Sustainable Intensification: insights from vertical farming on the links between Diffusion of Innovation and the Business Model

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Abstract

Producing more food without further damaging the environment (sustainable intensification) is a pressing global need. While there is increasing knowledge of how agriculture may be sustainably intensified through use of technology, there is less understanding of how knowledge reaches growers, especially in a market economy.

There remains a gap in the sustainable intensification literature regarding the contribution of companies selling innovative systems and agronomic knowledge for food crops grown in three dimensions (3D or vertical farming). This thesis explores how innovative companies provide goods and services with enhanced environmental value, drawing on the interface between the business model theory and diffusion of innovation.

Through a seven-year case study analysis of the UK-based agricultural technology company Saturn Bioponics the thesis shows how the company uses technological innovation and agronomic know-how alongside effective diffusion of innovation to contribute to sustainable intensification. This study follows how the company has revised its business model by adapting its goods and services to ensure they meet customers' business objectives while minimising environmental effects.

The time frame of the case study provides insights into how the company's communications strategies and its business model have evolved, including the delivery of value for itself and customers. The CEO has morphed from an innovator into an entrepreneur and opinion leader in the national agricultural sector, showing how innovation can drive a move towards sustainability.

The case study provides a conceptual bridge between sustainable intensification, diffusion of innovation and business model literatures as my contribution to theory. In particular, I have found diffusion of innovation to be key to value generation, thus providing a foundation stone for a business model.

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List of Abbreviations

ADAS	The Agricultural Development Advisory Service
AHDB	The Agriculture and Horticulture Development Board
AGRI EIP	The Agricultural European Innovation Partnership
BASIS	British Agrochemical Standards Inspection Scheme
BBSRC	The Biotechnology and Biological Sciences Research Council
BCPS	The British Crop Production Council
BRC	The British Retail Consortium
BREXIT	British withdrawal from the European Union
CAP	Common Agricultural Policy of the European Union
CEO	Chief Executive Officer
CGIAR	Consultative Group on International Agricultural Research
CPD	Continuous professional development
CTO	Chief Technical Officer
CGIR	Consultative Group on International Agricultural Research
EPI	European Partnership Innovation
EU	European Union
FACTS	Fertiliser Advisers Certificate and Training Scheme
FAO	Food and Agriculture Organisation of the United Nations
FYM	Farmyard manure
Global-GAP	Good Agricultural Practice
HSE	Health and Safety Executive
IPM	Integrated pest management
KTN	Knowledge Transfer Network
LEAF	Linking Environment And Food
LED	Light emitting diode
MRL	Maximum residue level
NGO	Non-governmental organisation
NFU	National Farmers Union
PLAID	Peer learning accessing innovation through demonstration
PO	Producer Organisation
R & D	Research and development
SME	Small & Medium Enterprises
SBRI	Small Business Research Initiative
SDSN	United Nations Sustainable Development Solutions Network
UK	United Kingdom of Great Britain and Northern Ireland
UKRI	UK Research and Innovation
VFS	Vertical farming systems
WBCSD	World Business Council for Sustainable Development
3D farming	Three-dimensional farming

Chapter 1 Introduction

Ways of contributing to solutions for the challenges of producing sufficient food for burgeoning populations, which are expected to increase by 34 per cent by 2050, are being sought across the world (IPCC, 2019, FAO, 2009).

Over the next fifty years the world population is widely predicted to increase (Beddington, 2009, Godfray et al., 2010, Frediani, 2011, Godfray and Garnett, 2014, Tscharntke et al., 2012, Garnett et al., 2013, Defra, 2014). This will bring challenges for both producing sufficient quantities of food and distributing them in an equitable form, ensuring they are available where they are needed. Not only is there is a challenge in growing food, any increase in crop yields will need to be achieved with minimal damage to the environment. As a result, Governments and NGOs are seeking ways of finding a more sustainable form of providing food (Godfray et al., 2011, Sutherland et al., 2015, Pretty and Bharucha, 2018).

It is generally agreed that sustainability is about is making the most of environmental goods and services while not degrading them so future generations are unable to benefit from them and is "Development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland, 1987pp 8-9). In addition, work to implement sustainable development is being done on land use and food production is being supported by the United Nations' Sustainable Development Solutions Network (SDSN, 2013) and the Montpellier Panel (2013).

The challenge is, therefore, the need to increase food production at the same time as minimising environmental impacts. This need has led to development of the concept and guiding principle of sustainable intensification, which is defined as a "process or system where yields are increased without adverse environmental impacts and without the cultivation of more land" (Pretty and Bharucha, 2014b p.3). It was first coined around the time of the Earth Summit of Rio in 1992 by the World Business Council for Sustainable Development (WBCSD) (Tittonell, 2014) and the term is now also widely employed in the agribusiness world and by large international donor organisations, although its broad definition has led to variations in interpretation (Pretty and Bharucha, 2018).

Sustainable intensification is closely associated with the concept of eco-efficiency, or producing more value with less impact, and has been widely adopted by international research and policy organisations such as the Consultative Group on International Agricultural Research (CGIAR), the Food and Agriculture Organisation of the United Nations (FAO) and the World Economic Forum (Davos, 2012).

These activities are complemented by national policies in some developed countries, such as the ‘Feed the Future’ program of the US Government. Defra’s sustainable intensification platform (siplatform.org.uk) and the Biotechnology and Biological Sciences Research Council (BBSRC) both support research about sustainable intensification.

There are, however, challenges to the concept of sustainable intensification, as there are no set goals to measure economic efficiency nor environmental sustainability (Godfray and Garnett, 2014, Godfray, 2015, Pretty et al., 2018, Dicks et al., 2019). This is partly because providing public benefits, such as environmental benefits, does not create a monetary value, which may make it difficult for companies to provide optimal allocation of such goods (Maréchal et al., 2018) and this may impact on the business model, as discussed below.

Innovation and technology arguably provide an important means for increasing output (Godfray et al., 2011), which should be measured together with environmental markers to preclude it leading to exploitation of the system by commercial organisations marketing biotechnologies, pesticides and fertilisers without the necessary green credentials.

There are also concerns that climate change will make sustainable intensification more difficult (Beck, 2013), and there are challenges to be overcome. For example, higher temperatures may increase the time-span when pests are active so they may be able to have a greater number of populations in one year, which can lead to faster development of resistance to pesticides. In addition, as the crops will need to be protected for longer, greater use will be made of pesticides, which can result in environmental issues. Higher rainfall will result in greater risk of nitrogen and pesticides leaching from the soils and contaminating water courses. These issues are all likely to impact on the environment, affecting food security (IPCC, 2014), and on drinking water availability.

One of the proposed methods for addressing such challenges is with indoor growing, as facilities can be designed with closed systems for nutrients and water, allowing for with more precise use of inputs and therefore reduce some of the environmental impacts of growing crops (Manos and Xydis, 2019), but the key question is whether there is a market for them.

While intensification is generally accepted to be connected to productivity (including yield and/or food nutrient levels) per unit of land area, the definition of the term ‘sustainable’ has been the subject of much debate from a broad spectrum of perspectives. In the agricultural context, sustainability is made up of three dimensions: environmental, social and economic (Struik and Kuyper, 2017).

Environmental sustainability comprises a broad spectrum of attitudes regarding ‘weak’ and ‘strong’ sustainability. In the former, natural and man-made capital are combined, with importance being given to the total availability, whereas natural capital is non-negotiable for strong sustainability (Neumayer, 2007). This is particularly relevant to this study because 3D farming uses both natural and man-made capital to provide food, and therefore arguably contributes to the social need of the well-being of the population. Economic sustainability is also briefly discussed in this chapter, but considered in greater detail in Chapter 7.

Combining sustainability and intensification together as one umbrella concept has further challenges and there are concerns that productivity has been ranked above sustainability in the context of biodiversity and social benefits (Whitfield et al., 2015, Godfray, 2015). On the other hand, any trade-offs which result in lower productivity per unit of land could lead to more land being brought into use for agriculture (Godfray, 2015). Franks (2014) argues that the Foresight Report (Godfray et al., 2011) does not mention bringing more land into production, thus it can be deduced that food production should be optimised from the land currently under cultivation, and higher yields achieved from the same amount of land. Nevertheless, as pointed out by Dicks et al. (2019), feasibility remains a challenge for sustainable intensification; which implies that not only are there technical challenges, but also a challenge of ensuring that such businesses are able to function competitively.

Three dimensional (3D) indoor farming technology is one of the responses to a call for new methodologies (innovations) to support agricultural production (Le Gal et al., 2011) and respond to environmental challenges in the food production sector (Lin, 2011). This is because a technology which uses the vertical plane as well as the horizontal to grow fruit and vegetables (vertical or three-dimensional farming), could be part of the answer to the food production challenge. Often termed vertical farming, 3D farming is a more accurate description as the crops are grown across the horizontal and vertical planes in a greenhouse or polytunnel. This is different from growing on a wall of a building, as is done using the vertical plane in urban farming, hence in this study the method of growing crops using the three planes will be called 3D farming.

The over-arching aim of this research is to better understand the socio-economic phenomenon of 3D indoor farming in the context of suppliers of specialist equipment to the sector. This thesis is aimed at gaining a holistic view of a potential contribution towards sustainable intensification from within a start-up commercial company which has developed an innovative technical means of growing crops indoors in a three-dimensional (3D) situation. Using a long timeframe element, it explores how 3D farming can be aligned with sustainable intensification, how innovation has been diffused, and the evolution of the business model used to take the innovation to market. These three specific but interrelated research domains have not previously brought together in this context.

This thesis has added another dimension to current academic knowledge about the interactions between the different literatures to bring about sustainable outcomes.

1.1 Key questions of the study

The research question addressed in this thesis are whether a small enterprise selling equipment and expertise facilitating 3D production methods for fruit and vegetables can contribute towards a pathway to sustainable intensification, and the evolution of its entrepreneurial activities towards this goal.

The main questions for this study are:

a. What is the relationship between sustainable intensification and 3D farming in terms of companies supplying equipment for protected cropping systems?
b. How is innovation diffused by a small agricultural technology enterprise?
c. What are the features of the business model of a small agricultural enterprise offering innovative technology?

The contribution to literature will be focused on the interactions of the three core concepts: sustainable intensification, diffusion of innovation and business model literatures. This will create a holistic understanding of how a small start-up company may have the potential to contribute towards producing food without further damaging the environment.

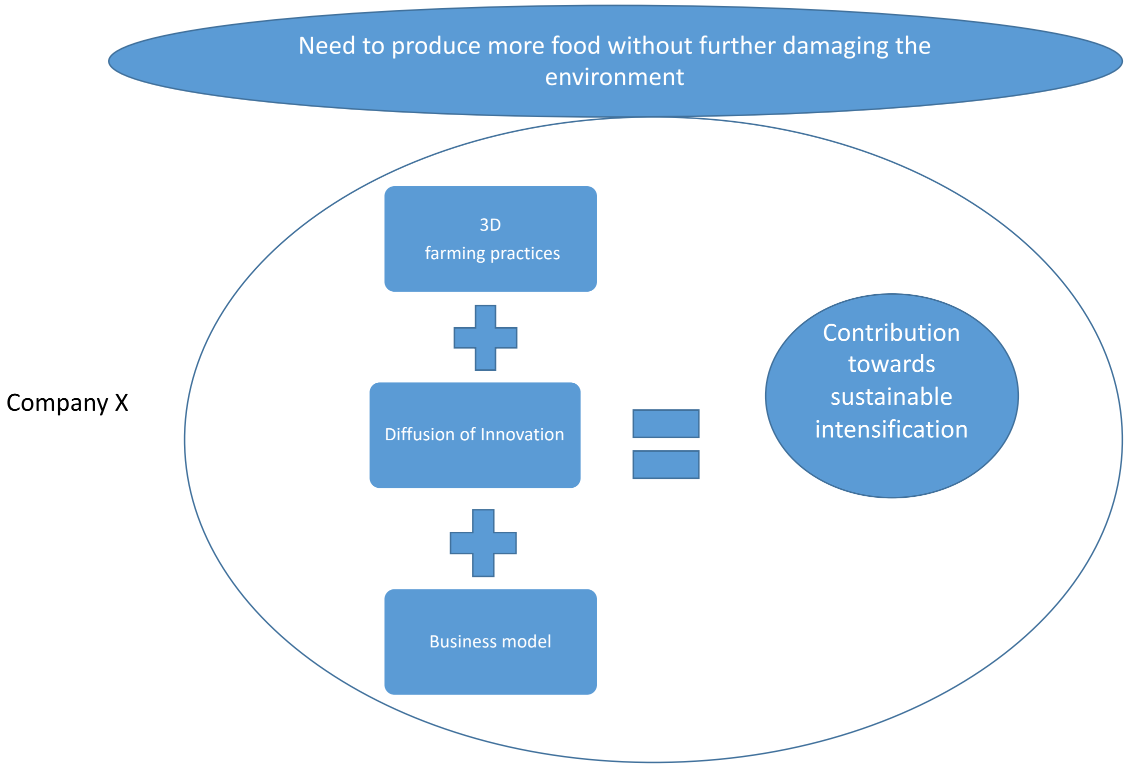

Figure 1 Combinations of concepts necessary to move towards sustainable intensification

1.2 Thesis Structure

This thesis continues as follows: The next chapter is the Literature Review, which critically appraises the literatures providing insights for the research questions. It begins with a review of sustainable intensification, then looks at diffusion of innovation and business models. This chapter identifies gaps in knowledge about the relationship between sustainable intensification, diffusion of innovation and business model evolution and how they fit together in the context of 3D farming.

Chapter 3 establishes the policy and context in which the study takes place, outlines how 3D farming works, and presents the principal actors, including the case study and other informants of the study. This is followed by Chapter 4, the Methods chapter, which introduces the research questions, and explains how the analytical framework was developed for the construction of the case study. It also describes how data collection and analysis were undertaken.

Chapters 5, 6 and 7 are the data chapters which explore the empirical findings. Chapter 5, Sustainable Intensification explains how the case study's technological innovation works before going on to explore the potential for an increase in productivity and the potential impacts of growing in this way. Highlights of this chapter include findings connected to the whole farm approach to sustainability, rather than just the area used for growing crops, in addition to eco-efficiency benefits.

This is followed by the Diffusion of Innovation chapter which analyses how a commercial 3D fruit and vegetable sector disseminates information about its innovation. Key findings from this chapter are the evolution of the diffusion strategy of the case study company, and the importance of the characteristics of the innovation from the point of view of potential adopters.

Chapter 7 explores the evolution of the business model of the case, how it creates value and reacts to the early adopter inputs for the innovation to ensure customer's perceive the value of the offering. Two of the key areas explored in this chapter are the evolution of the company's business model and its relationship with eco-efficiency.

Chapter 8 revisits sustainability and cost efficiency, and how diffusion of innovation informs empirical decisions concerning the business model. The main focus is on insights and reflections about the interactions of the three literatures and how they may contribute to a conceptual perspective with an interconnection of value at the centre. This provides an integrated framework which can be used for future studies.

Chapter 9 discusses the theoretical contribution of the study, and the potential for future research. It also proposes considerations for policy makers seeking to support and promotes promote agri-tech innovations. The chapter closes with reflections on the interdisciplinary nature of sustainable intensification, and how this can contribute to a wider adoption of these principles.

Chapter 2 Literature Review

2.1 Introduction

The purpose of this chapter is to critically review the existing academic and practitioner literatures relating to key perspectives of sustainable intensification, diffusion of innovation and business models in the context of 3D (vertical) farming. It seeks to inform understanding of the roles of diffusion of innovation and business models to a pathway towards sustainable intensification in the agri-food sector.

2.2 Sustainable Intensification

A growing world population is contributing to competing demands on a finite agricultural land area (Godfray et al., 2011). Providing sufficient food to feed a growing population is considered a ‘wicked problem’ because food production needs to increase but there needs to be consideration for future generations.

Producing more food may entail expanding the amount of land dedicated to agriculture or by increasing yields per unit of land. This could be through raising cropping intensity (such as growing more crops per unit of land) or ensuring crops receive inputs which help address growth limits, such as water or nutrition. Previous periods of intensification (such as the Green Revolution) have resulted in overall food production outpacing population increases since 1960 (Pretty, 2008). This is mainly thanks to the development of better-performing crop varieties, chemical crop protection and synthetic fertilisers. The problem is that these methods are generally considered to have compromised the environment (Pretty and Bharucha, 2014b), hence a search for alternative ways which reduce this damage and are more sustainable (Pingali, 1995). There are calls for sustainable intensification, which is defined as “a process designated to achieve higher agricultural yields whilst simultaneously reducing the negative impact of farming on the environment” (Godfray, 2015 p199). The basic principles of sustainable intensification as defined by Pretty (2008 p451) are "Using natural, social and human capital assets, combined with the use of best available technologies and inputs (best genotypes and best ecological management) that minimize or eliminate harm to the environment, can be termed sustainable intensification” and these are widely accepted. Considered by some to be a paradigm shift (Dicks et al., 2019), the concept of sustainable intensification has matured and divided into three categories: practical actions, approaches and scale (Weltin et al., 2018).

How sustainable intensification can be achieved has stimulated discussion on how some of the challenges should be addressed. For example, while Struik and Kuyper (2017) stress the importance of resource availability and its impact on productivity, there are disagreements around benefits and pitfalls of land sharing or land saving. Loos et al. (2014), argue for assessments of the long-term impacts of intensifying food production, yet Balmford et al. (2018) contend that the externalities from lower-input farming are often not accurately assessed. Indeed, Balmford et al. (2018) found land-efficient farming systems to have lower externalities per unit area in the areas of Asian paddy-fields, European wheat, European dairy and Latin American beef sectors. This implies that high density farming, such as 3D farming, using precision-applied pesticides, could fit in this scenario. However, would not necessarily apply to all agri-food production sectors, particularly those undertaken at broadacre level with high pesticide usage.

Environmental sustainability is related to natural capital, which comprises services that provide elements essential to life support (such as environment, water, clean air), supply raw materials, assimilate waste, and deliver ecosystem services (Ekins et al., 2003). Other types of capital are man-made capital, which includes factories and machinery, and human capital, which concerns knowledge.

Sustainability may be perceived as being either strong or weak; proponents of strong sustainability believe that the components of critical natural capital are non-substitutable with the other forms of capital, whereas weak sustainability permits their substitution (Dietz and Neumayer, 2007, Ekins et al., 2003, Brand, 2009). Blignaut et al. (2014) see the need for technologies capable of supplying the means of production and investing in restoration of natural capital as fundamental to sustainability. These concepts relate to the study because they provide a primary understanding of sustainability and a practical understanding of how sustainability is interpreted and implemented in the commercial sector is important to any study in the agri-food sector. Sustainability can provide social benefits, but given their speculative nature, the decision was taken to focus on environmental benefits.

Adoption of technological change to improve resource use efficiency could prove to be one of a number of practical approaches towards a pathway to sustainable intensification. Growing indoor crops using the vertical plane (3D growing) to achieve increased output per unit of area while taking measures to protect the environment is one example that is gaining increasing interest and uptake in academic and commercial sectors (Touliatos et al., 2020).

Tilman et al. (2011) note that one of the challenges of studying the concept of sustainable intensification is the lack of guidance on how it can be achieved, such as indications of which technologies or organising principles should be used. This indicates a need to revisit what sustainable intensification means to practitioners to build on what is already known about the concept and how they use innovation and technology to put it into practice. To drive better understanding of the holistic concept of sustainable intensification, this review now examines these two components and how literature guides identification or markers of sustainable intensification.

2.3 Measuring sustainability

Sustainability indicators are tools which facilitate measurement of progress towards environmental and social objectives (Reed et al., 2005). To provide practical guidance, they need to be independent and robust (Perales et al., 2019) in the context in which they will need to work. Decisions guiding which sustainability indicators to use depend on their relevance to what is being assessed and their context; those aimed at arable and livestock farming differ widely. Measurement of capital stock is complex, and some, such as Dietz and Neumayer (2007), advocate integrated environmental and economic accounting. As yet there is no guidance for 3D farming, hence it is necessary to understand those which are applicable to other areas of farming to provide an initial framework which can be adapted.

Measuring sustainability can be problematical because while it can include elements which are measurable (such as pesticide usage), there are also subjective components, particularly those with social elements. For example, Pretty (2008) highlights difficulties with putting a value on trust, social connections, human capital innovation and landscapes. There are, therefore, a range of social sustainability impacts, but given the difficulty in obtaining such evidence, it was decided to exclude them from the scope of this research project.

Current assessment tools work at different hierarchical levels (de Olde et al., 2017), going from the abstract to specific themes and indicators. Such complexity brings challenges; there are concerns about the validity of conclusions that can be obtained from such a wealth of variables. To address this, Firbank et al. (2013) suggests using a simple method that encompasses a small number of variables placed under group headings rather than trying to assess them all individually. These comprise measures taken from five ecosystem services: biodiversity, air quality, climate regulation, water quality and agricultural production. While all these different ways of measuring provide important information and feedback to those working to improve sustainability, it is important to ensure that they are also comprehensible for the providers of food and their work in practice.

As this thesis is focused on sustainability at farm (micro) level, it is important to use a tool that is relevant to this level. Gunton and Firbank (2016) have categorised four alternative versions of sustainable intensification: agronomic efficiency, agronomic sustainability, global efficiency and global sustainability. As the former two are key to farm level, they provided a guide for the framework and facilitated following the methodological approach indicated by Reed et al. (2005) of establishing context, identifying indicators and collecting data.

Optimisation of resource use to achieve better efficiency at farm level (Pretty and Bharucha, 2018), also contributes to sustainability, suggesting a need to include context of new technologies such as hydroponics in an indoor growing system. This way of producing crops contributes to averting use of unnecessary inputs, minimising greenhouse gases and more effective use of clean water. However, while some environmental benefits, such as input use, are easy to measure, others are more difficult. For example, terms such as 'pest avoidance' and whether it consists of treating pest infestations only when they have occurred or whether a prophylactic (preventative) approach may be better can impact on the farm's environmental impact, but are more difficult to quantify. Such questions can make an assessment of whether the resource use of a farming enterprise – including nutrients, water, labour, pesticides, etc. – is optimal, and aligns with agricultural economics literature. This connection is not explored in this thesis due to practical difficulties of obtaining confidential agronomic records and commercial price information.

There are some components normally connected with sustainability which are not compatible with indoor 3D farming. Pretty (2008) draws attention to the importance of integrating biological and ecological processes such as nutrient cycling, nitrogen fixation, soil regeneration, allelopathy (changes in plant growth as a result of chemical interactions among plants and other organisms) and competition with other plants. However, much of this is not relevant when considering protected crops because of the indoor environment. Soil quality, one of the major challenges of field-based agriculture is not considered in this study because the crops are grown hydroponically on a substrate. However, other important elements specified by Pretty (2008), such as nutrient management, water management and integrated pest management, have been drawn on as part of the framework for this study.

Farmer values and attitude towards sustainability may play a role; their understanding of what sustainability means may vary including what they consider the problem to be and the challenges in overcoming them (Garnett and Godfray, 2012), and any costs they may have to pay themselves. As a result, prioritisation of objectives may vary from farmer to farmer according to their perception of viability of the practices necessary for sustainable management. In many cases, economic appraisals underestimate or even deny the environmental risks (Silvasti, 2003), following the ‘productionism approach. Context, in terms of the industry sub-sector can make a difference in attitudes towards sustainability (Coteur et al., 2016, Silvasti, 2003), and Coteur et al. (2016) found those growing in the protected crop industry to be more sustainability focused. More recently, Dicks (2019), in work exploring benefits to productivity and the environment in the context of UK farming, has focused on practices advocated in the Integrated Farm Management elements developed by Linking Environment and Food (LEAF) (2018). Its criteria are valuable for this study because they are practical and possible to implement at commercial level. They include the whole farm and not just the proportion under cultivation and Dicks et al. (2019) has found them useful for assessing whether the principles of sustainability are being met while intensifying production. These finding have implications for the land saving/sharing debate referred to by Loos et al. (2014) because attention is on the whole-farm. When this study commenced there had been little published in academic literature on the standards developed by LEAF, but they have since become more prominent from the studies by Dicks et al. (2019) and Perales et al. (2019). This has vindicated the choice of their use as an important focus for this thesis.

2.3.1 Measuring food production intensification

Measuring the extent of intensification of food production can be complex and while some prefer either yield gap analysis or land-use analysis (Dietrich et al., 2012), the most common metric for measuring intensification remains relatively simple: yield per unit of land (Smith et al., 2017). From a practitioner point of view, marketable yield (which is the produce which is of sufficient quality to be deemed to comply with customer specifications), rather than total yield or biomass, needs to be considered as it is deemed crucial for professional growers as otherwise produce can be rejected.

Studies undertaken at a micro level have shown farmers in temperate zones such as the UK are already increasing levels of productivity (Firbank et al., 2013) through the use of precision farming. This type of production uses technology such as modern sprayers and tractors with IT systems on board to facilitate application of tailored inputs where they are needed, lowering the risk of over-application, run-off and subsequent environmental damage (Firbank et al., 2013). However, other studies have found little consistency in uptake (Rose and Chilvers, 2018), despite increasing knowledge about specific technologies, partly in response to the UK Government's AgriTech policy (see Chapter 3 Policy Context) and better understanding of environmental impacts of different forms of agriculture. This is because there remains a lack of understanding of how good practice using innovations developed by private companies might be shared effectively amongst commercial growers in a market economy. To address this challenge, there is a need to understand how Diffusion of Innovation of such technologies may be taking place (see 2.3 below).

Sustainable intensification on a macro scale can only be achieved by numerous farms contributing towards higher production without compromising the environment. This will entail greater efficiency within different aspects of agronomy and growing systems; for example waste, which may be from quality and customer specification issues, mechanical damage or over production can be significant and in some crops can reach 30 per cent (Flood, 2010). Despite the challenges, progress has been reported in both developed and developing countries as shown by a study of 286 farm-level projects undertaken by Pretty and Barucha (2018). This may be linked to eco-efficiencies which may help growers receive higher returns, some of which are criticised as not being true sustainability, as discussed below, but also form a link to the business model as used in the sector, discussed in 2.4.1 below.

2.3.2 Working towards sustainable intensification in practice

To achieve substantial improvements in productivity, agricultural systems have to be devised to optimise growing conditions and make the most efficient use of inputs (Pretty and Bharucha, 2014b) and perhaps also make use of any underutilised land (Weltin et al., 2018) which could be brought into production with the use of greenhouses or polytunnels. Digitalisation is transforming agriculture (Fielke et al., 2019) and a shift towards product innovation for farming has been observed, using technology such as satellites, drones, weather stations, tools to measure soil moisture deficits, amongst others. Innovative ways of sustainably intensifying food production may lie in part with suppliers of agricultural equipment (Konig et al., 2012) particularly when innovations are in areas that may lead to optimum growing conditions. This study was influential in the choice of case study because the potential contribution of indoor 3D farming technology is through the use of technology to provide optimum conditions for productivity in addition to those provided by using the vertical plane.

In this context, innovation emerges as critical to developing new combinations of technology and resources, such as those for the 3D farming sector, for maximising outputs of already existing resources. However, because of a potential relationship between efficiency, the environment and commercial needs, there are criticisms that such efficiencies may merely be ‘low-hanging fruit’ (Young and Tilley, 2006) which will continue to facilitate a productivist regime (Maye, 2018) and can lead to path dependency (Sutherland et al., 2012). Pretty (2008) emphasises that idealistic principles should fulfil the role of increasing production without further damaging the environment. This may be deduced to relate to weak sustainability (Dietz and Neumayer, 2007), in which natural capital is seen to be interchangeable with man-made capital (e.g. greenhouses) and human capital (knowledge), and hence providing background understanding for this study which uses natural and man-made capital together (technology and greenhouses) as a means of producing fruit and vegetable crops. In a commercial market economy, the companies providing such goods and services still have to make a profit, which connects to the Business Model paradigm discussed below in 2.4.

The concept of vertical farming (Touliatos et al., 2016), has the potential for higher yields, and therefore may provide a means for achieving a higher degree of intensification. This type of farming is usually undertaken indoors in glasshouses (greenhouses) or polytunnels or it can be on buildings (retro-fitted or specially constructed) and therefore the crops grown are less dependent on the weather. Plants can be grown in modules which have a growing medium inserted rather than soil (hydroponic), which allows for greater precision when applying nutrients and plant protection products than when done outside. For example, Despommier (2010) proposes a concept of vertical farming which is stacking high-tech greenhouses on top of each other and claims a number of benefits, including higher productivity as crops can be grown throughout the year, reduction in water use, reduced use of pesticides and herbicides. A weakness in the theory proposed by Despommier (2011) in his promotion of vertical farming is the lack of insight on how organisations can achieve these benefits by adopting the technology or evidence to show the farming technique fulfils the claimed advantages. Hence there are challenges about the validity of these claims

(Specht et al., 2013, Specht et al., 2015, Thomaier et al., 2014). This indicates space in academic understanding of how vertical – or 3D – farming is working in practice and how this is articulated by the companies undertaking this work. As such, there is a need to first understand the breadth of sustainability indicators described by academia to determine their relevance to this niche indoor sector and then consider their compatibility with current mainstream activities (Pigford et al., 2018) to understand whether 3D farming in practice can contribute to sustainable intensification (See Chapter 5).

2.4 Innovation, diffusion and communication

This section examines how academic research theory is contributing to the development of effective innovations within the agri-food industry and also how such innovators disseminate data about such innovations. Three main strands of literature have been critically examined, including diffusion of innovation, the innovations systems approach, and its development into Agricultural Knowledge Innovation Systems (AKIS). Each is important because they provide important background knowledge to help understand the operations of the case study.

