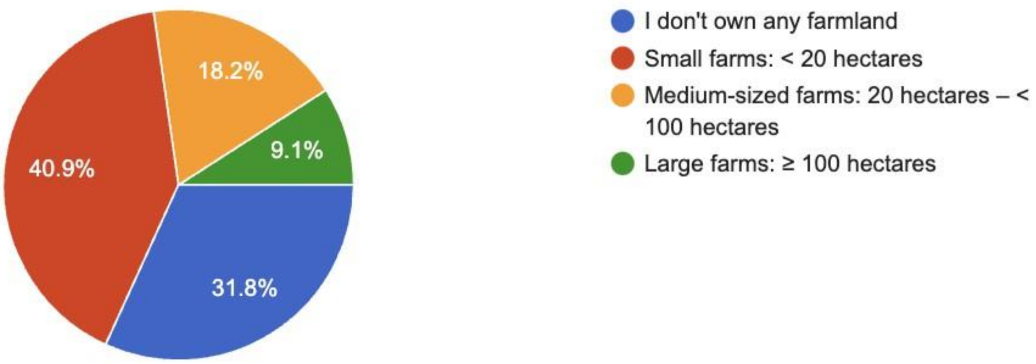

Figure 4-2: Farm sizes according to the land hectares

(3) Classification of farms according to their business nature

We asked the farms to classify their businesses into appropriate categories (i.e. arable, pastoral or mixed) and the finding is that 50% of them are pastoral farming, 45.5% are mixed farming, and only 4.5% are doing arable farming, as shown in Figure 4-3. The finding tells us that over 95% of the farms in Devon keep animals for meat, wool or dairy products.

Figure 4-3: Business nature of the farms

(4) The types of animals the farms raise and crops they grow

Most farms have more than one animal breed, crop or both. The finding is illustrated in Figure 4-4. In terms of raising animals, 90.9% of farms own cattle, followed by sheep with 36.4%. There are a small percentage of farms raising poultry (9.1%) and pigs (4.5%). This finding from the survey confirms with the fining from the contextual analysis in Section 3.

In terms of crops grown, the most popular type of crops with farms in Devon is cereals (wheat, barley and oats) – 36.4% of farms grow them. The second is forage plants at 31.8%, followed by industrial crops and vegetables (both at 18.2%). There is a small percentage of farms growing potatoes (4.5%) and other crop products (4.5%). Growing fruit seems to be not popular in Devon.

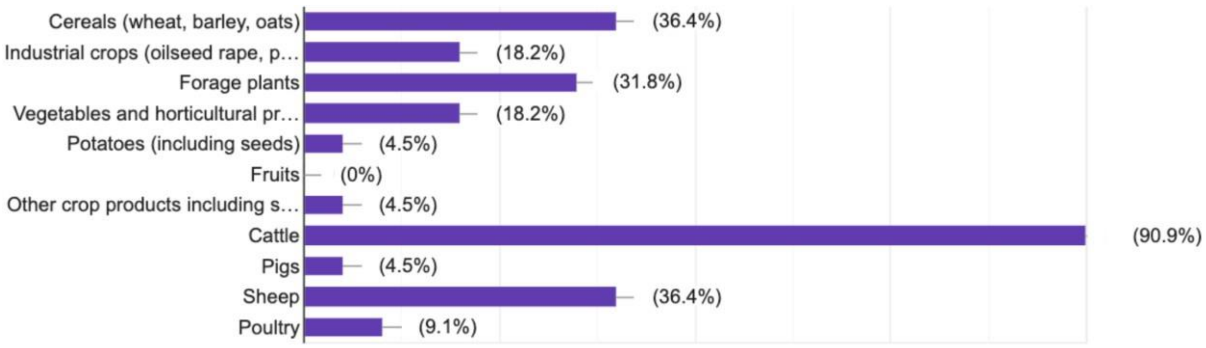

Figure 4-4: Types of crops grown and livestock kept

4.1.2 Profile information of agri-tech development businesses

About the agri-tech businesses which participated in our survey, their profile information is also analysed from four aspects: company size according to the number of employees, the types of agricultural technologies they develop, the types of crops/ animals their technologies can be used for, and the readiness levels of the technologies they develop.

(1) Company size according to number of employees

Among all the agri-tech developers took part in our survey, 12.5% of them are medium-sized companies which have more than 50 employees but less than 250 employees.

The remaining 87.5% are small-sized agri-tech developers which have less than 50 employees. In other words, all of them can be classified as SMEs.

(2) Types of technologies Devon agri-tech companies develop

The survey finding on the types of technologies agri-tech companies develop is shown in Figure 4-5. The same ten categories of technology as from the technology review in Section 3 are used here. Companies can tick multiple choices as their answer to this question in the survey, that is, if their company develops more than one type of the agricultural technologies. As can be seem from the Figure 4-5, the agricultural technologies developed by most agri-tech companies in Devon are IoT-based networks and biotech, both indicated by 50% of the participating companies. Light and heat control comes third, at 33.3%. The other two types of technologies, integrated sensors and soil technology, are both at 16.7%. The finding shows a clear gap in agri-tech development in Devon for the other five types of technologies. They are drones and robots, satellite photography, weather forecasting and tracking, automated irrigation, and soilless controlled environment such as vertical farming.

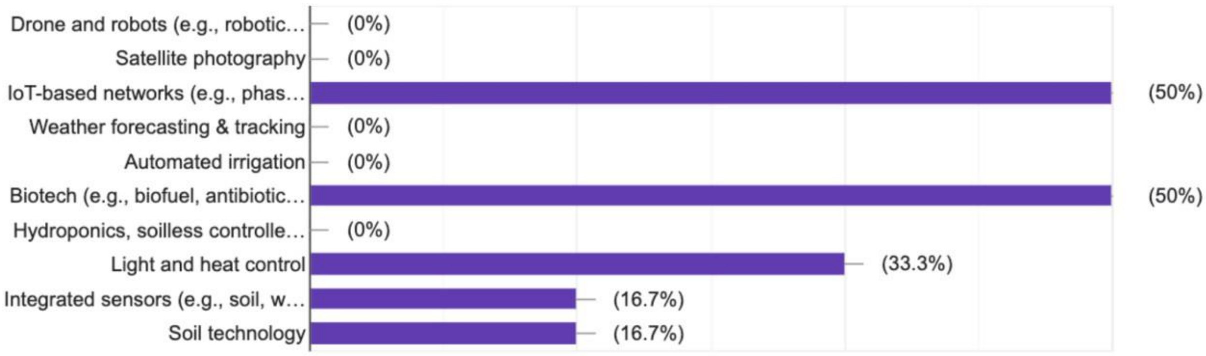

Figure 4-5: Categories of agricultural technologies developed by Devon agri-tech companies

(3) What types of farm animals/crops are the technologies developed by agri-tech companies for?

Our finding (illustrated in Figure 4-6) shows that most companies develop technologies for more than one breed of animals and crops. 87.5% of the agri-tech companies develop technologies that can be used for cattle, 75% for pigs, 50% for poultry, 37.5% for sheep, and 62.5% for cereals and 62.5% for industrial crops. This demonstrates that our agri-tech companies know well about the need of relevant technologies from the farm businesses in the county, because cattle, sheep, poultry and pigs are among the most raised animals in Devon and cereals are the most grown crops (refer back to Figure 4-4).

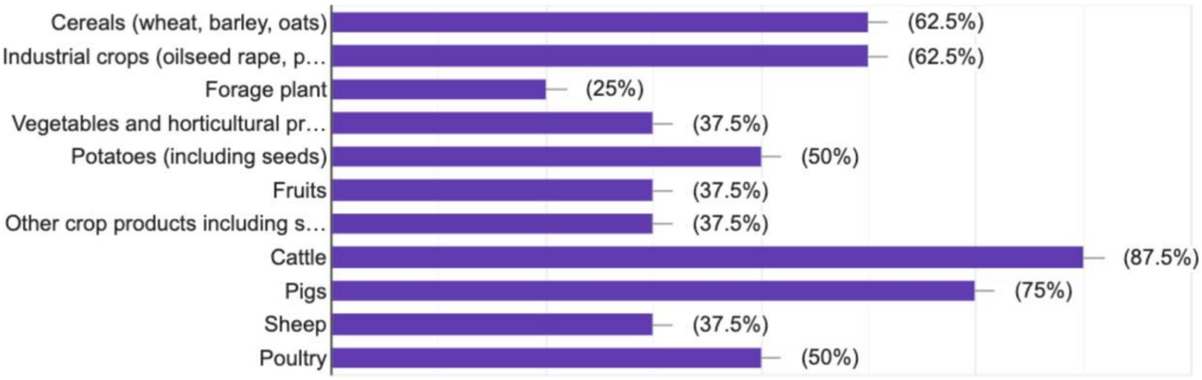

Figure 4-6: Application targets of agri-techs developed in Devon

(4) Technology readiness levels

Technology Readiness Levels (TRL) is a key factor affecting any technology adoption in businesses. We use TRL to assess the maturity of technologies. NASA defined 9 TRL levels which are widely used around the world for research and innovation (NASA, 2012). Low TRL, 1 to 3, means that the technology is in research stages. Level 4 to 6 is in development stages. The deployment stages are from Levels 7 to 9 (NASA, 2012). According to our survey finding (Figure 4-7), Devon agri-tech companies consider their technologies having high level of readiness, that is, 87.5% of companies' technologies reach TRL 9 and have been successfully commercialised. Only 12.5% of the technologies are considered at TRL 7, meaning in the experimental stage.

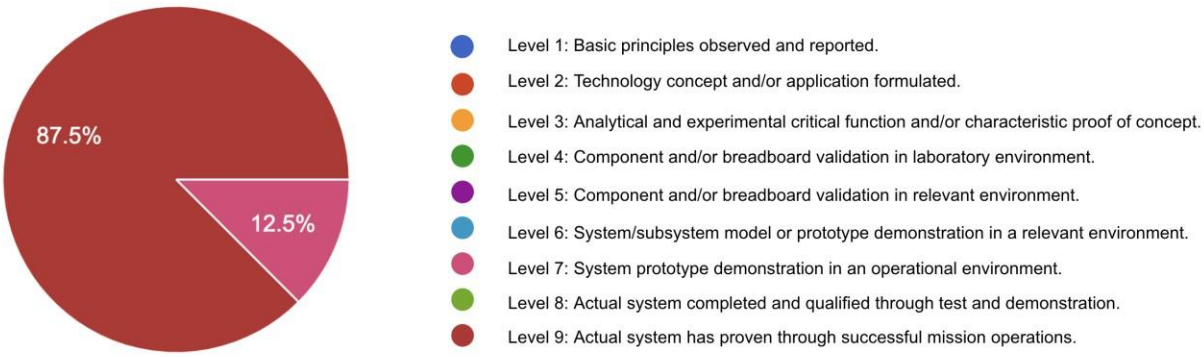

Figure 4-7: Devon agricultural technologies' readiness levels

4.2 Findings on the application status of technologies and farm businesses' attitude towards the technologies in Devon

This section presents the application status of the ten categories of technologies on farms and farm businesses' attitude towards the technologies in Devon. All survey participants are asked about whether they are currently using the technologies. If not, would they consider using in the future? If no, is it because the technologies are not applicable to their farm businesses or simply they are not interested? We will show you the findings on this point for all ten categories of technologies in Figures 4-8 to 4-17, and discuss some agri-tech categories in groups for comparison purpose.

Figure 4-8, Figure 4-9 and Figure 4-10 indicate that the respondents' attitude towards drones and robots and satellite photography are very divided. Around 50% of the farm businesses are currently using (in blue colour in the pie charts) or considering to use them (in red colour) in the future. The other 50% of the respondents believe that these agri-techs are not applicable (orange colour) to their farms, or they are not interested in the technologies (green colour).

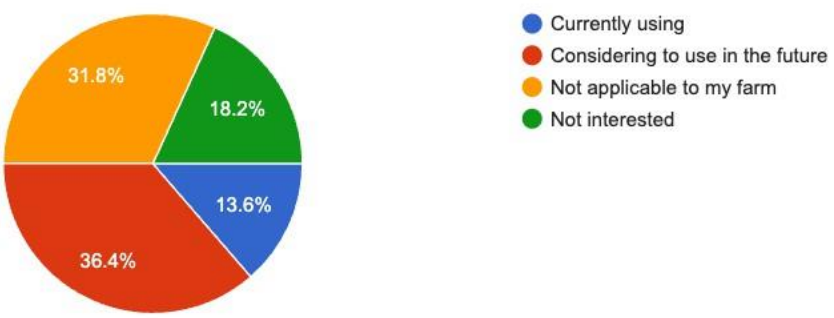

Figure 4-8: Farm businesses' attitude towards drones and robots

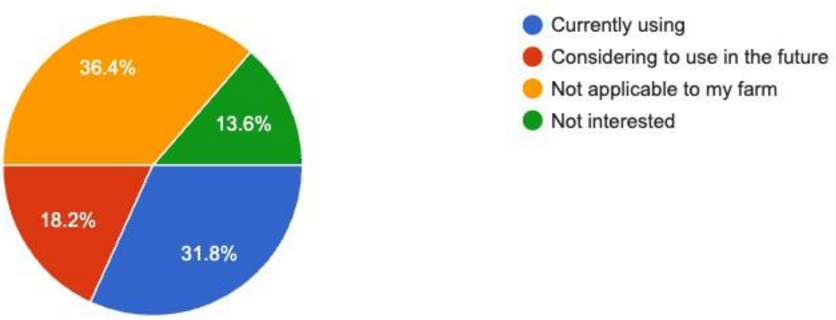

Figure 4-9: Farm businesses' attitude towards satellite photography

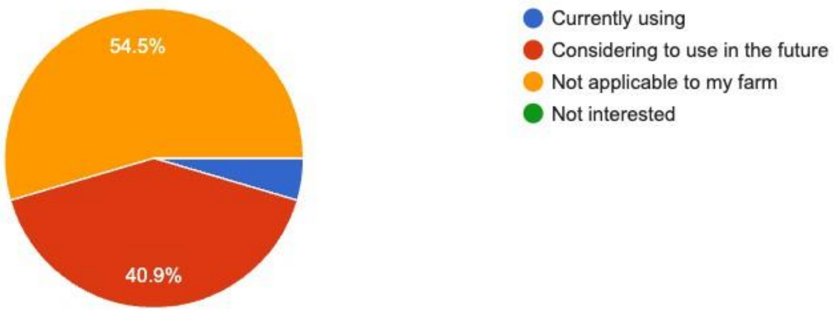

Figure 4-10: Farm businesses' attitude towards integrated sensors

Research finding shows that currently the most widely used agri-tech in Devon is weather forecasting and tracking technology (see Figure 4-11), with 59.1% of businesses are already using them and 31.8% are considering to use them in the future. Most of the respondents also show positive attitude towards soil technology, biotech, and IoT-based networks, as shown in Figure 4-12, Figure 4-13 and Figure 4-14.

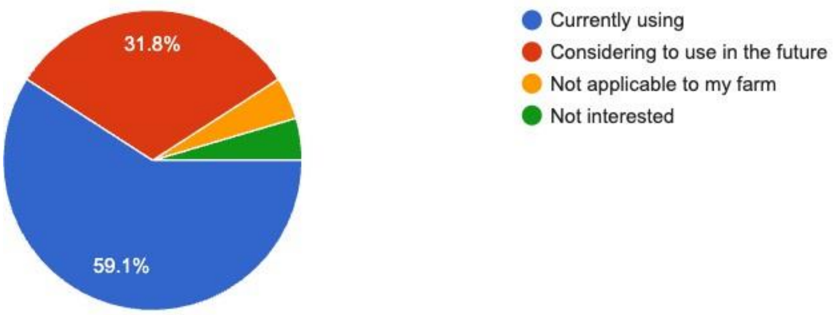

Figure 4-11: Farm businesses' attitude towards weather forecasting and tracking

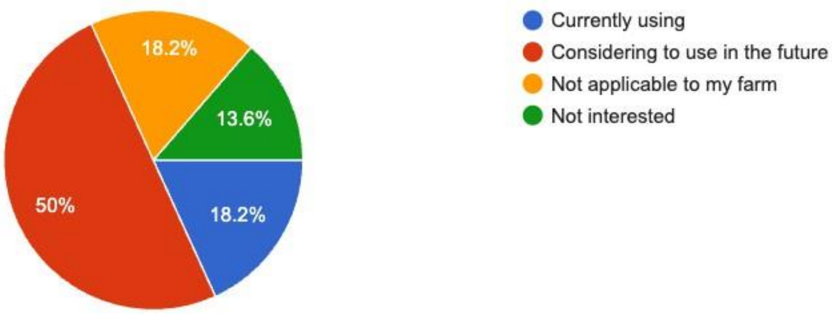

Figure 4-12: Farm businesses' attitude towards soil technology

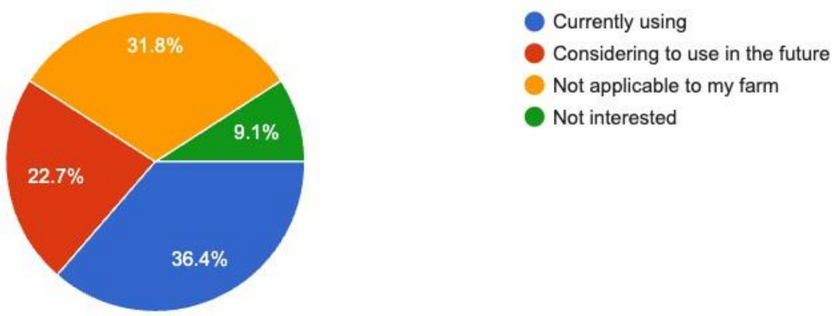

Figure 4-13: Farm businesses' attitude towards biotech

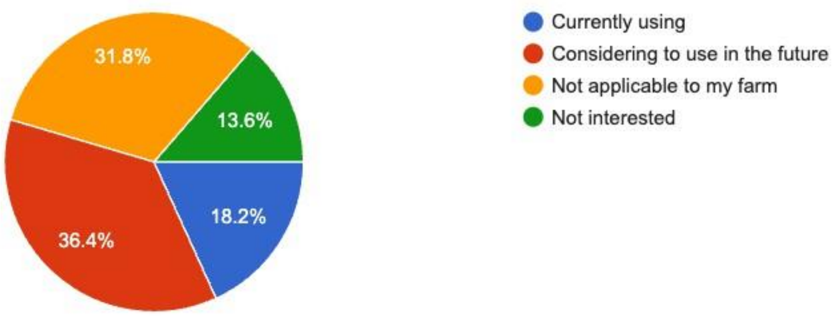

Figure 4-14: Farm businesses' attitude towards IoT-based networks

However, 70% to 80% of the respondents believe that automated irrigation, hydroponic controlled-environment farming, and light and heat control technology are not applicable to their farms or not of farm businesses' interest, as can be seen from Figure 4-15, Figure 4-16 and Figure 4-17.