In industrialised countries, the agricultural industry has become part of the highly competitive global supply chain (Hendrikse and Bijman, 2002, Klerkx and Leeuwis, 2008b), which has resulted in growers having to become more entrepreneurial in their actions (Sunding and Zilberman, 2001, Huylenbroeck and Durand, 2003, Klerkx and Leeuwis, 2008b), and learning more about how to market their products as well as focusing on growing them. As the agri-food system has evolved, so has innovation in the sector and it has become highly competitive, particularly in near-market sub-sectors such as fruit and vegetables. The socio-political, economic and institutional climate in which innovation occurs can help foster or discourage innovations (Klerkx et al., 2012), therefore the context in which farming and agricultural innovation plays a key role in the framing of this study because the actors are reacting to stimuli and challenges. This suggests a link between innovation and entrepreneurship, and a gap has been detected in academic literature on better understanding of other drivers of sustainable business outcomes from diffusion of innovation strategies in the private sector.

The task of persuading farmers to adopt innovations was, in the latter part of the 20th century, with agricultural extension services. Despite having been documented by the likes of Vijverberg (1996) as being effective and a good example to follow, nations such as the UK and the Netherlands no longer have them, having privatised them. This is broadly due to a global trend towards privatisation and reduction of governmental costs. Sutherland et al. (2013) report some benefits from the privatisation, noting that extensionists were often under pressure to ensure adherence to government policies and were not perceived as being in pro-farming, which raised issues of trust. However, growers are now reliant on commercial advisors and peers for information, and commercial advisors – often from large agronomy companies or agricultural chemical giants with large marketing budgets – can be under pressure to sell their company's products, leading to further questions of trust. Klerkx et al. (2017) when studying the evolution of advisory system in Norway, found three sub-systems of advisory needs of farmers; holistic, in which there was a crossover between farming and the whole environment; elitist, with consultants advising specialist producers; and public good advice, such as education. This highlights the importance of the ability of those who communicate information about innovations such as 3D farming to have the necessary specialist knowledge and at the same time be capable of building trust with potential adopters. The limitation of the scope of the Norway study Klerkx et al. (2017) is that while it focuses on coordination between actors, it does not follow commercial advisors in the private sector, possibly because Norway still has an effective institutional advisory system. Doernberg et al. (2012), whose research focused on agricultural innovations systems in Germany, questioned the extensionists' access to an extensive array of innovations. This highlights a gap in literature as there is a need for a broad base bringing together technology and commercially-sold advice.

There is wide availability of literature on farm characteristics which play a role in willingness to invest in opportunities, with large scale commercial growers being very different from those operating on a smaller scale (Stringer et al., 2020). This may be because large companies may have more expertise and available funds for innovations (Schumpeter, 1934, Avermaete et al., 2003), which can affect performance (Aspara et al., 2010). There are differences between well-established and older companies too; according to Hockerts and Wüstenhagen (2010), new companies are suggested to be more innovative when they first enter the market. This variability can make understanding uptake of innovation more complex, and calls for better knowledge of how decisions on adoption or rejection may be taken.

While theories can help inform innovating companies about their customers, there is no generally single accepted way of measuring innovation (Grunert et al., 1997, Avermaete et al., 2003); findings from empirical work do not always fit such theories about company age, size and regional performance or shifts in thinking.

Such considerations helped drive the study focus and frame the analysis of the business featured in the study, particularly as there is little information on near-market farming enterprises such as fruit and vegetable farmers.

One of the real-world challenges for new entrants to such a sector is not so much finding information about the desirable characteristics of their potential customers, but where their potential customers may be found. Certain locations may appear to hold higher numbers of acceptance of innovations in the farming sector, but studies by Daberkow and McBride (2003) found that this to be correlated with the concentration of vendors of farming technology and rather than other farming-related factors. Rogers (2003) found differences in the characteristics of early and late adopters (see Section 2.4.1). This means that adopter farmer characteristics play a role in such decisions, but results from studies are not unanimous about which ones are the most important drivers of adoption. For example, Daberkow and McBride (2003) found education to be linked to awareness but did not always lead to adoption; which could be explained by farmers having the ability to assess and reject such an advance if they decide it is not cost-effectively advantageous. Others, including Walton (2008) and Michels et al. (2020) found education to be a key characteristic influencing adoption; again this could be influenced by the evaluation of other key characteristics of the innovation such as the usefulness of the device. A study on the adoption of smart phones in the farming industry undertaken by Michels et al. (2020) found age to be another important factor influencing adoption, which may be because older people may be less willing to face a steep learning curve. Padel (2001), writing about adoption of organic farming practices, emphasises that an innovation also needs to be simple, understandable and low risk.

Generalising farming under one category may be insufficient to understand the specialised nature of the supply chain and specialised growers; Doernberg et al. (2012) indicates a need to subdivide the sectors of farming, the value chains and innovations. A gap has been identified in the need for a more nuanced and holistic view of how innovations and their communications undertaken by a company can help break path dependency and move towards adoption of agri-tech methods of growing, such as 3D farming, which may have a lower environmental footprint than current methods. As this study takes place in the highly specialist suppliers to the competitive indoor horticultural sector operating in a neo-liberal economy, this study can help fill this space.

2.4.1 Evolution of diffusion of innovation theory

Diffusion research traditions have been based around a number of different categories, including anthropology, rural sociology, communications, political sciences and agricultural economics, amongst others. One of the founders of diffusion literature was 19th century sociologist Gabriel Tarde, and a review of his work by Kinnunen (1996) emphasises his understanding that for social change to occur, innovation needs to be able to be accepted by a particular market or social group. Tarde's view was that this is achieved by the process of imitation, and his theory is mirrored in more modern diffusion literature.

The paradigm of diffusion of innovation was coined after a study by Ryan and Goss (1943) on the adoption of hybrid corn in Iowa and led to the categorisation of the characteristics of individuals who adopted a new technology and those who adopted it later. This study contributed to the establishment in Europe of agricultural extension networks after the Second World War, and rural sociology research on diffusion of innovations began because of "a need for extension officers to understand their relative effectiveness" (Rogers, 1962 p.90). In Europe, innovation systems were conceived as a policy concept in the 1960s, moving from extension services and institutional R&D to the installation of diffusion of knowledge offices and private consultancies (Klerkx and Leeuwis, 2008a, Alston et al., 1999).

Diffusion of innovation is defined by Rogers (2003 p5) as "the process in which an innovation is communicated through certain channels over time among members of a social system". His work identifies a process of passing knowledge to third parties as a means of persuading them to accept an innovation, and provides a structure that includes the attributes of the innovation, communication channels, time, adopter categories and the social system. Rogers classified adopters of innovation into Early Adopters, Early Majority, Late Majority and Laggards and this model was used for agricultural extension communications in the 1960s. Padel (2001), talking about adoption of organic farming methods, refers to three categories of adopters, ecosophilists, anthroposophists, and reformists, moving from the early idealists to the pragmatic, profit-oriented adopters. This suggests a different way of viewing adopters according to their personal philosophy.

Diffusion of innovation theory developed and published by Rogers in 1962 and later updated, follows the principle that when adoption of an innovation first starts, it is slow, but when it is successful, it then accelerates, and then slows down again as there are fewer potential adopters left in that particular social system.

This data, when graphed accumulatively, creates an ‘S’ shaped curve. This followed the premise that once an innovation had been adopted by some farmers, this would stimulate other farmers to adopt as well (Stephenson, 2003).

While some elements of diffusion of innovation theory, such as the characteristics of innovation, stages of adoption and the importance of farmer (adopter) involvement in diffusion (Stephenson, 2003) have continued to be valid, other sectors have been criticised. For example, 1960s agricultural extension followed productivist targets and had a tendency to benefit wealthier farmers (Stephenson, 2003). In addition, Stephenson (2003) notes the interaction of economics theory concerning increases in production on larger farming enterprises, which increased supply and therefore led to a drop in prices. This caused problems for smaller farmers, particularly in developing countries. Norton and Alwang (2020), following the evolution of extension, noted that methods of delivery have changed and now include marketing, risk management and environmental advice.

The work of Rogers (1971, 1995, 2003, 2004) on the Diffusion of Innovation paradigm has developed and been used across different sectors, including construction and healthcare, as well as technology and agriculture. His books, which are called “the most cited works in all diffusion literature” (Kinnunen, 1996 p437), have been updated as he has responded to reviews and criticisms. For example, in his 2003 edition, he recognised a pro-innovation bias in diffusion literature, noting that while an innovation may provide relative advantage to some agents in the social system, it may not deliver the same amount to everyone. Dearing and Cox (2018), in their review of Rogers (2003) Diffusion of Innovation theory from the perspective of public health management, observe that not all innovations are adopted. Understanding of complex reasoning on why certain innovations are not adopted is not yet well understood (Hubbard and Sandmann, 2007). This suggests that if there is little interest in such innovations and they disappear without trace, it is hard to monitor them and build empirical evidence on the reasons why they may have failed.

Literature suggests that older models of knowledge transfer have been replaced by interactive and systems models as proposed by scholars such as (Klerkx et al., 2012) Nieuwenhuis (2002), McCown (2001) and Leeuwis and Aarts (2011). More recent work has focused on the need for a pro-active approach towards the adoption of innovations, with access to knowledge and information from third parties being considered essential (Gielen et al., 2003, Klerkx and Leeuwis, 2008b).

Research has challenged some of the key tenets of the work of Rogers (2003) in that within diffusion of innovation theory, communications between innovators and researchers were considered to be linear. It is now generally accepted that innovation does not take place in isolation but within a transdisciplinary multi-actor system. This enables co-creation of innovation through the inputs of different actors (Fieldsend et al., 2021), with interactive knowledge exchange playing a key role alongside funding, policy, legislation and market demand (Klein Woolthuis et al., 2005, Klerkx and Leeuwis, 2008b, Klerkx et al., 2012).

An iterative view has been developed into farming systems research, with the subsequent emergence of Agricultural Knowledge and Innovation Systems (AKIS) (Klerkx et al., 2012). This is defined as "A set of agricultural organisations and/or persons and the links and actions a set of agricultural organisations and/or persons, and the links and interactions between them, engaged in such processes as the generation, transformation, transmission, storage, retrieval, integration, diffusion and utilization of knowledge and information, with the purpose of working synergistically to support decision making, problem solving and innovation in a given country's agriculture or domain thereof" (Röling, 1990 p.1).

Within the AKIS framework, interactive innovation is a key tenet; with input from actors from across different sectors, including agricultural researchers, technologists and institutions, with a focus on understanding the governance of activities and actors, alongside support structures (Klerkx et al., 2012). Theoretical perspectives on these disciplines have evolved from multi-disciplinary, to transdisciplinary (with public engagement), and in the Agricultural Innovation Systems (AIS) literature developed since 2000, they are seen as holistic (Klerkx et al., 2012), focusing on addressing climate-agricultural challenges and are often aimed at institutional change.

Charting the development of innovations and communications systems, Klerkx et al. (2012) draw attention to the Agricultural Innovation System (AIS) which developed in parallel to AKIS. AIS, which was developed from a research perspective in parallel to AKIS (Klerkx et al., 2012), goes beyond agricultural research to encompass wider influencing entities such as research institutes and also infrastructure. As such, AIS was developed to support a broader vision of dynamic analysis and network development than AKIS (Klerkx et al., 2012). While broadly similar in many respects, it was based more on an institutional approach, and the use of more private: public partnerships for innovation. It has principally been used in developing countries, but as it is based around interactive learning (Klerkx et al., 2010), there are criteria that have proved to be relevant to industrialised countries, particularly where social goods, such as environmental sustainability, need to be taken into consideration. This has provided useful context on systems relevant to this study. There are challenges to this approach, however, and Pigford et al. (2018) note that at times innovations have to compete alongside those already well-established in the sector, or even with others within the system, which can the slow progression towards sustainability.

One of the challenges highlighted by Klerkx and Leeuwis (2008b) is the diverse nature of the agricultural industry and its reliance on entrepreneurial ability to introduce innovation. Talking about adoption of organic farming methods, Padel (2001), points out that attention should also be paid to the economic, structural and institutional environment of farming. This is because a farmer may be willing to adopt innovations, but these external influences influence the ability to adopt, as do certain farm traits   Given that much of the innovation in the sector is undertaken by small and medium enterprises (SME), there can be certain skillsets which may be missing, hence there can be a need for intermediary agents who can help progress an innovation. The role of such agents is to articulate demand, broker networks, and may be funded by public and/or private finance (Klerkx and Leeuwis, 2008b). There is space for more theoretical understanding of the drivers of decisions on whether or not to use intermediary services, particularly any improvements to return on investment which may be gained.

Innovation and change in the agricultural sector is complex, with different networks and stakeholders all playing a role in interactive innovation, and, as pointed out by Klerkx et al. (2012), some of them may have conflicting perspectives. Separating an innovation systems approach into different groups, such as organisations and intermediaries, existing technologies, products and services, and the competitive environment can be helpful by facilitating analysis (Koschatzky, 2001, Malerba, 2002, Doernberg et al., 2012). Bergek (2008) proposed a systematic approach to analysis of innovation to identify the key practices and factors which may impact on the development itself and also how diffusion of knowledge can influence innovation. This concept, which was adopted by regional and national authorities, including the OECD, the European Commission and UNIDO has been broken down into a number of components to facilitate analysis (Bergek et al., 2008).

These are:

1. Agents and organisations
2. Interaction and intermediaries
3. Knowledge base and human capital
4. Institutions and politics
5. Analysis of existing technologies, products and services
6. The environment of competition

These processes benefit from overarching understanding of context such as the primary need for an innovation to resolve a particular problem. Doernberg et al. (2012) criticised this systems approach because it does not offer any empirical guidance on innovation process to facilitate understanding of the context of the innovation process and potential links with the other elements. To address this, Doernberg et al. (2012) developed a multi-level mixed framework which not only separated the sub-sectors of agriculture but also the type of innovation to build a more holistic view of how the system works. Their study was based on the German agricultural innovation system, and the framework provided an important means for understanding of how innovation is likely to occur in the different agricultural sub-sectors. For example, some technologies, particularly in the horticultural sector, are developed very close to market, so as the aim of the innovator is to develop something offering commercial advantage, development cannot be described as pre-competitive, thus there may be interactions between the fifth and sixth elements. The idea of looking at constituent parts of a process has been important because this framework shows how to provide a basis for deciding the boundaries of the case study and the different layers of context. There remains a need to look beyond the functions and systems, and build better understanding of how a company interprets operationalises them.

Work by Jansen et al. (2010) and Klerkx et al. (2017) has moved on from innovation adopter categories used by Rogers (2003), which were early adopters, early majority, late majority and laggards. While farmers are still assigned into different groups according to their attitude towards advisors and on-farm advice, they are sometimes now defined by those who actively seek assistance with innovation, those who prefer to experiment themselves, those who wait to see what others do before adopting, and traditionalists. One of the limitations of the newer method of segregating them is that it while it may facilitate identification of growers willing to help refine the innovation, innovators still need to be able to find growers who are willing and able to participate in the development of an innovation.

2.4.1.1 Interactive innovation

Successful innovators seek out suitable partners for their innovation (Gielen et al., 2003, Leeuwis and Aarts, 2011) and in the agricultural sector, farmers are not only capable of innovation, but also play an important role to ensure the innovation offers utility and value by solving the issue or problem that is limiting their current business situation. Lacy (2010) argued that farmers have knowledge and experience that can contribute to improving the multiple factors critical to improving productivity and gross margins, with peer to peer diffusion of knowledge and benchmarking playing an important role. This implies that diffusion of an innovation needs to start before the innovative product is completed and reflects work by Douthwaite et al. (2001) which found stakeholders to be an important source of innovation and led to interactive farming systems approaches, such as AKIS.

This originally comprised interactions between research, extension, training and support systems (Fieldsend, 2013), with the interactive innovation concept highlighting the importance of co-creation. According to the European Commission, the interactive innovation in this concept is based on “knowledge co-created between practice, scientists, advisers and NGOs etc. This involves looking at different dimensions including technical, organisational and social aspects which helps to bridge the gap between science and practice, applying a systems approach” (2017 p.3). The interactive approach adopted in the EU has evolved, and now includes groups such as foresters and farmers in AKIS projects such as EIP Agri (Fieldsend et al., 2021) and is a welcome addition because of their non-linear nature (Klerkx et al., 2012).

Prior to developing an innovation, literature implies that the first stage is to discover the problem that needs solving, and how important this is to the potential adopter (Jansen et al., 2010, Lowenberg-DeBoer and Erickson, 2019, Rojo-Gimeno et al., 2019, Caffaro et al., 2020): if the technology helps solve a problem, it is more likely to be adopted. One of the principal advantages of innovations being developed in a multi-actor framework which includes farmers, as promoted as part of AKIS, is to ensure they target what they consider an identified problem. For example, farmer motivation for change is one of the principal findings of Jansen et al. (2010); if change was deemed by the farmer to be effective to solving an identified problem, it would be more likely to be adopted. Work by Rojo-Gimeno et al. (2019) on the incidence of mastitis in the dairy sector and the importance assigned by different dairy farmers on addressing this disease which has implications for yield as well as for animal welfare. There are interesting parallels as calling a veterinarian to advise them could equate to using a paid advisor for environmental aspects of growing crops. In addition, the importance of welfare issues from infection could resemble attitudes towards the environment. However, while this may help increase understanding, many challenges are multifactorial, and thus there is no one simple panacea. While their work is focused on advice concerning animal health and public goods such as the environment, it has provided useful background knowledge for this study because of the case study company's sustainability ethos alongside its sales of hardware and hydroponic consultancy.

There may be further benefits to joint innovations because regular communications may help to build trust between the early adopter and the innovating enterprise (Nininen et al., 2007), thus setting the scene for long-term business between the them. This is particularly relevant to purveyors of equipment such as precision farming, hydroponics systems and 3D farming, if, in addition to the hardware, there are software sales to be gained.

2.4.1.2 Limitations of interactive innovation

One of the challenges for joint innovation to work referred to by Nininen et al. (2007) is that co-innovators need to agree to exchange and share data, some of which may be commercially sensitive. This raises a potential issue of trust and may influence the decisions by some commercial farming enterprises, such as potential adopters of 3D farming, to wait rather than be in the vanguard of adoption.

The ability to access knowledge and information from third parties is critical because feedback plays a crucial role and it is well established that farmers play a crucial role in innovation. Timely professional advice to help fill knowledge gaps can play a key role, for example on financial matters or specialist technology, but Klerkx et al. (2017) have found that such advisors may not always promote the creation of public goods which do not have a market price, such as environmental services.

Theoretical perspectives underpinning agricultural innovations work are important because they reveal that adoption of an innovation by farmers is not a passive act; farmers can provide more than just feedback and therefore should form part of the innovation process as co-developers. However, the innovator/entrepreneur's choice of which farmers to involve could be biased in favour of those who are more technically competent. Working with one set of farmers who may not necessarily be representative of other farmers, and their different perspectives may affect adoption. In addition, the stereotypes of late adopters may result in their exclusion from trials.

Factors diminishing the performance of innovations systems include path dependence, culture differences and lack of incentives, and there may also be technical difficulties caused by lack of infrastructure such as reliable access to the internet (Klerkx et al., 2012). While attitudes towards innovation may be positive, farmers able to participate in research and innovation projects need to have the time and resources available to do so, and therefore one of the criticisms of the AKIS is that it may favour wealthier farmers.

2.4.1.3 Contemporary understanding of farming innovations

Novel technologies and practices are aimed at ameliorating the concerns of climate change and food security (Hardy et al., 2018). Recent events, such as the Covid-19 virus, the war in Ukraine, and (in the UK) the effects of Brexit, alongside large increases in prices of fertiliser and energy are likely to impact on innovation and its uptake, but these events are outside of the scope of this research.

The global challenges are particularly relevant to the short term adoption of any farming innovations reliant on high energy inputs because of the need for economic profitability (Van Delden et al., 2021). Such concerns have led to calls for an integrated approach to food policy by bringing together innovation and agricultural support in an umbrella approach (Van Delden et al., 2021) while others believe the key is ensuring outputs are successfully translated and reach end users (Ingram et al., 2018). This suggests that effective diffusion of innovation strategies remain at the heart of successful and relevant outputs and uptake.

In response to social momentum created around food security, Klerkx and Begemann (2020) assert that scientific research still plays an important role in sustainable food production. They argue Agricultural Innovation Systems (AIS) are well placed because innovation is co-produced by actors from different sectors, and by bringing innovation and transition policies together, food security concerns can be addressed. End users are also important players (Ingram et al., 2018) and their acceptance of agricultural technologies is key.

Better understanding of some of the limitations of AKIS has led to other policy instruments being used in tandem. These are aimed at further facilitating the process and delivery of co-produced innovation and thus work to complement AKIS and drive higher participation (Fieldsend et al., 2021). Such instruments include LIFE+ and LIFE projects, Horizon 2020 and non-projects with or without funding at national or regional levels, amongst others. While for many, economic profitability is an important driver of uptake of technologies such as vertical farming (Van Delden et al., 2021), not all innovation is driven by techno-economic needs. There are examples of citizen-led grass-roots innovative initiatives driven by ideology such as conversion to organic growing (Sillig, 2022), which have been successful. Fieldsend et al. (2021) suggest that 'pump priming' grants could also be a useful way to support informal co-innovation networks.

Although there is a well-documented body of literature on the benefits of the interactive innovation within consortia of actors at pre-competitive level, I have not found the same evidence amongst competitive enterprises looking to develop differentiation. This may be because of concerns from end users about their unique selling point (USP) or confidentiality issues if actors leave a group to work with another. Such matters would need to be addressed in contracts, but this is outside the scope of this thesis.

2.4.2 Communications, communicators and opinion leaders

Looking beyond the initial development of an innovation can play a key role in its driving adoption. Persuasive communications can play a key role in attracting interest towards the innovation to convince potential adopters to trial it and move towards adoption (Kutter et al., 2011, Klerkx et al., 2017, Klerkx, 2020). This implies that the entrepreneur needs information on where to find the most effective channels influencing the target market to maximise the communications opportunities but despite its importance to new enterprises, as yet literature does not provide much guidance.

Although research on uptake of precision farming undertaken by Kutter et al. (2011) ranked some of the main channels open to growers in Germany, Denmark and Greece, there are limitations in that the work does not look beyond the initial communications with growers. The channels reviewed follow a mixture of literature and practical demonstrations, and other media, ranking professional literature and agricultural events as the most important, followed by workshops, the internet, advertisements and demonstration farms. What is interesting is that the study highlights other factors influencing uptake of new technologies, such as age, farm size (larger farms tend to have specialist staff), and obligatory compliance. This suggests that at empirical level, there needs to be a system of trial and error to find the right target market.

Communicators need to be persuasive and credible (Chan and Misra, 1990) so they are able not only to inform potential adopters, but persuade them to adopt a constructive attitude towards a certain good or service (Rogers and Shoemaker, 1971). As such, there is a need to align dissemination of strategic messages according to strategic goals, taking into account context and audience for targeted communications (Moore, 2010). For example, in a review of the diffusion of research concepts, Wilson et al. (2010) suggests that marketing social concepts may need a different strategy from purely commercial products. This may depend on the aims of potential customer enterprises and what they view as value from their investment; the promotion of certain characteristics may be more effective than others. These findings provide important context for this study.

Advisers and opinion leaders are capable of exerting personal influence on others, and are viewed as a different construct from those who use the opinions of others when making decisions. The traits found to be correlated with opinion leaders include knowledge about the product they are diffusing, a good level of education compared with those seeking their opinion, in addition to being confident and socially active (Chan and Misra, 1990). Trusted advisors may also play a crucial role in influencing uptake, as found by Owen and Mitchell (2015) who looked at their influence in the consumer uptake of new technology in energy sector. Their work is also relevant to other sectors, including agriculture.

While innovativeness can be one of the characteristics of opinion leaders, Rogers (2003) suggests that the innovators themselves tend not to make good opinion leaders because they are too change-oriented, so there is a need to seek other potential influences. Because of their potential for putting pressure on non-adopters, early adopters are considered effective opinion leaders in some sectors (Frattini et al., 2014). Peer opinion is also an important influence on adoption decisions, particularly in the agricultural industry (Pathak et al., 2019) and because of the lack of an extension service in the UK, there is greater reliance on such opinions. However, there are reservations that early adopters may be wary of giving away any commercial advantage from cooperative collaboration between growers (Van Oosten, 1998), thus there is a need to consider the context to better understand when peer-to-peer influence works and when it does not. These academic insights emphasise the importance of influencers, and drove the decision to include information on influencers in the framework to explore whether they are applicable in the context of this study.

Labarthe et al. (2018) have found decision-making by farmers to be complex and although cost: benefit analysis is important, other elements such as markets, technology and social norms also play a role. Motivation to make changes may depend on trigger events (Sutherland et al., 2012) and the context of the market in which they take place, particularly when such decisions are on whether to adopt a disruptive new technology. Understanding this context may be critical to a start-up innovative enterprise when developing an innovation and communications strategy. This is because of the need to drive customer adoption for the innovating company to achieve a successful business outcome. The implication is that there may be a need to use professional services such as those offered by specialised communicators and influencers.

Questions exist about who can become real opinion leaders in a new sector, and an important area of this research was to reveal whether newcomers to the industry can develop their skills and become respected in what is often regarded as a traditional sector. There are other important influences, such as consumers who have already purchased a good and are capable of inspiring others to want to imitate them (Flynn et al., 1996). However, while in the farming industry this might be the case when a purchase offers potential prestige, such as a new tractor, this may not be the case with a system which offers competitive advantage in what is already a highly competitive sector. No literature has been found concerning this possible constraint to peer-to-peer communications, and hence a gap in understanding within this sector has been perceived.

Perception of value may also depend on the decision-maker (Sutherland et al., 2012), and entrepreneurial ability in the sector to exploit opportunities has been found to be less developed than in other sectors (Pindado and Sánchez, 2017). Empirical work undertaken by Sutherland et al. (2012) has found on-farm adoption of innovation tends to be incremental in nature, progressing from particular established trajectories while disruptive innovations need a trigger event to promote adoption.

Literature suggests that embedded understanding of farmer needs can do more than just drive innovation as it can also influence decisions on communications about the innovation. As such, it can impact on grower decisions on whether or not to adopt new technology such as is used in precision farming, hydroponics or 3D farming. Despite innovation networks with public-private partnerships, analysis suggests there is as yet little consideration in agricultural literature about the development of commercial communications strategies used by micro-companies such as those providing novel equipment for commercial vertical farming.

2.4.3 Characteristics of the Innovation

The components of each of the characteristics of the innovation as depicted by Rogers (2003), and how they highlight customer needs have provided an important focus for this study. Attributes such as relative advantage, compatibility, complexity and trialability play an important role on uptake of innovation within the agricultural sector. It is generally accepted that farmers tend to adopt innovation more easily there is an opportunity to try it out at a small scale or cost (Rogers, 2003) or the risks of making these changes are relatively low and are often reversible (Pyke, 2011). Consequently, there has been academic focus on the need for a pro-active approach towards the adoption of innovations which uses terminology understandable for potential adopters (Gielen et al., 2003, Klerkx and Leeuwis, 2008b, Eidt et al., 2012) plus the opportunity to view innovations *in situ* so that they can assess the compatibility with their own system (Rogers, 2003). Such academic insights have provided important indicators forming part of the framework for better understanding decision factors affecting adoption of innovation in an empirical setting.

People working in agriculture generally have a reputation for being slow to uptake innovation (Rogers, 2003), and this has been corroborated in a recent empirical experiment undertaken in the UK by Rose et al. (2016) which found growing consensus on the desirable characteristics affecting adoption of new technology. This research validates my decision to include the characteristics of an innovation as part of my framework.

2.4.3.1 Influences on adoption or rejection

Diffusion of innovation depends on social capital and networks, and therefore, personal relationships between diffusor and potential adopter play a crucial role (Makkonen and Johnston, 2014), as can social pressure (Mills et al., 2018). Decision making can be influenced by unconscious thought processes that go beyond the tangible, measurable benefits (Nininen et al., 2007), and there may be occasions when decisions are made not to adopt, or even ‘un-adopt’ after having adopted an innovation. This may become particularly relevant when there are social benefits such as environmental sustainability, but also perhaps hesitancy in using internet services. There are concerns around ownership of data gathered from sensors and stored in cloud based systems, which may affect uptake.

Economic characteristics such as income and profit are important drivers for uptake of innovations (Toma et al., 2018, Filser et al., 2019) and Mills et al.

(2017) note that interest in an innovation, and willingness to adopt to not always translate into action. Thus it is important to understand these in the context of any altruistic motives of potential contributions towards sustainable intensification. Findings by Mills et al. (2017) suggest that at farm level attitudes differ between sustainable practices and environmental management, and that many who adopt environmental schemes only undertake the required minimum standards.

While many studies on drivers of adoption in the agricultural sector have been focused on farmer characteristics, Caffaro et al. (2020) found psychological constructs such as perceptions, intentions and goals, alongside perceived usefulness to be key drivers. These findings are similar to those of Mills et al. (2017) who found influence at farm, community and societal levels, with subjective norms including personal belief, self-identity and moral obligations important to decision-making. Such work suggests value perception as a key component of decision making on whether or not to adopt a new system, and it may be indicated by the reactions of potential adopters to the characteristics of an innovation as defined by Rogers (2003), see Section 2.4.3 above. This suggests that persuasive communications need to be able to raise the profile of a particular element or characteristic above competing ones and is highlighted in studies by Abson et al. (2017) which have identified the importance of leverage systems as a conduit for change to more sustainable practices. In this work, governance and policy, or knowledge exchange, can be conceptualised as levers as they can create a context in which such a transformation may be more likely to be uptaken. Effective diffusion of innovation depends on knowing which particular communications channels are best able to leverage communications messages.

Numerous studies have explored communications between farmers and advisors, including state-paid extensionists and independent advisors (Rogers, 2003), and the work of Klerkx (2020) on AKIS promotes peer to peer communications, while others have explored supply side leverage to encourage adoption of more sustainable methods of production (Long et al., 2016, Lüdeke-Freund and Dembek, 2017). A gap in empirical studies has been detected regarding commercial communications from an entrepreneurial perspective relating to sales of equipment in the small, highly competitive indoor horticulture sector.

2.4.4 Connections between evolving theory and practice

Balancing the complex needs of food supply with environmental protection and minimising climate change requires use of knowledge, including that which is yet to be produced (Ingram et al., 2018). This is reflected in the recent evolution of agricultural policy, such as the European Union’s Common Agricultural Policy

(CAP), as it responds to the information it receives. Policy tools, such as incentives and regulation, are used and/or amended to ensure the sector responds to interpretation of information and knowledge received. Until 1992 the CAP provided price supports, which then became compensation paid to farmers for price reductions for food produced. In 1999 the second pillar of the CAP introduced agri-environment measures; the next stage in its evolution took place in 2002 and decoupled production from subsidies. This move has resulted in support for innovation and its uptake as part of a drive towards more sustainable ways of producing food and other agricultural products.

The challenges the agricultural industry is facing are complex, and given the different sectors that now interact with agriculture, solutions depend on the expertise from the likes of specialists in IT, robotics, geneticists and agronomy to respond to user needs (Ingram et al., 2018). Supply and demand, and how they are articulated, also play an important role (Klerkx and Leeuwis, 2008a, Klerkx and Leeuwis, 2008b). In addition, given the supply chain structure and its complexities (Menary et al., 2019), innovations need to provide a relative advantage to different stages in the supply chain, so the relevant information is crucial. One such way to achieve this is through public-private partnerships, which have become popular as a policy instrument for many governments (Hermans et al., 2019) because of their potential for providing a framework in which agricultural innovation can thrive. Examples of the role of such interactive frameworks and their connections to evolving policies are related by Hermans et al. (2019), about the design of a sustainable and animal friendly stable in response to changes in animal welfare regulations. Stimulated by tax breaks for the commercial partners, the research illustrates that innovations and improvements in animal housing clarified what can be done for sustainability and animal welfare. These advances then led to a more stringent regulatory framework in the Netherlands. This is relevant to 3D farming, because if involved in similar research, it could help reveal the parameters of what is possible in terms of reduced environmental damage, setting a standard to be upheld.

In a similar way, two projects to develop knowledge of food and nutrition innovation as an Dutch export product were found to result in focused research between the different contributors, resulting in enhanced output. From the results of this project, Hermans et al. (2019) highlighted that as many as 38 percent of the projects would not have gone through without such support, and those that did were likely to have been smaller. There examples are important to the 3D farming industry because not only do they demonstrate the importance of interactive innovation, but also the public funding necessary for it to be successful. Risk undertaken the participants is also important, and Hermans et al. (2019) reveal that in the future private partners will have to share the risk if they stand to gain from the innovation. This however, may limit the ability of participants, particularly if they are SMEs to join such projects because of the resource costs such as time and labour which will be added to risk. Such constraints may limit the ability of innovative micro-companies – such as those in the 3D sector – to participate.

Evolving interactive innovation theories have been brought into practice with European and International Multi-actor Research and Innovation models, and Horizon 2020 Innovation Projects (van Oost and Geerling-Eiff, 2019). One such initiative, the European Innovation Partnership (EIP-AGRI), takes place at EU member state level and offers a platform for farmers and researchers to work together with each country having its own scheme. Based on the idea of producing innovation with co-ownership, it aims to foster innovation and sustainable agriculture across the EU through a coordinated approach (Barrett and Rose, 2020) which takes end user needs into consideration (van Oost and Geerling-Eiff, 2019) (see also Section 2.4.1 and 3.2). For example, in England, Innovative Farmers Field Labs have been established in which farmers collaborate with scientists and the supply chain on innovative projects. However, while AKIS sets the context in which an innovation is developed, Labarthe et al. (2018) detected knowledge gaps when farmers need support at certain stages, and which actors can play a role at such moments. This finding is relevant because it indicates that there are still gaps in empirical understanding, in particular where specialised sectors, such as 3D farming and other horticultural enterprises, are concerned because of their need to use expertise from other sectors such as technology (Drottberger, 2021). The use of actors from a broader range of sectors is now contemplated in an updated AKIS (van Oost and Geerling-Eiff, 2019), and the aim is to foster an innovations ecosystem umbrella concept (Drottberger, 2021). This suggests a flat structure from which the different actors from different sectors all have input and take joint decisions. in the context of 3D or indoor horticulture, the consortium is likely to need a specialist who understands the growing environment and able to measure the effects of different variables on the growing crop.

Since the UK’s withdrawal from the EU, land and agricultural policies are evolving, and Environmental Land Management Schemes (ELMS) are being developed as part of a move to reduce environmental damage and mitigate climate change. British farmers are being encouraged to sign up to these agricultural environment schemes which are different from the Stewardship initiatives they participated in while in the EU. As research shows such schemes can suffer from low uptake (Hurley et al., 2022), Defra has been engaging with the agricultural sector to promote co-design environmental land management schemes but with limited success. A study on this strategy by Hurley et al. (2022) detected some of the reasons behind this resistance, including ‘disengaged’ farmers and stakeholders who are harder to reach, separated by elements such as the remoteness of location and the digital divide, social capital and previous poor experience with bureaucracy. As these schemes will now include horticultural enterprises on highly productive land, who have not previously been eligible for such support mechanisms, there is also a need to recruit participation from this sub-sector. Hurley et al. (2022) emphasise that to contribute, farmers need to feel confident that they will see a value from their contribution; which may also be applicable to recruitment to multi-actor innovation platforms such as AKIS, and therefore of relevance to this study.

For the research addressed in this thesis AKIS has provided a transdisciplinary perspective of context, but a gap was detected in understanding of the evolution of young agri-tech company entering a 3D farming market as an outlier in which competitive advantage is crucial. This work aims to provide further empirical evidence of the heterogeneity of agricultural innovation.

2.4.5 Empirical studies parallel to this thesis

Different perspectives of vertical and 3D farming have recently been studied; in a review of alternative production methods for leafy salads, including vertical farming, Drottberger (2021), identified business opportunities for commercial greenhouse growers in Sweden. Following a framework based on Rogers (2003), she detected concerns about the rate of adoption of innovations amongst commercial greenhouse growers because of concerns about competitivity and pay-back time. However, this was the first paper and the time frame of this particular study was short, (2016-2018), which is effectively only three growing seasons. Analysis of adopter profiles showed more uptake of innovations amongst start-ups backed by venture capital. Further work in this context will drive understanding of how such innovations reflect contemporary pressure in the leafy vegetable sector.

Similar findings on farmer characteristics and uptake of innovation were found in a study by Michels et al. (2020) on the adoption of smart phones for digitisation of agricultural information and also communications. Using the characteristics identified by Rogers (2003) for the study, age, education and diversification of the farm influenced uptake, and suggested that older farmers were less likely to want to face a learning curve as they move towards newer technologies. This is important for understanding uptake of innovation, and further studies would be useful to build understanding if there is a correlation between uptake amongst other farmers and ease of use of the new technologies.

In another example of diffusion of innovation in vertical farming, Kalantari and Akhyani (2021) also used the Rogers (2003) diffusion of innovation framework to find out the extent of community acceptance of vertical farming and the fruit and vegetables produced by such methods. Social acceptability of innovative food production approaches such as rooftop greenhouses and urban farming was also the focus of a qualitative study by Specht et al. (2019), using a framework based on the Brundtland (1987) sustainability pillars. Findings revealed concerns in terms of capital and energy demands, and the need for technical solutions for better resources for energy, which are areas relevant to 3D farming too in terms of both sustainability and business profitability (see also section 2.4.1.3).

2.4.6 Innovation and diffusion summary

The transition to adopt new processes does not always follow a consistent path to its conclusion and a gap has been perceived in understanding at micro-level about how a commercial company interprets its communications and diffusion needs, and the activities it undertakes. One of the challenges of diffusion theory studies is the time scale for adoption to take place, even when there are clear advantages to adopting an innovation. This is particularly noticeable with potential benefits from organic farming, which can be considered a long term investment, particularly as yields are likely to decrease at the beginning, and despite soil health benefits, they may never retain equivalence to conventionally grown produce. There are certain parallels to this with regard to new sectors such as 3D and urban farming, because as yet there may be some uncertainty about benefits and the time taken to achieve them. As such, there is room for more detailed case studies at micro-level in a commercial context, to increase understanding of actions at company level, and the experiential learning approach of an enterprise selling equipment into the commercial horticultural sector. This would improve understanding of cases where, despite an innovation being apparently beneficial for both farmers and consumers, it has been rejected.

Literature on diffusion of innovation indicates the importance of developing a product for which the customer will perceive value (Kilelu et al., 2013, Klerkx and Leeuwis, 2008b, Klerkx et al., 2012), hence, in communications, there is a need to effectively portray the vision of value. This can be difficult to assess for a new company entering a new market such as precision or digital agriculture, because while they may be able to provide a good which has a measurable utility (such as eco-effectiveness), the perception of utility is subjective (Tomičić-Pupek et al., 2020). Therefore, understanding what customers perceive as utility and ease of use will help devise communications which project a vision that will resonate with potential buyers. As such, Value of Information (VOI) capable of bridging the gap between customer intention and action (Rojo-Gimeno et al., 2019) can play a key role in decision making on communications. The challenge to this is that the perceived value may differ according to farmer criteria, perception of problems which need addressing and their priorities. This suggests that communications may need to be modified and Rojo-Gimeno et al. (2019) argue that understanding VOI will help ensure it is correctly targeted. This is particularly relevant to new and innovative companies in potentially disruptive technological farming sectors such as 3D farming because the new sector needs to convince adopters that not only does the technology work but also of its reliability.

When looking through a business to business lens, for example, of a company supplying farmers, identifying and understanding their purchaser's customers and their market is central to commercialising a product. While much has been written about diffusion of innovation and communications in agriculture, a gap has been detected in empirical understanding about the learning experience a new start-up may need to go through as it becomes established.

The template developed by Rogers (2003) still has widespread academic acceptance (Sahin, 2006), and although academic understanding has developed about how change happens, modern studies about diffusion of innovation in agricultural settings still use his work. Criticisms of the theory include pro-innovation bias, and there may be suggestions that the use of the word 'laggard' may be derogatory because there may be external reasons for non-adoption of a technology, or even a better technology for the particular circumstances. Research by Hubbard and Sandmann (2007) undertook at 51-item survey using the Cervero model (Cervero and Rottet, 1984), and found that the theory developed by Rogers (2003) explains between 39 and 81 percent of variance between variables.

A literature review by Pathak et al. (2019) on determinants of dissemination and adoption of innovation covering between 1992 and 2010 found that the characteristics of an innovation were the most important influence followed by communications and the availability of information, with the socio-economic factors and the characteristics of the adopter behind. Recent work by scholars such as Michels et al. (2020) and Drottberger (2021), who have researched the adoption of different aspects of agri-tech innovations, use the work of Rogers (2003) as part of their framework to gain understanding of adoption. In addition, Stephenson (2003) found that theory on characteristics of the innovation had maintained its validity over time. This suggests that diffusion of innovation theory developed by Rogers (2003) still provides a useful means of understanding adopters and the characteristics of an innovation, and supports my decision to use it as part of my framework.

One of the main benefits of using this theory is that it provides a number of channels with their building blocks which can help understand diffusion activity within a particular system. According to Shang et al. (2021), who has explored diffusion of innovation in the context of uptake of digital farming techniques, the perceived attributes offer important insights on adoption. In addition, it can help understand non-adoption too, as they are elements farmers can relate to. From the innovator's point of view, it facilitates assessment of the potential of uptake of a particular innovation because it can help perceive potential attitudes of a potential customer. While recognising that the diffusion theory may have a pro-innovation bias, it is possible to work round that by using trusted advisors of less-innovative farmers, and although designed for linear structures, the key concepts used in this study proved adaptable to other innovation structures. To address shortfalls in some of the constructs developed by Rogers (2003), such as the recognition of the multi-actor role in innovation, more modern findings including the multi-actor work on innovations and the provision of an enabling socio-economic climate as identified by Klerkx et al. (2012). Rojo-Gimeno et al. (2019) and Caffaro et al. (2020) have also provided useful additions to the framework.

Agricultural knowledge systems theory highlights that learning pathways are social, experiential and technical, as innovating entrepreneurs react in ways to reduce their own risks. Even if access to resources is not an issue, there may be a need to prioritise which of the multiple challenges, needs to be addressed first. This is particularly important because the enterprises expected to carry out sustainable intensification are commercial growers working in a market economy, and therefore they have to make decisions which are commercially feasible for them to be able to make sufficient profit for their own needs, and therefore has a connection to their business model discussed in the next section.

2.5 Business Model

The business model is centred around business activity and how the entrepreneur designs content to create value (Zott and Amit, 2010). Despite some differences of opinion around the term business model (Morris et al., 2005, Zott et al., 2011), it is generally accepted that it includes information on how a company creates an offering, creates utility for its customers and secures profit (Slywotzky, 1996, Mayo and Brown, 1999, Morris et al., 2006). Identification of the customer and the customer's values (Drucker, 1992, Watson, 2002) also play a key role and this should preferably be done prior to innovation and construction of a business model. In an attempt to dissect the concept, some definitions divide business models into components: customer value, profit formula, key reserves and key processes (Johnson et al., 2008). Bolton and Hannon (2016), looking at uptake of technology in energy services companies, found commercial, technical and social components play a role and need to be brought together as part of the business model. However, there is still weakness as theory does not suggest the environment in which a particular model may be relevant.

The role of the business model received scant academic attention until the mid-1990s (Morris et al., 2005) when the concept came to prominence as the fast-expanding internet became a key place for trade. At this time, academia became aware that previous trading procedures did not necessarily work in the dynamic e-business market (Boons and Lüdeke-Freund, 2013, Magretta, 2002). The concept draws on a number of different sectors, such as the value chain concept (Porter, 1985), strategic networks (Jarillo, 1988), resource theory and transaction cost economics (Barney, 1999). Reviewing this background helped provide a framework to drive the development of theoretical insights into the nature of the business model used by the case study company.

The most commonly used components of a business model have been developed into nine interrelated building blocks by Osterwalder et al., (2005, 2010). Because of its use as a place to start developing theory (Barth et al., 2017), the building block concept has provided a means for organising data in this empirical study, and has been fundamental to this study.

Business model theory has been further advanced by Kuratkot (2015) who has identified a macro perspective of broad factors which determine the success or failure of an enterprise, and the micro-view, which looks specifically at the entrepreneur, and the ability to adapt outcomes of the variables, and undertake complementary activities which help retain customers (Amit and Zott, 2012). This appears to challenge the view of Timmers (1998), because it may not just be the features of the product that dictate the success of the enterprise but also the ability of the entrepreneur to effectively manage the marketing mix of price, promotion and place and calls for determination, technical knowledge and creativity (Kuratko et al., 2015). Putting this in the context of a new and developing market for 3D crop production, these academic discussions stimulated the idea that a framework following company development over an extended time frame would provide a means of monitoring the empirical evolution of the case study company, its innovation and its entrepreneur/innovator.

Innovation can be reflected in the business through remodelling the company or as an ongoing process to do so (Schaltegger et al., 2016), but it should not be viewed only in isolation, as a number of scholars argue that innovation and business models have a mutually influential relationship (Boons and Lüdeke-Freund, 2013, Chesbrough, 2010). This is fundamental because although technological innovation is important, it might not be sufficient to guarantee the commercial success of the company (Doganova and Eyquem-Renault, 2009, Zott et al., 2011). This links to the importance of Diffusion of Innovation, and results from failure detailed by Rogers (2003) which have been discussed in 2.3.3 above.

Barth has positioned a business model concept in the context of sustainability in the agricultural sector, forming a useful base to explore the sub-sector of 3D farming. Understanding the role of sustainability, which does not necessarily offer the company immediate financial benefits, is challenging because it may be closely aligned with the company's ethos or corporate responsibility.

Sustainability may be fundamentally important to the customers (either as a result of a regulatory environment or because of customer-facing ethical policies), and therefore is a deliberate intention of the company. It may also incur spillover which, while an outcome of company practices, is an unrelated impact which occurs from commercial activities as suggested by Davies et al., (2010). While some literature reveals the existence of trade-offs between the profit-seeking and social aspects of the business, Haigh (2012) calls companies who seek environmental improvements as one of the main objectives of the company 'positive deviants' because of their ability to bring together the environment, communities and the business. There can be instances of eco-efficiencies which mean that by using precision when applying an input, it both costs less money and there is less damage to the environment, or eco-effectiveness, in which move towards restoring and enhancing the environment (Young and Tilley, 2006), but questions remain on whether these provide a means for business as usual (Biloslavo et al., 2018). Any social benefits – including environmental ones – still need to be included in the financial objectives, as there is a need to seek an economic equilibrium when charging a premium for ‘environmentally friendly’ products. There is a need for more empirical evidence to better understand how such refinements to the building blocks fit into the business model for a company supplying agricultural equipment.

To gain a comprehensive picture of the business model of a company, a framework with a multiple lens perspective is desirable as there may be a number of interdisciplinary factors which impact on the business model, such as social entrepreneurship, sociology, and psychology in addition to finance and organizational aspects (Kuratko et al., 2015). This complexity becomes greater when there is a need to integrate both social and technical components into a business model (Bolton and Hannon, 2016), as is the case of a provider of 3D farming equipment which is aimed at offering both a satisfactory performance for growing fresh produce at the same time as reducing environmental impact. The complexity of a business model is such that some scholars indicate that they may vary between organisations working in the same competitive conditions (Hayashi and Strategy, 2012, McGrath, 2010), suggesting the need for experimentation to develop a successful conceptual model.

It can be argued that the way an enterprise conceptualises its business model, decides its own value proposition and undertakes activities to promote its value offering is fundamental to its success. Focus may be on creating value and capturing part of it (Doganova and Eyquem-Renault, 2009) or making money as its principal objective (Morris et al., 2006, Christiansen, 2001). To achieve either strategy Boons (2013) suggests the business model has two roles: to position the value proposition in such a way that it can decide on its market position and support the strategic marketing of an innovation and also use innovation in the same business model to reduce input costs or intermediary expenses to create competitive advantage. This strategy was part of the business model used by the computer company Dell and was built around the elimination of intermediaries (Morris et al., 2006) to reduce costs and/or improve direct access to the customer. Such strategies highlight the need for product innovation but also considering how the value from that product could be best delivered to the customer also implies that customers were not valuing the input from intermediaries.

Innovation and business models appear to be connected because the business model is used as a platform for taking a new product – such as a technological invention – to market (Doganova and Eyquem-Renault, 2009, Chesbrough, 2010). Despite this connection, the innovator is not necessarily the most appropriate person to take on the diffusion of innovation necessary to take a product to market, as the required skills are different (Chesbrough, 2012). There is some logic to this because the entrepreneur is normally seen as one of the persons with the greatest influence on the business: they identify potential new business and work towards capturing value (Knudson et al., 2004), and in some cases, attempting to balance profits with social aspects. Parnell et al. (2018) emphasise the importance of entrepreneurial ability to recognise threats and opportunities for the company and react by adapting the business model or the value offering accordingly. In addition, literature reveals that understanding customer demand is essential. As such, a connection between entrepreneurship and innovation which may be crucial to successful performance in the agricultural sector has been identified (Zeleny, 2012, Phillipson et al., 2004, Klerkx and Leeuwis, 2008a). This can also be related to agricultural economics literature as the findings of Knudson et al. (2004) take this further, building understanding of the characteristics of innovators and entrepreneurs, providing an opportunity for building on current academic understanding.

Despite varying points of view, it is clear that the business model represents a strategic framework which can lead to greater theoretical understanding of a value-based enterprise. One weakness of current understanding of the concept is that static business models look at the different relationships at just one point in time. However, some academic studies address the use of dynamic frameworks, for example see Barth et al. (2017). There is still a need for greater understanding of the drivers of a company's business model evolution, particularly adaptation to customer demand and the resulting uptake of its innovation.

Technological innovation (invention) is important to driving competitive advantage but it might not be sufficient to guarantee the commercial success of the company, for example if the company is unable to market its invention successfully (Doganova and Eyquem-Renault, 2009, Zott et al., 2011). The degree of importance of innovation as a key driver of competitive advantage is disputed (Chesbrough, 2010, Porter and Kramer, 2011, Zott et al., 2011), as it is likely to also depend on the product's ability to fulfil a perceived need and professionalism of the marketing mix. Thus an innovation requires the support of strategic marketing (Boons and Lüdeke-Freund, 2013, Teece, 2010, Zott et al., 2011) and entrepreneurship (Klerkx and Leeuwis, 2008a).

Entrepreneurship and innovation have emerged as being key to successful performance in the agricultural sector (Zeleny, 2012, Phillipson et al., 2004, Klerkx and Leeuwis, 2008a), and there also is a connection with the business model (Chesbrough, 2010, Doganova and Eyquem-Renault, 2009). Innovation and business models have a mutually influential relationship (Boons and Lüdeke-Freund, 2013, Chesbrough, 2010) which can be reflected in the business through remodelling the company (Schaltegger et al., 2016). These concepts have been explored in the study as part of a holistic view of the evolution of the innovation as the value offering and how the company learns to target its communications more effectively.

2.5.1 Business model and Sustainable Intensification

Pretty (1997) emphasises the need to clarify what is being sustained and it must be kept in mind that economic benefit is crucial to sustainability and growers need to be able sell their produce and make a respectable profit margin. The findings of Struik and Kuyper (2017) have shown there may be a need to adapt from a business-as-normal attitude to caring more for the resource base: the environment. This may entail a sustainability perspective being added to the mix although in the context of business models it may still only be an after-thought (Schaltegger et al., 2012b) or even a spillover, (Davies and Doherty, 2019, Santos et al., 2015).

According to Haigh and Hoffman (2012), it was traditionally considered that the role of the enterprise was to maximise profit for the shareholders while the government controlled environmental and societal issues through legislation. However, over the past few decades the importance of societal values, including sustainability issues, have become more prominent among both enterprise owners and customers (Haigh and Hoffman, 2012, 2015, Davies and Doherty, 2019, Santos et al., 2015). As pointed out by Biloslavo et al. (2018) the business model still needs to be economically viable and unpacking the different social and organisational models can be challenging, especially as prospective customers demand different degrees of sustainability or economic benefits.

There may be industry-specific influences, (Avermaete et al., 2003), and therefore a need to experiment to find the business model which works best under particular conditions (Hayashi and Strategy, 2012, McGrath, 2010). This implies that business models may pass through different stages prior to finding a model which will best work for a particular company. An example of this could be division of labour (Chakrabarti and Hauschildt, 1989), and such evolution illustrates a need to better understand the dynamics of such evolution, rather than understanding the business model at a static point in time. This is illustrated in empirical work by Sosna et al. (2010) who detected a learning curve as business models are adapted through trial and error. Adding in a time element, (Stewart and Zhao, 2000) allows the capture some of the dynamics of business model development, and is an important element of this study.

As this thesis explores sustainable intensification in a market economy, paying particular attention to the UK scene in which the supermarkets have substantially greater leverage than the grower/suppliers (Lanter et al., 2018), the mutual dependence between the natural and socio-economic spheres (De Groot et al., 2012) are arguably two of the most important topics for exploration in an empirical context. One of the dilemmas faced by marketers of ‘green’ products is how to promote criteria such as social justice and environmental protection at the same time as remaining (or, for new enterprises, becoming) competitive with conventional business. Fair trade company Cafedirect has sought to generate value through its business activities and has undergone a number of iterations (Davies et al., 2010), and changes in its business model towards more sophisticated packaging and marketing techniques have been adopted to try to achieve market success (Peattie and Belz, 2010). These are still ongoing (Davies and Doherty, 2019) as they attempt to balance the different elements. Supply chain leverage and dynamics can result in firms changing their environmental practices when they are subjected to pressure (Hall et al., 2010), particularly as they are complex and fragmented (Menary et al., 2019), thus companies may need to have their policies and practices ready to respond. Much of the sustainable business model literature is centred on business-to-consumer scenarios and focuses on customer values (Biloslavo et al., 2018) and less has been found about environmental values in a business to business context; nevertheless, ultimately the value created by the business is aimed at the consumer.

The importance of business decisions on ecological marketing may be relevant to other start-ups, particularly those in the consumer-facing food sector, because it highlights the importance of marketing for the final consumer (Peattie and Belz, 2010). The answer may be implied in corporate social responsibility literature; some companies express such commitments either altruistically or to add credibility to their value offering to maximise returns to the business (Du et al., 2010), either of which could arguably be behind the motives in the newly-established 3D farming sector.

The altruistic nature of sustainable corporate behaviour has activated academic discussions on implications of implementation and its potential to be rewarded by competitive advantage or become common practice in the sector in which it is adopted (Ioannou and Serafeim, 2019). These companies may be reacting to dynamics within their sector, and thus a gap in academic literature has been perceived to understand whether such companies may be working with ingrained sustainable ecological systems which are not promoted at that point in the supply chain.

2.6 Value theory

One of the underpinning theories of the above literatures is the theory of value, for which there are a large number of interpretations discussed by philosophers such as Riccardo and Marx, Pareto and Hicks (Pilling, 1972). The interpretation from Adam Smith's Wealth of Nations, as defined by Hollander (1904 p458), sheds some light on the concept as being "Value, in use is utility, in exchange, utility, associated with scarcity and necessary expenditure of labour, it confers value in exchange with which alone economic analysis is concerned".

In particular it is one of the basic structures of business model literature because a company aims to create and capture value, using resources that are "valuable, rare, and imperfectly substitutable" (Bowman and Ambrosini, 2000 p1) to create a bundle which will offer competitive advantage. This theory is also debated by the likes of Chesbrough et al. (2018) and Amit and Zott (2001), who, while accepting that Schumpeter's theory that innovation is the source of value creation through the deployment of resources, ultimately found value to be determined by the customer, and articulated through willingness to pay for a good or service. Business model activities to create value have a close relationship with resource theory, which then is unpacked into the two basic types of value: use value, which is customer satisfaction and exchange value, which translates into the price an actor is willing to pay (Bowman and Ambrosini, 2000) to obtain such satisfaction.

Value creation and capture is fundamental for firms aiming for corporate sustainability, but, rather than win: win scenarios, because of its complex nature Hahn et al. (2010) found many trade-offs and conflicts in its establishment. To address this challenge, Porter and Kramer (2019) advocate expanding value creation to include environmental and social value, encouraging a move away from the consideration that value is composed of short-term financial benefits brought about by competitive advantage. Nonetheless, one of the challenges of value theory is its relevance to the environment. For example, Pretty (2008), when viewing value through a sustainability lens, noted one of the differences between monetary values and environmental values is that if a monetary value is lost, allocation from another resource can compensate for the loss, but when it is natural capital, it is not so easy to restore. As this can be related to the land saving/land sharing debate (see Section 2.2), it provides some important considerations for context.

From unpacking the theory of value I detected that it becomes more complex as there are sub-sets of value discussed at academic level; these include terminology such as value uncaptured, missed, and even destroyed (Yang et al., 2017). Figge and Hahn (2013) identified that the opportunity cost of environmental resources can provide a link between economic and sustainability values, with the proviso that the value depends on its perception. All of these sub-sets of value, if applied empirically, could have implications for reflection on potential further development of business model theory.

Because of the subjective nature of value much has been written about this concept with continuing debate about its different aspects and importance. These different interpretations have provided important background for this study and gap in understanding has been detected concerning synergies within the conflicting demands for value which bring literatures together.

2.7 Summary

At present, there is insufficient academic understanding of how sustainable intensification and diffusion of innovation are linked to the business model in the agri-business sector, in particular the sub-sector which is 3D farming. This review has identified a number of areas for further exploration to better understand and illustrate ways in which the phenomenon of commercially undertaken 3D farming may be contributing to sustainable intensification within the context of a neo-liberal market economy.

A central theme has become apparent: innovation. This includes the technological response to the need to produce more food; innovation is an important element of the value offering of a company and also the need to spread the word about the existence of the technology and of the supplier companies. Technological innovation has been identified as crucial to improving performance in sustainable intensification, and for this to be uptaken by growers, it is necessary for such an innovation to be diffused. A gap has been detected in understanding of the relationship between diffusion of innovation and an empirical business model, particularly in the context of agri-food business, and this innovation could be evolutionary or revolutionary (Connor and Mínguez, 2012), depending on external and internal pressures on uptake.

Improved perception of how such businesses are operating, their evolution and relationship with sustainability will provide a framework that will help identify needs and sustain other start-up companies in similar sectors during their formative years, supporting a path towards more sustainable food production.

Chapter 3 Policy and context

3.1 Introduction

Following the motivation for this thesis described in Chapter 1, this chapter aims to set the context in which the study has been undertaken. This includes EU and UK policies to support initiatives, basic information about supplying UK retailers with fresh produce, and an introduction to the principal actors of the case study.

Policy support for companies seeking to work towards sustainable intensification, or even a fourth agricultural revolution (Lejon and Frankelius, 2015), may be crucial at various stages of their evolution. This is because growth may not be consistent; for example in the early stages taking on a member of staff or investing in equipment and capital goods can be ‘lumpy’ expenses (Goncharova et al., 2008), so help via incentives backed by policy can help inspire innovation. Overall, there appears to be a constructive policy context designed to nurture innovation in agriculture across the EU, and this is particularly relevant to innovative developments in 3D farming. This is important because support can help to provide a niche from which innovative advances can emerge.

The UK was still a member of the European Union during the timeframe covered in this project.

3.2 Key policy areas and approaches in Europe and the UK

As northern European countries are capitalist economies, any movement towards the objective of sustainable intensification has to be undertaken by the private sector, and is therefore governed by socio-economic factors (Scherer et al., 2018). Sustainability within the fresh produce supply chain is underpinned by a mixture of regulatory and voluntary approaches (Dicks et al., 2013) aimed at stimulating the private sector.