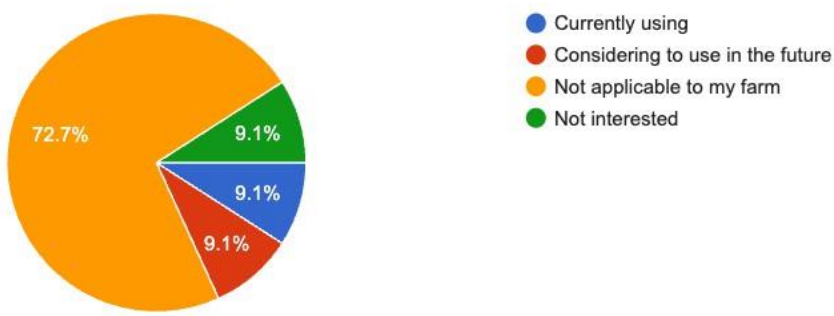

Figure 4-15: Farm businesses' attitude towards automated irrigation

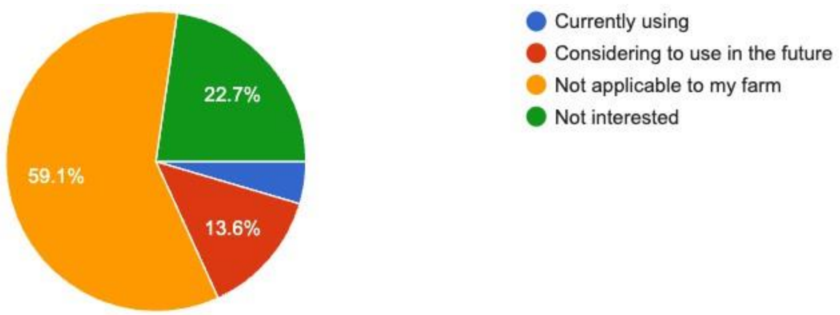

Figure 4-16: Farm businesses' attitude towards soilless controlled-environment farming technology

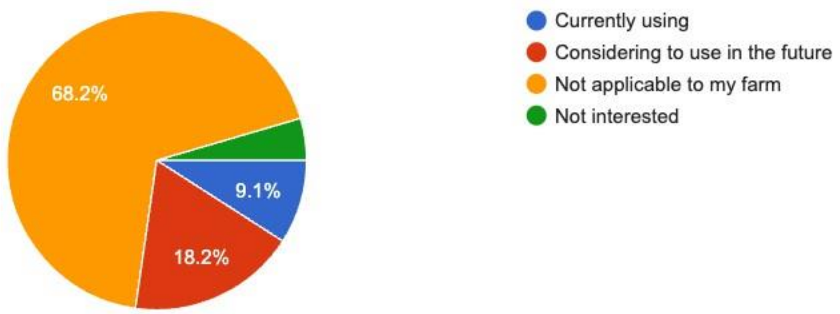

Figure 4-17: Farm businesses' attitude towards light and heat control

The findings emerging from this section indicate that the top five categories of technologies receiving the most effort from agri-tech development companies in Devon do not match the five most widely used categories of technologies by our farmers. This means that farmers will use technologies not necessarily provided by local or regional developers. The agri-tech developers do not necessarily place their emphasis on the technologies that are used by local or regional farmers. Both farmers and agri-tech developers look at wider global market when it comes to choosing what technologies to use or to develop.

4.3 Comparisons between farmers' and agri-tech developers' perceived usefulness of technologies

In order to measure the respondents' opinions about agir-tech's usefulness, ease-of-use, and benefits, a five-point Likert scaling system has been used in the questionnaires for this research. Scales 1 to 5 represent extremely unlikely, unlikely, neutral, likely, and extremely likely, respectively. The bigger the scale number is, the more positive it represents.

In term of the **usefulness** of the agricultural technologies, two measures are used in the survey: productivity and effectiveness. Firstly, about productivity, majority of the respondents from agri-tech companies believe that Agri-Techs can help farm businesses (Figure 4-18, top chart in purple) to improve their productivity, with 100% of respondents giving a score of 3 (neutral) and above, 62.5% giving a score of 4 (likely) and above, and 37.5% giving a score of 5 (i.e. extremely likely). However, farmers' view is quite different (Figure 4-18, chart at the bottom in blue). Only 13.6% gave a score of 5 which is considerably lower than that from agri-tech developers. Almost 25% of farmers gave a score of 1 (extremely unlikely) or 2 (unlikely), while no agri-tech developers did.

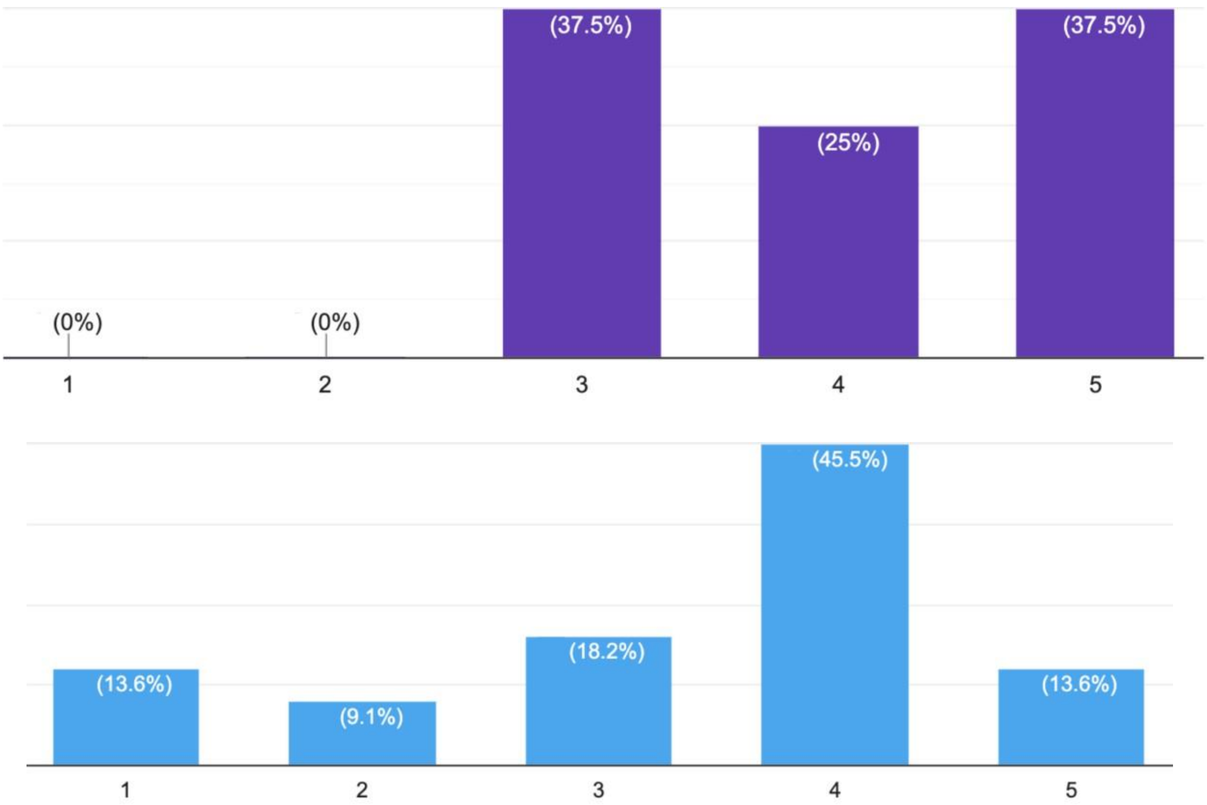

Figure 4-18: Agri-techs can improve farm businesses' productivity (top chart - Agri-Tech developers' opinions, bottom chart – farmers')

About whether technologies can improve farms' effectiveness, the findings are as in Figure 4-19. Again, the agri-tech developers' view is shown on the top chart (in purple) and the farmers' view bottom chart (in blue). Similarly, the agri-tech developers are more positive about the effectiveness of technologies and farmers have some doubts, but still almost 55% of farmers gave a score of 4 or 5.

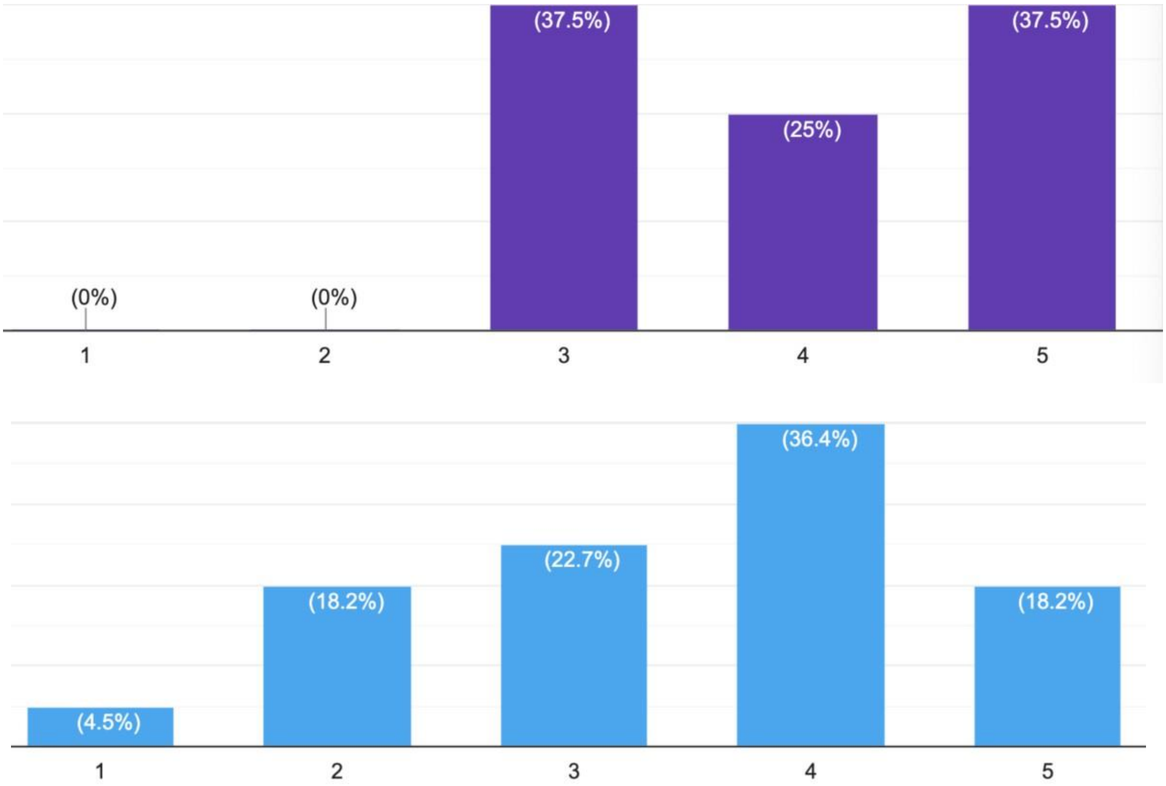

Figure 4-19: Agri-techs can improve farms' effectiveness (top chart - agri-tech developers' opinions, bottom chart – farmers')

4.4 Comparisons between farmers' and agri-tech developers' perceived ease-of-use of the Agri-Techs

As for agricultural technologies' **ease-of-use**, the opinions from the two groups of stakeholders are also quite different (see Figure 4-20, top chart in purple representing agri-tech developers' view and bottom chart in blue representing farmer's). As can be seen from the top chart, majority of the agri-tech developers consider that their products are easy to use by farmers, 62.5% scored a 4 (easy to use) or 5 (very easy to use). However, more than half of the farmers feel the opposite. As can be seen from the bottom chart in blue, only about 35% of farmers give a score of 4 or 5 but over 40% of farmers think that the technologies are very difficult to use (scoring a 1) or difficult to use (scoring a 2). The survey findings show a big gap between opinions from the technology developers and farmers in terms of the ease-of-use of the technologies.

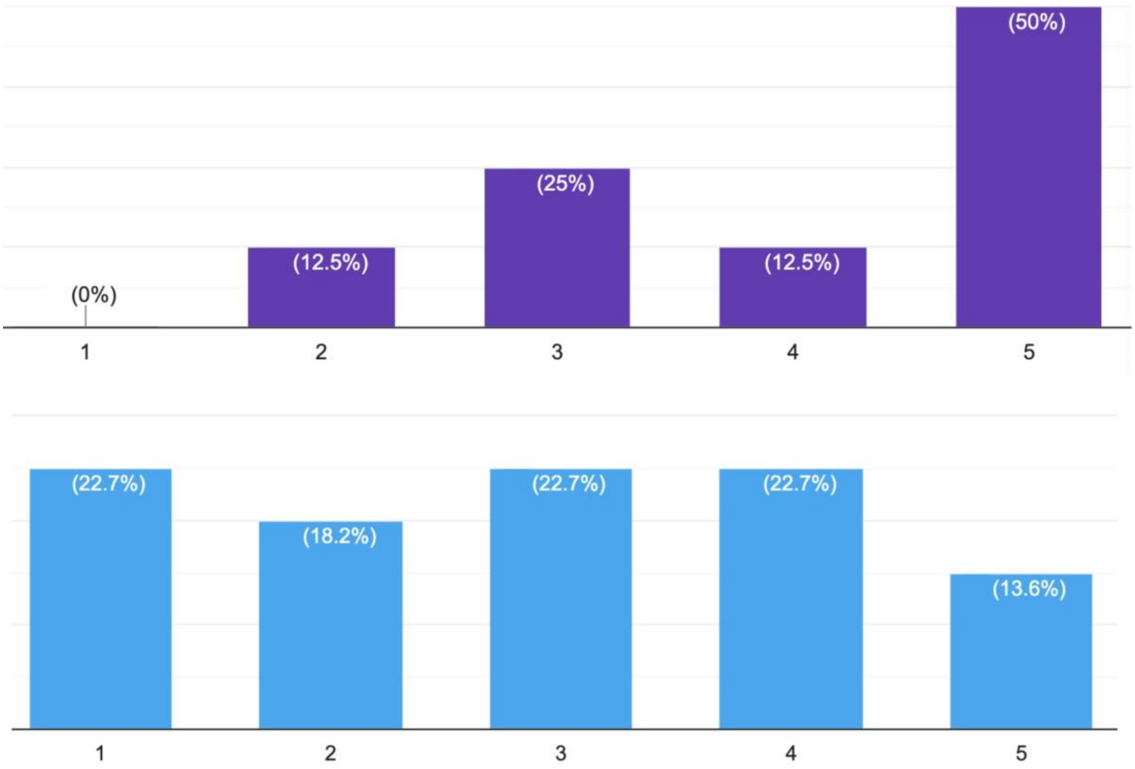

Figure 4-20: Are Agri-Techs easy for farmers to use (top chart - agri-tech developers' opinions, bottom chart – farmers')

4.5 Comparisons between farmers' and agri-tech developers' opinion on economic benefits of the Agri-Techs

The survey asked respondents to express their opinion on two measures of economic benefits: operation costs and yields. Firstly, in terms of reducing operation costs via using technologies on farms, the findings are illustrated in Figure 4-21 (top chart – tech developers' view, bottom chart – farmers' view). It seems that both agri-tech developers and farmers almost agree on the positive benefit of reducing operation costs on farms.

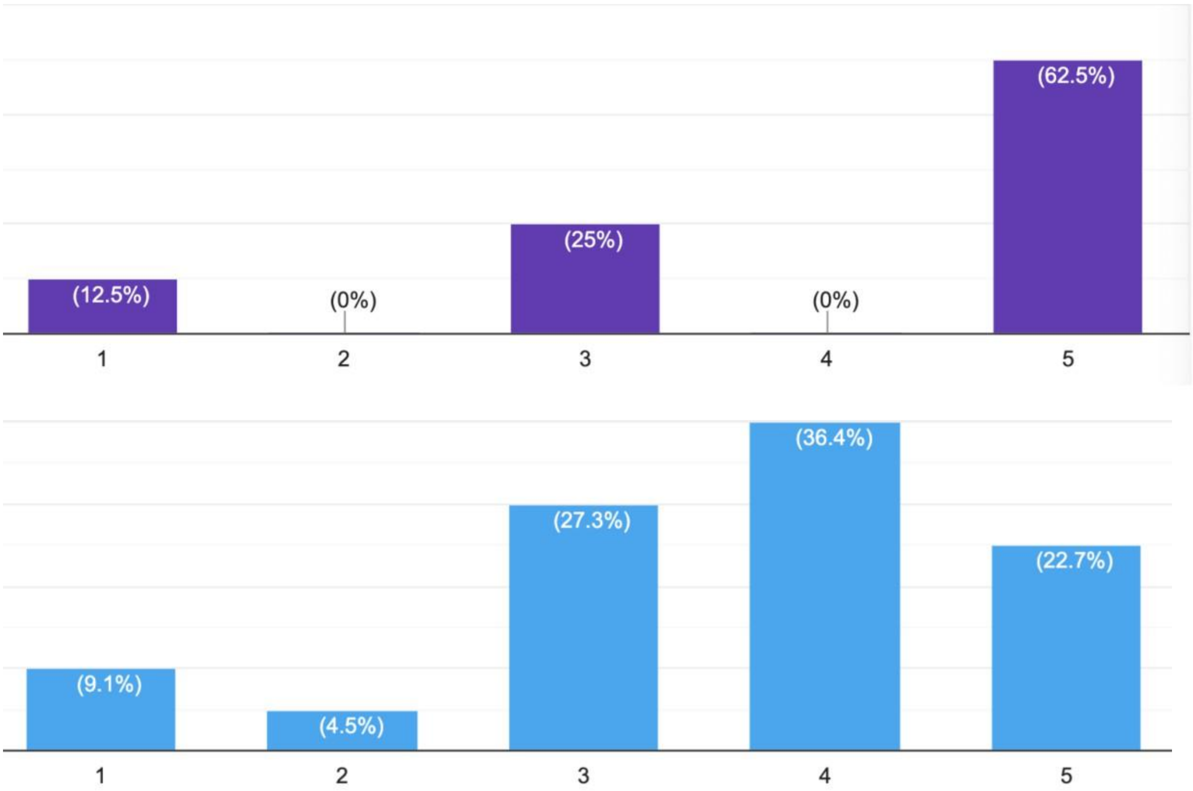

Figure 4-21: Using Agri-Techs would reduce operation costs for farmers (top chart - agri-tech developers' opinions, bottom chart – farmers')

About how respondents think that using Agri-Techs would increase the yields, findings in Figure 4-22 (top chart – tech developers' view and right chart – farmers') show that agri-tech developers are extremely positive about it, with 100% scoring a 4 or 5. Farmers' view is much varied, with over 30% scoring 1 (extremely unlikely) or 2 (unlikely) – a much more negative view. On this point, agri-tech developers and farmers again cannot agree with each other.

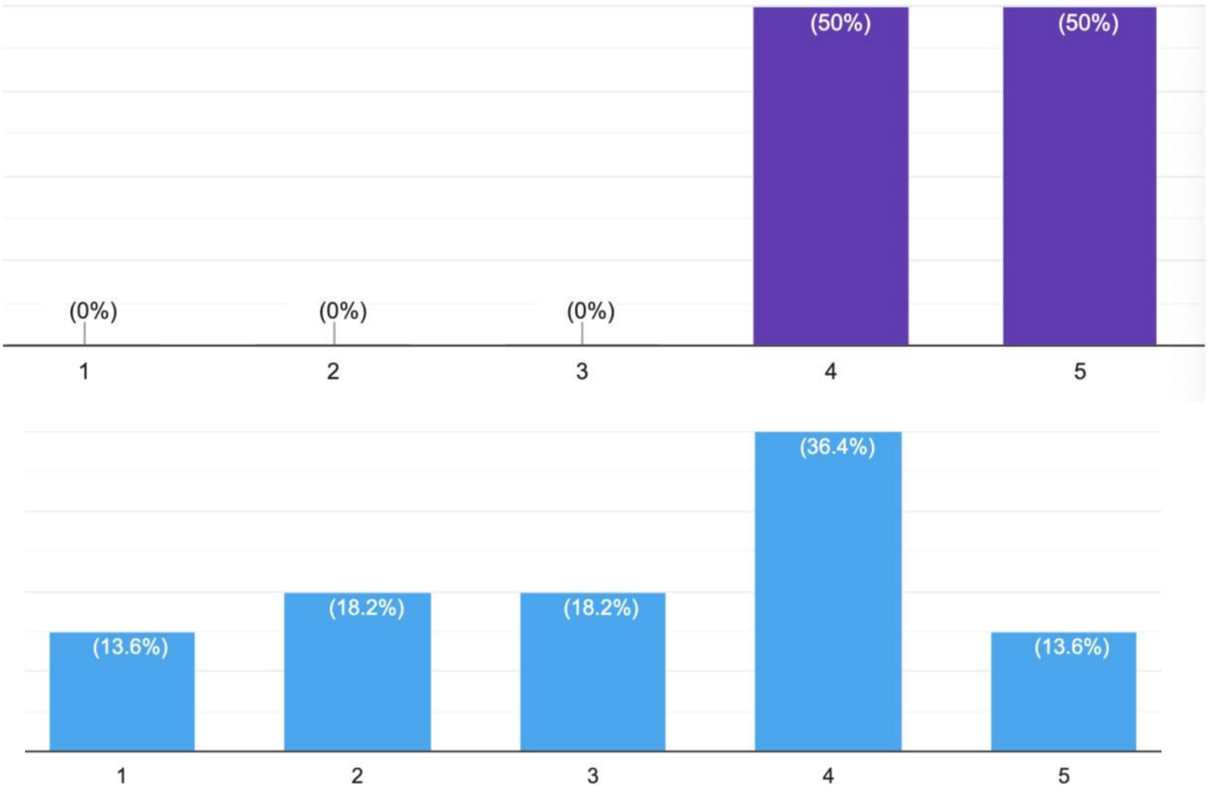

Figure 4-22: Using Agri-Tech would increase the yields (top chart -Agri-Tech developers' opinions, bottom chart – farmers')

4.6 Comparisons between farmers' and agri-tech developers' opinion on environmental benefits of the Agri-Techs

Two questions were asked about environmental benefits in the survey: one question about whether respondents think that using technologies can reduce energy and water consumption, and one question on using technologies to reduce pollutions e.g., from fertilisers, pesticides and packaging. The findings are illustrated in Figure 4-23 and Figure 4-24. Again, the views from agri-tech developers and farmers are compared.

As can be seen from the top chart of Figure 4-23, 75% of agri-tech developers think that it is extremely likely that using technologies will reduce the consumption of energy and water and 12.5% think that it is likely. These views are extremely positive. Comparatively, farmers are not as positive as agri-tech developers, but still gave very good scores with almost 80% thinking extremely likely, likely or neutral.

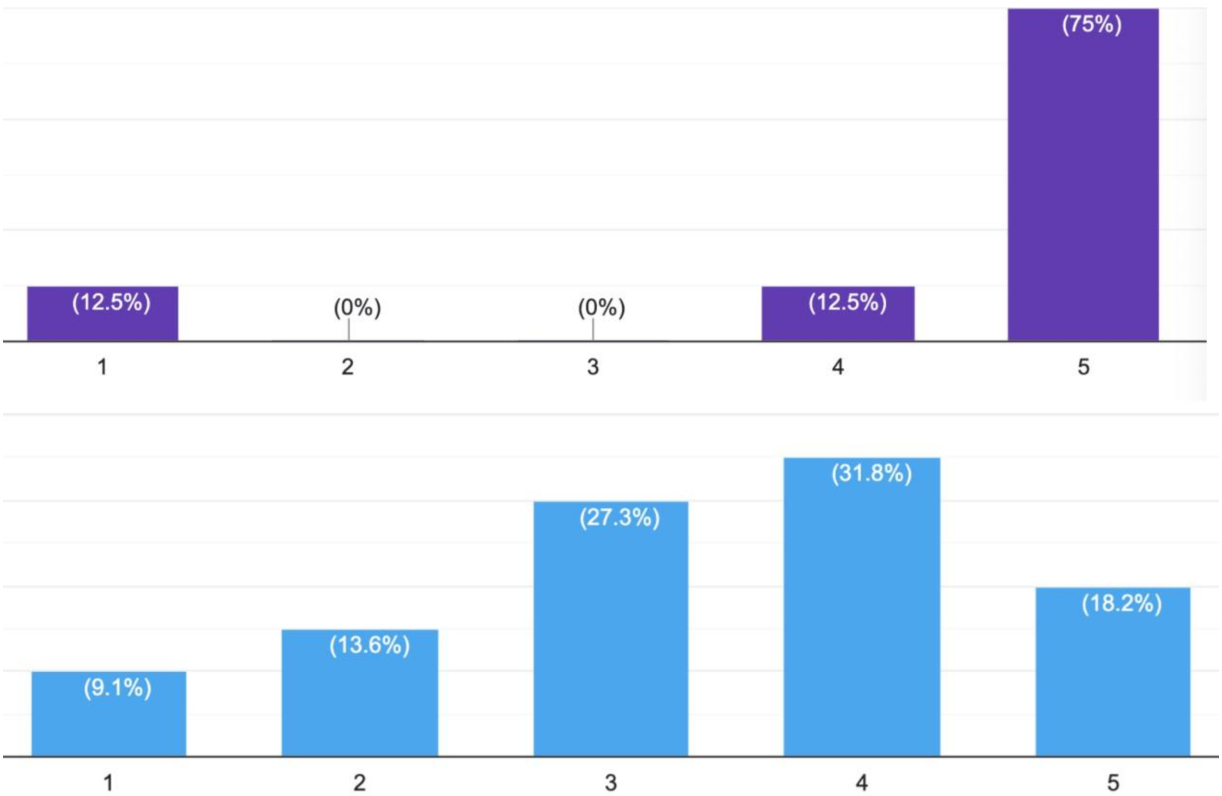

Figure 4-23: Using Agri-techs would reduce energy and water consumption (top chart - agri-tech developers' opinions, bottom chart – farmers')

According to the findings shown in Figure 4-24, about reducing pollutions via using technologies, all agri-tech developers believe that using technologies would extremely likely (75%) or likely (25%) reduce pollutions. However, farmers have more reservations on this point, with only about 45% scored a 4 and above.

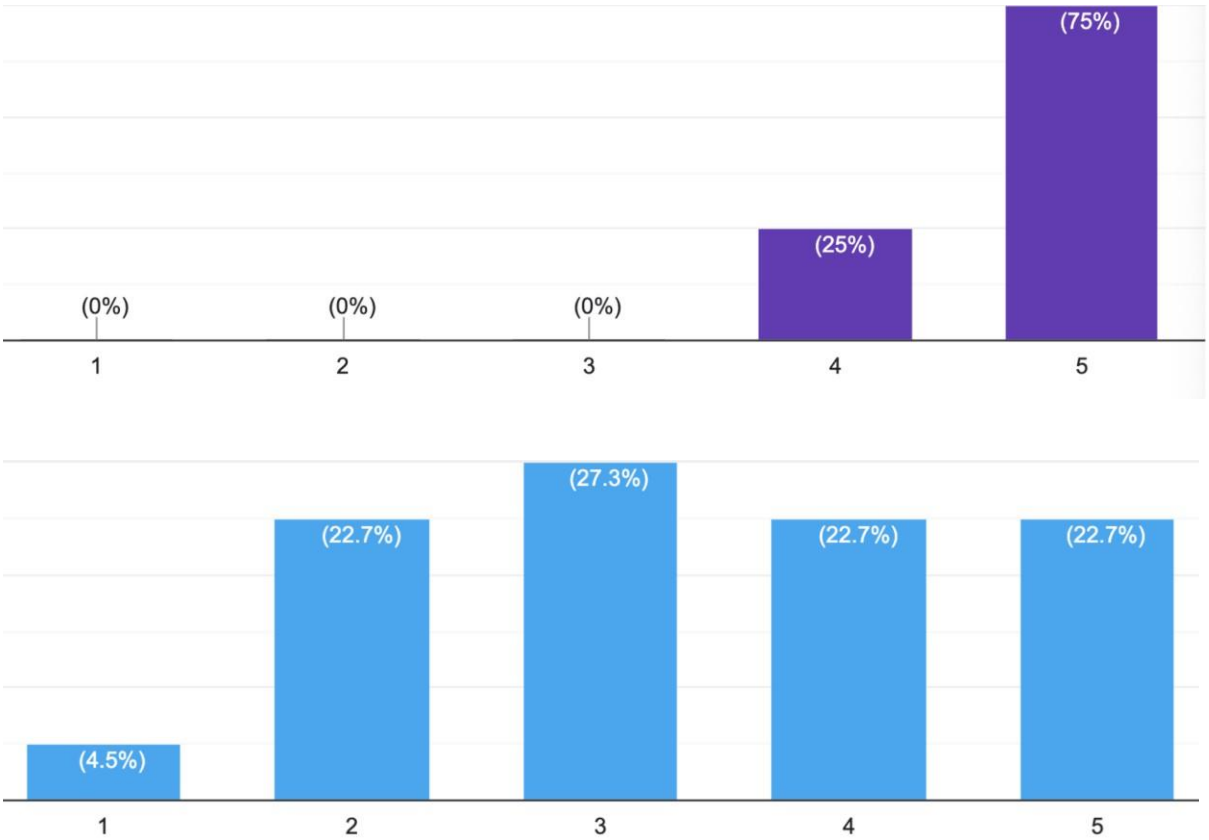

Figure 4-24: Using Agri-techs would reduce pollutions (top chart - agri-tech developers' opinions, bottom chart – farmers')

4.7 Comparisons between farmers' and agri-tech developers' opinion on social benefits of the Agri-Techs

Social benefits can be measured in various ways in different context. In terms of adopting Agri-Techs on farm businesses, the questionnaire asked respondents to express their opinion on three aspects of using technologies: improving farmers' working conditions, creating new job opportunities, and improving nutrition, health, and well-being. The findings are presented in Figure 4-25, Figure 4-26, and Figure 4-27.

As can be seen from the top chart (in purple) of Figure 4-25, 50% of agri-tech developers think that it is extremely likely (score of 5) using Agri-Techs would improve farmers' working conditions. The other 50% are split equally with 12.5% each giving a score of 4 (likely), 3 (neutral), 2 (unlikely) and 1 (extremely unlikely). The chart at the bottom (in blue) shows the view from farmers. Even though the percentage scoring a

5 is lower (specially, 18.2%) that than from agri-tech developers, there is a 22.7% of farmers think that using technologies is likely to improve their working conditions (score of 4). The highest percentage of respondents (i.e., 31.8%) gave a score of 3 (neutral). Only 9.1% of farmers think extremely unlikely (score of 1). The findings show that the benefit of improving farmers' working conditions is generally well perceived by farmers and agri-tech developers, hence no big gap exists.

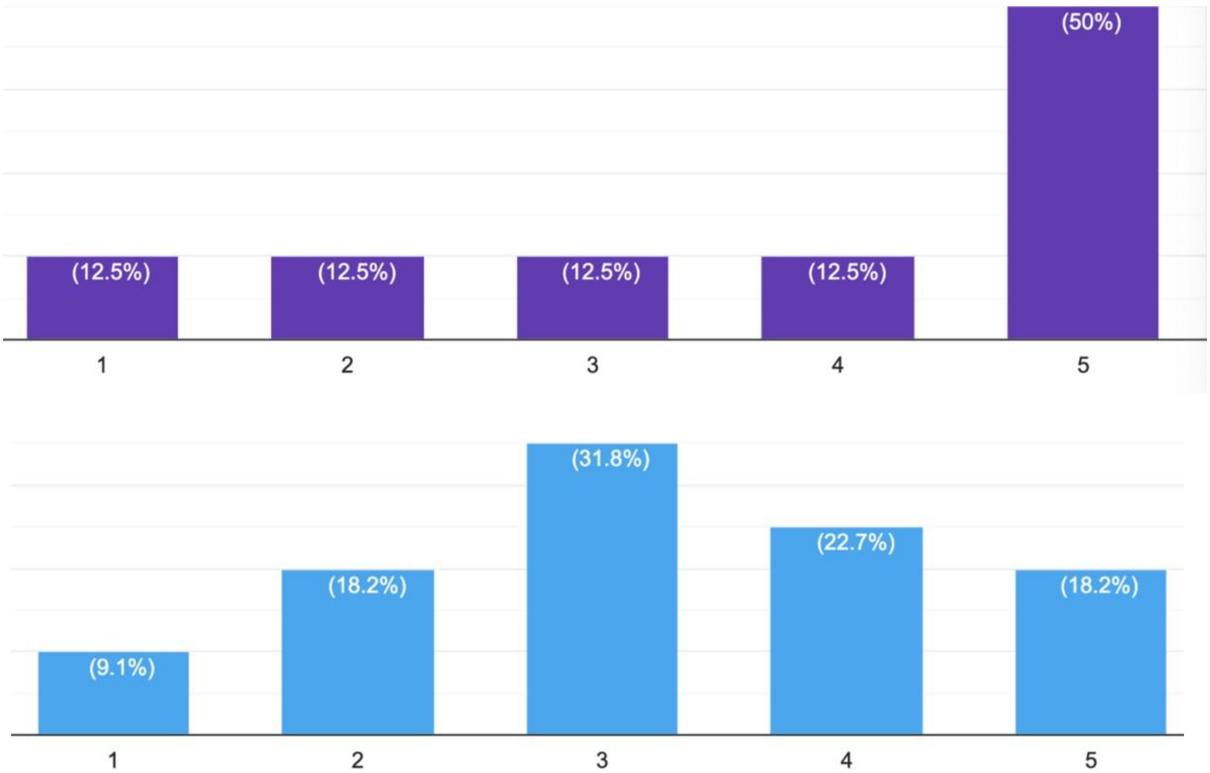

Figure 4-25: Using Agri-techs would improve farmers' working conditions (top chart - agri-tech developers' opinions, bottom chart – farmers')

Figure 4-26 compares the agri-tech developers' opinion and farmers' on the social benefit of creating new job opportunities to farming community. Again, the chart on the top represents agri-tech developers' view and the chart at the bottom farmers' view. The findings indicate quite positive perception from both tech developers and farmers.