Expressed in economic terms, one of the challenges of environmental sustainability is price inelasticity of demand (Smith et al., 2010), yet any move towards sustainability still has to provide an economic return for the company, or those involved in these activities, to remain in business. This is important because the agri-food industry, particularly the fresh produce sector, is part of an oligopolistic market in which there are a small number of large retailers governing a competitive supply chain which works to offer low food prices to consumers. As farmers do not have the leverage of the retailers, they are unable to influence prices, and are therefore price-takers (Hingley, 2005). At policy level, as environmental goods need to transcend individual enterprises and commerce, support needs to be received through agricultural policy (Maréchal et al., 2018). This is because within a larger economic system, one of the challenges for companies providing public benefits, such as environmental benefits, is that they do not have a monetary value, and thus existing markets are unlikely to be able to provide optimal allocation of such goods (Maréchal et al., 2018). To address this, there is a need for strong policy framework for a competitive, effective and sustainable agriculture in Europe. Between 2014 and 2020 the Common Agriculture Policy (CAP) support was based on two main elements: firstly, decoupled direct payments providing income support to farmers throughout the EU granting them enhanced possibilities to take their production decisions on the basis of market signals. Secondly, the rural development policy which focuses mainly on rural areas with a view to ensure a balanced territorial development throughout the EU.

The agricultural European Innovation Partnership for agriculture productivity and sustainability (EIP-AGRI) was founded by the EU to foster competitive and sustainable farming making best use of resources (VanHoye, 2013). The objective has been to provide funding sources to foster agricultural innovation projects, working through the European Rural Development policy or the EU's research and innovation programme Horizon 2020. It has provided a cross-stakeholder platform for producers, industry and researchers to exchange information on new farming techniques and to test innovative approaches. This has been to ensure that research insights are transferred to the daily life of agricultural production adapted to the specific peculiarities of single farm realities.

The new rural development policy supported several other measures fostering knowledge transfer, innovation and cooperation. The new research and innovation framework programme "Horizon 2020" has been established with the aim of securing food security, sustainable agriculture, marine and maritime research and the bio-economy. It has also supported research and innovation in different farming systems (including urban agriculture) and the overall supply chain.

While there are initiatives for best practice for sustainability around outdoor crops which advocate better care of soil through longer rotations, these are not necessarily relevant to the protected indoor crop environment. However, the EU also has schemes aimed towards the fruit and vegetables sector in which the adoption of new technology for growing could be placed; for example, the Fruit and Vegetables Aid Scheme enables officially recognised Producer Organisations (POs), which are formed of grower groups, to receive financial assistance to help increase their competitiveness in the supply chain. This PO funding can be used for a wide variety of actions including the employment of technical staff, large capital investments such as purchase of machinery or improvements to pack-houses or other research or experimental projects[1]. At one time this also included diffusion and marketing communications[2]. The Scheme is administered at country level, which, in the UK, is done by the Rural Payments Agency.

A government-funded Sustainable Intensification Research Platform (SIP) was also created to research ways in which agricultural stakeholders, scientists and farmers integrate knowledge, with the aim of encouraging best performance (Morris et al., 2017) at farm and landscape scale. Although this was more based around outdoor broadacre combinable crops and livestock farms, some of its principles can be used when exploring sustainable intensification in other agricultural sectors.

Support for agricultural technology has been organised through the UK government's agri-tech strategy[3], which was published in 2013, and aimed at developing sustainable intensification through agricultural research and innovation. This timing coincides with the time the case study company was founded. The strategy has worked to bring together private sector businesses and research so that technical advances are targeted towards what the industry needs to improve productivity without damaging the environment; such technology includes soil moisture sensors, drones, precision application of nutrients, amongst others

Given that 3D protected horticultural farming is a relatively new development, the tools referred to above were not specifically tailored towards this sector[1]. That has not, however, not prevented those undertaking such activities from applying for CAP support provided they met the various eligibility criteria set out at EU and national level. With regard to innovation, on the other hand, the CAP has taken into account that refining production and processing techniques through new technologies, transposing existing knowledge and new insights and strengthening the skills of farmers is a pre-requisite for making the EU agriculture more competitive, but also to introduce more resource-efficient and environmentally

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[1] Personal email from Romy Strachan, Scottish Government

[2] Personal experience of author as manager of an OP

[3]https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/227259/9643-BIS-UK_Agri_Tech_Strategy_Accessible.pdf

friendly production methods[4]. The EU has an amended Common Agricultural Policy (CAP) post 2020, which is designed to have a food chain approach for value-added in conjunction to delivery of environmental and climate public goods aimed at minimising environmental damage[5], but due to the withdrawal of the UK from the EU, access to such support will now be different for agri-tech companies in the UK.

The UK supports an atomistic approach in which individual enterprises are awarded grants and encouraged at local levels. Financial assistance is offered to facilitate development of prototypes, and also access to knowledge exchange entities which offer a platform for them to inform potential customers about their developments. This support of innovations is done through the national funding agency UK Research and Innovation (UKRI), a non-departmental public body which brings together seven research councils, including Innovate UK (formerly known as the Technology Strategy Board). This provides UK businesses and research organisations access to funds which can be secured through a competitive basis, and the case study company has received a number of grants from Innovate UK which have provided support at crucial stages of its development (see Section 3.4). However, although many growers may yet need to be willing to change some of their production methods to become more sustainable, there also needs to be a corresponding change in demand for such produce; consumer decisions made on price makes it more difficult to produce to better environmental standards.

3.2.1 Key players in food supply chains and sustainable agriculture in the UK

Table 1 below details the principal entities, both public and private, which govern or influence the food supply chain in England and Wales (of which some also function in Scotland). The highest of these is Defra, which has jurisdiction over agencies, and government departments, such as Natural England and the Food Standards Agency. The Agriculture and Horticulture Development Board (AHDB), which is a non-departmental independent public body, works with a statutory levy imposed on different crops and their outputs, including combinables, dairy, potatoes and horticulture, plus those who intervene in the supply chain (such as

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4 Personal email from Jerzy Plewa, European Commission Directorate General for Agriculture and Rural Development

5 EC 2017 communication from the European Commission to the European Parliament, the European Economic and Social Committee, The Future of Food and Farming.

packers). In exchange, the AHDB undertakes support via a number of ways; research, Public Relations and knowledge transfer activities. The table also includes certification bodies; Red Tractor and LEAF and GLOBAL-GAP. The latter is an internationally-recognised farm standards audit based on Good Agricultural Practice, which serves as a base on which retailers sometimes add other standards (such as Tesco Nurture).

Table 1 UK agencies, societies and government departments involved in support of agricultural sustainability

Entity	**Mandate**	**Public/Private**
Government Department for Food, Environment and Rural Affairs (Defra)	Formed in 2001 from the former Ministry of Agriculture, Fisheries and Food, Responsible for environmental protection, food production and standards, agriculture, fisheries and rural communities.	Public
Centre for Environment, Fisheries and Aquaculture Science	Executive agency for Defra	Public
AHDB Agriculture and Horticulture Development Board,	A statutory levy body funded by levies on agricultural production and the food supply chain, supporting the industry with practical research and diffusion of knowledge.	Public/private
Environment Agency (EA)	Government agency to protect and enhance the environment	Public

Entity	Mandate	Public/Private
Food Standards Agency (FSA)	A non-ministerial government department of the Government responsible for protecting public health in relation to food.	Public
Rural Payments Agency (RPA)	Executive agency of Defra	Public
Natural England (NE)	Government advisor for the natural environment	Public
Animal Health and Veterinary Laboratories Agency (AHVLA),	Animal Health	Public
Local Authorities	Planning	Public
The National Farmers Union (NFU)	Lobbying	Private
Trade Associations e.g. Fresh Produce Consortium, Agricultural Industries Confederation, British Retail Consortium	Technical information and lobbying	Private
Linking Environment and Farming (LEAF)	Organisation promoting sustainability with food assurance standards certification	Charity
Red Tractor Assured Food Standards	Food assurance scheme	Not-for-profit
Global GAP	Food assurance scheme	Not-for-profit

Source: Entity websites

In the UK, Defra (Department of the Environment, Food and Rural Affairs), responded to an independent Regulatory Task Force established to review and make recommendations for farming, including food and environmental standards[6]. This has resulted in a move towards finding non-regulatory solutions to problems such as pollution of environment from run-off of water with nutrients, before moving towards legislation.

Defra encourages trade associations to participate in initiatives such as the Voluntary Initiatives on Pesticides and the Campaign for the Farmed Environment. It also advocates the application of peer and market pressure to develop high standards for farming and food-processing businesses (and hence fruit and vegetable growers), and also the use of behavioural science to promote best practice for environmental and business performance.

Industry bodies such as the non-departmental independent public body AHDB, which is funded by a levy on farmers and processors, encompasses horticulture, potatoes, dairy, beef and lamb and pork, and works to raise the profile and success of these sectors. Each of these sectors has panels (including field vegetables, soft fruit and protected edibles) which are made up of growers who represent their industry.

3.2.2 Supplying fresh produce for processing retail or processing

The UK is more than 74 per cent self-sufficient in total agricultural produce yet cannot produce all its fruit and vegetables. Around 60 per cent of fruit and vegetables are imported, mainly from within the EU, providing consumers with produce outside the UK season as well as varieties which cannot be grown in the UK due to the climate[7]. Nevertheless, UK growers have increased the production of some crops (such as strawberries and tomatoes) under cover, prolonging the season, and also grow others which are less suited to the climate. Growing crops indoors (also known as protected cropping) has a number of potential benefits for the environment (see below) and crops can be grown independently of weather conditions. But there can be challenges too; because polytunnels or greenhouses are structures, there can be issues with planning permission.

There is an opportunity for corporate social responsibility from the retailers, who sometimes develop their own sustainability criteria for contracting suppliers which are above the legal minimum. These are often audited food standards certifications such as Red Tractor. If their aim is to ensure and demonstrate compliance to sustainability and environmental standards, these are certified

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6 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/69506/pb13717-farmregulationtaskforce-response.pdf

7 Source: Personal email Fresh Produce Consortium 2013

LEAF Marque. While certification and labelling are increasingly looked for by socially conscious consumers' demand for more clean label products (Asioli et al., 2017), Maréchal et al. (2018) argue that there is still a need for intervention to overcome the market failure from not assigning environmental goods a value.

3.2.2.1 Resource use and causes of waste

Growing indoors (also known as protected growing) has a slightly different use of resources from outdoor horticulture; for example, as the soil and rain provide water and some of the necessary nutrients for outdoor crops, there can be less reliance on inputs (depending on the weather, soil type, previous crop, etc.). However, if growing indoors, particularly if crops are produced hydroponically, all the nutrition and water needed by the crop will be applied and the correct root zone conditions for a healthy plant needs to be provided. Evaluating these needs in this context is known as hydroponic science. Indoor growing facilitates much tighter control of resources so they are not wasted or cause pollution than is possible for conventional outdoor horticulture as it is easier to prevent run-off of valuable nutrients.

Not all the produce reaches its intended market outlet; it can be rejected if it does not meet the required specification, or it can receive mechanical damage, such as bruising, when being harvested or moved. Pests and disease can also affect crops, preventing them from achieving their genetic potential in addition to causing internal and external damage and even rots in storage. This all leads to waste and impacts on producer profit margins.

3.2.2.2 The use of pesticides, regulation and consumer reaction to pesticides

In conventional crops, plant protection products are normally used to prevent or limit damage to crops; these comprise insecticides, fungicides and herbicides. In the European Union, pesticide regulation is rigorous and growers are encouraged to follow integrated pest management (IPM) approaches to slow down increasing resistance to the active substances used for plant protection (Oerke, 2006, Collier et al., 2016, Bruce et al., 2017, Dewar, 2017, Van Emden and Harrington, 2017). This is backed by legislation which ensures rigorous re-testing of products when their licence period ends at European (European Chemicals Agency) and country level (Chemicals Regulation Division, HSE). Supermarkets, particularly in Europe, are also responding to consumer concerns by seeking to drive down pesticide use. All the major UK retailers test fresh produce for pesticides to ensure they do not exceed legal maximum residue limit (MRL). Even when this requirement is met, pesticide residues can often still be found, and salad vegetables which are eaten raw, are of particular concern (Santarelli et al., 2018). Some UK supermarkets are doing more than others to reduce usage by working closely with its growers and suppliers, with Waitrose and Marks and Spencer considered to be the best.[8]

Access to agricultural labour is an area of concern for many UK growers in the face of the withdrawal of the UK from the European Union. This is because of the end to free movement of labour which has been crucial for recruitment of both seasonal and permanent of workers which is expected to end (depending on the final withdrawal bill, yet to be decided). AHDB figures estimated around 22,500 EU nationals to be working in agriculture in the UK in June 2015[9].

3.2.3 Supporting sustainable agriculture - knowledge exchange

The UK is one of a number of European countries which no longer have a national advisory service for agriculture, which may compromise independent knowledge transfer and/or exchange. Cuts in government spending in Britain led to the government extension service ADAS, which used a linear network, being sold to the private sector in 1996. There are a number of different providers of advice, such as governmental and non-governmental knowledge diffusion on environmental protection, research institutes, commercial agronomy advisors and consultants, plus apolitical levy bodies, such as the AHDB. Multinational agricultural-chemical companies, such as Bayer and Syngenta, who sell to large portfolios of growers across the world, undertake their own diffusion of innovation via their marketing teams.

Moving towards more sustainable food production, and indeed sustainable intensification, requires more than just innovation at farm level (Morel et al., 2020). Whilst changes seem to be necessary to support sustainable intensification in food production, there are some suggested alternatives, such as better efficiency in the food chain. Many of the examples in the Foresight Report (Godfray et al., 2011) are concerned with livestock farming, animal conversion rates and the association between increasing wealth and meat in the diet. However, there are some suggestions for reducing waste in the fresh produce supply chain, which could be facilitated by enabling growers to produce certain crops such as salads so that they are ready to supply exactly according to consumer demand (Kirwan and Maye, 2013). Nevertheless, if these are to occur,

8 Pesticide action network https://www.pan-uk.org/supermarkets/

9 AHDB Horizon 2016 Report

there will need to be support from policy makers to support such initiatives, such as the AgriTech policies in the UK. Farmers will also need to be willing to adopt new techniques (see Section 6.4.4), and consumers willing to purchase foods produced by such methods (Smith, 2013). At the time of writing, GM technology which would facilitate breeding crops which are tolerant/resistant to pests is not permitted to the UK or the EU, but is very likely to help reduce the application of pesticides.

Convincing farmers to adopt new techniques and technologies can be complicated, therefore the first stage is to persuade growers to look at the potential merits of new systems and technologies, and hence there is a connection between policy and diffusion of innovation. A UK government-funded Sustainable Intensification Research Platform (SIP) created to research ways in which agricultural stakeholders, scientists and farmers integrate knowledge, is aimed at encouraging best performance (Morris et al., 2017). Although this was more based around outdoor broadacre combinable crops and livestock farms, some of its principles are relevant to sustainable intensification in the context of indoor 3D farming.

Membership cluster organisations which support start-up, innovative companies in the agricultural sector, also play a role in diffusing innovations. An example cluster organisation is of this is Agri-Tech East (also known as Agri-TechE), which was founded in 2014 and is funded by the Government's Local Growth Deal. The organisation undertakes activities to bring together scientists, farmers and the supply chain. Founded in 2014 in response to the Government's national industrial strategy, and Innovate UK, the non-departmental public body funded by a grant-in-aid from the UK, with guidance through a local Business Board, Agri-TechE was the first to be established, and was based in the Eastern counties of England because of the region's close association with agriculture. It organises events which promotes the innovations and brokers collaborations leading to investments and long-term relationships. Events organised by this body typically attract a broad audience of supply chain actors, innovative growers and potential funders of innovation and provide a platform for diffusing innovation. The enterprise also works with the Department of International Trade to showcase start-ups and scale-ups that are looking for investment to international investors.

3.2.4 Challenges for building infrastructures

One of the challenges to be addressed before erecting infrastructure to house three-dimensional indoor farming facilities such as polytunnels or greenhouses can be local planning regulations. There can be objections from neighbours, as they can impact on the landscape. Refusal of planning permission has affected a number of companies in this way, including some of those included in this study, such as Plantagon (one of the original companies considered for the study, Ref: VF01).

3.2.5 Linking policy context and research questions

The EU/UK policy context is relevant to the research questions because they provide the framework within which agri-tech companies, such as the case study, have to operate. There is a clear connection with the first key question of this thesis which explores the relationship between 3D farming and sustainable intensification and the policies discussed above, such as the CAP, the Sustainable Intensification Platform and Horizon 2020. This is because they are aimed at supporting best use of resources in agricultural and food production, often with a focus on research and innovation to move towards sustainable intensification. This is why the sub-text of my research question is about how practitioners translate sustainable intensification into practice.

Policy affects the dynamics of diffusion of innovation strategies in agri-tech companies. This is because through the use of incentives and tools, policies can foster conditions which help innovative start-ups, and can influence the ability of certain actors to become key players, and also motivations and barriers to adoption, all of which are included in my research questions about diffusion of innovation. For example tighter regulation around plant protection products can drive growers to seek out more sustainable ways of growing such as Integrated Pest Management in which different methods of pest control are used (see also Sections 2.3, 3.2.2.2, 5.2). Other policies can such as those that determine whether applications for change of land use to allow the construction of greenhouses and/or polytunnels for growing fruit and vegetables can be granted, are also important to enabling or constraining innovation development and uptake.

The policy context also has indirect effects on my research questions about business models. This is because incentives and regulations affect all aspects of the business, including an overall business framework for upstream and downstream supply chains and the innovative company’s contacts (see River of

Life, Section 8.1.2, Figure 17), in addition to the businesses of adopters (potential, actual and non-adopters). Policies designed to help innovation aimed at addressing the production of food with a lower environmental footprint provide a framework within which value can be created (and connect with those which are aimed to promote sustainable intensification). As such, they can be related to my research questions on value creation. The provision of grants at strategic times can provide the innovative company breathing space to assess whether its innovative offering complies with demand or to amend its business model.

This thesis seeks to build empirical understanding of how a small company builds its business case around an innovation to produce food with a higher output per unit of area with a lower environmental footprint, thus policy context provides an important framework.

3.3 Outline of three-dimensional farming

The concept of vertical farming, which extends plant cultivation into the vertical dimension (Touliatos et al., 2016), has the potential for higher yields, and therefore may provide a means for achieving a higher degree of intensification. However, as urban farming has hijacked the term ‘vertical farming’, for the purpose of this study it will be referred to as three-dimensional or 3D farming.

This type of commercial 3D farming is usually undertaken indoors in glasshouses (greenhouses), polytunnels or within other buildings (retro-fitted or specially constructed) and therefore the crops grown are less dependent on the weather. Plants can be grown in modules which have a growing medium inserted rather than soil (hydroponic), which allows for greater precision when applying nutrients than when done outside. Thus, while innovation may be assumed to be implicit in the hardware used for growing the product, agronomic expertise in developing best practice for delivery of plant nutrition or by diffusing the light in such a way that the plants at the bottom of the stack receive sufficient light for photosynthesis to grow at a similar rate and to a similar quality to those at the top, also plays an important role. As discussed in the Literature Review, Despommier (Despommier, 2012) proposes vertical farming to raise production but fails to offer guidance on how to obtain the benefits (Tilman et al., 2011, Specht et al., 2013, Thomaier et al., 2014, Specht et al., 2015).

3.4 Evolution of the case: Saturn Bioponics

This thesis comprises a case study undertaken to explore the evolution of a provider of equipment and agronomic expertise, Saturn Bioponics. The company works in the conventional commercial indoor farming sector, and not urban farming, high value production or niche markets. The first contact was made with the company's CEO, Alex Fisher, early in 2014, who first perceived an opportunity for increasing productivity in the indoor fresh produce sector in 2010.

The company was founded in 2011 by Alex Fisher, the Chief Executive Officer (CEO), and the firm won a DEFRA Innovate UK For Growth competition in 2012 which enabled it to develop an initial prototype of its innovation the Saturn Grower. In the early days, the CEO worked together with a biologist to establish a smart system of multiple layer growing for leafy green vegetables and soft fruit, called the Saturn Grower. Further funding was secured 2013, provided by Innovate UK. The plan at that time was to be become commercially viable by the end of 2014, and the company aimed to sell its technology to various subsectors of the horticultural industry, such as strawberry and leafy green producers. By 2014 trials on brassicas and strawberries were being undertaken in a greenhouse in Birmingham; this work helped to draw interest in the firm, and it was the winner of Farm Business Awards and AgriTech Catalyst Awards.

In 2015 the company received an Innovate UK grant of £127,400, which was used to fund a collaborative project with Valefresco, a large-scale salad supplier to many major British supermarkets. Valefresco has played a key role in the venture as it enabled Saturn Bioponics to showcase its product in a commercial environment and was also able to provide technical feedback from a commercial point of view. Valefresco director Nick Mauro is also an AHDB Protected Edibles Panel Member. That same year, Arnoud Witteveen, a specialist in hydroponics, joined the company as Chief Technical Officer (CTO), and Saturn Bioponics established relationships with early adopters who helped refine the innovation with improvement of fruit/vegetable results in terms of yield and supermarket specification using the Saturn Grower. Other employees have gradually built up as the company has expanded, and by 2020 numbered nine (including some part-time workers). The company was a finalist in UK Grower Awards in 2015.

The company continued working on building its networks, especially in other EU countries such as Italy and Portugal, after the 2016 Brexit vote stymied grower investment in the UK. By 2017, the company had increased its ability to respond to market indicators and nuances of customer demand. This was shown in three major areas: there was a perception of different opportunities from hydroponic consultancy which works with the Saturn Grower but also with other hydroponic equipment; a change in target customers at this time, which changed to a new business model with just a few big customers and the influence of the business model of each potential adopter on uptake of innovation. The growing reputation of the company in the sector secured it a mention in Defra’s 2018 25-year Environment Plan (2018 p36).

The company has continued to grow and expand its networks, to date it has received a total of seven Innovate UK grants. The CEO has contributed to discussions such as a Prosperity UK panel on How Technology is Transforming Farming (Ref: AS30).

There was also a strategic move to considering the use of business agreements with others further back in the supply chain, such as well-established greenhouse specialist company Idromeccanica Lucchini, which was founded about 75 years ago. There is a mutual agreement in which both companies acting to act as distributors. Since the end of 2019, Scottish investor company Shockingly Fresh is developing a number of farms across the UK using Saturn Bioponics’ technology and hydroponic science consultancy.

3.5 Other players informing the research

While not forming part of the case, other vertical farming companies have been interviewed. One of note is Aponic, which has devised an aeroponic vertical farming system (in which crops are grown without soil and receive water and nutrients in a spray) and devised specialised software to help monitor crops and synchronise nutrients with light levels has also informed the research. It was named as a top 100 UK small business in the Small Business Saturday Top 100 in the Guardian in 2016. Other vertical farming companies interviewed are listed in Appendix I.

3.6 Conclusion

This chapter sets out the market and institutional context in which the case study used in this thesis is operating and some of the policies which have helped it during its evolution. Establishing this context has been important because this thesis follows a case study format, which is a study of a particular phenomenon in its context. The next chapter is the Methodology which details the research questions and the framework used for this study.

Chapter 4 Methods

4.1 Research Strategy

The overall research question addressed in this thesis is whether and how, within the context of a market economy, a small enterprise selling technology and expertise for the production of fruit and vegetables grown by indoor 3D methods can contribute towards a pathway to sustainable intensification, and the roles played by diffusion of innovation and the business model.

The research questions in this study were drawn around three concepts, and the results explored to understand their interfaces. The first research question was aimed at understanding the relationship between 3D indoor farming and sustainable intensification. Once this had been established, the second question addressed was how the company diffused its innovation through its evolutionary course to discover some of the factors that have influenced its progression. The third question was to understand how the company used its business model to create value, and the different elements of value within this context. The research questions are covered in more detail in section 4.2 below.

As 3D farming is a “contemporary phenomenon in a real-life context” (Yin, 2003 p13), it was decided to follow a case study approach as advocated by Yin (2003) because of its potential to better understand its context and complexity. The approach followed has generally been qualitative, using a framework to explore the relation between the case and ‘sustainable intensification’, ‘diffusion of innovation’ and ‘business models’ to identify interactions between these different elements.

Following the single case study format outlined by Yin (2003), the study follows a producer of 3D farming equipment, Saturn Bioponics, a provider of vertical farming equipment, in its early years of business between 2014 and 2020. The boundaries of the case study were set to include companies using Saturn Bioponics’ innovation and, where possible, downstream members of the supply chain, such as early adopters and other specialists, to provide multiple sources of evidence. This case study boundary extension was not only to collect more data but also to understand complex interactions between the three concepts.

Data have been recorded from expert interviews with the CEO of Saturn Bioponics. Contact was first made in 2014 and followed up with visits (made once a year or more), emails and telephone calls until February 2020. This has been supplemented with information obtained from interviews with early adopters, potential adopters and other experts in the sector, emails, reports, trade press articles and trade conferences (see Appendix for further details of these sources). Together they have created a narrative on the evidence-based practices and farm realities of how sustainable intensification may work in practice, and the evolution of diffusion of innovation and the business model.

Potential ethical concerns addressed in the study of this nature included informed consent and also any issues around commercial confidentiality, and are discussed in more detail 4.1.2 below.

4.1.1 Pragmatist philosophy

The research is empirical and applied, although informed by theory, and draws on constructivism in that the observed reality and analysis has been based on the themes that emerged and the constructs that they illustrate (Creswell and Miller, 2000). It was decided to take a pragmatic theoretical approach to the thesis because the phenomenon being studied is in constant flux, resulting in a need for change and adaptation. This is supported by critical examination of the theoretical framework and empirical data collected as part of this research study.

4.1.2 Ethical considerations

The University of Leeds Faculty Research Ethics Committee reviewed and approved the research application. It found the main ethical risks to be related to commercial confidentiality. This included concerns that in some cases, it may not be possible to make data anonymous/ aggregated or if, given the small size of the sector, someone could work out from the data which company is doing what. Therefore, no changes to the research design were made after the Ethical Review, and any confidential data collected was evaluated for its importance to answering the research questions, and discussed with supervisors whether the material could be omitted without harming analysis.

Prior to interview participants were for their consent in participating in the research; and the data collected was not personal, but about the enterprise, although their points of view on issues such as sustainability were asked for. Following advice from Miles and Huberman (1994), to address any changes of circumstance, this was checked again. Interviewees were be given the option of being named as the information source or being kept anonymous, if desired. For example, those who requested not to be named have been anonymised according to their profession, for example as a ‘Grower’ or ‘Processor’..

Companies were offered the opportunity of getting sight of the information and analysis and allowed to clarify facts without any right to veto, influence or change any analysis. This would allowed them to highlight any areas that may be under embargo as commercially sensitive, if appropriate.

Other data that is in the public domain, such as conference speeches, marketing materials and website information has also been used to triangulate information. This strategy, which is advocated by Yin (2003) is useful for helping to maintain objectivity and is discussed in more detail in 4.3.3 below.

Building good relationships with the CEO of Saturn Bioponics and other people in the related companies offered advantages such as information not available to the general public. However, this also meant that there were times when the author became aware of some facts about which the interviewees requested confidentiality, which then needed to be balanced against the need to maintain objectivity. To address this, the principal case study actors have been given the option of reviewing the data chapters, clarifying facts and vetoing any potentially commercially sensitive information, but not any of the analysis.

As the Data Protection Act 2018 came into force during the time of this study, care has been taken to ensure the management of personal data is compliant. Part of this is the need to have a lawful basis for processing the data, which in this case is research as a task in the public interest. When collecting personal information, I applied data minimisation, only collecting the data that I needed. Electronic data is held in password protected files, and data on paper is securely stored. These criteria were already within the procedures in place, so no changes were made in these areas. In accordance with the Data Protection Act 2018, the time limit for data storage will be adhered to.

4.2 Research questions

The focus of this research is a multi-disciplinary evaluation of the relationships between the three concepts outlined in Chapter 1, Figure 1 and detailed in Tables 2, 3 and 4 below. Exploration has been made through three different lenses to get more holistic understanding looking through layers of context.

The research questions addressed in this study include an evaluation of the relationship between sustainable intensification and the case study, the diffusion of innovation structures that enable interaction with potential adopters, and how the business model of such a company may evolve over time, plus an exploration of the links between them. These are set out in Tables 2, 3 and 4, mapped to the different data sources that were used to address questions. Information on how relevant data was selected, including choice of interviewees, is detailed below in 4.3.3, and, where relevant, is explained in more detail in the data chapters.

Table 2: Exploring the case's relationship with Sustainable Intensification

Research question	Data sources
a. What is the relationship between sustainable intensification and 3D farming in companies supplying equipment for protected cropping systems?	Interviews, email exchanges with the company, technical articles and observations Expert interviews with case study entrepreneurs, employees early adopters and industry experts Observation notes and photographs Agronomic methods used for putting sustainable intensification into practice Website and marketing materials Attendance/speeches at conferences/trade shows Contact with quango and government sources for data and information (AHDB, European Commission, Eurostat, Defra, ADAS, Scottish Government etc.). Technical press articles
b. What is their perception of the benefits of their technology in terms of sustainable intensification?	
c. To what extent do they promote their products with the principles of sustainable intensification?	
d. How do they put sustainable intensification into practice?	
e. To whom do they communicate the sustainability benefits of their technology? (this is an interface with Diffusion of Innovation)	
f. Do the actors perceive sustainable intensification to be part of their business model? (This is an interface with BM)	

Table 3 Building understanding the case's Diffusion of Innovation strategy

Diffusion of Innovation	Data Sources
a. What are the characteristics of the innovation and what is their importance to potential adopters?	Expert interviews with: Managers in the case study company Other agri-tech entrepreneurs, Early adopters, Potential and non-adopters, Professional agronomists Supply chain specialists, Professional knowledge exchange intermediaries Agricultural communications experts
b. Who are the key players in the case's social system networks and how they have developed over time	
c. Which communication channels are used and how have their use evolved over time?	