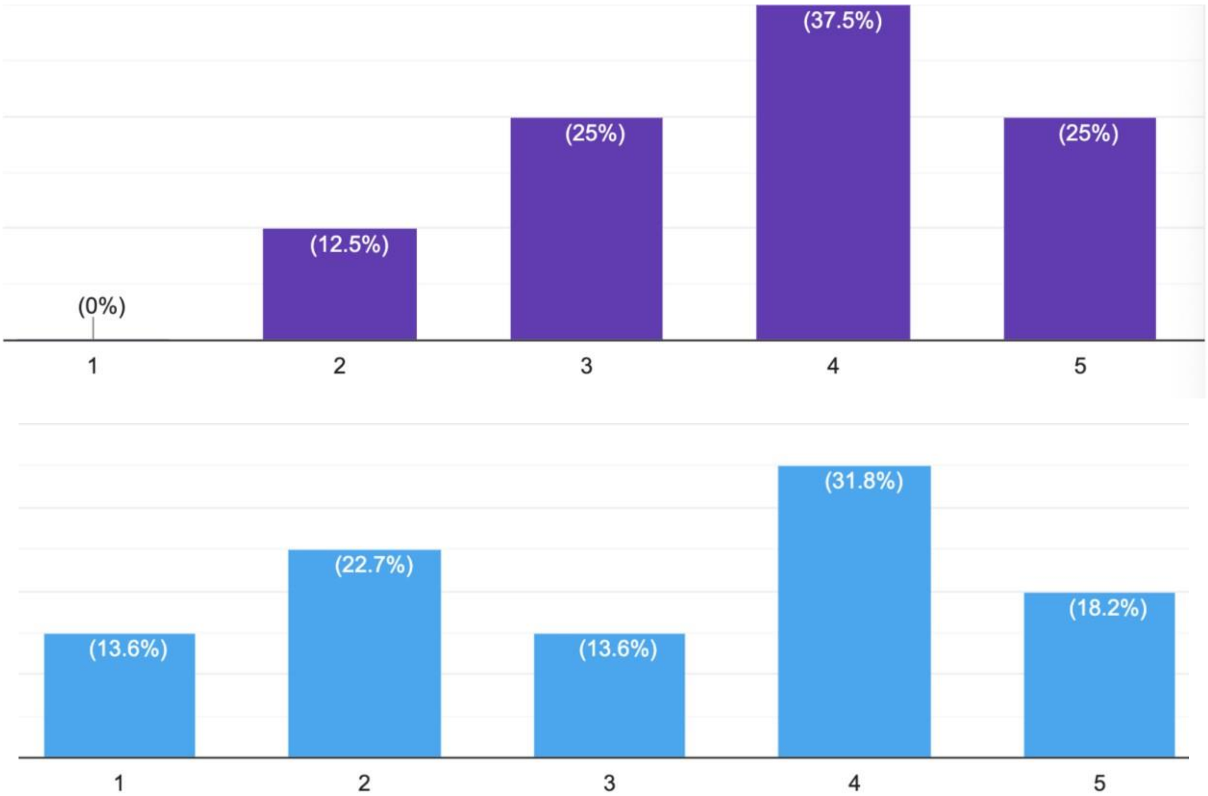

Figure 4-26: Using Agri-techs would bring new job opportunities for the farming community (top chart - agri-tech developers' opinions, bottom chart – farmers')

Finally, about using Agri-Techs to improve nutrition, health and well-being, tech developers gave really positive response, with 50% of them gave a score of 5 and 87.5% gave a score of 3 and above. Only 12.5% gave a score of 2 or less. In contrast, 22.7% of farmers think that using technologies is extremely unlikely or unlikely to generate the social benefit of improving nutrition, health and well-being, and a big percentage of 36.4% are neutral. On this point, there is some gap between the Agri-Tech developers and farmers.

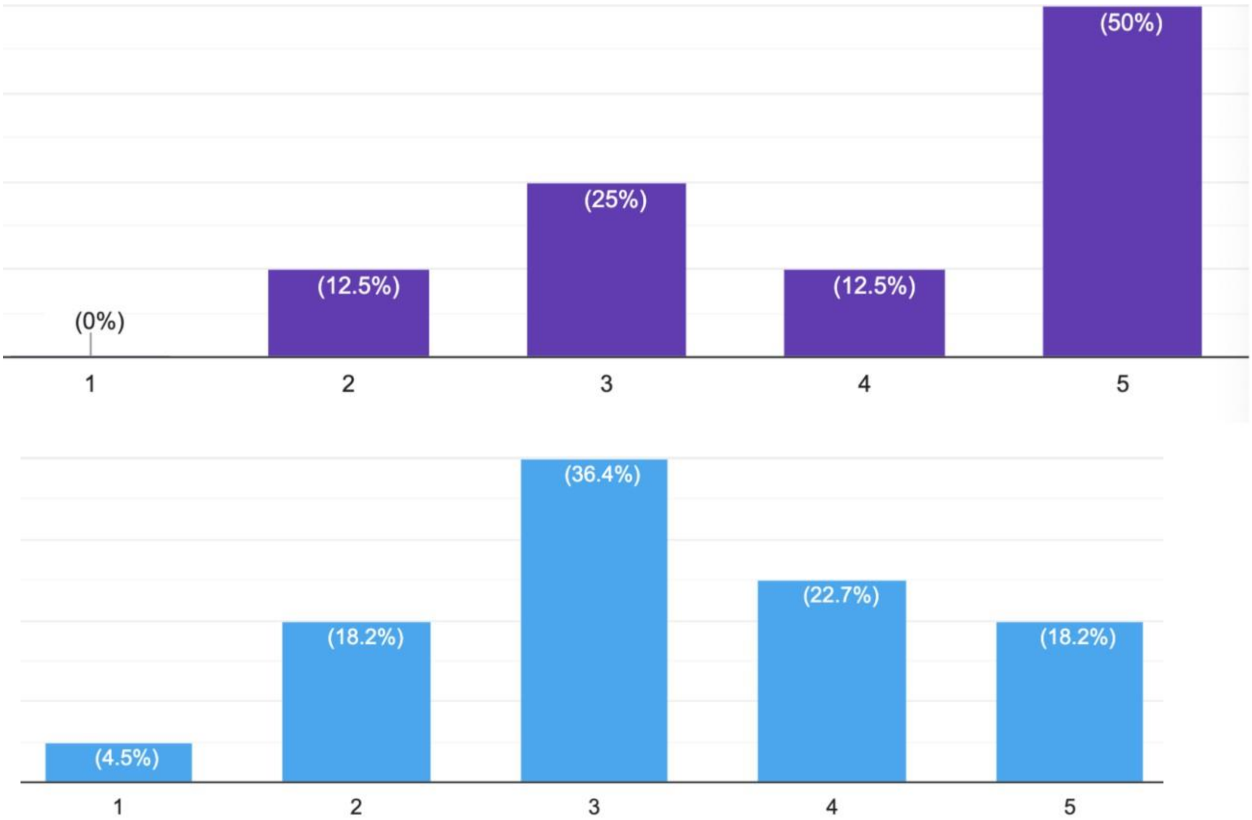

Figure 4-27: Using Agri-techs would improve nutrition, health, and well-being (top chart - agri-tech developers' opinions, bottom chart – farmers')

5 Main Findings from In-depth Interviews – Key Barriers, Challenges and Opportunities

This section presents the second part of the main findings based on our empirical research, that is, primary data collected via in-depth interviews. It is important to understand the key barriers to adopting technologies in Devon farming businesses, the key challenges our farming businesses face and potential opportunities the technologies will bring to the businesses. Hence, we conducted in-depth interviews with a selection of farm businesses and agri-tech companies, complemented by a number of farm business experts (i.e., consultants) to gain opinion from a third perspective. As we have observed from the findings based on questionnaire survey in Section 4, farmers and agri-tech developers have different opinions on many of the aspects regarding adopting technologies, sometimes the gaps between the two groups of stakeholders are significant. Having a third opinion will provide us with extra insights to help bridge the gaps. These farm experts have worked and interacted with more than one single farm or agri-tech company, hence provided us with opinion from a more neutral standing.

Section 5.1 will present the farm businesses' perspective on the key barriers, challenges and opportunities, then Section 5.2 details the views from agri-tech companies, followed by farm experts' view in Section 5.3. Finally, Section 5.4 will discuss the challenges and opportunities from a more holistic view by integrating the three perspectives.

Before we get into details of the findings, Table 5-1 provides an overview of the key barriers, main challenges and potential opportunities based on the insightful discussion with the three groups of stakeholders during interviews.

Table 5-1 An overview of interview findings – barriers, challenges and opportunities

	Key barriers	Main challenges	Opportunities
Farm businesses' perspective	• Farm size • Cost • Bureaucracy • Inapplicable technologies • Organic farming and approach to technology • Subsidies	• Labour and skills • Pace of technology • Carbon emission • Inputs Cost	• Carbon sequestration • Agri-forestry, biodiversity, and silver pasture • Unified Farm assessment system • Technological opportunity for no-fence collar • Solar panel on farm building rooftops, not on land • Best farming practice • Brand organic • Community engagement
Agri-tech developers' perspective	• Small size operations • Investment cost • Bureaucracy around funding • Lack of clarity around policies	• Training, skills and knowledge • Lack of investment and achieving Net Zero • Landlords and tenant farmers relationships • Achieving sustainability and resilience	• Compressed natural gas (CNG) facilities • Young farmers • Land management and biodiversity • Animal welfare
Farm experts' perspective	• Farm size	• Skills and knowledge gap • Crop management • Efficient use of resources and funding • Soil loss and environmental cost of food production	• Biological technology • Organic farming and biodiversity

5.1 Farm businesses' perspective

5.1.1 Barriers to technology adoption

Farm size - Most farmers mentioned the differences between emerging technologies and other equipment such as guided tractors, which are unsuitable for small fields, for example, where the need for weeding and preserving biodiversity become very difficult to manage. As one farmer eloquently put it: "*I have tried using guided tractors, so you've got a sprayer of 24 meter wide where you go around the outside and it's got trees overhanging and you keep losing the segment, which is one of the reasons people go for steering tractors*".

Cost – Farmers shared the view that technologies such as drones, GPS and self-steering tractors are expensive for the scale of their operations even with the Government subsidies. One farmer put it in these terms: *"A lot of Government grants and ELMS and the old ones under productivity scheme are just giving money to manufacturers".*

Most interviewees admit they are open to new ideas and new ways of doing things, but not more costs and more technology because it is fashionable. One farmer said: *"I want to be keeping up with the latest but there must be a better way than just giving GBP 18,000 to a manufacturer".*

Farmers operating on very tight margins argued that technology seems to be pushed to farmers as a key driver of productivity without due consideration of their needs. The policies seem to be prematurely launched as one farmer explained: *"I can't see how all those pieces of the puzzle ELMS, carbon and biodiversity net gains all tie in together, make sure they are not just policies in isolation but there is a future there".*

Bureaucracy – Farmers mentioned the increase in regulation and paperwork as a challenge that requires so much attention it leaves little time off the field to really think about technological solutions to improving productivity, so they tend to stick to what they know or what they can handle. As one farmer put it: *"any help to streamline these activities, make sure you don't fall foul of any of these schemes or penalties is really useful because that's when the farmer is not on the land".* In addition, there are complexities linked to being part of environmental stewardship and using traditional arable rotation and practices.

Inapplicable technologies - Most technologies are inappropriate for the size and type of farming found in Devon. All interviewees commented that the Devon agriculture landscape dominated by cattle and could not effectively apply the technologies available on the market for their type of farming. As one farmer explained:" *the idea of a sort of robots etc., coming in on the landscape, I don't necessarily see the value added with the additional cost and I have a big concern."*

Organic farming and approach to technology - Organic farmers in Devon face different barriers to technology adoption. For example, precision technology for soil mapping is not efficient for small farm size under 10 hectares. As one farmer put it: "*When I test each field individually, I am already precise, well not so precise but I have got attention to detail, which large farmers are struggling to get back".*

Subsidies - Organic farmers viewed subsidies as a barrier to sustainable farming because of the increasing levels of food waste coupled with food dependency. They argue that it is a contradiction that harms good farming practice and deceive consumers who are addicted to cheap food. One farmer encapsulated this view in these words: *"Okay, anything that is a waste of resource and energy affects the planet in terms of food; there is an element of health and social cohesion that is much severe in the developed world".*

5.1.2 Challenges to technology adoption

Labour and skills – The labour shortage seems to be experienced by all farmers irrespective of their size. Some farmers have adapted their operations more quickly since Brexit by using innovative approaches to land management, such as herbal lays to control or suppress weed growth. Others have adopted flexible working hours offering more job opportunities in their communities. Dairy farms reported least issues related to labour. However, they all feel that more skills and knowledge would be required for them to take the full advantage of emerging agricultural technologies

Pace of technology - Farmers are confronted with problems in the field and for some there are no readily available technological solutions. Particularly in organic farming where pesticides are not used, farmers rely on mechanical methods to remove the weeds and significant ploughing to create the seedbeds that are required for organic crops. The following comment encapsulates this problem: *"Any technology that would allow for reduced tillage for horticultural methods sealing, if something can shoot lasers than us having to dig up lots of soil, get rid of them, that would be ideal".*

Farmers commented that despite the fast pace of technology, they are yet to see innovation that address repetitive tasks in small farms, e.g., weeding, folding, cattle control.

Carbon emission – Most farmers advocate sustainability with the use of electric cars, and no pesticides sprayed on the fields. However, the challenge remains on land management and pollution. They argue that a payment or disincentive system is required to foster sustainable farming in the following terms: *"maybe not necessarily organic but organic as a baseline and then you can measure aspects of soil health, water quality, biodiversity etc., and then you measure those, and you pay people on the outcomes… the beneficial outcomes".*

Inputs Cost - Recent price rises driving inflation have affected farmers disproportionately, particularly those who use fertilisers and pesticides. Organic farmers seem to fare better, as well as dairy farmers whose operations rely on electric vehicles. As one dairy farmer explained: *"the most significant price is our cow cage and the concentrates that we feed cows that has risen from GBP42 to GBP62 over the last year"*.

Most farmers shared the view that inflation, coupled with reduced subsidies has affected their business already operating on very small margins and debt, adding more factors that they cannot control and making them less resilient.

5.1.3 Opportunities

Most participants acknowledge that farmers and landowners have great opportunities from the land, and these include not just food production, but also the community and environment.

Carbon sequestration – Carbon sequestration puts farmers and landowners in a prime position regarding reduction of carbon emission. However, the carbon trading market is not properly regulated, as one farmer stated: "*There is a real risk of people signing up to 30 years contract without fully understanding what they are setting off,* *and then putting themselves in a very detrimental situation when carbon taxes come in and the price will go up tenfold".*

In the same vein, farmers call on DEFRA to regulate the market and to set standards and metrics to address what looks like a '*cowboy industry'* as one interviewee put it, adding: *"at the moment it seems to be down to individual farmers to broker their own deals, and it just feels very risky to me at the moment".*

Agri-forestry, biodiversity, and silver pasture – Tree planting with animal grazing was mentioned as entirely compatible with food production. However, there are some limitations to be carefully examined when promoting such schemes, such as restoration grazing which is not easily applicable to farms with large cattle as one farmer explained: *"when you have 150+ running around, don't' worry, they will just disappear and up in the river or something*".

Unified Farm assessment system – Facing numerous challenges, farmers spot an opportunity for a unified assessment system to ensure the same set of metrics are used across the board. They feel this will eliminate a lot of problems in land management particularly and greenwashing in the agriculture sector. It is also cost-effective by eliminating the need to undertake expensive RandD internally in search for the best tool to measure their farm. One interviewee summed up this point in the following terms: ***"****everybody would be able to say my soils are this, my biodiversity is this, my water is this etc. and then everyone would be comparable against each other or at least a lot more than they are now. It would be so much easier".*

Farmers were very positive about the opportunity to regulate the carbon market, which will help to address the environmental aspect for their sustainable business. They see it as another revenue stream but not joined up.

Technological opportunity for no-fence collar – Farmers with large stock face particular challenge during winter months with cattle grazing under severe weather conditions. This simple technology will enable farmers to remotely control their stock from the comfort of the office, and free time to devote to other activities. Animals are always much happier outdoors and in the UK, we have very good quality meat because the livestock grazes freely outdoors.

Solar panel on farm building rooftops, not on land – Farmers would like to see an end to solar panel farms and instead expand the use of farm building rooftops for solar panel installation to secure a sustainable energy source. This could be used to power other operations on farm and hopefully power little robots who can do all sorts of tasks on farm.

Best farming practice - On the same topic, some farmers mentioned the need to spread best farming practice, particularly among smallholders whose use of technology is limited for now. Particularly on land management, the use of ploughing should be discouraged because it affects the soil structure and make weed stronger when chemicals are used on the land. This would make farmers think in a more innovative way and consider alternative such as cover crops and using livestock on farms to control weeds.

Participants argued that intensive farming is bad for the environment and bad for health due to excessive chemicals. However, land share and land sparing must be managed in practice to encourage biodiversity. Organic farming is carbon neutral and works best with multiple crops that attract a variety of wildlife as one farmer explained: ***"**We've got kites, we've got peregrines falcons, they are all part of the system, someone with no practical understanding will do intensive farming on the best farmland and plant trees on the rest and this causes problems".*

Farmers remain suspicious of technology solutions at the expense of biological solutions based on nature and the environment, as expressed in their own words: "*why is it that all the solutions to all the problems in farming seem to involve chemicals and technology? Nobody looks at how nature can work best because there is no money in it".*

They cite the case of Sri Lanka to argue that change is evolutionary, not revolutionary and policy makers must listen to farmers before spending taxpayers' money on grants that only benefit manufacturers, because the technology is not appropriate to the problems faced by farmers. It may work elsewhere in the world but not in Devon.