<table>
<tr><td></td><td rowspan="4">Emails with the case study company
Technical articles
Observations from attendance at agri-trade shows and specialist conferences
Radio and TV programmes
Blogs and social media
Observation of other novel technology launches
Press briefings for other novel technology launches</td></tr>
<tr><td>d. What roles do opinion leadership and peer-to-peer communications play?</td></tr>
<tr><td>e. How do communications flow?</td></tr>
<tr><td>f. What are the motivations and barriers to adoption?</td></tr>
</table>

Table 4 Driving understanding of evolution of the case's Business Model

Business Model	Data sources
a. How does the case create value?	Expert interviews, emails and telephone calls with: The case study company CEO and CTO Early adopters Other agri-tech entrepreneurs, Supply chain specialists, Technical articles and observations, Attendance at agri-trade shows and specialist conferences Blogs, vertical farming company websites Observation of other novel agri-technology companies Press briefings of other novel agri-technology launches
b. For whom is the value created?	
c. What is the firm's economic model and key resources?	
d. How does the business model express the purpose of the company in the context of sustainable intensification?	
e. How does the business model influence diffusion of the vertical farming innovations?	
f. How does the business model evolve over time?	
g. What is the link between this evolution and Diffusion of Innovation?	

4.3 Framework for the study

The research has been organised around three core concepts which have been brought together into a comprehensive framework; Sustainable Intensification, Diffusion of Innovation and the Business Model in the context of suppliers of equipment for 3D indoor farming. For each one, a working definition has been identified from an existing body of knowledge for *a priori* themes to explore to build a rich understanding of that concept within its context. These have subsequently been used to guide and structure the analysis. The findings from the complex interrelationships between the three concepts has provided a more complete framework for better empirical understanding of this new sector. The Discussion in Chapter 8 reflects at greater length on the contributions to theoretical insights provided by this framework.

4.3.1 Research strategy

The research strategy was guided by Creswell (2009) and Miles and Huberman (1994). As the 3D farming sector is relatively young, there is not yet much data in the public domain or even recorded in a systematic way, therefore, a strategy of primary empirical research was needed. The sector is still very small and there are not a large number of people involved in it, so the idea of following a survey-based research was dismissed as it would not give the richness of data needed to address the research objectives. Given the exploratory nature of the research questions and qualitative nature of the data consideration was given to Grounded Theory developed by Glaser and Strauss (1967), which follows a continuous appraisal from data to build theory (Eisenhardt, 1989). However, it was decided that given the empirical nature of the study and literature already published which could help to provide an initial framework, that the case study method would be the most appropriate study method.

The research design is centred around one main case study, and comprises different layers that form the boundaries of the case (See Figure 2). The strengths of using a case study research design as proposed by Yin (2003) include the potential of obtaining data with more depth and detail than when methods such as surveys are followed. The collected data has been used to provide descriptions which, by drawing on the three concepts described above, can help to derive explanations. Collecting data from interviews with the entrepreneur and others within the case boundary provided rich information which helped to explore for answers to the research questions and achieve better understanding of how a small supplier of three-dimensional indoor farming equipment could be contributing to a move towards sustainable intensification within a market economy.

4.3.2 Selection criteria

An initial exploration of the three-dimensional, multi-layer, indoor cropping sector identified a number of enterprises based in the UK, Sweden and the Netherlands were working towards this objective, as shown in Table 5. Different circumstances, including a denial of access from a desire to protect commercial confidentiality, to changes in strategies, finalisation of projects, or the business closing down, led to most of them being rejected for the purpose of this study.

The choice of the principal case study was partly driven by accessibility and that it is already functioning and playing an active part in the 3D farming sector supplying high-tech 3D growing equipment and corresponding technical expertise in hydroponic growing methods. Partial access was given by Aponic.

Table 5 Companies considered for selection as part of the case study

Company	Business aim	Funding	Reason rejected/accepted
Plantagon (Sweden)	Part social, part commercial	Crowd funded	Enterprise did not build any technology and went into liquidation
Saturn Bioponics (UK)	Commercial	Private investment/Defra grants	Access granted, and used as case study
Zero Carbon Food (UK)	Commercial	Crowd funded	Challenges with access
PlantLab (Netherlands)	Commercial	Research agreement with Syngenta	No access granted
Cornerways Nursery (UK)	Commercial	Owned by British Sugar, part of AB Foods	Changed this part of its business to growing non-food crop and access not allowed
Paignton Zoo (UK)	Demonstration exhibition	N/A	Project and demonstration ended
Aponic	Commercial	Private investment/Defra grants	Limited access

4.3.3 Construction of case study

The study was constructed by firstly by selection of a core company working in the relevant industry. The chosen case study consists of an innovative company, Saturn Bioponics, which has developed a tower method for growing fresh fruit and vegetables (called the Saturn Grower) and has developed corresponding scientific hydroponic expertise. It stood out from the other companies considered for this study because from the beginning it was using consultants to ensure the horticultural product was the right fit for the market.

Once the main case study company to follow had been determined, the decision was taken to focus initially on the case's potential to contribute towards sustainable intensification, then build up information about how the innovation was being diffused (which included collecting data at industry events) and business model used to take the innovation to market.

Selection of interviewees within the operating landscape in which the case works followed a progressive strategy and evolved over time, as outlined in more detail below. Choice of whom to address was guided by their ability to provide different perceptions about the processes and issues related to at least one of the main concepts of the study: sustainable intensification, diffusion of the related technologies or the business model. This helped to build more information and understanding of context as well as adding further detail. When specialists were approached, the data was examined to see whether the same patterns were observed as those derived from the data collected from other interviewees, as suggested by Miles and Huberman (1994). For example, insights from the data collected from knowledge transfer specialists was compared with those collected from industry practitioners in the context of opinion leaders to explore similarities and convergences. Further information with a summary table with total number of interviews and types of interviewees is shown in Table 6 below, with further details in Appendix I.

Interviewees were selected because they had certain characteristics, such as knowledge of a particular sector to be explored. Each empirical chapter had a slightly different set of interviewees; for the Diffusion of Innovation chapter, understanding of communications and diffusion of innovation within the agri-tech sector were key selection criteria, whereas for the Sustainable Intensification chapter, interviewees with technical understanding of how sustainable intensification in a practical situation were chosen. The individuals to be interviewed were selected on the basis of their roles in the organisation (for example they established the companies, or they played a key role in the development of the company and its technology. Some of the contacts were selected from the author’s industry contacts as an agricultural journalist, which involves participation in press events leading to insights on developments and introductions to key individuals in the sector. In addition the ‘snowballing’ technique was used to generate personal introductions, identify relevant industry events and technical articles which then led to the identification of further opportunities to interview people connected with 3D indoor farming or who work to foster competitive and sustainable farming.

The initial approach to the prospective interviewees was through email, with an introduction and informing them about the planned research. Acquaintances known through having worked in the industry were approached informally and asked if they were willing to provide information for the PhD. Following the protocols in the Ethical Review, they were then given a written sheet about the study, and asked for permission to interview them. Participation was voluntary and no financial or other type of inducements were offered at any time.

4.3.3.1 Case study boundaries

Within the boundaries of the case study there are various layers of context (see Figure 2 below) and at the centre is Saturn Bioponics, the company that has created the innovation. The next layer is growers, which includes early adopters, and then moves out to feature others in the supply chain, such as fresh produce packers and processors plus specialist advisors to the industry such as agronomists, agricultural knowledge exchange and PR specialists, and the UK levy body Agriculture and Horticulture Development Board. The outer level is composed of government policy makers and regulators. In addition, other sources, such as interviews with CEOs of other vertical farming equipment companies and trade articles were used to provide supplementary information. These were not limited to the UK, but included the US, Finland and Sweden (See Appendix I). This was complemented by conversations with others in the industry such as the CEO of Linking Environment and Food (LEAF) and the CEO of AgriTechE to gain more detail and context. Delegates attending an urban farming conference held at Harper Adams University that attracted enthusiasts and professionals were also approached for their insights and views to gain a wider appreciation of the context in which the vertical farming equipment sector is functioning (see Appendix I, Refs: HA01, HA02, HA03, HA04)

Government policies on the agri-tech industry provided some important context which may have influenced financial and non-financial decisions made by the company, and its long and short term objectives. This has been important as it helped provide understanding of the factors that may shape the industry's development.

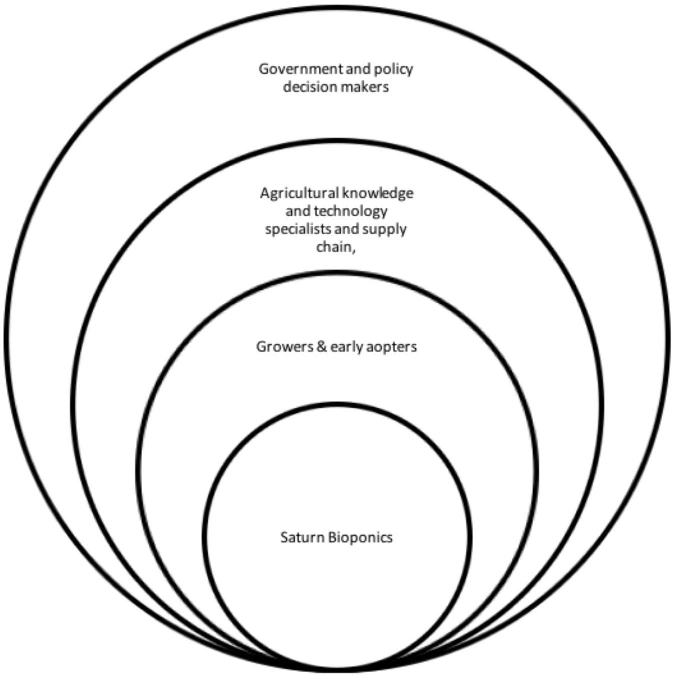

Figure 2 Layers of case study context for Saturn Bioponics

Because the case study approach can attract criticisms such as lack of rigour or insufficient evidence for generalisation (Yin, 2003), it is necessary to address these within the research design. This included ensuring close reference to the research objectives to keep on-course, working to ensure consistency in coding and internal validity and coherence by triangulating data where possible. In addition, key informants were invited to review the information.

A potential weakness of this method can be the failure to understand context (Hsieh and Shannon, 2005), so to address this, contact with the case study was made over a longer time period to show changes in temporal context. The spatial context of where the case can function is driven by the political policy context, which is currently undergoing sweeping changes as the UK prepares to leave the European Union, making this a highly complicated area to address as it is constantly in flux, creating uncertainty in the market (see Chapter 3, Policy and Context). To help ensure integrity of the data collected data from a variety of informants with different perspectives and the interviews were triangulated with written materials including trade magazines and other identifiable material such as independent academic trials on three-dimensional growing and the Government's 25-year plan. These worked as datasets in their own right.

4.3.4 Data collection

The qualitative material under analysis was collected from a series of interviews, emails and telephone calls, observations from visits to the site owned by the innovator, including an experimental station and also the farms of the early adopters (see Appendix I). Where possible, direct observation and exploratory face-to-face interviews took place with stakeholders, with field notes being taken. When this was not possible, interviews were held by Skype or over the telephone.

The aims of these interviews were:

- To obtain an expert/practitioner view of sustainable intensification and its importance to the business, the processes of knowledge exchange and the business model being used
- To observe and discuss the agronomic methods used for putting sustainable intensification into practice

The advantages of this method have been to obtain the views and reflections of the actors but the disadvantage is that the some of the information, such as crop yield data, was collected by the case. To overcome this, other players in the outer layers of the case study parameters have been interviewed, such as early adopters of the system, and other reports in the public domain scrutinised. These data have also been triangulated by drawing on independently collected data on yields using a similar system undertaken by Touliatos et al. (2016).

The information gathered from direct sources has been complemented by analysis of presentations at conferences by Saturn Bioponics and other technical specialists in horticulture/three-dimensional farming. Content analysis of technical magazine articles, press releases and marketing materials to help reveal further information on the practicalities of environmental sustainability in an agricultural context. Printed information from LEAF Marque on requirements for certification to triangulate the data concerning the sustainability aspect of the crop were also used (see Appendix, Ref: LME 01).

Agri-TechE was approached because it is an independent cluster organisation established to work as an incubator for innovations in agriculture and horticulture to improve international competitiveness (Chapter 3 Policy and Context). The organisation has supported agri-tech companies including some vertical farming enterprises. Further data were obtained from discussions with other growers and agricultural scientists attending agricultural industry conferences such as

CropTec, Agronomists' Conference and Agri-TechE at which innovations and their diffusion are featured.

In addition content analysis was undertaken of publicly available information from webpages, public communications such as speeches at conferences and articles in the trade press. This data has been complemented with material from conferences where the company has made presentations, such as GrowQuip, plus presentations made available from other agricultural events and conferences such as Agri-TechE and CropTec (see Appendix). Technical articles about the company and details submitted by Saturn Bioponics for entry for innovation prizes and commercial launches of other technical products in the agricultural sector has also been explored for further information. To widen the scope, interviews were also conducted with other industry players, such as other growers in the protected and unprotected crop sectors, agronomists, knowledge transfer professionals, supply chain specialists, agricultural public relations professionals and representatives from LEAF.

By broadening the boundaries of the case study the data attempts to fulfil the four elements of validity (Yin 2003). These include construct validity, which has been met by obtaining data from multiple sources of evidence, external validity by using pre-established theoretical frameworks as a basis for the study and for internal validity it has been checked for factual accuracy by the case. To help ensure reliability of analysis, a common database for coding through use of NVivo software has been used (see Section 4.3.5 Coding and Data below).

A summary of data collection is shown in Table 6 below, for further details see Appendix I.

Table 6 Summary of sources of data collected for the study

Meetings	Face to face	Telephone	Emails	Trade magazines, media platforms, reports, conference presentations Other
CEO Saturn Bioponics/early adopters	9	7	20	28
Others in VF industry	2	6	4	16
D of I experts	3	2	3	
Other growers/processors	5		2	
Other agricultural industry experts		5	3	18
Other information				
Websites	Saturn Bioponics, GRDC, Sustainable Intensification Platform, Agrilinks, European Innovation Partnership-Agri (EIP-Agri), Peer to Pear Learning Accessing Innovation through Demonstration (PLAID), Knowledge Transfer Network			
Trade Magazines/Media	Horticulture Weekly, Vegetable Farmer, Commercial Greenhouse Grower, Farm Business, Agriculture Technology, BBC Radio 4 Farming Today			56
Trade and academic conferences/trade shows/industry meetings	3x Agri-Tech East 4 x CropTec 2 x Vertical Farming conferences 3 x Agronomists' Conferences 3 x Cambridge University Farm conferences x GrowQuip Commercial Conference			

4.3.4.1 Interview technique

Following Yin (2003), who advocates interviews as an important means of case study information, this study combines semi- structured interviews with the key case study, a corporate practitioner manufacturing vertical farming equipment, early adopters who are stakeholders who are buying vertical farming equipment, and other specialists who work in the supply chain and/or in knowledge exchange. The choice in using this approach was based on the ability establish rapport, helping to target questions towards relevant information, facilitating the analysis of causal inferences and explanations (Gray, 2013). Holding regular interviews with the CEO of Saturn Bioponics facilitated exploration of the changes in the company's opportunities and challenges and how it changed its strategies as it reacted to them.

There are, however, a number of weaknesses in this method which needed addressing, as interviewees may not reveal information as they are subject to time constraints, or due to memory lapse, or confidentiality issues at the time of interview. To minimise this effect, data from multiple elements have been used, including content analysis of articles in 'grey' technical journals, conferences and media interviews, interviews with a range of other specialists associated with the three-dimensional farming sector (see Figure 2 Case Study layers of context) plus information and notes made by agricultural journalists from interviews they have done on the topic. This has helped to shed light on strengths and limitations of vertical farming equipment as the value offering for an example of sustainable intensification in practice from an empirical, pragmatic, point of view.

Mode of interview varied according to availability of interviewee; face-to-face was the preferred method but when this was not possible, email and telephone interviews were undertaken. Other information, such as speeches at conferences and online information was already available in the public domain.

4.3.5 Coding and data analysis

Because of the large body of data collected from interview transcripts, trade magazine articles and conference presentations, a qualitative analysis software package was used. NVivo was chosen because of its capacity for storing and organisation of data and ease of coding and re-coding, facilitating the use of 'trees' for analysis of empirical data. Other advantages of this system included ease with which it is possible to locate text and/or passages when revisiting the data.

Prior to the coding process, data was critically evaluated on whether it was critical to the concept being studied. Data which met these criteria were digitised and uploaded to NVivo. An initial coding frame was set up using the criteria from the framework and scrutinised for patterns which offer insights across the different data (Miles and Huberman, 1994, Glaser and Strauss, 2009, Bazeley, 2009). Initial document analysis using the pre-defined codes provided both information on the development of the core case study and context from the other players. It was then re-read to become familiar with any emerging themes at an early stage, as recommended by Gray (2011). Key words used for coding were initially determined and used thematically with reference to the research framework, and content analysis of the documents was used to identify these categories in the text.

For the subsequent phases other categories of coding were added from their individual frameworks, with some data being cross coded across different categories to show different dimensions of the information as different lenses were used for analysis – for example yield and sustainability data from the Sustainable Intensification chapter were re-coded as part of the value offering of the business model.

Figure 3 below represents a snapshot of the early coding structure employed for the case study on diffusion of innovation. The screenshot illustrates how the initial framework helped structure the coding categories.

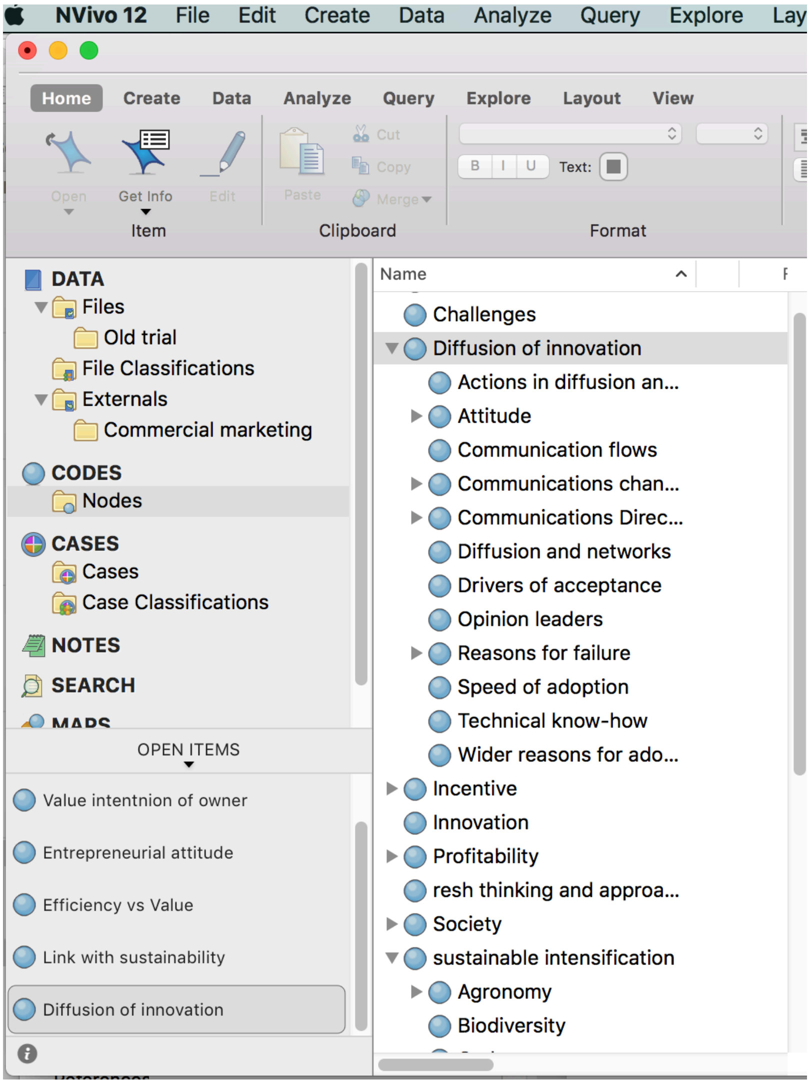

Figure 3 Initial coding in NVivo

To understand more detail about the case, a decision was made to use conceptualisations from within accepted academic literatures of sustainable intensification, diffusion of innovation and business models as a basis for building the frameworks for this study. This was helpful as it provided initial pre-defined categories for coding the data. For example, for the business model terms such as 'value proposition' and 'value capture' made a good point from which to start. The key stages comprised initial coding of information as a concept, which was then broken down into sub-headings (tree nodes with branches); for example value capture was assigned a further seven categories. Insights from the initial analysis, alongside annotations were then used and compared with other academic literature indicate similarities and differences and were used iteratively to suggest questions in later interviews. Re-coding according to the umbrella themes was then undertaken to help explore any connections. As the project developed, some of the *a priori* codes were amended and *in vivo* codes added during re-reading of documents and interview transcripts. For example, some of the *a priori* codes in Figure 4 below are Value Intentions; as analysis of the data progressed, it became evident that this broad coding needed amending to allow inductive emerging themes to be better understood. This included themes such as ‘Attitude to change’ and ‘Efficiency vs Value’ collection to be added, and the data was then revised to detect where these might have occurred previously. Some of the texts were coded more than once because they were relevant to more than one chapter of the thesis. One of the challenges of such analysis was to ensure context is not lost, particularly as different lenses were used to view the case. Mitigation strategies included coding whole phrases and, where possible, pictures, diagrams, matrices and tables were used to give a more holistic view when comparing data.

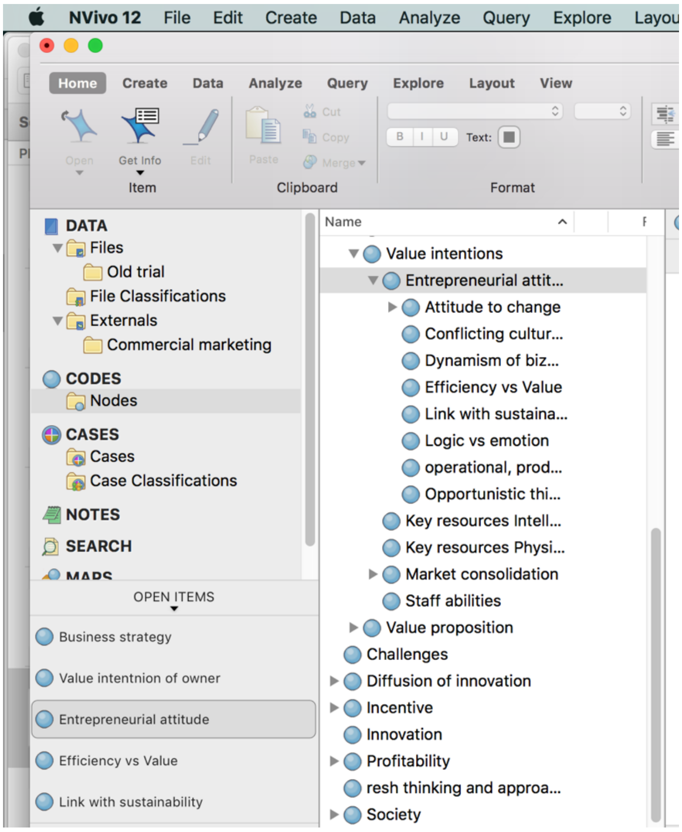

Figure 4 Developing themes in NVivo

Data were initially descriptively coded and the frequency of codes noted. Deductions were then made and the data was then further coded to facilitate interpretation to explore underlying information reflected and using both NVivo and revision of memos and texts, searched for patterns connecting the empirical data with the frameworks detailed above. The methodology follows the suggestions of Yin (2003) to ensure consistency and credibility of coding. Narrative was then used in the data chapters to convey these findings, which was important in itself, as it often raised more questions and discussion of themes, leading to further analysis.

To better understand sustainable intensification, coding categories were arranged to reflect the dynamics between the subjective building blocks of sustainability and other, more quantitative data such as yield differences. For the environmental theme, first level coding was summarised segments of data, dividing the information into 'intensification' and 'environmental' factors. This facilitated the focus of further data collection and subdivisions were made, for example, for intensification coding included terms such as water use, pesticides, recycling and their synonyms, while for intensification 'yield', 'saleable crop' and 'productivity' were sought. To identify the underlying factors influencing yields and environmental impact, data on both physical methods such as agronomy and user attitudes were collected over a number of interviews, observations and data in the public domain. The information was then re-read, tables and diagrams constructed and memos written as a means of scrutinising for patterns (Miles and Huberman, 1994) to identify factors identifying potential areas where the 3D Growing technology could contribute to sustainable intensification at farm scale and thereby be aligned with this concept at farm level.

To better understand Diffusion of Innovation the synthesised information was used to reflect on communication flows, exploring changes in the company's target market, thereby following the company's evolution of how it diffuses its innovation and its impacts on the uptake of vertical agriculture technologies and practices across the UK. This led to preliminary conclusions which were noted in memos and then related back to explore where they confirm or add further empirical evidence to current theory and where they differ from academic thinking. Strategies to validate findings included revisiting the results and considering the underlying meaning, comparing what had been expected and what had been surprising. These finding were then re-assessed, and considered again within its context to explore whether the same conclusions were reached. At times interpretation led to new questions.

Using an inductive process, patterns and relations between the nodes were sought to explore links between the business model used by the case study and environmentally sustainable practice. The aim was to advance theoretical concepts in business model theory within the concept of sustainable intensification by looking for associations between the different concepts, to take the study beyond each concept in isolation. Patterns revealed through analysis of the case study were cross referenced with information on other vertical farming enterprises or other agricultural industry specialists (see Appendix), thereby expanding the initial conclusions of a case study to try and ensure robustness of the developing theories in the different theories of diffusion of innovation and business model. Once these had been classified, a more focused reading of the text facilitated scrutiny for patterns (Miles and Huberman, 1994) to identify potential areas of their relation with current theoretical models of sustainable intensification, and hypotheses were developed on whether they conformed to current theoretical models. These were complemented by visualisations and tables to inform analysis, particularly turning points, and some were also used as a focus for discussion discussed with key informants.

Translating data into the data chapters commenced by building a series of notes of observations seen from analysis of the data. These were then developed into text and tables, with diagrams and drawings help build the story of the case. The process of writing also played an important role in analysis, as it recalled data, and the way it could be viewed, throwing up further questions, hence revisiting the data or resulting in itinerant expansion of the data sources as specialists were asked for more information, or new potential interviewees approached.

4.4 Positionality of the author

The author is an agricultural journalist with agronomic qualifications and an MSc in Agricultural Economics who has worked regularly for a number of specialist agri-food trade publications such as Vegetable Farmer, Farmers' Guide, Farmers Guardian, Potato Review, amongst others, for over fifteen years. Previous work in the sector includes the post of Manager of a large agricultural cooperative producing fruit and vegetables for export, coordinating investment projects financed as part of the EU's Producer Organisation scheme (see Policy and Context chapter) and advising the Board on strategic matters such as mergers with other agricultural cooperatives. She also worked for the Vegetable Growers Association (now British Growers) overseeing collection of primary data on supermarket prices and quality and its subsequent analysis for the growers. She also has experience in public relations, and has worked with levy bodies, commercial seed houses, agronomy firms and agricultural chemical companies.

The benefits of this include prior understanding about the sector and a broad number of acquaintances across agronomy, communications and business sectors, and therefore context. Knowledge of the industry has also facilitated understanding of some of the technical benefits and pitfalls of the new sector explored in this thesis. In many cases levels of confidence had already been built with interviewees, or, were easier to build because of mutual acquaintances and prior understanding of many of their challenges. Being a journalist already known in the industry facilitated access being granted for some interviews where other researchers may not have been allowed. It was originally thought that due to work as a journalist in the sector, there might be some refusals to interview, but this was not found to be the case. This may be because of trust built up over years and the promise of anonymity if desired.

Interviews were undertaken as purposeful data collection exercises, but, given the author's background in the sector, there has been a need to examine any prior conceptions to ensure data rigour. There are opposing views on whether preconceptions should be examined, acknowledged and side-lined, or whether we all have 'inherited knowledge' from being in the world, as discussed by Lowes and Prowse (2001). Reflection was found to be fundamental in attempting to ensure objectivity as a researcher, and, following the advice of Lien et al. (2014), and this has been attempted throughout analysis of the theme plus when seeking meaning from the data. This has helped ensure rationality of thinking and repeatability of the conclusions if another researcher were to analyse the findings.

Disadvantages of this background included the need to step back and re-examine any pre-conceived notions about the sector, setting them apart, as advocated by (Husserl and Kersten, 1985) and ensuring that analysis reflected the data and maintained objectivity. The ability to question what are often accepted industry practices was learned as part of the development as a researcher. Triangulating data and broadening its information base also proved to be a useful strategy as it gave more information for reflection. Ensuring objectivity was particularly important when reflecting on findings in Chapter 6, Diffusion of Innovation, where, as an agricultural journalist, the author is a player, particularly as some of the findings were not what had been expected as an industry norm.

4.5 Summary

This chapter has illustrated how the research, data collection and analysis have been carried out, and the Thesis now moves on to present and discuss the findings. The first data chapter (Chapter 5, Sustainable Intensification) assesses how the case understands sustainability in practice, and exploring its alignment to sustainable intensification. The next data chapter shows how this methodology has been put into empirical context, providing a detailed overview of the relationship between the case and sustainable intensification practice, is linked to the company as an innovator and how it spreads practice through diffusion of its innovation, and the third data chapter helps consider what drives its operations as a company and how it evolves over the time frame of the study.

Chapter 5 Sustainable Intensification

5.1 Introduction

The objective of this chapter is to explore the practices of three-dimensional indoor farming, and consider the potential of this method for farm-scale contributions to sustainable intensification, thus increasing production without further damaging the environment. Sustainable intensification relates to the relationship between on-farm crop yields and eco system services and forms part of the land sharing or land sparing debate, where there can be a trade-off between agricultural production and an ecological benefit such as species conservation or biodiversity (Gunton et al., 2016).

3D farming may provide one of the potential pathways towards sustainable intensification of fruit and vegetable production at a commercial scale. There is a need for empirical exploration of how a multi-layer growing system operates in real-life farming operations to better understand how sustainable intensification may function in practice at farm-level, a gap that this thesis attempts to close.