Brand organic – Organic farmers particularly are keen to demystify the brand and help to address food waste. They contend that public perception of organic food as expensive and therefore unaffordable is costing the NHS more in terms of health issues. They go as far as suggesting that subsidies will help to educate consumers on food quality that they can value more as a factor of good health. One farmer argued that *"it is inadmissible that in this country with all the good agricultural land we have, we are 60% sufficient and we keep importing crap".*

In the same vein, farmers agreed that the disruptions caused by the war in Ukraine is a wake-up call to supply chain resilience. They acknowledge that organic farmers are somewhat shielded from most recent price rises, but the transition to organic farming requires a long process that is worth considering. There should be more incentives to go organic, with the right approach to communication and some government support. One interviewee added: *"people think organic food is very expensive because it has become almost exclusive, but the difference may be very little, a right way to subsidise it at the supermarket or wherever to make it cheaper, I think it will be a really positive thing".*

Other unexpected outcomes emerged as derived benefits from organic farming. For example, a farmer growing mushrooms has secured a supply of sticks from an organic farmer near Honiton because sticks from non-organic farms infect that particular type of mushrooms and stop them from developing. Another surprising outcome was the successful experiment of a quinoa farm due to perfect soil conditions and biodiversity on the farm.

Community engagement – Most farmers are positive about closer links with the community. This includes activities such as school visits to understand healthy food, use of green spaces for social events such as weddings, school plays, etc. The objective is to break barriers between farming and the community, establishing connections at an early age and working with local authorities to expand the number of with small allotments. Some farmers are already doing this in Devon and it is generating support for local farmers and attracting young people into farming.

5.2 Agri-tech developers' perspective

5.2.1 Barriers to technology adoption

Small size operations – Small farms are at a disadvantage when it comes to funding and return on investment, and this deters their appetite for new technology. As one interviewee explained, cattle farming in Dorset and Cornwall easily has 5,000 to 10,000 cows on the field. When they make investments in technology these have to be at such scale to have an impact. With the government promising grant of between GBP25,000 and 250,000 in slurry for example, and the Government paying 50% grant, the farmer still have to cover 50%. One interviewee added: ***"****There is a lot of farmers in Devon who cannot afford it"****.***

Investment cost – Agri-tech businesses which we interviewed all agree that investment cost was the main barrier to technology adoption in farms. This situation is made worse by additional pressures from price rises in major inputs such as energy, and fertilisers. The reality is the same across England but particularly in the South West and Devon, farmers said they are not prepared to invest in new technologies or new systems.

Bureaucracy around funding – For farmers on the ground, trying to make a decision to invest in new technologies is very frustrating. There is a myriad of funding options that are quite complicated, and the amount of paperwork puts farmers off, not to mention the planning process involved with some funding.

To illustrate this point, one interviewee used the example of slurry where they have expertise covering England and Scotland: *"Just around slurry, which is my bit here, there is the slurry gran which covers slurry to reduce emissions. There is technology improvement fund which is your application for slurry handling equipment. There is a separate grant for agriculture building. That's just three for slurry and that is not necessarily for infrastructure, feeds, soil improvement or anything like that"****.***

Lack of clarity around policies – Interviewees conceded that the lack of clarity around Brexit has created a lot of confusion and resentment among the farming sector. Devon farmers probably feel that they were promised that funding would stay the same along the lines of the single farm payment, and that is the traditional money that they need to invest. The grant situation in Central Government has changed precisely at a time when other pressures on price and labour are adding on. Some farmers are wondering whether it is worth the trouble and are considering adjusting their operations in response to this confusion. As one interviewee stated: *"We come across a few farmers who are already gearing their operations towards sustainability, financial sustainability, without subsidies".*

Admittedly, this lack of clarity is having a negative effect on farm practices already, particularly on dairy farming where the use of maize or corn as feedlots is becoming attractive to farmers. One such example is encapsulated in the following words: ***"**So this farmer will be producing between 800-1000 cattle for milking, but only on 200 acres, actually I think less than 100 acres. Now, these cows won't really see much of outside".*

5.2.2 Challenges to technology adoption

Training, skills and knowledge – Interviewees agreed that farmers are reluctant to attend skills workshop, particularly the smallholders who are predominantly family business and pride themselves on being self-sufficient, as described in the following words by one interviewee: *"they need to have things within their business that they can manage and run themselves… rather do things in-house".*

Data management is a bit area where gaps in knowledge and skills persist within the farming community. Whether it is genetic information, breeding more carbon efficient animals, or sharing schemes for circular energy and carbon reduction, farmers lack the knowledge and skills to grasp the complexities if systems they are required to work with. As a default, this is subcontracted to parties that make a profit without much value added.

Lack of investment and achieving Net Zero – Interviewees warned of the effects of not investing enough in the farming community, either as a result of small size farm or other forms of investment. This will hurt the local industries dependent on farming activities as is the case in most of the South West and in Devon in particular where farming and food remains a strategic sector in terms of employment and gross value added to the local economy. When the environmental legislation comes to deadlines 2030 and 2050, the investment would already be in a state that cannot support farmers to achieve those goals.

This is made worse by the fact that some of the methods used by small farmers such as circular system for energy and fertiliser production from farm waste are not subsidised. For example, the anaerobic digestion is not just for bio-fertilisers by-product but can also provide energy for heating, keep dry, and run milk pasteurisation operations. It is very energy efficient and carbon neutral. However, the lack of joined up thinking from Central Government constitutes a real challenge for the farming community who tends to respond by resisting investment.

In the same vein, the lack of certainty on the policy side makes it harder even for the farmers making a commitment to new technologies or new systems. The lack of clarity around policies and subsidies related to rewilding, Agri-forestry over the next decade and more is preventing farmers from investing, as one interviewee eloquently summarised: *"when farmers make investment on technology it's got to be technology that is around for 10-20 years and still sustainable and still valid because that's the sort of cycles they're working on".*

Landlords and tenant farmers relationships - One practical issue that was raised is that by replacing income with capital grants, you are requiring tenant farmers to persuade their landlords to pay for the capital improvement to the farm. As tenancy agreements are becoming shorter compared with the traditional agricultural tenancy, there is no incentive for the farmer. Moreover, there is no collateral for them to raise the capital required for the 50% investment that the grant does not cover. As one interviewee explained: *"we've seen instances where landlords are reluctant to pay for the capital improvement. Can't blame the landlord either because realistically you take slurry storage, having a hole in the ground full of slurry is of no benefit to the landlord".*

Farmers face a unique challenge in that they need to be able to increase scale, but they do not have the capacity to increase the landmass of their farm.

Achieving sustainability and resilience – Interviewees expressed some concern around achieving sustainability and resilience in farm business at the same time. Particularly, dairy farm is changing in the sense that for it to be profitable, it is all about efficiency and for this to work, the scale of operations must increase. Without clarity on the policy side, they fear that the traditional British farming will not resist pressures from the system that is contemplating an American or Australian style farming. This view is summarised in these words: *"farmers' point of view is moving towards cost sustainability. That is very different to what environmentalist groups are advocating".*

Farm-tech think that intensive farming will become unavoidable and when you add land management issues you end up with a real challenge and farmers across the country, not just in Devon, are confused and lost. Striking a balance between what is financially viable, what is practically possible and what is socially demanded is going to be much harder going forward.

5.2.3 Opportunities

Compressed natural gas (CNG) facilities – Farm-tech businesses advocating for this market use two approaches. Either you use a hub and spoke approach with a large digester site at a convenient place around several farms. This depends on what feedstock is available from farm and what infrastructure and access to a gas grid are available for central processing. Another approach is to make small projects centrally on farms if you are limited in terms of infrastructure or land availability. This energy can be used to run tractors without having to shift to grid. The challenges in small projects is to ascertain what feedstocks are added in the process from various farms. These projects are not typically owned and run by farms due to the complex data system required so farmers are at mercy of project owners for what they receive in exchange, e.g., fertilisers.

There seems to be a policy support here given the long-term nature and the size of investment required to make it work. As one interviewee put it: *"There is a perception that from an environmental perspective, the world has to change, and farming has to change to more natural methods".*

Young farmers – There is a feeling that a generation of young and tech-savvy farmers are embracing the sector with a more open mind to technology adoption. There is a desire to change what has been going on and treating farming more as a business, as argued in these words***:*** *"there is a real opportunity because they are looking at technologies to try and make their farms more efficient and more effective".*

Land management and biodiversity – Farm tech businesses were keen to distance themselves from intensive farming to embrace systems that are more holistic, with positive impact on biodiversity and climate. This includes choosing the right animals for the right location, in the right density and this means less use of animal feed and medication and more reliance on *'regeneration'*. As one interviewee explained: "if you introduce animals into arable farming systems you can reduce soil disturbance and increase soil health. One interviewee commented: *"this in itself is a massive carbon sink, bigger than tree planting, it is about sustainability".*

In addition, the use of bio-complex for virus control also proves effective to prolong the shelf life of crops without any harm to human health. The bio-complex can also be added to animal feeding (cattle, pigs, chicken) so as to achieve a better feed conversion ratio and therefore the farmer makes more profit. Other benefits include reduction in carbon emission in that *"if you can improve feed conversion ratio by having a healthier stomach you can also reduce methane emissions because the methane is converted into body weight, and we have a better quality manure to put into the anaerobic digestion process".*

Animal welfare – New breeding techniques are available to help farmers select breeds that are more resilient to diseases to address the pitfalls of intensive farming whereby cows are milked three or four times a day and grass is brought to them in a shed. The practice of running tractors 24h a day to feed cows in a concrete barn is madness as they put it: *"you end up with lower levels of butterfat, low protein levels and high quantity. That is not sustainable, and it is questionable".*

Farm-tech businesses believe that with the right support, the type of technologies that is suitable for smallholders is deliverable, if the Government can take time to understand the sector and its challenges, and design policies that are effective, especially with the goal of achieving Net Zero by 2050.

5.3 Farm business experts' perspective

We interview two farm business experts who shared some of the views expressed by farmers and farm-tech businesses. We report below their specific views that were not expressed by farm businesses and far-tech businesses.

5.3.1 Barriers to technology adoption

Farm size - Although farm size is perceived as a barrier to adopting certain technologies, farm experts differ in that they propose alternative solutions to existing technologies mainly drawing on best practices observed elsewhere. For example, whereas the GPS will not work well on sloppy land, other simple techniques will, such as planting in circular rather than vertical lines. As the expert pointed out: ***"****you cannot programme a GPS on a tractor to actually work along the contours".* This corroborates with a comment made by a crop farmer near Honiton.

5.3.2 Challenges to technology adoption

Skills and knowledge gap – Farm experts argue that the reluctance to adopt technology due to skill gap is not necessarily true. In their view, manufacturers just want to sell stuff without thinking about the usage environment and the ease-of-use for new learners with no support. Learners support often comes in a form of classroom or workshop learning, which farmers think is a complete waste of their time. Going to college to learn at their age, they think they know it all. They contend that farmers learn on farm where they can apply their knowledge and skills, assess the benefits and limitations and come back to it with an open mind. They suggest ***"****demonstration* *days looking at best practice on strategic farms called monitor farms where farmers come together and discuss ways to increase productivity".*

Farmers' education is key to addressing this gap. It is no good having technology if the farmer cannot utilise it. As one interviewee stated in the case of an investment grant: *"they bought technology and did not use them because they do not understand the difference between aerated soil and non-aerated soil……… there are many cases of misuse or unused equipment or machinery because the farmer has not been educated in the usefulness of the machine".*

Crop management – A lot of farmers have relied on the single farm payment since 1973 and now with the new system coming they will only get about 1/3 for farming. There is a challenge to define a win-win scenario by encouraging farmers to farm better with what they already have. They argue that output per crop is about 2/3 of what can be achieved in Devon, and more output can be achieved without chemical use. The challenge is how to achieve more by a biological and coexistence of symbiotic relationship with other plants that are helpful. They assert: "*yes, it is technology, but it's also farmers understanding the technology and I think that's the biggest hurdle we have".*

Efficient use of resources and funding – There are instances in Devon where large crop farmers took advantage of 50% grant to invest in a very expensive equipment to increase yield and reduce cost. To achieve both, they need to ensure that the ground conditions are conducive to what they aim to achieve. Because the ground conditions were not good to start with, the result was a reduction of 20-30% in yields. This is observed across the country. Our interviewee put it clearly in these words: *"it is about getting the basics right……. it is about education, understanding what conditions that the machine can be used ultimately to produce the right crop and yield".*

Soil loss and environmental cost of food production – Experts quote a study by Sustainable Food Trust which revealed that for every pound spend on food there is one pound of environmental damage. An example is the river Tamar where the riverbanks must be dredged out to remove silt that cannot be reapplied to the land because of risk of releasing other toxic matters in the water. This is an expensive activity that cost the Water Management company not only money but could lead to litigation. The pollution needs to be stopped at source when chemicals are used intensively for farming.

5.3.3 Opportunities

Biological technology – Devon farmers, particularly young farmers, can easily understand that minimizing the amount of machinery on their farm and literally trying to make maximum use of the land is a more viable option. This approach to using nature rather than machine and fertilisers is the right approach to farming that can also increase productivity in a more sustainable manner. As our interviewee put it convincingly: *"steel is expensive, and it has a high footprint. …… technology is not just computer-related it is also about biology…"*

In the same vein, the use of fungi and smart grass by mixing herbal lay can increase yields to levels equal to using chemicals that emit ammonia and other hazardous substances that are damaging to human and animal health. Animal performance is just as good, and the biggest benefits are savings on fertilisers and clean environment.

Organic farming and biodiversity - Experts think the direction of the new policy may work well if there are systems in place to support farmers to adopt best practices. Organic intensive farming using all the products and technologies available should not be pursued at the detriment of the environment.

5.4 An holistic approach – integration of the three perspectives

This section takes an holistic approach to evaluate the key findings, drawing on interview results from all three groups of participants. First, the challenges are discussed from a sustainability perspective to give due consideration to the future of farming and food in Devon and how technology fits in. Thereafter, we present market opportunities emerging from the study and evaluated in light of current research.

5.4.1 Main challenges in farm business and technology adoption in Devon

The results from the study highlight three key areas of challenges which can be discussed around the sustainability pillars of economic, environment and social dimensions.

5.4.1.1 Economic dimension - Productivity and resilience

The economic challenges facing farm businesses in Devon can be summarised as small size farm, cost of inputs, unaffordable or inadequate technology, price competition particularly for organic farmers, skills shortage and limited staff availability. These challenges are evaluated with the productivity lenses. Productivity is commonly defined as the ratio of a volume of measure of output to a volume measure of input use (OECD, 2001). In simple terms, productivity measures the amount produced by a certain group, e.g., farm business, given a set of resources and inputs.

Yields and productivity - Output in farm business is referred to as yield. It is measured in volume or in monetary value terms. For example, crop output per land area is often used in farming, with a higher yield representing a higher productivity (FAO, 2017a). As a ratio, improved productivity can only be achieved either with an increase in yield or output, or a decrease in input costs or volume. The dynamics of this relation are more complex in practical terms, because a higher yield may be the result of improved practices on the farm, land quality, better educated workforce or efficient application of capital (Higgins et al, 2019). More significant is the fact that yield improvement could happen beyond the control of farmers, for example soil conditions and weather (Fuglie et al, 2012).

It has long been argued that the transformation of inputs into output is largely affected by efficiency and technological changes (Ludena, 2010; Nishimizu and Page, 1982). However, efficiency and technological changes may not explain productivity variations in instances where external factors such as price shock would result in significant changes in yield. This phenomenon could happen, not necessarily when yield is measured in monetary terms. As the limitations of the *'green revolution'* of previous decades illustrate, it is now recognised that the gains generated by efficiency and Agri-chemicals often result in negative effects on land, water and biodiversity (FAO, 2011). Another study by FAO (2017b) revealed that yield in certain crops such as maize, rice and wheat barely increased by more than 1 percent since 1990s, compared with the 1960s levels, and this in spite of increased use of fertilisers and Agri-chemicals.

This sheds a new light in understanding the low appetite of technology adoption among farm businesses in Devon, and the increasing drive towards organic farming. For a small size farm relying on pesticides and fertilisers to increase yield, the cost of introducing new technologies is limited by the disproportionate low increase in output, as the FAO (2017b) study reveals. Even considering the capital grant applicable in certain cases, the return on investment is not an incentive. With regards to organic farming, research suggests that yields currently stands at 2/3 of levels that could be achieved (Roos et al, 2018). However, the limited use of mechanical and automation applications suggest that yield output improvement would require additional costs, hence limiting productivity. This is equally the case for cattle farming where the grazing landscape presents a set of challenges to farmers due to the absence of appropriate technology (Wagenberg et al, 2017).

Policy changes and Resilience - Similar to other farms in the UK, Devon Farm businesses' resilience has been tested over the decades with many changes to the EU Common Agricultural Policy (CAP), and more recently, Brexit. The resulting negative effects have eroded farm businesses' capacity to recuperate from external shocks, leaving many farm businesses in a more vulnerable position when the ongoing inflation occurred in early 2022. With the single farm payment system ending in 2023, some farm businesses are assessing whether financial resilience could be achieved without further reliance on subsidies, as the study reveals.

This presents a new challenge when the new policy under the Environment and Land Management System (ELMS) will come into force. Investment in farm businesses requires a longer period to yield a positive return because profit margin on farm business operations are relatively much lower (OECD, 2017b). Furthermore, the ongoing inflation has affected farm businesses' commitment to investment, as the study reveals. For smallholder farmers, these shocks can exhaust scarce resources of cash, seeds, and livestock, making farm-technologies adoption much harder to achieve.

5.4.1.2 Environmental dimension - Carbon emission, waste, and biodiversity

The rising concern of feeding the world's growing population is global by nature. Farmers face the challenge to adopt practices that are supportive of resource conservation, while at the same time increasing productivity. To respond to this challenge, farming needs to adopt innovation to improve the efficiency with which inputs are turned into output; and also, to conserve scarce natural resources and reduce waste (OECD, 2011; Troell et al, 2015). This study reveals that Devon farmers are more prone to look for practical approaches where technological solutions are either inexistent or deemed unaffordable even with subsidies. There is an increasing interest and practice of custom-made biological production systems combining plant diversity, perennial cover such as herbal leys, and tree planting for weed control.

With regards to conservation and the use of natural resources, the study shows that there was a shared concern about reducing pollution and waste generated by farming. Organic farming particularly helps to address this concern with the re-introduction of biological complexity. By closing the nitrogen cycle, Agri-ecological farming improves the efficiency of food production and generates environmental co-benefits (FAO, 2015). However, the challenge remains with organic and conservation agriculture with no tillage to stabilise yields and reduce variations across the field (Knapp et al, 2018). In the same vein, the fact that climate change effects vary across different places within and between countries, there is still a lot to do to address barriers to adoption of farming methods that are compatible with the environment (Grabowski et al, 2016; Arslan et al, 2013).

5.4.1.3 Social dimension - Welfare

The study findings identified three key areas under welfare underpinned by the social dimension of sustainability.

Human / animal health

As several past incidences have shown, intensive animal husbandry increases yield at the expense nutrition quality and safety, because it increases the prevalence of pathogens in flocks and herds and leads to incidence of food-borne diseases (FAO, 2017). Participants to the study described this conflict between yield and safety in compelling terms:

"You end up with lower levels of butterfat, low protein levels and high quantity. That is not sustainable, and it is questionable".

"So this farmer will be producing between 800-1000 cattle for milking, but only on 200 acres, actually I think less than 100 acres. Now, these cows won't really see much of outside".

On the positive side, there is emerging evidence in Devon on affordable technology using feed conversion ratio to improve animal health, reduce carbon emission from methane and limit hazards to human health (Ekogea, 2020). Such approaches to animal husbandry should be diffused for much wider application.

Community engagement

With regard to community engagement, the key challenge is to shift consumers' perception about the real cost of food from a multi-factor perspective: food waste, environment pollution, health hazards (Sustainable Food Trust, 2019). The polarizing debate on GMOs has led to the unfortunate consequence of overshadowing the positive achievements based on biotechnologies that are found in organic farming as well. Consumers need to be won over the fact that feeding the growing world population requires innovation, and some are very safe (FAO, 2016).

Landlords tenants relationships

A significant proportion of smallholders in Devon are tenants. When it comes to investing in new technologies to improve farm practices or yield, farmers are unable to meet the cost alone, while landlords see no inventive to invest in non-profitable operations such as slurry. The UK Agriculture Act 2020 establishes a new agricultural system based on the principle of 'public money for public goods'. It will provide powers to give financial assistance under a new system where payments may encompass environmental protection, public access to the countryside and measures to safeguard livestock and plants. It will also have the ability to establish an enforcement and inspection regime including powers to set out terms and conditions of future financial assistance.

In the meantime, the Basic Payment Scheme remains in place until 2027 with a reduction in subsidies. Coupled with a potential increase in export tariffs due to Brexit, it is likely to lead to some downward pressure on farm rents. Although the new ELMS is likely to create opportunities for farmers and landlords, landlords will need to be willing to allow tenants to make structural changes to their businesses, be more accepting of alternative farming methods and be mindful of the potential cash-flow issues their tenants will face during the transition from BPS to ELMS. The growing interest among young farmers also presents new sets of challenges, although it is anticipated that they will be more willing to adopt technology and introduce more sustainable practices in farming.

5.4.2 Opportunities

Some opportunities emerge from the study, which we categorise under markets, technologies, and best practices.

5.4.2.1 New markets

Organic farming and new products - The increasing awareness of the relationship between food, nutrition and health among consumers can open new markets, particularly for organic farming. Consumer demand for organic products has increased dramatically, with global sales more than threefold since 2000s (Reganold and Wachter, 2016). Particularly in Europe, sales of organic food now represents more than 10% of total food sales and in countries like Sweden sales have recorded an increase of 18% since 2016 (Ekoweb, 2017). This trend can generate new markets for UK exports, particularly in markets where UK beef and lamb already sells at a premium.

Organic farming also generates opportunities as a result of land recovery practices whereby some farmers have tried new crops such as quinoa, resulting in growing, although still niche markets. Derived demand for organic farm waste used in other crops such as mushroom farming also generate secondary markets that could help develop new supply chains and value in organic farming.

Sustainable energy sources – Farm waste is increasingly used for energy supply, such as compressed natural gas (CNG). CNG can now be used as a fuel for gas-fueled captive power plants. Natural gas as fuel source has a significant number of benefits versus diesel including reduced emissions and reduced fuel costs. As the study reveals, there are ongoing projects in the UK to develop CNG in rural areas where land availability can facilitate such operations. Smallholders can also share facilities and reduce the reliance on diesel. Depending upon the price of natural gas compared to diesel and the distance which the gas has to be transported from the point of compression, the fuel savings can be in the region of 30% (Maidi et al, 2019).

5.4.2.2 New technologies

Carbon sequestration – An increasing number of farmers perceive benefits in using the land to reduce CO2. Soil carbon sequestration implies transferring of atmospheric CO2 into soil. Apart from benefits to the environment such as water quality, other benefits include enhanced food and nutritional security, improving biodiversity, and strengthening elemental recycling (Lal et al, 2015). In addition, farmers can generate additional income on the carbon trading market. The real opportunity here is to device a system that facilitate market interactions and to make knowledge and information easily accessible for farmers.

New product development - The study shows that not all technologies are applicable in Devon. However, farmers particularly are imaginative when facing a challenge. Some farmers even collaborate ingeniously to adapt existing tools and equipment to meet specific needs for which no alternative is available in the market. This challenge presents a unique opportunity for new product development that could be used elsewhere in the UK or around the world. Clearly, the concern to ensure animal safety when grazing in expansive areas near the sea is not exclusively a Devon problem. Thus, something like a no-fence collar for example can help address problems on a global scale. Global expenditures on agriculture R&D are on the rise after a period of slow growth in the 1990s and represent 1/5 of total R&D expenditures worldwide (FAO, 2017b). With the pressing need to feed the world while reducing effects of climate change, investment in R&D holds promises for new technologies developed in Devon with global applications.

Best Practice, knowledge sharing and dissemination – It emerged from the findings that attempts to address knowledge and skills gaps via the traditional methods do not work with farmers, for a variety of reasons. Similar to entrepreneurs, farmers fall into the category of "learning by doing". Thus, new ways to deliver knowledge and share best practice among farmers should be designed. Although AHDB already has the farm monitor system in place, it would be useful if at a more local level other forms of support are put in place. Regenerative farming is gaining momentum not only because of benefits for soil and the environment but also because it offers new sources of income. Learning about regenerative farming calls on educators to address knowledge gaps. So far, farmers themselves have been at the forefront of a renewal movement educating other land users how to farm beyond conventional modern systems (Burns, 2020). It is possible to merge regenerative farming with natural resource conservation profitably (LaCanne et al, 2018).

6. Conclusions and Recommendations

Based on the main findings from the desk research (Section 3) and primary research (survey findings in Section 4 and interview findings in Chapter 5), the following conclusions can be drawn.

(1) Supporting the adoption of agricultural technologies and on-farm take-up of new innovations is extremely important because both farm businesses and Agri-Tech developers see great potential benefits (economic, environment and social) in adopting the technologies. This is clearly supported by the evidence from research findings detailed in Section 4.5, Section 4.6, and Section 4.7. Furthermore, all ten categories of technologies included in the technology review are being used on farms in Devon (evidence in Section 4.2).

(2) A wide range of emerging agricultural technologies are readily available from global market (Section 3.2 technology review). In addition, there are a great number of agri-tech companies in Devon which are delivering technologies with a high level of readiness (evidence in Section 4.1.2). Our research findings show that the technologies from agri-tech developers in Devon are concentrated on five out of the ten categories of technologies as reviewed in Section 3.2. There is a clear gap in the technology categories that currently needs to be filled by agri-tech development from outside Devon. This can be seen as an opportunity for future innovations in the region.

(3) Perceived usefulness of agricultural technologies differs between farmers and agri-tech developers (evidence in Section 4.3). Research findings show that agri-tech developers are really positive about the technologies' usefulness, however a significant percentage of farmers have reservations. This gap between the agri-tech developers and farmers needs to be closed in order for the technologies to be adopted on farms.

(4) Perceived ease-of-use is another significant gap between the farmers' and tech developers' views (evidence in Section 4.4). However, this gap can be bridged

by various programmes such as knowledge sharing, technology demonstration, on-the-farm training and peer learning.

(5) The main barriers to adopting technologies are numerous, but the top three barriers based on research are investment cost, access to funding and farm size (evidence in Section 5.1.1, Section 5.2.1, Section 5.3.1). Farm businesses in Devon are predominantly SMEs (evidence in Section 4.1.1). Most of them cannot afford expensive new innovations and technologies without funding support from appropriate sources.

(6) Key challenges highlighted by all three types of participants in our primary research are mostly related to farm business employees' skills, knowledge and access to training (evidence in Section 5.1.2, Section 5.2.2, Section 5.3.2, Section 5.4.1). Farm businesses with only a small number of employees cannot afford the time or money to receive training full-time. Can on-the-job training be delivered on the farm site providing farmers with hands-on experience in using the technologies that are applicable to their farming operations (i.e. "learning by doing")? In addition, farmers may not prefer to learn from classroom or laboratory-based lectures, but can learn well from peers (i.e. other farmers) in the farming community. What type of approach to training is appropriate to equipping farmers with the right skills and knowledge to adopt technologies?

(7) Despite all the gaps, barriers and challenges, our research participants see a range of opportunities by adopting new technologies, such as in sustainable farming, attracting young farmers, land management and biodiversity, and organic farming (evidence in Section 5.1.3, Section 5.2.3, Section 5.3.3, Section 5.4.2).

Our main recommendations are:

a) Create an integrated knowledge sharing platform that can bring together all groups of stakeholders (communities and individual users), for example, from farmers to agri-tech developers, from farm business experts to professional educators/researchers, from policy makers to funding agencies. The main purpose of such a knowledge sharing platform would be really useful in helping farmers to improve their access to knowledge, linking them to markets, helping them to better understand new technologies, and in sharing good practice and lessons learnt. Example functions provided by such an integrated knowledge sharing platform can include:

- Solutions Library: such a library will deposit proven solutions to practical issues that farm businesses can use, such as solutions related to pest control and animal/crop health monitoring.
- Advisory Service: providing advice/answers to farmers who have ad hoc questions.
- Toolbox: mature tools from agri-tech developers can be demonstrated or licensed. The platform can further serve as a Technology Marketplace.
- Good practice and lessons learnt
- Information sharing and linking farm-market apps.
- On-line training materials and programmes: video, audio and other multi-media forms
- Community groups and peer-learning

It is highly likely that such a knowledge sharing platform will work as an existing agricultural knowledge sharing platform in international context has already been created via a Horizon 2020 project, RUC-APS (2016-2022), funded by European Commission. The platform connects farmers, tech developers, researchers, educators and other stakeholders in eight countries across Europe (UK, France, Italy, Spain and Poland), South America (Chile and Argentina) and Asia (China). University of Plymouth was the lead in creating the RUC-APS knowledge sharing platform. To learn ideas from RUC-APS, please visit RUC-APS project website: https://ruc-aps.eu/

b) In order to bridge the gaps between agri-tech developers and farmers on a range of aspects related to adopting new technologies, more direct interactions and more effective communications among the two groups is recommended. If necessary, third parties such as farm business experts (consultants, educators, research scientists) can also be involved. Agri-tech developers can benefit from the Agri-Technology Acceptance Model (Agri-TAM) developed in this research by taking a more comprehensive view when developing technologies. Besides the usefulness and ease-of-use, the technologies developed should also have clear benefits (economic, environmental, and social) to farm businesses. In the meantime, agri-tech developers should be well aware of potential barriers and key challenges that farm businesses face.

c) The research findings from DATA project would be useful to policy makers and funders. Devon farm businesses are predominantly SMEs in terms of the number of people operate on the farms. Over 80% of farm business have fewer than five employees. There is an urgent need to provide support to these small sized farm businesses, especially by providing fund for investment in new technologies and providing access to new skills/ knowledge required to properly use the technologies. Otherwise, the potential benefits from new agricultural technologies cannot be harvested on farms in Devon at large scale.

d) Training on multi-criteria decision making should be provided for farm businesses to facilitate them to make the right decisions while adopting new technologies. There are so many emerging technologies available in the market, and each technology has potential benefits in many different measures, especially the environmental and social benefits claimed by agri-tech developers are not understood equally by farmers. It can be a daunting task for farmers to choose the right technology from the market while a wide range of criteria need considering. Providing training on multi-criteria decision analysis would be beneficial to farm businesses which wish to adopt emerging technologies.

e) The multi-perspective approach taken in this pilot project, DATA, should be adopted and enhanced, if possible, for future research. It is clear that farm businesses, agri-tech developers and farm business experts do not have the same opinion on many of the aspects of adopting emerging technologies. By integrating the opinions from multiple perspectives, we get complementary views and can form more balanced conclusions.

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Appendix A Details of ten categories of Agri-Techs included in the technology review

This appendix provides details of the ten categories of emerging agricultural technologies included in our review.

Category 1: **Agricultural drones and robots**

Agricultural drones are Unmanned Aerial Vehicles (UAVs) used for precision agriculture, which is a modern method of farming that uses Big Data, aerial imagery and other means to optimize efficiency. They offer powerful data processing capabilities afforded by Cloud-based computing to deliver aerial monitoring, inspection, and intelligence-gathering capabilities (Chuchra, 2016). A drone is a high- tech aircraft which has a camera system. In crop fields, drones can scan the fade part of the crops and image them. A drone also has a GPS tracker map which is a highly appreciated feature in today's agricultural sensors. It is widely used in agriculture, such as, crop assessment, counting cattle, monitoring for disease and pesticide, water watch, mechanical pollinators.

1) **Crop assessment:** Farmer can combine UAV Aerial Imagery with Machine Learning systems for Crop yield forecasts, accurate crop count, crop emergence analysis, irrigation monitoring, crop health, crop damage assessment, field soil analysis, etc. High-quality drone data and Photogrammetry guard crops to guarantee productivity and to equip farmers with all benefits accessible (Equinox Drones, 2020).
2) **Counting cattle:** Automated cattle counting with drones saves time and is more accurate. Managing cattle inventory and reconciling yard sheets plays a major role in any feedyard operation (Gibson,2019). Combining drones and machine learning can automate the cattle counting process. The result is a quick turnaround time. Typically, it is able to deliver results within 24-48 hours of flying the feedlot (Gibson,2019).
3) **Monitoring for disease and pesticide:** Drone pilots can obtain high-resolution data that can provide vital information for measuring and documenting disease to crops. Data from drones with remote sensing capabilities and Photogrammetry acts as evidence for farmers to apply pesticide or claim crop

insurance or to obtain an estimate accordingly. Data retrieved from advanced sensors represented as 2D or 3D Orthomosaics help farmers understand and find novel alternatives to increase crop yields and reduce crop disease simultaneously (Equinox Drones, 2020).

4) **Water watch:** It traditionally takes 5 to 6 hours to spray in one acre of field. Whereas with the drone this work will be done in the same area within 7 minutes. Spraying in one acre manually will take 150 liters of water. Whereas the drone will do the job in just 10 liters (NewsNCR, 2022).
5) **Mechanical pollinators:** Mechanical pollinators is using drone technology to help achieve more accurate and precise pollination of orchard crops with its automated program (Manning, 2019). The drones use artificial intelligence to autonomously navigate and avoid obstructions, such as, animals, trees, or other drones busy spreading pollen, as they carry pollen between plants that stick to simulated bee fur. And if the weather takes a turn for the worse, a message from the “hive” calls them back (Singh, 2021). An artificial beehive that would house a bunch of small drones within a bigger, arm-length drone. This beehive will be able to attach itself to a tree, opening up to unleash a swarm of tiny drones.

The broader category than agricultural drone is agricultural robot, that is, agricultural drone is one of special agricultural robot. Agricultural robots are specialized artefacts of technology that are capable of assisting farmers with a wide range of operations for improving the quality and efficiency of yield, minimizing reliance on manual labor, and increasing overall productivity (Mordor Intelligence, 2022). They have the capability to analyze, contemplate, and carry out a multitude of functions. Agricultural Robots can be used for an incredible number of tasks to ease the burden on the farmers. Their primary role is to tackle labor-intensive, repetitive, and physically demanding tasks (Kootstra et al., 2021). In recent years, however, robots are being used for various specialized chores as well that were previously only tackled by experienced farmers. This includes the ability to pick out sensitive fruits and vegetables such as lettuce and strawberries (Tucker, 2019). There are many applications of robots in agriculture, such as, robotic harvesting equipment, robotic weeding equipment, robotic spraying equipment, robotic feeding systems, voluntary robotic milking system, robotic transplanting, autonomous driverless tractors or platforms (UK government, 2021). All these equipment can be on its own autonomous platform or propelled as an attachment to existing farm tractors (UK government, 2021).

1) **Robotic harvesting equipment:** An autonomous harvesting machine must use computer vision or sensors to detect, select and harvest individual fruit or plants in the crops, leaving the remainder of the crop to be harvested later to optimise productivity (Onishi et al., 2019).