To explore behind the rhetoric, a case study method of a practical application of 3D technology in a commercial context has been used. This is important because in many cases agricultural innovation has resulted in systems only suitable for research stations (Pretty, 1997, Carter, 1995). Sustainable intensification can only be achieved by numerous farms contributing towards higher production without compromising the environment. Contributions towards this can entail greater efficiency within different aspects of agronomy and growing systems, in addition to reducing waste not only of inputs but also product rejections due to mechanical damage, pest and disease, and failure to meet customer specification.

The case study chosen was a company that has developed a 3D farming system for protected crops (grown indoors) which is suitable for commercial growers (see Section 4.3.3). Using data collected over a seven year period, this chapter explores whether potentially higher yields (intensification) are achieved while minimising environmental impacts when this system is used. The framework discussed in Section 5.2 below is then related back to the academic literature on sustainable intensification in agriculture of for critical assessment of how practitioners interpret the concept within the context of indoor horticulture in the UK.

There is a challenge as not all advantages from activity towards sustainability are easy to see (Carolan, 2006). Guidance on choice of sustainability indicators shows there is a need to establish the environment and context where work is taking place, and then consider the goals, identify indicators and collect data (Reed et al., 2006). Decisions guiding which sustainability indicators to use depend on their relevance to what is being assessed; those aimed at arable and livestock farming differ quite widely, and as yet there is no guidance for three-dimensional farming in a protected crop (grown in a greenhouse or polytunnel). As this chapter is focused on sustainability at farm (micro) level, it was decided to use a tool that is focused at this level and is not over-complicated to use. Agronomic efficiency and agronomic sustainability, two of the indicators identified by Gunton and Firbank (2016) can be focused at farm level, thus they have provided a guide for this framework discussed below in Section 5.2.

Best use of resources to achieve better efficiency at farm level calls for attention to detail at each level of production, and Pretty (2018) advocates the adoption of new technologies to achieve intensification because, due to their precision, they can also help minimise environmental damage. This is because the avoidance of unnecessary inputs helps minimise greenhouse gases and optimises the effective use of clean water. Such characteristics are also considered indicators of a farming enterprise moving towards sustainability, and are included as criteria used as part of the audits for sustainability by Linking Environment and Food (see Section 3.2.1).

The aim of this chapter is to understand the relationship between sustainable intensification and 3D farming, perception of the benefits of the technology in terms of sustainable intensification, and to observe how the case study company Saturn Bioponics and early adopter Valefresco interpret sustainable intensification and put it into practice. This has been done by categorising the data into the technical characteristics of the innovation and potential for yield increases and environmental impact as a means for contributing towards sustainable intensification.

5.2 Framework

Given the complexity of sustainable intensification discussed above, the evaluation framework for assessing alignment between sustainable intensification and vertical farming has looked to advice and elements from both academia and the agricultural industry. It draws on the overarching theme of agronomic efficiency and sustainability coined by Gunton (2016) and attempts to remain simple by keeping to just a small number of variables clustering related factors together, as advocated by Firbank (2013). When considering practices to take into consideration when looking at sustainable agriculture as defined by Pretty (2008) it was observed that while integrated pest management, nutrient use, and water harvesting are relevant to the hydroponic growing methods used with the three-dimensional farming equipment in this study, the others are not. As a result, in addition to the case study companies' data, this study has also included some of the sustainable practice criteria used in the Linking Environment And Food (LEAF) Marque certification scheme, since this takes account of the whole farm and not the cropped area. This, therefore, includes habitats such as hedges and grass margins which are not used for farming but which have potential for providing enhanced environments for vertebrates and invertebrates. Dicks (2019), in work exploring benefits to productivity and the environment in the context of UK farming, has also based academic work around practices advocated in the Integrated Farm Management elements developed by LEAF (2018). The Integrated Farm Management concept was also adopted by the European Initiative for Sustainable Development in Agriculture[10] of which LEAF was a founding member.

In this project, the criteria have been amalgamated into a framework to form a basis for reviewing the environmental criteria relevant to a system such as the 3D Growing technology, The study looks for potential improvement of sustainability, following Pretty and Bharucha (2014b) who, as noted above, assert that it is not important to have accurate measurements, as any improvement is a step in the right direction. To assess intensification, a simple increase in yield per unit of land as one unit of measurement considered to be a contribution (Smith et al., 2017). This is because it is arguably the main driver of intensification from the grower's point of view, but also take into account reasons behind the increase. It is important to emphasise here that farmers are focused on increasing the saleable yields they produce so they can earn sustainable profit margins and this is reflected in the data as each interviewee refers to this.

Table 7 below collates the criteria for sustainable intensification from the findings of Pretty (2008) and the LEAF certification scheme, noting the criteria that are relevant to vertical farming and those that are less so, such as soil health because the crops are not planted in soil but grown hydroponically on a medium such as clay balls.

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[10] http://www.sustainable-agriculture.org/eisa-publications/eisa_framework_english/

Table 7 Framework of building blocks for potential alignment between 3D farming and sustainability

Criteria	Alignment potential	Alignment to agronomic efficiency	Alignment to agronomic sustainability
Increase in yield (intensification)	✓	✓	To be explored
Decrease in crop waste	✓	✓	✓
Decrease in pesticide use	✓	✓	✓
Nutrients/Water efficiency	✓	✓	✓
Land suitability	✓	✓	✓
Soil health	N/A	N/A	N/A
Biodiversity	x	N/A	N/A
Lighting/UV for photosynthesis	✓	✓	N/A
Carbon footprint	Variable	N/A	Variable
Agro-ecological system	N/A	N/A	N/A
Relationship with the whole landscape	When whole farm-scale is taken into consideration	✓	✓
Livestock Integration	N/A	N/A	N/A

Criteria	Alignment potential	Alignment to agronomic efficiency	Alignment to agronomic sustainability
Aquaculture	There is potential integration for this to work with three-dimensional farming	N/A	N/A
Technology and growing substrate	Potential for this to work with three-dimensional farming	✓	✓

Source: compiled by author, based on Pretty (2008), Gunton et al. (2016) and LEAF Marque Standard audit criteria (2018)

LEAF inspections evaluate the sustainability of its members' production methods and because its criteria are more stringent than government regulations they make a useful proxy for measuring the extent of the environmental impact of the three-dimensional farming system. Proof of concept can be determined by assessing whether the method of using the 3D Growing technology is acceptable for certification by examining their criteria against those used for standard LEAF Marque certification (LEAF, 2018). There are a number of organisations providing certification, including the British Retail Consortium (BRC), Sedex and GlobalGAP which also cover supermarket schemes (see Policy and context chapter) who audit food producers and the supply chain for compliance in areas such as health and safety, labour rights and traceability. LEAF Marque was chosen because it is more centred on environmental sustainability than the others and takes a whole-farm focus in addition to providing a platform for knowledge exchange between innovative farmers. The criteria from the published standard of its published standard audit papers make a useful base for helping to understand on-farm sustainability (LEAF, 2018).

Table 8 (below) details the certification criteria applied by LEAF Marque and explores whether they could be considered applicable to three-dimensional farming methods applied by Saturn Bioponics. Valefresco, as a supplier to fresh produce and packers, is LEAF Marque certified, thus it provides proof of concept that it can achieve these standards.

Table 8 LEAF Marque certification criteria for Integrated Farm Management

Criteria	Benefits	Applicable to 3D farming
Organisation and Planning	Identification of what needs improvement, drive forward improvement and chart progress	Yes
Soil management and fertility	Optimise soil health for yield and maintain/improve biodiversity	No
Crop Health and Protection (Pesticides)	Clear documented policy showing strategies to IPM and conventional, cultural and biological means of controlling pests and disease	Yes
Pollution Control and By-Product Management	Reduce, reuse and recycle; use of carbon footprint tool to understand environmental impacts	Yes
Animal Husbandry	Animal Welfare and Health, protection of resources and optimisation of grass production	No
Energy Efficiency	Optimisation of yields rather than maximisation	Yes

Criteria	Benefits	Applicable to 3D farming
Water Management	Optimisation of water use for crop while reducing leakage and environmental impact from Its discharge.	Yes
Landscape and Nature	Aims to enhance the farm and encourage greater biodiversity and enhance landscapes on the farm, and the protection and maintenance of archaeological or historical sites.	Yes
Community Engagement	Regular communication and participation with local community initiatives to communicate a balanced and positive approach to farming.	Yes

Source: LEAF Marque Standard Audit (LEAF, 2018)

To complete the assessment and include intensification, the above factors have been added to those assessing commercial yield (including crop quality aspects) by looking at agronomic efficiency (Gunton et al., 2016). Input efficiency and reduction of waste through yield variability also form part of the framework for assessing intensification.

5.3 Material and Methods

To explore the potential of three-dimensional farming to contribute to sustainable intensification, a case study approach has been used for this research with the aim of using a case study to gain insights into commercial firm perspectives on sustainable intensification and to learn about implementation of 3D farming in practice. Sources include semi-structured interviews, observations, presentations at conferences and other data in the public domain, including trade publications and websites. More details are in Appendix I. The methods used for analysis of the data are described in Chapter 4, section 4.3.5.

5.4 Findings

This section presents the details of the key elements of three-dimensional farming system and assess their potential for alignment with markers that imply sustainable intensification.

5.4.1 Characteristics of the innovation

To facilitate understanding, it has been important to first understand the technology used for growing in three dimensions. The innovation is called the 3D Growing technology and it comprises modular towers with holes for plugs for the crop. It uses a hydroponic (soilless) growing system in which water and nutrients are circulated through a closed system. This is complemented with tailored nutrition and agronomy based on hydroponic science also provided by the company. This method of growing is suitable for a number of crops, including leafy salads, pak choi and strawberries. Saturn Bioponics has continued developing its innovation by creating a management system which is run remotely from the company's headquarters.

Picture 1: The Saturn Bioponics innovation, the Saturn Grower

Credit: Alex Fisher

5.4.2 Attitude towards sustainable intensification

Data collected from discussions, observations, trade articles and conferences were used to assess the potential of the 3D system for sustainability (see Appendix I). Discussions with Saturn Bioponics and early adopter Valefresco between 2013 and 2020 (see Appendix I) explored their attitudes and interpretation of sustainable intensification and identified key responses showing sustainability to be of high priority. Saturn Bioponics CEO emphasised that "sustainability points have great value to us" (Ref: SB28). The aim of the company has consistently been to provide a "safe food supply with lower chemical inputs" (See Appendix 1 Ref: SB05) and this attitude has been maintained throughout the time of contact. The confidence held by Saturn Bioponics' CEO in the ability to provide a product which facilitates sustainable growing practices was evident in the comment: "All waste needs to be properly recycled, and if the 3D Growing technology were not a clean and recyclable system I would not promote it" (Interview April 2016, Ref: SB05 and reiterated in December 2018 Ref: SB21).

When taking both sustainability and intensification together, Saturn Bioponics' CEO said it was about "producing more with less" and thus drew attention to the importance of using "more space which becomes available in the three dimensions" when using systems such as the Saturn Bioponics' towers (Ref: SB05). Discussions also stressed that to achieve sustainable intensification factors to consider include financial sustainability, as the grower needs to make sufficient profit to remain in business, and this may affect investment decisions (and is discussed in more detail in the Business Model, Chapter 7). If grower or supply chain profitability comes under threat, "ethics do not enter into it as commercial pressures are enormous" (CEO Saturn Bioponics Ref: SB05), hence care for the environment could be considered to be at risk if growers do not make enough margin for their own survival. There is a clear view that "for sustainability there needs to be profit through productivity" (CEO Saturn Bioponics 24th June 2014, Ref: SB01), and this has been corroborated in more recent interviews with the company (Ref: SB21, SB28).

The need to create a system capable of providing benefits for the environment and grower needs became apparent because of the time Saturn Bioponics took to develop its hardware and software systems: "Work has been slow at the beginning to get things right for the farmer and the environment" (Ref: SB05). The company took five years in creating a system which it deemed capable of providing a return on investment for the grower as well as minimising impacts on the environment. To achieve this, the company emphasised the importance of its work "collecting data on resource use and associated costs", which included chemical inputs for nutrients. The latter proved challenging because "intensification can mean higher rates of pest and disease, so good solutions are needed to control diseases" (Ref: SB05). This concurs with the view of horticultural agronomists because pests and diseases can move quickly through mono-cropped areas (BCPC Pest and Diseases conference 12 October 2018, Ref: MI20) and also work published by Roberts et al. (2020). Such factors emphasise some of the challenges of 3D growing and the importance of the work being done in Saturn Bioponics with reference to plant health and the agronomy of hydroponic growing methods to ensure that plants are grown in the best possible conditions to reduce stress. Lower levels of stress in a crop means that the plants are less susceptible to pathogens and is therefore important to yield and quality.

5.4.3 Exploring the potential for sustainable yield increases

Detailed information from trials undertaken by Saturn Bioponics and presented at the GrowQuip Conference 2017 (Ref: SBC01) showed single-cut yields doubled in size, (reaching 3.25 kg/sq. m compared with 1.6 kg/sq. m using a gutter system), thus showing an increase in production per unit of land. Data from Valefresco, who installed a system for pak choi production, also shows an increase in yields from 3kg per square metre to 11.5kg per square metre per crop cycle (see Appendix II).

Attention to detail in a number of areas has played a key role for the system developed by Saturn Bioponics. These include:

- Knowledge of which varieties are more suited to the growing medium;
- A tailored nutrient strategy which provides the right nutrient at the right time to maximise growth and crop quality;
- A reduction in time between crops as improved plant health means less time is needed for sterilisation, and faster turnaround of crops

Shortening the growing cycle (See Appendix II) allows more crop cycles per annum, which can make a significant difference to the total annual crop yield. Mr Fisher said: "If you shorten the growing cycle from 45 days to 35 days, you gain ten days, and over the length of the year this builds up to three more crop cycles, which can make a significant difference to the bottom line" (Ref: SBP11). Speed and ease of harvesting can also reduce damage to plants at harvest and facilitate a fast turnaround to plant another crop and; which can impact on productivity.

“Using Saturn Bioponics’ Grower system, placing the plant plugs in the apparatus takes between one and a half and three seconds/plug, with harvesting taking between four and eight seconds/plug, as it consists of simply pulling out the plant and then placing it in a harvesting cart, while trimming the plant will add up to three seconds” (Ref: SBP11).

Crop yield and quality need to work in tandem to achieve higher saleable yields and the emphasis on ‘saleable crop’ is apparent throughout the documents and interviews. In the commercial arena, crops which do not conform to the parameters specified by customers are rejected and wasted. This can be due to a number of factors, such as not being the right shape/size, contamination (e.g. soil or insects), mechanical damage and bruising.

Valefresco sells to some of the UK’s biggest processors and retailers and ultimately, if the crop does not meet customer specifications, there is no market for it, so product quality and consistency are crucial to the business. If criteria are not met the commercial grower then either sells at a lower price than agreed in the contract with the buyer, with subsequent lower profits, or may even have to destroy the crop. However, issues with specification do not arise with the crops being grown using the 3D Growing technology, as Valefresco reports customer enthusiasm for the reliable quality of crops grown by this method (Ref: SB13). This reliability has led to the negotiation of a new contract, and the company has extended the system to cover all their pak choi production and have trialled it for premium lettuce too, suggesting the acceptability of return on investment and the speed at which it can be achieved. “We sell to some of the UK’s biggest processors and retailers and they absolutely love it – in fact we’re negotiating a new contract off the back of it” (Ref: SB13).

It is also significant that Valefresco has increased the area using the 3D Growing technology as it has found the system to be a success for the company’s business strategy as it helps to increase profits: “We are looking at rolling it out for all our pak choi production and are trialling it for our premium lettuce too. We are really happy with the payback figures; it makes the investment much more attractive” (Director, Valefresco, interview Ref: SB13). This underlines the business needs of growers as an important element when working towards sustainable intensification, and is discussed in more detail in Chapter 7, Business Model.

5.4.3.1 Waste reduction

Saturn Bioponics CEO Alex Fisher claims that in lettuce crops, tightly controlled growing conditions led to growers participating in company trials achieving very high levels of saleable crop (Interview Ref: SB01). This was confirmed by the director of early adopter Valefresco: “Waste on the field is typically 10-15 per cent, but this is very much reduced when we are using the 3D Growing technology” and “The company is producing nearly ‘100 per cent clean’, saleable crop year-round” (Interview, Ref: SB13). The 3D system has been shown to contribute to achieving lower levels of waste, which, due to the effect on yields of pathogens, weeds and invertebrates, can be as high as 30 per cent in some crops (Pretty and Bharucha, 2014b, Flood, 2010). In hydroponic systems a growing medium is used rather than soil, so there is less likelihood of soil-borne pests contaminating the system and subsequent waste. Reduction in waste may also be achieved by targeting harvesting times according to consumer demand, which could also help reduce the need for storage (Interview Ref: SB05). In addition, adjustments in efficiency such as looking at how to reduce staffing-hours for the various tasks including planting and harvesting help facilitate a rapid turnaround and therefore contribute to the production of an extra crop per season: “In our design, we have kept in mind not only the agronomic conditions the plant needs, but also how to keep labour costs down by making planting and harvesting easy and quick for the workforce” (Ref: SB05). When the work is easier to perform, there is less likelihood of damaging the crop while picking, which also reflects on waste. These details are connected with sustainable intensification, because the less the waste, the higher the commercial yield. There is of course, an environmental benefit to lower waste levels too.

5.4.3.2 Agronomy

The important role played by agronomy should not be underestimated; the right blend of nutrients needs to be provided at the right time for plants to achieve their optimum yield potential in optimal time, thereby enhancing crop efficiency. Whilst Pretty (1997) makes reference to nutrients and crop protection, successful agronomic practices include monitoring growth rates and calculating when apply nutrients to get the optimum results. This is an area of focus for Saturn Bioponics, and CEO Alex Fisher said: “We have also been fine-tuning efficiency throughout the system; for example, water and nutrients are delivered automatically and recirculated, ensuring maximum efficiency and no waste or threats of nutrient run-off” (Ref: SBP11) and feeds in to the subject of eco-efficiency discussed in section 5.4.4.1 below. A similar view is taken by vertical farming company

Aponic, who emphasised that the importance of applying “the right nutrients, at the right doses and delivered at the right time” (Interview Ref: AP01).

In a confined space, it is easier to use biological crop protection (See Glossary) because by being a regulated atmosphere it can provide the correct environment for activity of predators of the pests threatening the crop (Conference discussion, Ref: AG03). These methods are not yet as consistent as conventional pest control, so their use would add another variable to trials of the Saturn Grower, hence, although adopted in other areas of the farm, Valefresco has not yet used them with the Saturn Grower (Telephone interview, Ref: SB20). There is, however, potential for the system to work using biologicals.

Saturn Bioponics has worked to provide the necessary phytosanitary conditions to prevent losses from disease such as root rot, and by using internal sterilisation of the root zone with a substance which is biodegradable and not a contaminant (Saturn Bioponics, 2 February 2018, Ref: SB18) and this also contributes to the environmental profile. Other vertical farming companies have devised different ways of dealing with challenges such as the higher humidity from high density planting. For example, USA-based company Urban Produce has developed a dehumidifier for use in the greenhouse, which helps reduce the risk of rots developing (Press interview, Ref: VFC1), and illustrates different ways of approaching challenges of high density indoor growing.

Healthy, unstressed plants are also more inclined achieve their genetic potential for yields. “The increase in saleable yields is partly because by using Saturn Bioponics’ system has effectively reduced root zone fungal disease from the system, meaning that phytophthora is not a problem” (Email: Ref: SB10). Attention to detail in nutrition and plant protection is a driver of yield and therefore enhances crop productivity per unit area, hence this is an important element of the company’s strategy.

5.4.3.3 Comparisons with outdoor growing systems

Using data collected by Saturn Bioponics and early adopters Valefresco, Table 9 explores some of the practices which help achieve greater productivity by the use of a system such as the 3D Growing technology compared with broadacre farming (Interview and trade press, Refs: SB05, SBP07). Measurements are not showing a direct comparison as conventional broadacre farming is done in soil, whereas the Saturn Bioponics 3D farming system uses clay balls as a growing medium, however, other quantitative studies on vertical and horizontal hydroponic systems using lettuces also show increases (Touliatos et al., 2016).

Table 9 Comparison of yield between conventional and 3D farming and the resulting potential contribution to sustainable intensification

Criteria	Attribute	Conventional outdoor broadacre farming	Vertical farming using 3D Growing technology	Contribution towards sustainable intensification
Yield per unit of land	Yield of pak choi	3.5kg/sq. m	11kg/sq. m	Higher plant density per sq.m leading to yield benefit
Input efficiency	Phytosanitary standards sterilisation time	Not relevant to soil-based growing systems	Fast crop turnaround thanks to development of methods to change water and sterilise hydroponic system	Timing and crop health benefit, resulting in yield benefit

Criteria	**Attribute**	**Conventional outdoor broadacre farming**	**Vertical farming using 3D Growing technology**	**Contribution towards sustainable intensification**
Input efficiency (labour)	Labour working characteristics for Harvesting and planting times	As planting and harvesting is done by hand, staff have to bend down to work at ground level.	The lowest level of the towers is 30cm above the ground the others plants are placed up to 170cm, so the labour force spends more time in a comfortable position	Consideration for labour conditions is a social aspect of sustainability
Yield variability	Quality	Average wastage 10-12 per cent	Waste : very low because plugs for simple cutting at harvest reduces bruising and other mechanical damage	This may benefit both environment and commercial yields, thereby contributing to sustainable intensification

Sources: Saturn Bioponics data (Appendix II) and author

The yield increase per unit area of land achieved by the growers trialling the 3D growing technology show that by using the vertical space, although varieties may be close to their genetic maximum yield, growers can still increase marketable yield per unit area of land because of the use of the vertical plane which offers a higher planting density.

Table 10 below illustrates how both conventional and three-dimensional indoor growing facilities share a number of benefits over outdoor growing, including making crop operations easier and quicker to undertake. There is a need to explore the characteristics which are applicable to both to be able to deduce whether the real difference is arguably the higher density cropping facilitated by the case’s technology system and its agronomy.

Table 10 Comparison of benefits of conventional indoor growing and 3D systems compared with broad-acre cultivations in the context of potential contribution of 3D farming to productivity and environmental impacts

Concept:	Potential benefits from indoor growing:	
	Three-dimensional Farms in greenhouse/polytunnels	**Conventional growing in greenhouses/polytunnels**
Yield benefit	✓	✓*
Water efficiency/recycling	✓	✓
Ease of planting	✓	✓
Ease of harvesting	✓	✓
Nutrient efficiency	✓	✓
Wastage (field scale)	✓	✓
Wastage transit/grading	✓	✓
Weather independent	✓	✓
Potential for biopesticide use	✓	✓

* Yield can be higher because of the controlled climate, but when the vertical plane is used, there is higher potential to increase yields.

Water efficiency plays a role in contributing to sustainability. The 3D system works in a closed loop, and was observed at the premises of Saturn Bioponics and also discussed during the presentation at GrowQuip, where "optimal water use" was referred to (Ref: SBC01). Water savings were also highlighted in the technical article in Fresh Plaza which explained how excess water is recirculated with the Saturn Grower system (Ref: FP01), and farmer Nick Mauro of Valefresco who uses the Grower referred to "water use savings" from using the technology.

Other protected growing systems and vertical farming outfits also refer to the efficiency of such a system that recirculates water. Vertical farming company Aponic CEO Jason Hawkins said: “They are proven to be 90 per cent water efficient because any water not up-taken by the plant is returned to the system to be used again” (Ref: AP01). A further benefit of a closed loop indoor system is that there is no danger of nutrients leaching out into water courses and as water is recycled, any unused nutrients may be taken up at the next irrigation event. Such efficiencies also contribute to cost savings which are explored in section 5.4.4.1 below.

One of the challenges of sustainable hydroponic systems is that organic fertilisers are not suitable for such a system because of the nutrient accuracy needed. It is difficult to measure the nutrients available in organic fertiliser, such as farmyard manure (FYM), and the nutrients are not consistent. As a result, Saturn Bioponics has developed its own nutrient base which uses fertiliser processed from kelp which complies with requirements for accurate nutrition for hydroponic cultivations. Other vertical farming companies have taken the decision to apply more conventional fertilisers as they have seen insufficient payback for using organic nutrients. Hydroponic cultivations are not considered appropriate for organic status in the UK because they are not grown in the soil, although they do qualify in the US. In an interview, Ben Raskin, head of horticulture at Soil Association (which audits for organic status in the UK) said: “Vertical farming systems are very interesting and have potential for high value crops in areas where there is no soil, though currently have a narrower range of micronutrients than crops grown in healthy soil. Most liquid feeds have no more than 20 nutrients while we know that over a hundred are needed for good human health”, personal email Ref: ORG01).

5.4.4 Using the whole-farm approach to explore environmental impacts of 3D growing

From a practical point of view, “sustainable intensification is delivering support for the environment, society and economics. It is trying to maximise the potential of what sustainable delivery can achieve” (LEAF CEO, Ref: OB01). LEAF Marque Certification uses a whole-farm concept, and if growers opt for this, their farm is subjected to a nature and environment audit, and farmers also have to fill in an ‘enhancement plan’. Farmers choose from a broad spectrum of themes to improve, which can include how field boundaries are managed, care and planting trees where appropriate, care of ancient monuments, monitoring habitats and food for wildlife, water management and pollution control, use of recycling where possible, amongst others. For certification, they then have to demonstrate that the plan is being carried out.

The whole farm concept means that where infrastructure, such as greenhouses or polytunnels, is used for growing crops, other parts of the farm can be dedicated to environmental services; “given that vertical farming is done in a glass-house, biodiversity can be centred around these areas, such is done in areas around the crops and this can be highly beneficial” (Interview, CEO LEAF, Ref: OB01). This illustrates how the individual farm can use non-crop areas for biodiversity and other environmental services, once the above-mentioned core elements for sustainability have been fulfilled and feeds into the concept of weak sustainability discussed below in 5.6.3 Weak Sustainability.

From systematic analysis of communications with the CEO of Saturn Bioponics over seven years, it has been revealed that the company recognises the importance of the environment in all the key areas relevant to 3D farming (Interviews June 2014, April 2016, January 2017, August 2020 (Ref: SB01,SB05,SB12, SB28), and this has been consistent throughout the period of study. Valefresco is LEAF Marque certified and therefore the company is already complying with the wider criteria such as landscape and nature, and organisation and planning. With regard to community engagement, the company has also hosted events for local students, especially those studying horticulture at the local college, which was reported in the Worcester News (Ref: SBPF01). The key factor emerging from the use of the criteria used for LEAF Marque audits is that sustainability outlook of the case study company and early adopter is wider than just the area under cultivation and expands to cover the whole farm and perhaps even the neighbourhood.

5.4.4.1 Eco-efficiencies from input use

The tendency towards eco-efficiency is reflected in the company’s actions in working to create a system which optimises inputs. These have double benefits as they are aimed at attracting customers because of cost efficiencies, but at the same time have environmental benefits, or at least minimise damage. This has been illustrated by promotion of the business benefits of fertiliser efficiency by claiming an efficiency perspective: “Growers can see lower nutrient bills thanks to the controlled system being developed by Saturn Bioponics” (Ref: SB11).

The company has highlighted eco-efficiencies in articles in technical journals, for example “with the savings in labour and resource use, alongside the yield increase, the modular system improves profitability to such an extent that a grower can expect a payback of between six months and three years" (Ref: SBP11). The need for efficiency has been echoed by other vertical farming companies, where, at a vertical farming conference held at Harper Adams University one vertical farm grower said: "Efficiency is crucial; to be competitive you need to be efficient…the nature of the business model means that sustainability and efficiency are not disconnected…however, If there is pressure for sustainability, the customer [consumer] needs to pay as well" (Ref: HA02). This emphasises the challenge of the need for goods and equipment, while environmentally sustainable, to be price competitive.

5.4.4.2 Crop health

Saturn Bioponics has worked on creating a growing environment "in which the plant is as healthy as possible and best able to resist pest and disease" (Interview 12 April 2016, Ref: SB05) and thus keep usage of plant protection products to a minimum. Crop health is an important factor not only for saleable yield, but care has to be taken with crop protection products to ensure there are no environmental impacts. This is also regulated by law, with only BASIS qualified agronomists being able to recommend use, with further guidance from certifying entities such as LEAF Marque and GlobalGap[11].

As the 3D growing system is used in polytunnels/greenhouses, when plant protection products are needed, there is no risk of runoff and contamination of the environment. As part of its strategy, the company Valefresco is: "doing its best to keep it completely chemical free, and so minimising pesticide use" (Ref: SB13). This could be a result of the ethos of the proprietors of the company or from a push-pull situation; with the push of regulation on pesticide use together with the pull of the supermarkets who are keen on reducing maximum residue levels (MRLs) in response to customer demand, which may be more stringent than those covered by legislation and guidance on Good Agricultural Practice (Ref: Def04).

[11] GlobalGap is an internationally-recognised farm standards audit based on Good Agricultural Practice

5.4.4.3 Energy

Energy use not only uses up environmental resources and increases the carbon footprint of the operation, but can impact on input costs, and therefore commercial viability. This is not an issue for the case, because the system is minimised as it is built around using natural light, and has devised a method to optimise natural light to facilitate a more even distribution for photosynthesis and therefore yield. Not all vertical farming companies use natural light and their use of artificial light incurs an energy cost. For example, a Finnish company that grows micro-greens and herbs, uses Light Emitting Diode (LED) lights, which are less expensive than sodium lights but still have a cost. “Given the dark, cold conditions using artificial lighting is crucial to the business, but it still has to be cost effective” (Ref: VFC2).

Lighting is also indispensable for indoor growers using infrastructure other than glasshouses or polytunnels. This impacts on energy use, which, in other vertical farming enterprises, is estimated to make up for 20 to 30 per cent of the total production cost (Ref: VF12). Speaking at an AgriTechE event, managing director James Lloyd-Jones of JFC, a vertical farming company growing herbs noted: “We learned before going into this that the main reason for companies going bust was electricity,” (Ref: VF12). The differing needs of lighting depend on location of the crop, but it can be suggested that making use of natural light where possible, as done by the main case study company, is a more environmentally sustainable option.