2) **Robotic weeding equipment**: Has the ability to identify and treat individual weeds while leaving the crop untreated or identify individual crop plants and remove the unwanted plants (weeds).

3) **Robotic spraying equipment**: Has the ability to identify and treat individual plants. They accurately place chemicals on individual plants while leaving the remainder of the crop untreated. This could be to apply herbicides or pesticides to individual weeds or diseased plants or apply fertilisers and trace elements to individual plants in the growing crop.

4) **Robotic feeding systems**: Autonomous system which mixes, transports, and delivers feed to the animals, without the need of a rail system to guide delivery of food.

5) **Voluntary robotic milking system**: A voluntary robotic milking system which allows the cows free access 24/7. The system undertakes, without human intervention, all aspects of the milking process from cleaning the udder, pre-milking, milking and analysis, through to teat dipping after milking. Systems which require the cows to be herded (or driven) into the parlour as part of the milking routine are not considered voluntary.

6) **Robotic transplanting**: These are autonomous systems used for transplanting cuttings / seedlings / plugs into pots or beds. Transplanting is an agricultural task of transferring and planting seedlings grown uniformly in a nursery to a field. A automatic transplanter is an agricultural machine that performs transplanting and is crucial for labour reduction and timely cultivation. The plant robots are featured with an easy depth control and automatic plant distance control for optimal dimensions and a high productivity. It is suitable for planting various plants and vegetables, such as: brassica, romaine, tomato, tabacco,

fennel, sugar cane, forestry seedling, etc.

7) **Autonomous driverless tractors or platforms**: Autonomous driverless tractors or platforms navigate fields and undertake farming operations using conventional farming equipment.

<u>Advantages of using drones and robots:</u>

- Improved efficiency: Agricultural robots are designed to improve the efficiency of farms, and they have the capacity to help farmers harvest crops rapidly and process crops quickly for distribution. Robots can run without pause and with no need for breaks, and they have the ability to carry out tasks at a much faster rate than a human worker could (Cyber-Weld, 2022).
- Avoiding waste: If farmers are unable to harvest or process their crops, those crops can rot in the ground or in warehouses. This can lead to vast quantities of unnecessary waste, and it’s a particularly prevalent problem in countries where farmers struggle to find seasonal workers. Robots can provide farmers with an essentially unlimited supply of labour, ensuring that crops can be picked when needed and will not go to waste (Soffar, 2016).
- Accuracy and precision: Agricultural robots offer a level of accuracy and precision that humans often cannot match. They have the capacity to perform tasks such as separating bad crops from good crops and can provide accurate levels of crop or soil monitoring (Soffar, 2019).
- Cost-effectiveness: Robots can be set to work 24 hours a day, seven days a week, ensuring that farmers can not only pick, and process crops efficiently but that large farms can be run cost-effectively. This helps farmers to keep their running costs low, which in turn means that consumers can enjoy lower prices in the supermarkets.
- Improved health and safety: Farm work is physically demanding, and workers can be injured on the job and be affected by long term issues, such as repetitive strain or back injuries. Robots can replace repetitive and strenuous farm jobs that often lead to such injuries, thereby leading to improved health and safety on farms (Cyber-Weld, 2022).

Disadvantages of using drones and robots:

- It costs a lot of money to make or buy robots. They need maintenance to keep them running. Energy issues are costly (Soffar, 2016).
- Maintenance cost: Robots need maintenance to keep them running (Roboticsbiz, 2019).
- Farmers can lose their jobs to robots. Robots can change the culture / the emotional appeal of agriculture. Field tasks which are monotonous can be easily automated, which can gradually make certain roles obsolete. Humans will be replaced by smart robots that can safely navigate the space, find and move agricultural products as well as perform simple and complex field operations (Soffar, 2019).
- The cost of technology such as drones has made it unavailable outside of the government and research bodies. It is costly to buy the drones, the biggest challenge will be funding internally from the government efforts and research institutions (Roboticsbiz, 2019).

Successful **commercial examples** of agricultural drones and robots:

- Earth Rover Company (UK) https://www.earthrover.farm/
- Augean Robotics Company (USA) https://burro.ai/
- FarmWise Company (USA) https://farmwise.io/
- Advanced Farm Technologies company (UK) https://advanced.farm/
- RObotics Plus company (New Zealand)

https://www.roboticsplus.co.nz/ Category 2: **Satellite photography**

Satellites are one of the most used means in agriculture to perform remote sensing. The satellite imagery in fact allows to monitor crops remotely in a precise and efficient way (Nakalembe et al., 2021). Satellite images are becoming more frequently employed to monitor agricultural activities, providing important data which details objective estimations of crop conditions and yields (Geocento, 2022; Kubitza et al., 2020).

There are many satellites that acquire multispectral images from space: the most common are Sentinel-2 and Landsat 8, Planetscope and Sky Sat. The images obtained have a spatial resolution of a few meters: Landsat 8 provides data with a spatial resolution of 30 meters, while Sentinel-2 of 10, 20 or 60 meters (depending on the band), Planetscope of 3 meters and SkySat of 1 meter. The temporal resolution is in most cases regular. For example, Landsat 8 is available every 16 days, while Sentinel-2 is available every 3-5 days (depending on the zone). Planetscope and Skysat have a daily resolution. The regular passage of the satellites determines the availability of the data in several phases of the growing season, but it is also important to underline that during the satellite transit, where the area under examination is covered by clouds, the data is not usable (Agricolus, 2022).

The integration of satellite imagery is done through the DIAS (Copernicus Data and Information Access Service) service of the ONDA consortium, initiated by the European Commission, and ESA. Satellite imagery is then cropped to field boundaries with the support of L3Harris Geospatial technologies. Finally, Sentinel-2 bands are processed to calculate multiple indices of vigor, water stress and chlorophyll. Indices are provided for all available dates, automatically excluding images with cloud cover (Agricolus, 2022).

Advantages:

- Precision data collection, soil sampling, and data analysis enable localized chemical applications and planting density to suit specific field areas (Sparkle, 2019).
- Accurate field navigation can minimize redundant applications and skipped areas. It enables the maximum ground coverage in the minimum possible time.
- The ability to work through low visibility field conditions such as rain, dust, fog, and darkness increases productivity.
- Elimination of the need for human “flaggers” increases spray efficiency and minimizes over-spray.
- Savings on seeds, water, pesticides and fertiliser thanks to input optimisation during the planting and growing phases (Das, 2021).
- Increasing the overall crop yield, e.g., through variable rate nitrogen application.
- Improvement of the quality of crops as well as more informed decision-making

on crop type and land use.

Disadvantages:

- Satellites is high dependency on weather conditions, and particularly clouds, and limited spectral resolution of the satellite data. Usable or valuable satellite imagery is highly dependent on weather conditions, as clouds can completely obscure objects on the ground.
- Unfavorable or periodic revisit time of a satellite can also pose a problem for multiple agricultural applications. Revisit time of imagery may not be favorable for specific needs, as the combination of weather and revisit time may increase the waiting time for a valuable image, which could be problematic.
- Spatial resolution and accuracy may not be high enough to provide the necessary detail.
- Satellite imagery can help farmers monitor specific locations but doesn't necessarily explain what's going on. For example, satellites can tell us that crops are unhealthy, but the reason why can't always be interpreted from the imagery (Growers, 2022).
- Typically, there are requirements for a minimum order of the satellite data, that can cost up to several tens of thousands of dollars, as the order for the satellite data is usually placed for 100's to 1000's sq. km (Igor, 2017).

Successful **commercial examples** of satellite photography:

- Growers Rally Company (USA) https://growers.ag/
- AAAKSC Company (UAE) https://www.aaaksc.com/
- FARMTOGETHER Company (USA) https://farmtogether.com/
- PLANET Company (USA) https://www.planet.com/
- SKYWATCH Company (USA) https://skywatch.com/

Category 3: **IoT-based networks**

Internet of Things (IoT) refers to devices or things that are embedded with sensors, so they can measure and transmit data via a network. Devices can mean anything from pumps, sheds and tractors to weather stations. Essentially, IoT means that these physical devices can send and receive information via the Internet. On farms, IoT allows devices across a farm to measure all kinds of data remotely and provide this information to the farmer in real time (Tao et al., 2021). IoT devices can gather information such as soil content, moisture, chemical application, pest infestation, dam levels and livestock health as well as monitor fences, vehicles and weather. Information generated by IoT devices allows farmers to track farm operations and performance, make better informed decisions to improve farm productivity and quality, respond more quickly to issues, minimise risk and waste, and reduce the effort required to manage crops (Zhang et al., 2020). Application of IoT in agriculture promises previously unavailable efficiency, reduction of resources and cost, automation and data-driven processes. For example, farmers can now know when to check on water supply to a trough, how much fertiliser to apply to a crop, and which ewe to check during lambing, etc.

Radio frequency identification (RFID) is one of early and mature technology of IoT, RFID can help to improve the management of information flow within the supply chain and security in the agri-food sector. RFID has already been used for years in animal identification and tracking and in the food chain for traceability control (Ruiz-Garcia and Lunadei, 2011; Rayhana et al., 2021; Murakami et al., 2017). IoT can forward apply to phase tracking and farm management solution, intelligent software analysis for pest and disease prediction, soil management and other involved analytical tasks, monitoring and analyzing farming activities such as crop rotation, pest control, fertilizer/water saturation, seeding/harvesting, streamlining production and work schedules (Acharya et al. 2022).

<u>Advantages:</u>

- Excelled efficiency: IoT-enabled agriculture allows farmers to monitor their product and conditions in real-time. They get insights fast, can predict issues before they happen and make informed decisions on how to avoid them. Additionally, IoT solutions in agriculture introduce automation, for example, demand-based irrigation, fertilizing and robot harvesting (Elijah et al., 2018).
- Expansion: IoT-based greenhouses and hydroponic systems enable short food supply chain and should be able to feed these people with fresh fruits and

veggies. Smart closed-cycle agricultural systems based on IoT allow growing food basically everywhere (Sinha and Dhanalakshmi, 2022), in supermarkets, on skyscrapers' walls and rooftops, in shipping containers and, of course, in the comfort of everyone's home.

- Reduced resources: Plenty of agriculture IoT solutions are focused on optimizing the use of resources—water, energy, land. Precision farming using IoT relies on the data collected from diverse sensors in the field which helps farmers accurately allocate just enough resources to within one plant (Torky and Hassanein, 2020; Madhumathi et al., 2022).
- Cleaner process: Smart farming using IoT is a true way to reduce the usage of pesticides and fertilizers (Dayoub et al., 2021). Not only does IoT-based farming help producers save water and energy and make farming greener but also significantly scales down on the use of pesticides and fertilizer. This approach allows getting a cleaner and more organic final product compared to traditional agricultural methods.
- Agility: With IoT-based real-time monitoring and prediction systems, farmers can quickly respond to any significant change in weather, humidity, air quality as well as the health of each crop or soil in the field (Kumari and Paul, 2018). In the conditions of extreme weather changes, new capabilities help agriculture professionals save the crops.
- Improved product quality: IoT-based Data-driven agriculture helps both grow more and better products. Using soil and crop sensors, aerial drone monitoring and farm mapping, farmers better understand detailed dependencies between the conditions and the quality of the crops (Madhumathi et al., 2022). Using connected systems, they can recreate the best conditions and increase the nutritional value of the products.

Disadvantages:

- Poor cellular connectivity in rural areas (Tzounis et al., 2017)
- Cost of solution implementation (Suresh and Priya, 2020)
- Infrastructure cost and complexity (Aarthi and Sivakumar, 2019)
- Challenges of ease of deployment

- Complex environment (indoor/outdoor)
- Total asset visibility
- Asset security

Successful **commercial examples** of agricultural Internet of Things:

- allMETEO Company (USA) https://allmeteo.com/
- Farmapp Company (USA) https://farmappweb.com/
- AGROINNOVA Company (Africa) https://agroinnovagh.com/
- LUXELARE Company (Mexico) https://luxelare.com/en/
- ALLFLEX Company (USA) https://www.allflex.global/
- COWLAR Company (PAKISTAN) https://www.dairy.cowlar.com/

Category 4: **Weather forecasting and tracking**

To produce a successful crop, a farmer needs to be aware of the moisture, light, and temperature. Detailed weather information, which includes past records, present weather and future forecasts are required. The agricultural industry can use weather forecasts to efficiently manage operations based on weather conditions, resulting in better crop yields. Weather forecasting can help with a farmer's business decisions. Forecasts can help them plan for the many day-to-day decisions. These decisions include crop irrigation, time to fertilize, and what days are suitable for working in the field. The decisions that farmers make will result in a profitable crop or failure (Len Calderone, 2020).

The weather tracking monitor used in agriculture usually consists in two core technologies. The first technology is a network of sensors that capture data about the weather through the weather tracking station. The second one is a computer system used for extracting data to warn farmers against potentially harmful weather forecasts. The technology brings huge benefits for the farmers. It significantly reduces the risks that farmers must face when meteorological uncertainty occurs. Additionally, farmers can make better predictions of crop needs to prevent them from over or underwatering

(Carlos Lin, 2021).

Advantages:

- By utilizing connected apps, you can do more than just monitor the basic weather conditions metrics as outlined above. This allows you to get better insights from the data analytics provides. For instance, the app can also allow you to better monitor the risk of diseases in crops, including common diseases for wheat, vine, and apple crops (Sigfox, 2022).
- All available data can also be viewed in the date ranges the user has set, so his or she is able to see the historical trends of data to make patterns (Sigfox, 2022).
- Having the advantage of knowing in advance the atmospheric conditions for a specific location can save your crops, protect your property, and even save your life in extreme situations. Medium-range forecasts can equip you to take appropriate measures to cope with the anticipated weather (DTN, 2021).
- Even modest advantages can make a big difference when weather impacts so much of the economy. An extra day or even an hour of warning about a weather event can make a difference to farmers, airlines, utility companies, rescue crews, etc. (Jon Walker, 2019).

Disadvantages:

- The cost/benefit equation for having access to reliable weather forecast information is not always easy to quantify, but it’s a decision that’s easy for most large growers and producers to make (WeatherDecTech, 2018).
- Weather is extremely difficult to forecast correctly. Weather changes all the time: The weather is a phenomenon that changes all the time. This means that any delay in data collection may sometimes result in useless data. (lidarradar, 2019)
- It is expensive to monitor so many variables from so many sources and perform the millions of calculations.
- Relies on intense datasets. There is a huge dataset associated with the weather

that needs to be analyzed before any decision is made. This data is so big that it may take a considerable amount of time to analyze fully.

Successful **commercial examples** of weather forecasting and tracking**:**

- Croptracker Company (USA) https://www.croptracker.com/
- DTN Company (USA) https://www.dtn.com/
- Sigfox Company (France) https://www.sigfox.com/
- Intellias Company (Germany) https://intellias.com/
- EOS Company (USA) https://eos.com/
- Enviraiot Company (Spain) https://enviraiot.com/

Category 5: **Automated irrigation**

Automatic irrigation is the use of a device to operate irrigation structures so the change of flow of water from bays can occur in the absence of the irrigator. Automation can be used in a number of ways: to start and stop irrigation through supply channel outlets; to start and stop pumps; to cut off the flow of water from one irrigation area — either a bay or a section of channel - and directing the water to another area. These changes occur automatically without any direct manual effort, but you may need to spend time preparing the system at the start of the irrigation and maintaining the components, so it works properly (Nicole George, 2021).

An Automatic irrigation system is a computer/ timer-based water supply for crops which minimizes human intervention to just supervision. All water delivery systems like drip, surface, or sprinklers can be automated. There are various benefits for automation, while the major one is reducing labor cost in exchange for an efficient water supply system. Usually, the automation is installed by an engineer after assessing the field length, weather, micro-climate, humidity, soil properties and water requirement by the crops for efficient watering of plants (Gremonsystems, 2020).

The frequency of irrigation can be controlled with the help of a computer (in the modern system) or with a timer (in conventional automation). An irrigation controller is a device to operate automatic irrigation systems such as lawn sprinklers and drip irrigation systems. In automatic water system, fertigation can be easily done which further reduces the labor cost and ensures the safety of workers. Also, one profound benefit of the Automatic irrigation system is the 24×7 irrigation irrespective of the labor availability, which will contribute towards the overall yield and profit.

Advantages:

- Cost savings due to minimized water waste
- Reduced human efforts
- A unified view of soil characteristics, including moisture and nutrient contents (Intellias, 2021)
- Smart notifications in case of abnormalities
- Better long-term landscape health
- Timely irrigation — plants being watered when needed
- Management of higher flow rates
- Accurate cut-off of water compared to manual checking
- Reduced runoff of water and nutrients
- Reduced costs for vehicles used to check irrigation.

Disadvantages:

- Costs for purchasing, installing and maintaining the equipment
- Reliability of irrigation system (due to human error when setting up)
- Increased maintenance of channels and equipment to ensure it is working properly (Agriculture Victoria, 2020).

Successful **commercial examples** of automated irrigation**:**

- Intellias Company (Germany) https://intellias.com/
- Agriculture Victoria Company (Australia) https://agriculture.vic.gov.au/
- Farm Management System Company (Australia) https://farmmanagementsystem.com.au/
- Eaton Company (USA) https://www.eaton.com/
- Gremon System Company (Hungary) https://gremonsystems.com/

Category 6: **Agricultural biotech**

Agriculture biotechnology applies to all technologies used on the farm involving biological or chemical processes. It is a broad category involving many different types of technology and science, including breeding, genetics, microbiome research, synthetic chemistry, and animal health. Large agri-businesses have been innovating in biotech for many decades to increase and protect crop yields with synthetic fertilizers, crop protection products like pesticides and genetically modified seeds. Animal health Agri-Biotech startups are also responding to consumer backlash against antibiotic use by creating alternative therapies. This new landscape creates an interesting opportunity for startup companies to build businesses, if perhaps reducing the potential pool of acquirers.

There are many different kinds of agriculture biotechnology regarding to different function and application. Agriculture producers can adopt different agriculture biotechnology according to the need of agricultural production (Louisa Burwood-Taylor, 2017). The following are some commonly used in agricultural production.

Biofuel/Bioenery: The technology is to capture and repurpose fugitive methane gas from agricultural and other sectors. It prevents this harmful greenhouse gas entering the atmosphere and processes it into liquid methane for distribution and use as an energy-rich renewable biofuel.

Minichromosomal technology: Minichromosome is a small structure contained in a cell. The minichromosome includes very little genetic material but can hold a quantity of information. Agricultural geneticists can add dozens of traits to a plant using minichromosomes. These traits can benefit a plant with drought tolerance and nitrogen usage. Minichromosomal technology does not alter the plants genes in any way. Resulting in faster regulatory approval and a quicker acceptance by farmers. This technology provides a way to add genes to a synthetic chromosome in a sequential manner. Telomere shortening, united with the introduction of site-specific recombination, which is when two molecules of DNA exchange pieces of their genetic material with each other, has proven to be an easy method to produce minichromosomes (Len Calderone, 2020).

Cellular agriculture: Cellular agriculture is the direct production of agricultural products from cells (Agronomics, 2022). It is the production of animal-based products from cell cultures rather than directly from animals. After hunting and domesticating animals, cellular agriculture looks set to become the third phase of human sourcing of animal protein (Memphis Meats, 2020).

Antibiotics: Antibiotics are widely used in healthy food-producing animals to promote growth and prevent disease. This practice contributes to the emergence and spread of resistant bacteria in both animal and human populations (Farmhealthonline, 2022).

Vaccines: Vaccination protects the welfare of farm animals by preventing or reducing disease, which in turn reduces the pain and suffering often associated with illness. Healthy animals are also the cornerstone of healthy food and so vaccination can help safeguard our food produced from animals. The animal medicine sector works to provide farmers with the range of vaccines they need to protect the health and welfare of their animals. These vaccines are licensed and produced under strict regulatory conditions ensuring their safety, efficacy, and quality (NOAH, 2017).

Plant and animal breeding: Scientists and farmers use selective breeding to improve the characteristics of plants and animals. This includes genetic sequencing - a process which allows scientists to determine the precise sequence of DNA nucleotides for a living organism (BBC, 2022).

Pest resistant crops: Pest resistant crops, have been genetically modified so they are toxic to certain insects. They are often called Bt crops because the introduced genes were originally identified in a bacterial species called Bacillus thuringiensis (Genewatch, 2022).

Nutrients supplement: Founded on the need for a more simple and effective means of ensuring animals have what they need when they need it, the complete range of feedblocks, powdered minerals, and mineral and feed buckets have been specially designed to help address the wide range of production challenges faced by beef, sheep, and dairy farmers at different times of the year (Carrs Billingon, 2021).

Abiotic stress resistance: Abiotic stresses, such as drought, submergence, salinity, and low temperature.

Industrial strength fibers: Lignocellulosic agricultural byproducts are a copious and cheap source for cellulose fibers. Agri-based biofibers have the composition, properties and structure that make them suitable for uses such as composite, textile, pulp and paper manufacture. In addition, biofibers can also be used to produce fuel, chemicals, enzymes and food. Byproducts produced from the cultivation of corn, wheat, rice, sorghum, barley, sugarcane, pineapple, banana and coconut are the major sources of agri-based biofibers. This review analyses the production processes, structure, properties and suitability of these biofibers for various industrial applications (Reddy and Yang, 2005).

Advantages:

- Higher crop yield
- Higher Protection of Crops
- Increased Nutritional Value
- Enhancements in Food Production Processes
- Better Flavors
- Fresher Produce/ Increased Shelf-life
- Benefits to the Environment
- Improvements in Developing Countries (Ahsen Soomro, 2022)

Disadvantages:

- Allergens and Toxins
- Antibiotic Resistance
- Potential of ‘superweeds’
- Gene Escape
- Effect on ‘non-target species’
- Insecticide Resistance
- Loss of Biodiversity in Organisms
- Food Labels
- Suicide Seeds (Ahsen Soomro, 2022)

Successful **commercial examples:**

- Agronomics Limited Company (UK) https://agronomics.im/
- Lifeasible Company (USA) https://plant.lifeasible.com/
- Carr's Billington Agriculture Limited Company (UK) https://www.carrs-billington.com/
- GWF Nutrition Company (UK) https://www.gwfnutrition.com/
- NOAH Company (UK) https://www.noah.co.uk/

Category 7: **Soilless controlled-environment farming**

Controlled-environment agriculture (includes indoor agriculture and vertical farming) is a technology-based approach toward food production. Its aim is to provide protection from the outdoor elements and maintain optimal growing conditions throughout the development of the crop. Production takes place within an enclosed growing structure such as a plant factory or greenhouse (Ting, et al., 2016).

Vertical farming is the practice of growing crops in vertically stacked layers. It often incorporates controlled-environment agriculture, which aims to optimise plant growth, and soilless farming techniques. Vertical farms can use soil, but most utilise hydro, aero, or aquaponics (Gerrewey et al., 2022). These methods use much less water than typically used in soil. Hydroponics replaces soil by using a circulating water and nutrient mix for plant growth (Prayoga and Putra, 2020). Aeroponics uses an open membrane and water mist spray with a nutrient mix. Aquaponics uses hydroponics and aquatic ecosystems to balance nutrients in both systems (Al-Kodmany, 2018). Growing medium (e.g., rockwool, coir, perlite, etc.) for some plants only needs to be changed once a year. Some common choices of structures to establish vertical farming systems include buildings, shipping containers, tunnels, and abandoned mine shafts. As of 2020, there is the equivalent of about 74 acres of operational vertical farmland in the world (Terazono, 2020). Current applications of vertical farming combined with other state-of-the-art technologies, such as specialised LED lights, have resulted in over 10 times the crop yield than would receive through traditional farming methods (Benke and Tomkins, 2018). Countries, such as Japan, Singapore, China, Holland, Sweden, South Korea, Canada, Italy, U.S, United Arab Emirates, and the UK are largely growing different types of crops in vertical farms (Kalantari et al., 2018).

The development of vertical farming includes three phases:

Phase 1 (current phase). For leafy greens and herbs, such as lettuce, microgreens, kale, basil, chives, mint, and strawberries. It is already technologically and economically viable. Leafy greens, such as lettuce, do not require much light to grow as they are made of around 95% water. Phase 1 is very successful in Japan and Singapore at present.

Phase 2. For vegetables, fruits and roots, it requires 2.5 times more energy per kilo than phase 1. It can be viable in some countries where they do not have enough sunlight, producing these vegetables locally is difficult and expensive, have less farmland, and/or energy cost is relatively lower).

Phase 3. For Staple Crops (e.g., rice and wheat), nuts, and Tree fruits. This phase will have the greatest global impact (the largest provider of global human calories), but it is also the hardest to achieve for this technology. Current production of these crops already benefits from a massive economy of scale and have small profit margins. They are also classed as commodities, as such, there is little benefit from the high-quality product that vertical farms can achieve. Staple crops store well, thus neutralising the freshness value that vertical farms provide. Additionally, staple crops are generally tall, which hurts the growing density advantage of plant factories. However, the biggest barrier of all is the 30 times greater energy requirement compared to leafy greens (Phase 1) (Despommier, 2020).

In order for vertical farming to have positive impacts on the world, it needs to be technologically feasible, environmentally sustainable (or at least better than current practices) and economically viable. While this industry is still in its early phase, from a technological standpoint, vertical farming works. It has been successfully commercialised in Japan and Singapore, especially in planting leafy greens and herbs. However, “one size does not fit all”. Different geographies and locations, such as Devon, require site-specific research and customisation. Paignton Zoo in Devon has already set up a VF to grow herbs, leaf vegetables and fruit as food for its animals.

Advantages:

- Localisation (support local economy, increase employment rate, reduce transportation and logistics cost, etc.)
- Increasing space use efficiency (farmland is shrinking all over the world)
- Resistance to weather (e.g., undesirable temperatures, rain, monsoon, hailstorm, tornado, flooding, wildfires, and drought) and year-round production.
- Traceable for customers (food transparency: where does it come from, check the nutrition–how many/what/when fertiliser has been used).
- Traceable for farmers (data about yield, crop value, full control over how much you grow and where, etc.).
- Water efficiency: circulatory system (can be with or without fish farm), can save up to 90% water consumption.
- Nutrients efficiency: cannot be flushed away by rain or flood or sink into soil. Plants get all their nutrients in liquid form, every detail of every single nutrient is exactly controlled.
- None or very little pesticide usage, since crops are planted in a soilless controlled environment. So it reduces water and soil pollution (Kalantari et al., 2018; Abdullah et al., 2021).

***Disadvantages*:**

- Electricity: power consumption is high.
- Availability of talent requires people with high level of skills to implement the technology.
- Finance support (globally): high start-up costs.
- Needs crop insurance support like traditional farming (Kalantari et al., 2018; Abdullah et al., 2021).

*Successful **commercial examples** of vertical farming**:***

- Jones Food Company (Europe's largest vertical farm) (UK) https://www.jonesfoodcompany.co.uk/
- Sky Greens (Singapore) https://www.skygreens.com/
- Veggitech (UAE) https://www.veggitech.com/
- Mirai Company (Japan) https://miraigroup.jp/en/
- VertiCrop (Canada) https://verticrop.com/?page_id=8

Category 8: **Light and heat control**

"Light and heat control" can use LEDs to produce very precise wavelength in order to control crops' size, shape, growth speed, etc. Since there are no seasons in controlled environment farming, many plants can be harvested 3 or 4 times a year. Intensive lighting regimes have shown that it is possible to create, under extreme conditions, eight harvests a year of wheat.

Light powers photosynthesis in plants, and controlling light therefore has a direct impact on agricultural production. The ability to mass produce LEDs with different light frequencies has revolutionised undercover cropping, changing the economics of production and enabling a much greater range of plants to be produced in vertical farms. Light also impacts on many underpinning biological processes, including those that influence plants' ability to manage drought stress and resist pests, providing new targets for breeding and innovation (Agri-Tech-e, 2022).

Advantages:

- Healthier plants (Cindy, 2019)
- Fast harvest cycle (Titanledus, 2019)
- Targeted wavelength
- Environment friendly and environmental safety
- Enhanced lifespan/cost saving (Qudos-group, 2022)
- Energy efficiency and saving
- Cooler operating temperature

- Full spectrum
- Durability and performance
- Common applications (Titanledus, 2019)

Disadvantages:

- Costly (Cindy, 2019)
- Direct light and cover a smaller area (Currey, 2017)
- Sensitive to heat (Titanledus, 2019)
- Less effective with age

Successful **commercial examples:**

- Greenforges Company (France) https://www.greenforges.com/
- Titanledus Company (USA) https://www.titanledus.com/
- Qudos-group Company (UK) https://qudos-group.co.uk/
- Freightfarms Company (USA) https://www.freightfarms.com/
- Rutronik Company (Germany) https://www.rutronik.com/

Category 9: **Agriculture Sensors**

The key element of the IoT is sensor. It determines the success of IoT application in agriculture. All agriculture data must be picked up by sensors, and then can be stored, transferred and analysed, so as to gain the data, knowledge and understanding of the situation of the agriculture product. There are many different kinds of sensors regarding to picking up and processing different information of different things. Agriculture producers can adopt different sensor according to the need of agricultural production. The following are some commonly used in agricultural production (Fizza et al., 2022; Gsangaya et al., 2020; Xue and Huang, 2021; Kiani and Seyyedabbasi, 2018; Navulur et al., 2017; et al., 2022).

Location sensors can determine latitude, longitude and altitude of any position within required area. They take help of GPS satellites for this purpose.

Optical sensors use light in order to measure properties of the soil. They are installed on satellites, drones or robots to determine clay, organic matter and moisture contents of the soil.

Electro-chemical sensors help in gathering chemical data of the soils by detecting specific ions in the soil. They provide information in the form of pH and soil nutrient level (e.g. nitrogen, carbon, and organic matter)

Mechanical sensors are used to measure soil compaction or mechanical resistance.'

Dielectric soil moisture sensors measure moisture levels by measuring dielectric constant of the soil.

Air flow sensors are used to measure soil air permeability. They are used in fixed position or in mobile mode. The desired output is the pressure required to push a predetermined amount of air into ground at a prescribed depth. "

Animal sensors are used to collect and process the data of animal. Cattle can be outfitted with internal sensors to keep track of stomach acidity and digestive problems. External sensors track movement patterns to determine the cow's health and fitness, sense physical injuries, and identify the optimal times for breeding. Others use miniature sensors that measure bee movements in commercial honey hives.

Advantages:

- They are invented to meet increasing demand of food by maximizing yields with minimum resources such as water, fertilizers and seeds. They fulfill this by conserving resources and mapping fields (Pantheon, 2012).
- They are simple to use and easy to install.
- They are cheaper.
- In addition to agricultural use, they can also be used for pollution and global warming.
- They are equipped with wireless chip so that they can be remotely controlled (Renkeer, 2021).

Disadvantages:

- Smart farming and IoT technology require continuous internet connectivity. This is not available in developing countries.
- There is presumption in the market that consumers are not always ready to adopt latest IoT devices equipped with agriculture sensors.
- The basic infrastructure requirements such as smart grids, traffic systems and cellular towers are not available everywhere. This further hinders the growth of its use.
- If there are faulty data processing agriculture sensors then it will lead to the situation where the wrong decisions are taken (Riyo, 2019).

*Successful **commercial examples** of agricultural sensors:*

- allMETEO Company (USA) https://allmeteo.com/
- Renke Control Technology Co.,Ltd. (China) https://www.renkeer.com/about/
- Sensoterra Company (USA) https://www.sensoterra.com/
- Seeedstudio Company (China) https://www.seeedstudio.com/
- COWLAR Company (PAKISTAN) https://www.dairy.cowlar.com/

Category 10: **Soil technology**

Huge benefits can be achieved through soil technology, leading to a more sustainable environment that is resilient in the face of changing land use, climate change and extreme weather events (Jacqueline Hannam, 2017). Reconstructed Soils from Waste (ReCon Soil) is a University of Plymouth led project working with partners including Cornwall College and the Eden Project to examine how to divert 60 million tons of soil away from landfill by repurposing them for commercial and agricultural/ horticultural re-use (University of Plymouth, 2022).

Soil technology aims at soil health, and regenerative and restorative agriculture. Regenerative agriculture practices primarily aimed at boosting yields (e.g., agroforestry, which integrates trees and shrubs on farmland, and can sequester carbon in soils and vegetation as a co-benefit) and/or practices aimed at regenerating lands that no longer produce food (e.g., reforestation, peatland restoration, riparian buffer zones) (Ranganathan et al., 2020).

Regenerative farming is a system of producing food and biomass that focuses on building functional biodiversity and soil health to produce consistent yields without relying on synthetic inputs (herbicides, pesticides, and chemical fertilizers). Despite growing interest in regenerative agriculture, there is no centralized “official” definition because regenerative agriculture is not a static state. Rather, regenerative agriculture is a journey that involves fundamentally changing our perspectives about nature and agriculture – in short, a shift in our mindset.

Although regenerative agriculture has no universal definition, the term is often used to describe practices aimed at promoting soil health by restoring soil’s organic carbon. The world’s soils store several times the amount carbon as the atmosphere, acting as a natural “carbon sink.” But globally, soil carbon stocks have been declining as a result of factors such as the conversion of native landscapes to croplands and overgrazing. One goal of regenerative practices is to use some of the carbon that plants have absorbed from the atmosphere to help restore soil carbon (Louisa Durkin and Andrew McCue, 2021).

Practices grouped under regenerative agriculture include no-till agriculture — where farmers avoid plowing soils and instead drill seeds into the soil — and use of cover crops, which are plants grown to cover the soil after farmers harvest the main crop. Other practices include diverse crop rotations, such as planting three or more crops in rotation over several years, and rotating crops with livestock grazing. Sometimes any practice that involves reduced fertilizer or pesticide use is considered regenerative agriculture.

Advantages:

- Good for soil health and have environmental benefits .
- No-till reduces soil erosion and encourages water to infiltrate soils (although it can require greater use of herbicides).
- Cover crops can also reduce water pollution.
- Diverse crop rotations can lower pesticide use.
- Increase grasslands, vegetation and protect water sources (Louisa Durkin and

Andrew McCue, 2021).

- Feed the world
- Decrease GHG emissions
- Reverse climate change
- Improve yields
- Create drought-resistant soil
- Revitalize local economies
- Nurture biodiversity
- Improve nutrition (Regenerationinternational, 2022)

Disadvantages:

- Costly
- Lack of practical knowledge the farmers cannot handle the practices properly.
- While the cost of maintenance is very high.
- Overuse of machines may lead to environmental damage.
- It is efficient but has many side effects and drawbacks (Riyo, 2019).
- Farmers will need to acquire new knowledge and skills
- Less tilling may lead to more unwelcome plants
- Some farmers compensate by increasing their use of herbicides
- Potentially lower yields, dependent on crop and local conditions
- The transition away from conventional methods will take time (Eitfood, 2020)

*Successful **commercial examples** of soil technology**:***

- Continental Soil Technology Company (UK) https://www.continentalsoiltechnology.com/.
- Soil Technologies Corp Company (USA) https://www.soiltechcorp.com/.
- Stansted Environmental Services Company (UK) https://stansted-environmental.com/.
- Soiltech Company (USA) https://soiltech.net/

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