Indoor growing systems can also offer growers the potential to take advantage of selling out of season when retailers are more dependent on imports and are likely to pay a premium price for produce. This was emphasised by Aponic CEO Jason Hawkins, who said: “Lighting means growers can take advantages of times when retailers are likely to pay a better price for them” (Ref: AP01). However, if heating were also necessary at these times of year, energy costs would be likely to impact on profit margins.

After lighting, air management (such as temperature, humidity, and air movement) is the second biggest cost, according to Cambridge Consultants associate director Chris Roberts, speaking at the Bringing the Outside In conference (Ref: AG01). This is corroborated by others in the sector; in an article published in the trade publication Commercial Greenhouse Grower, Ian Metcalf, director at CMW Horticulture expressed that “energy efficiency is still the main driver for glasshouse technology…energy efficiency is still top of the agenda for growers” (Ref: AS26a). This may be less of a concern by many of the growers for the environment and more about eco-efficiency, and the need to earn a sustainable profit.

5.4.4.4 Economic Sustainability

The importance of economics has featured heavily in discussions with Saturn Bioponics as the company understands clearly any potential customer will keep this in mind when deciding whether to move to this method of growing. Saturn Bioponics understands the motivation of profit to be key to commercial growers, and this can be at the expense of any environmental considerations when margins are narrow. The company referred to the business case at the GrowQuip conference: “Gain in yield per square metre plus reduced costs of production result in increased profitability with a payback of between 1-3 years depending upon crop type and local market values” (Ref: SBC01).

One of the challenges for evaluating return on investment for a new growing technology is that costs and returns can vary for each grower, according to site location, contracts with suppliers and customers, which means there is no real benchmark from which to work. While “the farmer should know his or her own costs of production” (Ref: SB05), it is difficult to provide an accurately costed business case. However, from the potential adopters’ point of view, there is value from receiving commercial data on growing crops with this sort of system, even when it is from just one site, rather just from trials done in research stations. This is because labour costs have to be minimised in a commercial situation, hence there is less time to pay minute attention to detail, which can be done in a laboratory. Saturn Bioponics has noted input costs as being of crucial importance to farm profitability, and in communications it has highlighted savings in water, nutrients and energy from recirculating irrigation (FP01, SBC01) and therefore input costs – all of which can be termed eco-efficiencies.

Commercial pak choi growers Valefresco, who have all the above-mentioned business related pressures, perceived the time needed for growers see a return on investment resulting from increased revenue from using the 3D Growing technology as “feasible” (Interview 3 March 2017, Ref: SB13). The payback time on pak choi is one of the longer periods as it is envisaged at three years, whereas for herbs it is projected at being less than 12 months (SBC01).

Herbs are considered to offer higher returns than many other crops, and therefore faster payback time for investment in the infrastructure: “the potential for high-value herbs such as basil is huge, with trials producing premium quality, with significant yield improvements and a shorter crop cycle than with a conventional grower" (Ref: SB10).This is supported by information from other start-up vertical farming enterprises which are confident of commercial success: "The farm is currently growing herbs and leafy greens, like most vertical farms. Technically it's possible to grow any plant – but basil, dill, chives and the like are a lot more financially viable, mostly because they are smaller and can be grown at scale" (Ref:VF12).

The emphasis placed on return and investment and profitability for the client, and the value that the customer places on the innovation is discussed in more detail in Chapter 7, Business Model (Section 7.5.2). Eco-efficiency emerges as an important driver of uptake of sustainability and is discussed in more detail in Chapter 6, Diffusion of Innovation, section 6.5.2, Chapter 7, Business Model, sections 7.2, 7.5.4.1, 7.5.8, and the Bridging the Chasm, Chapter 8, section 8.5).

5.5 Sustainable intensification: comparing indoor and outdoor farming

Growing crops outside has lower infrastructure costs and in many ways there are very different challenges from growing indoors, with a number of variables influencing crop yield and quality. Farming is dominated by weather and its uncertainty, too much or too little water can stress and stunt crop growth, partly because water affects the soil and soil structure. Soil can become compacted from being wet and the use of heavy machinery, which makes it difficult for roots to develop and scavenge for nutrients and water. For crop initiation a fine tilth is needed for seed to soil contact, but heavy rainfall may cause the soil to cap, affecting crop emergence. Also, heavy rainfall events can result in applied nutrients such as nitrogen moving through the profile and not being available to the crop at the right time. Poor weather can make harvesting difficult, too, as it can be difficult to travel on the land. This was particularly evident in the wet autumn/winter of 2019/2020 as vegetable growers struggled to get their crops out of the ground; some were observed by the author to have resorted to using heavy machinery on tracks to move across the fields.

Growing indoors may be done in greenhouses or polytunnels and the biggest variation with outdoor growing is the ability to control the crop-growing environment. There can be other challenges, such as crop protection which may be slightly different, and there are differences between table-top growing and 3D growing, and these have been subject to a scientific review by Roberts et al. (2020). Saturn Bioponics recognised this challenge, and in 2015 employed a hydroponics specialist, Arnaud Witteveen (Ref: LI01), who has been researching and refining the system.

The above points reflect on some of the challenges for successful indoor growing, and the next section explores whether there is a potential for this technology to contribute towards higher productivity without increasing environmental damage.

5.5.1 Exploring a potential contribution to sustainable intensification

Table 11 below explores some of the potential benefits and drawbacks of using the 3D Growing technology in terms of contribution to sustainable farming. These have been assessed according to their apparent contribution to sustainable intensification. Some are difficult to categorise, for example, the substrate currently used by Saturn Bioponics is made of clay pebbles, are of natural provenance. Likewise, using kelp as fertiliser is more environmentally friendly than synthesised fertilisers, although it has also undergone a degree of processing.

Table 11 Summary of considerations benefits and drawbacks of using the 3D Growing technology compared to broadacre in terms of contribution to sustainable intensification

Factor	Contribution towards sustainable intensification	3D Growing technology	Outdoor broadacre farming	Link to framework
Marketable Yield	Higher saleable yields per unit of land with the quality demanded by the sector can contribute to intensification	Yes; Indoor farming can create more consistent environment	Difficult to achieve due to outdoor environment/pests/disease	Reference in literature is to total yield/productivity, biomass production, but not the edible components (Smith et al., 2017)
Waste	Agronomic strategy, hygiene and ease of harvesting lead to waste levels of 1-2%, down from 10-15%, contributing to both intensification and sustainability.	Yes, as above	Difficult to achieve, as above	Referred to by Pretty and Bharucha (2014b) and Flood Flood (2010)

Factor	Contribution towards sustainable intensification	3D Growing technology	Outdoor broadacre farming	Link to framework
Pesticide use	Closed environment reduces the threat of pesticide run-off, contributing to sustainability.	Yes, indoor environment permits precision applications, and because of the controlled environment, greater use can be made from beneficials (natural enemies of pests)	Difficult to achieve, although following Voluntary Initiative code of practice can help reduce this threat, as can Integrated Pest Management (IPM)	Difficult to reduce without yield loss as noted by Pretty (2008), but use of new technologies can help make best use of resource management (Pretty and Bharucha, 2018)

Factor	Contribution towards sustainable intensification	3D Growing technology	Outdoor broadacre farming	Link to framework
Water use	Controlled and recycled use of water helps optimise its use, and a reduction of up to 95 per cent in water use in some crops, contributing to sustainability.	Yes	Difficult to achieve; while irrigation strategies using probes for decision making can be useful, applications are subject to weather conditions e.g. imprecise application resulting from wind	Using technology for optimising resource use (Pretty and Bharucha, 2018)
Potential to bring in new land unsuitable for outdoor cropping	Contribution to intensification.	Yes	No	Making best use of all resources, (Pretty, 2008), but not mentioned directly

Factor	Contribution towards sustainable intensification	3D Growing technology	Outdoor broadacre farming	Link to framework
Weather independent	Crops do not suffer from stresses which reduce yield (such as drought, hailstones or cold). Growing indoors can enable a lengthened growing season, contributing to intensification.	Yes	No	Need for better weather predictions for field scale farming, Keating et al., 2010) while indoor crops do not have this problem (Despommier, 2011)
Substrate provenance and biodegradability	Clay balls take time to break down, but may be more environmentally friendly than other hydroponic substrates such as rockwool.	Yes	Soil-based, therefore biodegradable substrate	Making best use of available resources (Pretty, 2008)

Factor	Contribution towards sustainable intensification	3D Growing technology	Outdoor broadacre farming	Link to framework
Biodiversity	Normally the growing environment of a glasshouse/polytunnel is set up with the ideal conditions for one crop	Potential, as with the 3D Growing technology there are a number of pumps per x metres, there is the potential to grow more than one crop in each glasshouse/ polytunnel	Yes, but depends on crops being grown	Not discussed in this context in literature
Soil health	Not relevant to indoor cropping	No	Yes	Systems which do not care for soil health impact on sustainability and the possibility for future generations to grow food. (Pretty, 2008); hydroponic systems use resources in a different way

Factor	Contribution towards sustainable intensification	3D Growing technology	Outdoor broadacre farming	Link to framework
Lighting	Natural light can be used. LEDs and sodium lights can be used when natural light is insufficient.	Yes	No	Light can be a limiting factor for indoor crops (Specht et al., 2013)
Kelp fertiliser	Choice of fertiliser can influence environmental sustainability and yield response. Organic farmyard manure is unsuitable for indoor growing as it has too variable levels of nutrients and minerals which does not lend itself to precision placement.	Yes	More options for synthetic and natural fertilisers	Optimising use pf resources (Pretty, 2008)

Factor	**Contribution towards sustainable intensification**	**3D Growing technology**	**Outdoor broadacre farming**	**Link to framework**
Technology and equipment: Carbon footprint of plastic for towers	The plastic for the towers is durable, thus will last for a long time and not need replacing for a long time. However, it is recyclable.	Yes	N/A	Use of resources (Pretty, 2008)
Relationship with the whole landscape	When whole farm-scale is taken into consideration	Yes	Yes	Multifunctionality within the whole landscape is one of the key principles of sustainability (Pretty, 2008)

Source: Saturn Bioponics, Agronomists, IPM conference (Warwick 5 Feb 20 Ref: AG03) and author

The data explored in Table 11 above suggest that agri-tech developments such as using 3D farming methods can improve farm performance as such technology facilitates precision farming and resource efficiency. This hypothesis has been supported because the company has received a mention on p36 of the UK Government’s 25-year Environment Plan (2018) as an example of sustainable intensification. The report states that this method of growing “has demonstrated between a three- and four-fold increase in crop yield on the same land area, with reduced input requirements (water, fertiliser and pesticides) and improved crop quality”.

5.6 Discussion

Critical assessment of growing methods and crop yields reported when case’s technology and hydroponic science expertise has been used suggests that the system may make a potential contribution towards sustainable intensification on a micro-scale (See Tables 9, 10 and 11). This is because the system harnesses efficient use of water, energy and other inputs and can increase productivity per unit area of land, thus fulfilling a number of the criteria for sustainable intensification, as determined in the framework for this study.

Part of the contribution to yields is because growing indoors shows potential for extended growing seasons, which is general to all indoor systems (although there may be heating and lighting environmental and monetary costs.) In addition, as infrastructure can be erected on land which is not suitable for growing crops and it may bring previously uncultivated areas into production, increasing potential resources. This aligns with the views of Pretty (1997) who believes that human ability for innovation will make improvements in crop growing possible even in areas which have been degraded. The use of greenhouses, or polytunnels, plus the use of hydroponics, correspond with the practical criteria for sustainable intensification considered by Pretty et al. (2018). This potential of growing without taking up more acreage offers the possibility of leaving land for other uses, which refers back to the land sparing paradigm (Firbank et al., 2013).

Nevertheless, by concentrating the unit area of crop production, there is a potential for boosting the land available to the environment in non-cropped areas, which can be used to create ecosystem services for beneficial vertebrates and invertebrates, including pest predators and pollinators. The land sparing debate is discussed in more detail in the discussion in chapter 8, Bridging the Chasm.

5.6.1 Commercial sustainability

If a grower cannot make sufficient profit, the business cannot be maintained, hence there is a need for ‘profit through productivity’ as emphasised by Saturn Bioponics’ CEO (Ref: SB01). The findings from the data referred to above in economic sustainability fit with suggestions made by Pretty et al. (2016), who advocate changing land use from low value crops or commodities to those that receive higher market prices or have better nutritional content. This, therefore, is another area where we can observe a correlation between Pretty’s views on how sustainable intensification should look and how Saturn Bioponics’ methods are developing the means of putting them into practice.

Arguments made by Pretty (1997, 2008) state that successful sustainable intensification is not a static process, and dynamism has been observed as the case study company has evolved and enhanced its value offering. The motivation behind the approach to horticultural production by the case study companies tends to be practical; they are focusing on what the farmers need in agronomic terms to increase commercial yields without significantly upping their costs. This implies they are seeking eco-efficiencies discussed in more detail in Chapter 7. This could be a driver motivating growers to develop a philosophy that will encourage them to abide by the highest ethical and environmental dimensions, although many may need some incentive, for example legislation or a financial incentive from better sales prices or longer term market linkages. In some cases, particularly growers looking to supply UK supermarkets, gaining LEAF Marque Assurance Scheme certification means they may receive a higher price for their goods with 23% premiums and 36% increased income from CCRI study on LEAF Marque (Ref: LME01).

One of the major challenges of field-based agriculture is soil quality. Large areas are unsuitable for growing unless the crops are provided with a protected environment. Pretty (1997) believes that human ability for innovation will make ‘substantial growth’ possible even in areas which have been degraded. This can include greenhouses, or polytunnels, plus the use of hydroponics (Pretty et al., 2018) as well as space saving innovations such as multi-level growing. As the 3D Growing technology is primarily designed for indoor growing, land-type becomes irrelevant and it may bring previously uncultivated areas into production, making more use of potential resources. The potential of growing sufficient crop for market but without taking up more acreage offers the possibility of leaving land for other uses, whether other crops or for the benefits of the environment, thereby referring back to the land sparing debate (Firbank et al., 2013).

Sustainability is not just about the environment, there is also a need for business sustainability or financial business benefits and return on investment, including infrastructure and input costs. These areas are all referred to by Pretty (2008, 1997) and the information gathered by this study on the productivity and sustainability of methods of growing using three-dimensional farming under the different growing and market conditions supports his argument that successful sustainable intensification is not a static process, but rather an adaptation to different conditions experienced by farmers. Analysis of the information collected suggests there is a correlation between minimising inputs and environmental benefits; the fewer the inputs the better for the environment and the profit margin is higher too, providing a win-win situation. This could be a driver motivating growers to develop a philosophy that will encourage them to abide by the highest ethical and environmental dimensions, although many may need some sort of incentive, for example legislation or a financial incentive from better sales prices or longer term market linkages.

5.6.2 Linguistic differences and farmer perspective

There are some differences in the vocabulary used by commercial growers and suppliers compared with academic terminology, which could impact on response to the call for sustainable intensification. However, while communications between scientists and farmers is seen to be important (Teschner et al., 2017) there appears to be little about the language used in this context in academic literature on sustainable intensification. Content analysis of trade articles (Ref: SBP02, SBP03, SBM01, SBP04, SBP11, MI19), transcripts of presentations and interviews, plus personal observations, have revealed that while academics talk of ‘intensification’, growers talk of yield and especially marketable yield. This could be due to their focus being more on the micro-scale, whereas academics are often considering more at the policy level, looking through a macro lens. Sustainability is used by both academics and growers; the growers participating in this case study recognise the need for environmental sustainability, but they see it more in terms of passing the natural capital of their land on to their descendants rather than from a more conceptual point of view.

These differences in interpretation have been developed from the epistemological differences between the commercial world and academia, or more simply the gap between theory and practice. As scientific, reproducible measurement in commercial agriculture is not possible because of all the variables which contribute to sustainable agriculture, Pretty (1994) claims that sustainable agriculture is not an objective construct subject to independent verification. This is supported by Daston (2008) who points out that more than one variable may change at one time, and suggests that constructivist epistemologies can accommodate different points of view. While academics appear to be more aware of the complexity of the agro-ecological system, using both microscopic and macroscopic lenses, the stakeholders interviewed for this case study had a more microscopic perspective. This can be seen with the use of terminology such as ‘intensification’ and the big picture of what needs to be done described by the likes of Pretty (2008, 2016, 2014a, 1997) and Godfray and Garnet (2014), whereas the practitioners in this case study talk more of ‘yield’, ‘planting rate’ and ‘crop turn-round time’. This is because of the practical dimension to sustainable intensification and growers are looking for practical knowledge about growing crops which builds on what they already know. The ability to understand grower needs is crucial to understanding their motivations; they live with the day-to-day requirement of producing higher commercial yields and providing a business which they can pass on to their children as it does not damage the environment (economic sustainability). Growers see things in terms of commercial yield (which is the crop which meets customer specification and can be sold rather than jettisoned as sub-standard) and the repeatability of obtaining high commercial yields; this is one of the perceived benefits of their technology.

5.6.3 Weak sustainability

Data collected from observations and interviews suggests that three-dimensional farming methods, such as the technology developed by the case, are aligned to what is known in the ecological economics literature as weak sustainability. This is because natural and man-made capital are being combined to create value from the ecosystem services that the land can provide. The equipment and hydroponic science devised by the case uses both in the form of buildings, growers and equipment but also allows its customers (the growers) to leave other areas of land for eco-system services, hence it considers the total availability of capital. While for proponents for strong sustainability, natural capital is considered to be non-negotiable and when used the effects are irreversible, (Dietz and Neumayer, 2007, Neumayer, 2003) there are suggestions that technological progress can at least reduce the consumption of natural capital, or even increase it faster than it is depleted.

High input: high output systems are not generally thought of as contributing to sustainability, with many academics arguing for de-intensification. There are potential problems caused by conventional intensification, such as lack of local biodiversity present in land-saving system while, on the other hand, there are advocates of extensification who propose sharing more agricultural land with nature with less intensive cultivations proposed for wildlife-friendly farming (Tscharntke et al., 2012). Analysis of data collected suggests however, while this method of three-dimensional farming departs from agro-ecological views which argue for extending and extensifying cropping, (Tscharntke et al., 2012, Tudge and Moubarac, 2013), by intensification of the area used for growing these particular crops, it leaves other land for other environmental services.

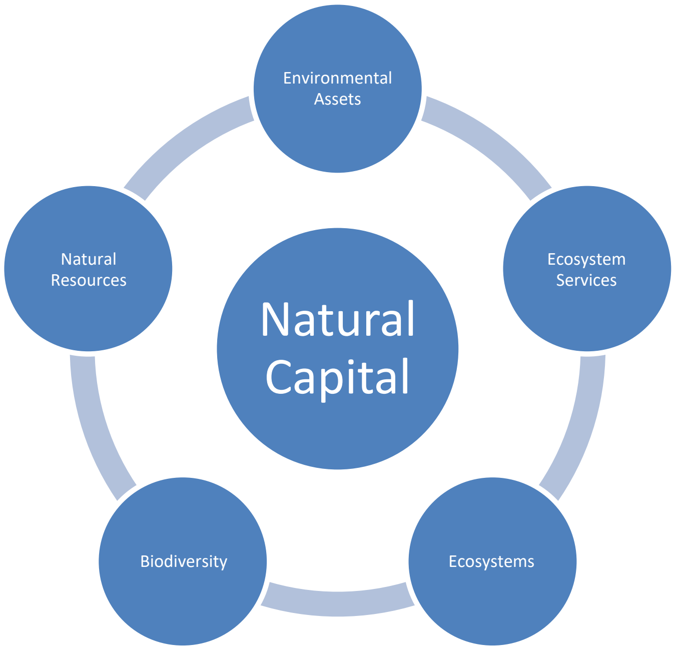

Figure 5 Components of natural capital

5.7 Conclusion

The data gathered in this study illustrate the potential and actual sustainability benefits which can emerge from 3D farming and can help promote sustainable intensification, including an increase in yield per unit of land alongside reductions in negative environmental impacts. The contribution to enhanced efficiency by controlling the use of nutrients, water and pesticides by using tailored agronomic strategies helps to increase yield (intensification), which helps minimise environmental damage (sustainable). This is enhanced when the whole farm perspective is taken into consideration as land outside the direct area used for cultivation can be reassessed, and can be dedicated to environmental services, which can help to offset some of the more negative aspects of this intensive form of farming.

On the basis that the key tenets of sustainable intensification are about producing more without damaging the environment, the case study demonstrates this particular practice of 3D farming fulfils a number of the necessary criteria, specifically contributing empirical evidence that crops can yield more while minimising damage to the environment. By highlighting some of the difficulties practitioners have in translating sustainable intensification theory into agricultural practice, this study has helped build empirical evidence which can be added to existing literature so policy makers can better understand some of the challenges the sector has to address.

Taking the whole-farm approach as adopted by LEAF Marque in its certification criteria could help to encourage farmers to make a difference to eco-system services on their farm, by creating areas set aside for beetle banks, sown with flowers for pollinators and can use areas of the farm such as boundaries for these environmental services. This holistic approach is relevant to 3D protected farming system which optimises rather than maximises production, as having one area for concentrated production such as in greenhouses and polytunnels, but setting aside other areas around the farm dedicated more to the creation of habitats to improve the environment. This could provide a vision for contributing to sustainable intensification at farm level by using the latest technologies, with the proviso that other variables such as mineral fertiliser, pesticides and water use conform to best practice principles for sustainability.

By growing indoors, there is less risk of production loss from climate change. The documented increase in yields, and the whole-farm approach discussed above help build better understanding the intentions and perspectives held by organisations about sustainable intensification as their business develops. The next stage is to understand how the innovative equipment for vertical farming is diffused to potential adopters, and the business model necessary for such an enterprise to be commercially feasible, and are discussed in Chapter 6 Diffusion of Innovation and Chapter 7, Business Model.

Chapter 6 Exploring diffusion of Innovation and its effect on the uptake of three-dimensional indoor farming in the UK

6.1 Introduction

The objective of this chapter is to present the findings of how diffusion of innovation is being undertaken in the case of Saturn Bioponics and how its communications have evolved over time. This will provide part of a novel contribution to literature about a micro-company's ability to improve future food security while minimising environmental damage. Spanning a timeframe from 2013, just after the company had devised its original innovation, until Spring 2020, I start by examining the characteristics of the innovation and follow the choices made by the case study company on communication channels, key messages, and the role of early adopters.

Recent research on Agricultural Knowledge Information Systems (AKIS) and Agricultural Innovations Systems (AIS) has provided useful context for this chapter. Systems approaches to innovation are based around co-innovation with actors from different fields, such as research institutes and farmers, playing a crucial role in the development of an innovation and have been well documented by Klerkx et al. (2012). These have provided information on which to build to improve understanding of the interaction between the roles of the different actors in the specific context of 3D farming. The limitation of these studies is that they have a macro focus, while this study is more about contributing to learning in the 3D agricultural context at micro level in a commercial setting. A difference has been detected between innovations developed by research institutes together with growers and those created by small players such as Saturn Bioponics. This is because of the effects of competition-driven limitations impacting on how networks can function. Where innovations are developed by small start-up companies in a highly competitive market, sharing information may not always be feasible because of confidentiality concerns, and this may constrain development and diffusion of the innovation.

More nuanced interpretations of knowledge exchange and dissemination of information which build on the work of Rogers (2003) emphasise the importance of co-development of technological innovations such as 3D farming equipment. For example, Caffaro et al. (2020) note a continuing focus on farm characteristics and economic variables when assessing the potential value of an innovation. However, limitations of this diffusion literature detected include challenges at empirical level; for example, it may be difficult for a new company entering the sector to recruit potential adopters capable of perceiving the usefulness of an unfinished innovation. This can make it difficult to acquire early adopter contributions to the innovation, and a gap has been detected in understanding of the characteristics of adopters who are more likely to take on such a role. As such, there is space for better empirical understanding of how a start-up commercial enterprise puts co-evolution of an innovation into practice within the constraints of a market seeking to provide competitive advantage for its customers.

One of the challenges of innovating and disseminating knowledge in this sector is the wide diversity of agribusiness in the sense of number and size of players, and the complex value chain elements, each with different demands. For example, the value chain comprises micro-companies and large corporations, from market gardeners supplying local markets to multinationals supplying fertiliser to the growers. Growers, who are primary producers, are usually smaller enterprises, and research by Hingley and Lindgreen (2010) has shown that if a retailer loses a supplier, it is much easier for it to find another supplier than the other way round. This is one example of the result of an imbalance in power, in which retailer dominance results in its ability to dictate prices, payment terms and quality demands (Hingley, 2005, Hingley and Lindgreen, 2010). Lack of security impacts on financial and investment decisions and can leave growers behind the curve for adoption of agri-tech innovations. Although much has been written about diffusion of innovation in in agriculture (Rose et al., 2016, Menary et al., 2019), there remains a gap in the understanding of effective diffusion activities in the context of 3D farming, including communicators and the communications channels used.

One of the key drivers of businesses supplying technology and know-how is a need to fulfil the needs of the customer's customer, such as major retailers and eventually the consumer. Touboulic et al. (2014) suggest that not all the influence retailers have over their suppliers is negative, as it can also be used to ensure sustainable practices too, particularly in the light of growing consumer concerns. As this is the context in which the case study company is working, this chapter contributes to understanding how the company operates within the confines of its market, learning how to best build and exploit its networks.

Entering the 3D farming sector requires substantial investment in new equipment and technology, and there are factors outside the influence of the innovators, such as policy changes and structural elements such as access to the internet. Rogers (2003) suggests criteria about an innovation which could influence potential adopters to consider investment which help understand, at micro-level, some of the factors an innovative company should consider while creating an innovation to resolve a pre-determined problem. These criteria are discussed in more detail below in section 6.2, below.

This chapter critically analyses the diffusion of the innovation that is the Saturn Grower and the corresponding hydroponic science through its evolutionary course to discover some of the factors that have influenced its diffusion and progression. The chapter starts by outlining the characteristics of the innovation, before moving on to diffusion networks and communications flows, and then reflecting on the empirical data in the light of previous academic work.

6.2 Framework

The framework used in this chapter draws on classical diffusion of innovation theory, based on the work of Rogers (2003) with developments on this foundational theory from social and psychological constructs, such as those used by Caffaro et al. (2020) in their Technology Acceptance Model, to bring in more nuanced understanding from agricultural economics literature. The framework has been influenced by the work of Rojo-Gimeno et al. (2019), who studied farmers' drivers of intention to adopt technical innovations. In addition, it draws on systems approaches such Agricultural Knowledge and Information Systems (AKIS) documented by Klerkx et al. (2012) to understand the interface between business and research. This provides a route to improved understanding of an outlier company such as used in this case, and where it sits within the innovation system. Given the empirical nature of the study, consideration is given to current industry best practice, based on recommendations by the entities such as the Agriculture and Horticulture Development Board (AHDB), the Knowledge Transfer Network, Peer to Peer Learning, Accessing Innovation through Demonstration (PLAID, and the European Innovation Partnership - EIP-Agri, which is the operational division of AKIS).

The theories used to develop this framework were selected because they had been originally devised for agriculture and provided a targeted means of looking at the diffusion undertaken by the case. For example, the classical diffusion of innovation theory developed by Rogers (2003) was based on agricultural extension and it underpins much of the later work in newer sectors such as agri-technology. There are recent concepts and ideas that can be applied at micro-level in a small enterprise that have roots in this foundational diffusion of innovation theory, for example those identified by Pathak et al. (2019) and Wright et al. (2021). These have provided a complementary addition to the framework, particularly as they were looking at value and perception of different kinds of information on decision-making. The psycho-sociological concepts of perceived value and perceived ease of use, which portray interaction between the product and the customer, have provided a means of understanding how the characteristics of the innovation are interpreted by different parties according to their particular needs. Abson et al. (2017) have contributed a means of understanding how diffusion of innovation needs to work to encourage uptake. This is through the consideration of leverage points, which are small interventions with potential for wider influence, to build potential adopter perception of value and help break path dependency. Their study, which has been influenced by innovation theory developed by Schumpeter (1934), has focused on a move towards sustainability and responses to external and internal pressure in this context. The leverage area critically assessed in this chapter is how the knowledge produced about the innovation can influence the perception of value of the innovation of Saturn Bioponics.

The priorities of the framework, which are the core thematic headings of the sub-chapters, include the innovation process, characteristics of the innovation, diffusion networks and communications vision and channels. These are based on the theory developed by Rogers (2003) and complemented by the nuanced understanding brought by the other literatures to facilitate understanding of the case within its context. These are shown in Table 12 below and have been brought together to form my own framework for this chapter.

Table 12 Development of Diffusion of Innovation framework

Rogers (2003)	**Leeuwis & Aarts(2011)**	**AKIS/AIS**	**Caffaro (2020), Abson (2017), Rojo (2019)**	**Practical agricultural criteria**
Characteristics of the innovation	Collective process of innovation development	Performance driven by stakeholders, networks and public: private partnerships	Assessment of value of information and the application of leverage points Social and psychological constructs such as perceived value Barriers and incentives to adoption	Value to customer's business and ease of adoption
Diffusion networks & the social system Opinion leaders	Parties involved in communications	Combination of actors with technical/economic expertise to gain a holistic perspective Coordination between actors	Understanding of how knowledge is produced and then flows through systems of interest;	Peer-to-peer communications Personal, on-farm contact Web-based exchange of information

Rogers (2003)	**Leeuwis & Aarts(2011)**	**AKIS/AIS**	**Caffaro (2020), Abson (2017), Rojo (2019)**	**Practical agricultural criteria**
			How is knowledge legitimised	
Communications channels and flows		Vision is reflected in communications	Path of information to providing value Structure of information flows	Opportunities to view practical examples (as part of the communications strategy)

Source: compiled by author from Rogers (2003),Klerkx et al. (2012) Leeuwis and Aarts (2011) Caffaro et al. (2020), Abson et al. (2017), Rojo-Gimeno et al. (2019) Agriculture and Horticulture Development Board (AHDB), the Knowledge Transfer Network (Ref: AS14, AS15), Peer to Peer Learning, Accessing Innovation through Demonstration (PLAID, Ref AS13) and the European Innovation Partnership- Agri (EIP-Agri),

6.3 Material and Methods

Using a case-study approach explained in Chapter 4, the activities undertaken by Saturn Bioponics, a provider of 3D farming equipment and hydroponic science, were followed over a seven-year period. By collecting data over this period, it has been possible to critically assess the development of the company's diffusion strategy and its alignment with sustainable intensification, building an evidence-based narrative around its practices. For this chapter, engaging with independent specialists who have experience in encouraging uptake of innovation or are in positions in agricultural companies in which they take decisions on uptake or rejection of innovations, was a particular focus. Some of the data were sourced through press conferences which form an important part of the work of an agricultural journalist, offering insights which would probably not be available to others who do not already know the sector and have not built up relationships of trust.

Work contacts also ensured invitations to Agri-TechE meetings. This independent cluster organisation was established to work as an incubator for innovations in agriculture and horticulture and assist them in improving their competitiveness. The organisation has supported a number of vertical farming enterprises. Contact was made with other specialists in the protected crop sector and more widely across fresh produce and combinable farming; as it is difficult to speak with later adopters, conversations were held with advisors who work with a broad spectrum of people. Insights were also obtained from observation, trade presentations and discussions with other growers and from agricultural industry conferences such as CropTec and Agronomists' Conferences at which different technological innovations and their diffusion are featured. To provide greater context and understanding about opinion leaders in the farming sector, and any differences across the sectors, instances of leadership from growers in other subsectors of agriculture (such as combinable crops) were also explored.

6.4 Findings

This section details the key elements of the diffusion of innovation strategy used by the case and follows their evolution over time to assess their potential for alignment with markers that imply sustainable intensification.

6.4.1 The Innovation

The innovation comprises specialised towers as a means of growing fruit and vegetables using the vertical and horizontal planes (3D), with the corresponding agronomic know-how. Value is created by two means: sales of “hardware”, which is the innovation that is the Saturn Grower devised by Saturn Bioponics, and “software” (consultancy on hydroponic science, which was originally devised to help customers obtain better results from their investment in the towers). The aim of the innovation is to provide competitive advantage to commercial growers in the indoor horticultural sector in addition to causing less damage to the environment than many other systems. More technical details of the innovation are discussed in Chapter 5 (Sustainable Intensification) and its characteristics are explored in section 6.4.3 below.

The case study company, while benefitting from some Innovate UK funding, was not working as part of an integral innovation system, but as an independent commercial start-up, effectively as an outlier in the agricultural knowledge and innovation system. This is because it was not part of an organised system bringing together researchers and industry, but reacting from the perception of a market opportunity which would also provide potential environmental benefits. As such, it was autonomous and did not have to address tensions between players with different aims, but it had to grow its own expertise levels.

6.4.1.1 Company timeline

Data was collected on the company between 2013 and early 2020, which enabled data collection to follow its development and innovation, and how information on its innovation has been diffused. The initial focus of Saturn Bioponics was on developing the agronomics and growing techniques so they presented a viable product and service for their customers. The aim was to ensure an enhanced growing method for better yields per square metre which would not prejudice the environment. This resulted in a five-year lead-in (Ref: SB05, SB06) as the company developed its innovation; after this it recruited early adopters who then played an important role in refining the technology so it offered tangible benefits such as the ability to grow uniform produce with the characteristics demanded by the supply chain.

Table 13 below follows the business evolution of the company and its communications and diffusion strategy. The table shows that from the start the company had already decided on its target market, and this has amplified a little to include growers who have already invested in hydroponic systems, rather than only those who have still to make a transition to a more technology-driven method of fruit and vegetable production. The first stages have more of a backroom focus, and once the initial adopters were recruited, communications strategies commenced their evolution to attract potential customers.

Table 13 Business evolution of Saturn Bioponics over the first ten years of the innovation

	2010-11	**2014**	**2016**	**2018**	**2019/2020**
Hardware 'Saturn Grower'	Research and Development	Research Trials in Birmingham	Trials with growers Market sales	Trials with growers Market sales of commercial system	Trials with growers Market sales
Software – hydroponic science	Initial development	Further development	Initial sales	Growth in sales	Market sales
Hardware - joint venture				Initial discussions	Discussions, demonstration & trial system being set up. Joint venture in preliminary stages
Software – joint venture					Development of commercial relationship with Shockingly Fresh
Targeted market segment	Commercial indoor fruit & vegetable growers	Commercial indoor fruit & vegetable growers	Commercial indoor fruit & vegetable growers	Commercial indoor fruit, vegetable & non-food crops, using hydroponics	Commercial indoor fruit, vegetable & non-food crops, commercial growers using hydroponics

Source: Data from Saturn Bioponics,

Preliminary work on building a model for 3D farming sought to understand where a new way of growing could offer its customers competitive advantage. This meant that this work was done at micro-level rather than as part of a system sharing knowledge with industry, growers and institutional researchers. While related to accepted agricultural knowledge information systems, in that it has evolved its own system and has participated in knowledge network events such as organised by accelerator Agri-TechE, it has always had its own vision which it has worked to bring to reality.

Building on personal contacts, it initially focused on collecting information on the needs of the different sub-sectors within the protected horticulture industry, so that it could ensure the innovation filled a relevant business gap. Work was also done to attempt to anticipate the practical challenges and the company used the expertise of consultants already in the industry to develop a technology which would be relevant to the needs of the sector. The aim was to ensure robustness of the innovation, to address potential concerns about trust in the growing system technology and ensure it achieved the high environmental standards demanded by the innovator, which were observed to be higher than those demanded by their customers. Subsequent work has continued as a response to market needs and demonstrates the adaptability of the company and its innovations and is discussed in more detail in Chapter 7.

The company has evolved and learned more about how to optimise crop quality and yield through fine-tuning its innovation and developing the hydroponic science which is also sold either independently as a consultancy or together with the Saturn Grower. This has broadened the offer to reach more potential adopters and also has benefits for the case study company; rather than relying on a one-off sale of the technical innovation, i.e. the hardware (which in this case is the Saturn Grower). The consultancy has become integral to sales both with and without the hardware platform: “The consultancy on hydroponic science was originally devised to help customers obtain better results from their investment in the towers…Our most important milestones have been the initial trials, the achievement of big sales over time, starting the consultancy plus complex hydroponics for non-food crops” (Saturn Bioponics CEO Alex Fisher, Ref: SB21.) This indicates the CEO’s attitude towards development of technical services which offers potential extra value to customers, and is discussed in more detail in Chapter 7, Business Model, Section 7.4.8.

6.4.1.2 Innovation process

In a small start-up company, there are no specialist departments which can offer opinions. Entrepreneur Alex Fisher, CEO of Saturn Bioponics, has demonstrated the ability to work across technical and social fields, accepting that part of being a successful communicator and entrepreneur is the ability to listen to others and accept feedback, and if necessary, take action. This is shown below to have been a key element of the strategy taken by Saturn Bioponics not only in the development of the hardware element of the Saturn Grower, but also in the hydroponic consultancy.

A business opportunity in the vertical farming sector was perceived by the CEO in 2010, and initial work carried out on the hardware over an approximate five-year timespan. The next major step in the process was in 2015 to enlist commercial growers, who were very early adopters, to help refine the system and their contribution helped ensure a design which was fit for purpose (Ref: SB05). The time taken from conception of the idea to recruitment of early adopters was used to study market demand as well as devising a prototype. The objective was clear: the innovation needed to be something that would solve customer problems and provide value to them. Similar views on the importance of seeking feedback are held by the CEO of Vertical Farming 2 company, who reflected: “Operations need to be focused and work with farmers who do their own designs” (Ref: AS18). This links with the development of the value offering as part of the Business Model discussed in Chapter 7 as feedback helped to fine-tune the innovation to ensure it provided value.

Observations have shown that innovations need to be driven by need or demand. Contact with innovative, early adopter farmers and acceptance of their feedback helped ensure the potential offering was likely to fulfil such a need. There are occasions when technical innovators spend more time seeking technical viability potential without first assessing market demand and highlighted by Agri-TechE CEO, who warned “Many are engaged in developing gadgets which the growers and supply chain neither want or need” (Ref: AS16). As a result, these are highly unlikely to be adopted and highlights the need for innovators to do market research and communicate with the sector to understand what their challenges are and what they need to help their businesses, and also their available budgets.

6.4.2 Production of knowledge of interest to target adopters

The commercial nature of early adopters was important because of the perspective they offered on acceptability in the supply chain of the crops grown by this method, and therefore its value. They also facilitated knowledge which would be of interest to other potential growers. This included marketable yield figures per square metre rather than laboratory figures improving customer potential perceived utility by providing information which helps visualise what they would be able to achieve in a commercial situation and potential relative advantage (see Section 6.4.3). It is generally accepted in the horticultural industry that marketable yields figures from using similar management practices to the ones they use help drive decisions on whether to invest in a new system, and this has been highlighted at industry events (Refs: CUP01, TAS13).

Empirical exploration through talking to industry members and agricultural research scientists at the Agronomists' Conference (Ref: AS13) revealed disparate opinions about the value of replicated trials compared with on-farm trials, and the importance of both to the decision-making process. This illustrates that one of the primary decisions the innovating company has to make is how to target its research to produce the data and information that customers will value. Conceptually, this could be seen as the first step towards building leverage of the product, as long as the produced knowledge is considered as legitimate, as noted by Abson et al. (2017), and is discussed in more detail in 6.5.3 below.

Sector-level impacts play a role in the uptake of innovation because of the nature of agriculture; a plant may not achieve its maximum genetic yield potential for a number of reasons, including environment, biotic and abiotic stress, nutrition, with these factors all needing management. Such factors influence growers considering an innovation because they need to trust that the technical system will not break down. This can make them more risk-averse and illustrates the need for the data for them to be better able to evaluate what can be achieved in a commercial practice, using different ways of gathering data to confer legitimacy. Using replicated trials is one way to address this gap in knowledge. "The challenge with all field trials is that, because of crop variability, you may need between 8 and 11 replicates of each treatment in order to prove they [have yields that] differ by 10 per cent" (Ref: AS13). Both types of trials demonstrate observability of any relative advantage, which was highlighted by growers to be very important to decision making shown above in Section 6.4.3. However, small plot scientific trials do not replicate the sort of conditions a crop would be grown in under commercial conditions as they are often hand-planted and carefully tended by the scientists and are therefore more likely to achieve their genetic potential (Ref: AS13). There may be differences in scientific acceptability in terms of repeatability (Ref AS13) because of the biological variability of soils across a field, or, in the case of indoor-grown horticultural crops, humidity, hours of sunlight and pest pressure.

Grower decisions are not only made on yield because the picture is complex. For example, labour costs of time available for nurturing the crop, which can influence yield and quality are important, but in a commercial context labour may not be available, or be too expensive and therefore not cost-effective. High yields driven by high inputs can result in a narrow profit margin, hence the potential customer may consider a trade-off between financial returns on best quality and yield compared with outgoings. These factors are all related to the importance of demonstrating tangible competitive advantage and usefulness of the innovation to the customer in a way which will resonate with them so they perceive value.

The relationship with early adopters corresponds with the post-1990s ‘subjective’ concept put forward by Leeuwis and Aarts (2011) in that successful innovations have inputs from users and intermediaries in addition to the inventor who creates the innovation. The development of trust between two companies has been particularly successful in the case of Valefresco and Saturn Bioponics, and a trial greenhouse has been set-up as a joint venture between the two, with both having technical input (Ref: SB26, SB25). This suggests that, if successfully implemented, the relationship has the potential to be more of a partnership than direct linear communications from innovator to customer. This is also contemplated in marketing literature, as customers are considered as being integral to a company’s journey (Wright et al., 2021). While using the premises of an early adopter for demonstration purposes can help to build sales, the CEO of Saturn Bioponics has recognised that there could be conflict of interest if the innovation gives a commercial benefit, so not all early adopters would be willing to introduce it to competitors on a peer-to-peer basis. As a result, although the company still perceives peer influence to be important, the company has evolved its strategy more towards improving its networks by making connections during trade shows (Interview, Ref: SB18). This is discussed in more detail in sections 6.4.6 and 6.4.7 below.

6.4.3 Characteristics of the Innovation

The technical characteristics of the innovation are discussed in more detail in Chapter 5; the system is sold in modules, facilitating trials in small areas of a greenhouse as long as there is a pump to deliver irrigation and nutrients to the plants. This allows potential adopters to trial it on a small scale to assess whether the system would work with their current practices. Characteristics which have been highlighted in communications events include the modular nature which keep initial investment costs down, with a relatively quick return on investment, for example the company calculated that the return on investment for pak choi was within three years (Ref: SBC01); suggesting the company’s understanding of what customers perceive as valuable information.

Discussions with growers highlighted the value assigned to certain characteristics of the innovation (see Table 14 below). These traits are arguably important drivers of decision-making by potential adopters, who need to assimilate knowledge to evaluate a perceived value. For example, discussions with growers have detected that adoption needs to offer relative advantage, and this is illustrated in Table 14. Also important are small trials and observability which help to understand the innovation and provide information in the context of their own farms. A relationship has been detected between the characteristics of the innovation, data about the innovation and social-psychological constructs, but not all of these are used in communications. Decisions on communications messages were made about they are expected to be received and acted upon by potential adopters, which suggests there may be a learning and adaption process.

Table 14 Characteristics of the innovation, their relation to the hardware and software marketed by Saturn Bioponics and relation to value perception constructs

Characteristics of innovation	Saturn Bioponics hardware and software innovations	Collective process	Relation to value perception /value to business	Leverage point	Sustainability concepts	Communications channels and messages to drive value perception
Relative advantage	Potential increase in productivity	Developed in conjunction with early adopters	The potential for customers to assess value by their own perception of usefulness	Return on investment	Potential for eco-efficiencies but sustainability is often viewed as a cost	Different channels with messages about productivity and profitability
Trialability and Observability	Modular-base facilitates trials on a small scale	Observable at test facilities and adopters' premises	Facilitates assessment of perceived uses and usefulness of the innovation	Any perceived ease of use and perceived usefulness may help break path dependency	Opportunity to test eco-efficiencies	Face-to-face communications and observations by potential adopter

Characteristics of innovation	**Saturn Bioponics hardware and software innovations**	**Collective process**	**Relation to value perception /value to business**	**Leverage point**	**Sustainability concepts**	**Communications channels and messages to drive value perception**
Compatibility and complexity	The idea in itself is not complex and has hydroponic consultancy availability. System compatible in different indoor systems Hydroponic science can be applied in other growing systems	N/A	Customer evaluation of the extent of compatibility to work with the currently used system and the need for staff training, compared to use of current resources (see comparative advantage).	As above	Fit with whole-farm sustainability ethics (if appropriate)	Not observed in direct communications, but related to trialability (above)

Source: Own data from interviews and observations

These findings show that, in theory, the characteristics of the innovation should help effective diffusion of the innovation because they can be used to see where value is perceived by customers. In Table 15 below, these characteristics have also been compared with data from growers, advisers and other links in the chain to better understand their perception of these characteristics and acceptance by complying with these characteristics.

6.4.3.1 The value of characteristics of innovation to customers

Once the above observations had been documented, their relative importance to potential customers, or the customer's customers, was assessed. Data collected from interviews about uptake of Saturn Bioponics' innovation and also general agri-tech advancements have been synthesised to highlight the importance of these characteristics and what is perceived as value from the innovation from different perspectives (Table 15). This information is taken forward in communication messages and discussed in more detail in section 6.4.7, Communications.

Observations show the perceived value may be at more than the immediate business-to-business level, and the customer's customer can influence uptake of an innovation. For example, top-of-the-range supermarkets have tight product specifications together with sustainability criteria which need adhering to, both of which are facilitated by 3D farming (Ref: SB13). Valefresco director Nick Mauro revealed that product consistency was so good as a result of using the Saturn Grower that his main customer, who supplies all the principal UK supermarket chains, had increased the contracted volumes (3 March 2017, Ref: SB13). Together with gaining a relative advantage from an innovation which translates into improved profit margins, this can provide an important perception of value and therefore drive further adoption.

Table 15 Potential customer views on importance of characteristics of innovation

Characteristics of innovation	Grower 1	Grower 2	Grower 3	Grower Adviser	Processor	Agri-Tech specialist
Relative advantage	Customer consideration is key. Price concerns of total price of installation	Not maximising yield but maximising returns. A lower yield with lower costs would make it more likely to adopt and innovation	Hydroponics can offer a big advantage because no foreign bodies (e.g. stones, insects etc.) appear in produce. The relative advantage has to take costs of installing new technology into consideration.	If adopted, consideration of time any relative advantage may last before competitors also adopt it (hence no longer providing relative advantage). Consideration of economics of adoption and elasticity of supply curve and whether an increase in supply would result in a fall in price.	Needs to be clear advantage for productivity and ROI Improvement for the environment may be considered as relative advantage if customer driven	Important for most growers

Characteristics of innovation	Grower 1	Grower 2	Grower 3	Grower Adviser	Processor	Agri-Tech specialist
Compatibility	It is important for continuity, but cost is more important	Industry is not good at ensuring compatibility. Farmers concerns around too many different platforms. For the right kit they would change things around	Cost is more important	For incremental change and minor shifts, it is important, but when there is a real shift then compatibility is no longer important (e.g. the move from horse to tractors)	There is a need to ensure it works with the company's operating system and talk to other equipment and the computer	An innovation needs to fit the model of technology/method currently being used

Characteristics of innovation	Grower 1	Grower 2	Grower 3	Grower Adviser	Processor	Agri-Tech specialist
Complexity	This is linked to trialability and complexity, as trials help discover the complexity of a system	If use is simple the technology can become low hanging fruit if it is cheap to buy and offers potential benefits such as information. Much of the decision depends on individual preference & interest. Peers create interest and offer advice	Trials help discover the complexity of a system. The Saturn Grower is simple, and builds on knowledge from hydroponic tomato growing over thirty years	Complexity is acceptable if it reduces costs	Businesses already work with a reasonable level of technology, so not an issue	The more complex to use, the less likelihood of adoption
Trialability	Very important for convincing decision makers and company directors	Very important to know if it will work in the growers particular conditions without making a large investment first	Very important to convince peers and colleagues	Doing trials themselves allows them to discover whether the technology offers them an advantage; measurements must be relevant	Compulsive viewing – particularly if another company has got the technology, but needs critical evaluation	Adopters need evidence that something will work

Characteristics of innovation	**Grower 1**	**Grower 2**	**Grower 3**	**Grower Adviser**	**Processor**	**Agri-Tech specialist**
Observability	Observability convinced directors to adopt	Linked to the above, and helps to justify costs first	Observability crucial to adoption	If it is more observable it will help them to adopt sooner	Observability and trialability fit together	Observability and trialability interconnect ineffective innovations will be abandoned

Sources: Data collected by author

These data illustrate that perception of value from the characteristics of the innovation is central to decisions on adoption or rejection. Interviews across the supply chain (Ref: SB13, INT02, AS20, PR02) indicate this to be the case for both growers and the next link in the supply chain, the processor, who can also influence the primary producers (see Section 6.4.5).

Decisions partly depend on the ambition of the potential customer, and influence their perception of value. This indicates the need for the innovator's team to embark on person-to-person communications to discover the needs in each particular instance so that information can be correctly targeted. To consider investment in a new technology, such as hydroponics and growing crops in 3D, potential adopters need confidence that they will achieve sufficient profit margins to earn a good return on investment. Not all producers consider that yield on its own provides a relative advantage; for some, relative advantage may come through solving other challenges such as access to labour and speed with which tasks can be carried out, or to increase profit margins through the control of inputs. It can be surmised, therefore, that what constitutes value through relative advantage to one grower will not necessarily provide the same reaction in another. As a result, communications messages tailored to include information about different sources of potential advantage are likely to be more effective.

The opportunity for potential customers to evaluate how well a system works for them on their own premises has been observed to be a key element driving value perception. The interviewees featured in Table 15 above expressed the importance of trialability, often linking it with observability as being key to decisions. This is understood by Saturn Bioponics CEO Alex Fisher: "When growers see vertical farming modules in action, many people become interested and would like to see it go forward" (Ref: SB05). This was particularly important for larger enterprises which have a board of directors to convince who may not be very knowledgeable about agronomics. Highlighting this, one farmer (Ref: AS31) says: "Trialability is very important so you can evaluate if it does not work properly or will work in a particular situation". Further consideration of trialability reveals its importance because a potential adopter can then better evaluate characteristics of the innovation to determine its value for them.

When analysing attitudes towards complexity, I found interviewees had not ranked it as being an important determinant of rejection. This may be because in Northern Europe there are already high standards of business knowledge and increasing use of technology across the agricultural sector, including soil moisture sensors, drones, soil type and green area index mapping, amongst others.

6.4.4 Barriers to adoption

Even when value is perceived, an adopter may not be in a position to take advantage of it. One of the challenges of uptake of such an innovation has been shown to be the intense competition between retailers driving down prices (Refs: PB01, PB02, SC01), and the lack of contractual security, which impact on investment decisions. Discussions revealed that there is often awareness of new innovative technology, such as hydroponics, but, because of financial insecurity, they may not feel they are in a position to adopt it and was highlighted by Valefresco director Nick Mauro (Ref: SB 26) who said: "There is a great deal of activity in the hydroponic space, but food is too cheap so no-one wants to invest money". This underlines the need for the characteristics of such a system to offer a distinct advantage to the adopter, not necessarily in yield, but in profit margin.

One of the barriers to adoption is that in some cases growers are not looking to invest in higher production as they may have other priorities, such as reducing reliance on labour. Over the time period used for the case study there have been significant political changes, one of the most important of which is Brexit, which has affected the availability of labour for fruit and vegetable enterprises. This was referred to by the CEO, Saturn Bioponics, who said: "Farmers in the UK are on hold, there has not been much going on since the Brexit vote" (Ref: SB17). Many growers have been re-thinking their growing strategies, with many looking to invest in robots to replace labour where possible, or perhaps equipment which will work with robots.

Others have actively been looking to invest in opportunities arising from the potential for greater demand for produce grown in GB (Ref: VF02). With the outcome of the post-EU withdrawal trade deal not known at the time of writing, this disruptive event has affected investment priorities and decision making, and has impacted on the sales of the Saturn Grower (Ref: SB18). Labour issues may have impacted on uptake of the hardware because the focus has moved away from increasing productivity and yield, to seeking ways in which companies can work with a very much smaller workforce (Ref: SB18, HP0, AS16).

From a commercial point of view, when events outside the influence of the innovating company provide a barrier to adoption, the company may respond by broadening the sector from which it draws its target adopters, for example to non-food crops. While this may not be an ideal situation from the perspective of a move towards sustainable intensification in food growing, the decision has to be made to use time and resources where it is most likely to have commercial success through adoption of its innovation.

6.4.5 Diffusion networks

To gain a contextual view of where persons involved in selling 3D farming equipment are situated, one of the first areas taken into consideration was the social system of which these players are members. Initial networks formed by Saturn Bioponics in 2016 included early adopters who either supplied processors or packers, and which was then sent for retail. One such company already had established markets for sales of its fresh produce prior to trialling the Saturn Grower, and feedback played a role in helping Saturn Bioponics fine-tune the innovation (Ref: SB05, SB06) to ensure the quality of the fresh produce was that demanded by the supply chain including processors and retailers. This is discussed in more detail in Chapter 7.

6.4.5.1 Combinations of actors used in diffusion networks

Observations highlighted that this social system in which the case operates is commercial and highly competitive, and early adopters are commercial growers who are motivated by the need to make sufficient profit to stay in business themselves. This underlines some of the difficulties in diffusing innovations in a neo-liberal economy which does not have an independent extension service. Early adopters provided a useful means of creating networks further back in the supply chain, introducing the company to their own suppliers of other equipment such as greenhouses, irrigation pumps, etc. This removed the initial element of introducing their competitors to a system which gives competitive advantage.

Evidence suggests the complicated dynamics of strategic networks were adjusted according to the particular circumstances. For example, an introduction to a well-established specialist commercial greenhouse designer based in Italy (Ref: SB13) became an important part of the network (Ref: SB18) and has become a distributor for the enterprise in Italy. This has an added bonus in that the enhanced conditions provided by ultra-modern, high-tech greenhouse can also be refined to enhance crop yield and output, thus providing a more complete service, adding to the total value.

Interviews with the CEO of Saturn Bioponics, Alex Fisher, (April 2016, November 2018, December 2019) also provided evidence of a broadening of the networks over time to include the customers of their customers (i.e. processors, packers, and retailers) creating the potential for communications with both ends of the supply chain, thereby creating a web of information available to potential adopters. This also links back to the importance of the characteristics of the innovation. For example, processors may perceive relative advantage when their work is facilitated (and costs less) when certain specifications regarding size, quality and lower mechanical damage are achieved (Ref: SP01). Thus when a system offers this potential, it may be to growers' own advantage to recommend it to their fresh produce suppliers.

A simplified view of the position of Saturn Bioponics within this complex supply chain can be seen below in Figure 6.

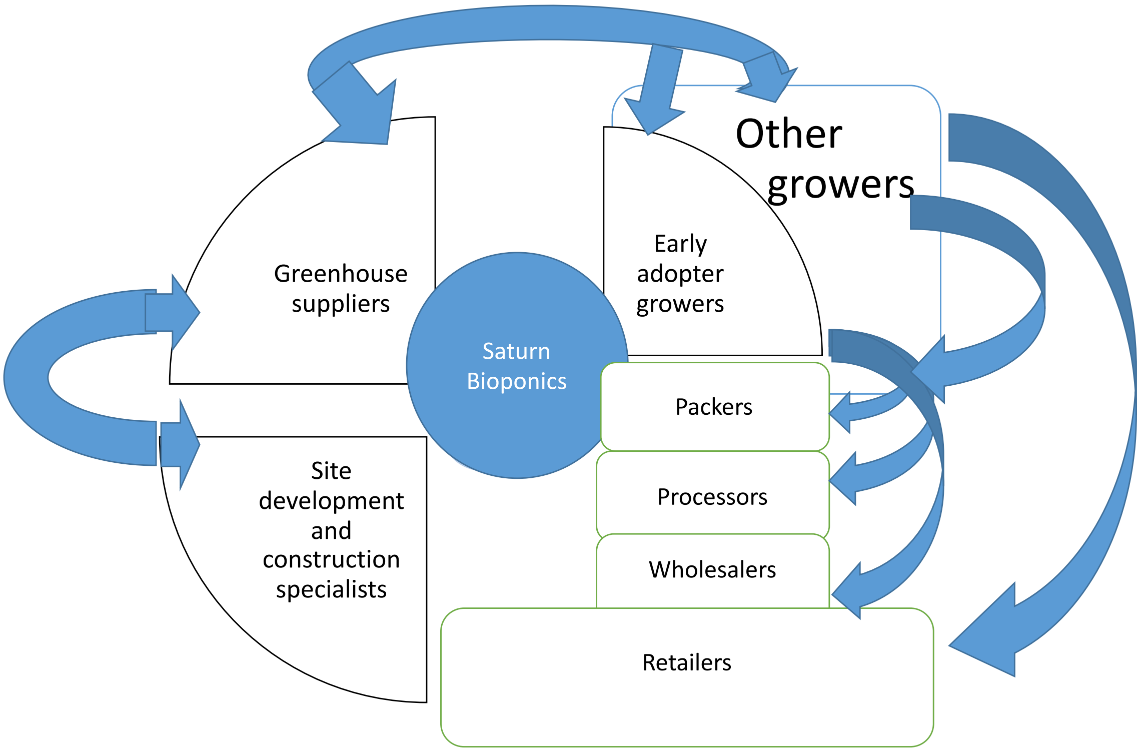

Figure 6 Developing Saturn Bioponics' networks upstream and downstream along the supply network

Figure 6 above shows that Saturn Bioponics within its context of networks; it has direct relationships with growers, both early adopters and other growers (the channels it uses for communications are detailed in Section 6.4.7 below). It also has built relationships with other suppliers such as those which provide complementary goods or services such as greenhouses and construction services. This illustrates there is a systems approach to the network in that the company's target customers, the growers (including early adopters) interact with their own customers further down the supply chain, such as packers, processors and retailers. Saturn Bioponics has developed communications to build relationships not only its direct customers, but also the customers of the customers.

This systems approach created an advantage from a degree of heterophily through cross-enterprise opinion leadership, for example showing innovations to an allied but different agricultural sector (Ref: AS12). Growers of non-food crops were taken round the installations at early adopters' premises (Ref:SB28), with the aim of generating discussion and feedback. Demonstrating an innovation to a different sector in such a way avoids some of the issues of revealing competitive advantages from its use to direct competitors.

6.4.6 How knowledge is produced

Part of being a successful communicator and entrepreneur is the ability to listen to others and accept feedback, and if necessary, take action. This is shown to have been a key element of the strategy taken by Saturn Bioponics who enlisted commercial growers to help refine the system (Ref: SB05). This links with the development of the value offering as part of the Business Model discussed in Chapter 7. Similar views on the importance of seeking this early feedback are held by the CEO of Vertical Farming 2 company, who reflected: "Operations need to be focused and work with farmers who do their own designs" (Ref: AS18).

The commercial nature of these early adopters facilitated marketable yield figures per square metre rather than laboratory figures. This is of particular interest when communicating with other potential adopters as it helps them see what they may be able to achieve in a commercial situation, and links to relative advantage (see Section 6.4.3). Such figures provided useful on-farm information for the innovator which could be compared with similar hydroponic systems to assess the potential competitive advantage of the new system. Understanding how to make optimum use of the growers' knowledge and expertise with particular crops, taking into account other factors which will be important to potential growers, was observed to be an important means of enhancing and refining an innovation.

There are other factors influencing growth when crops are grown commercially, such as labour costs of time for nurturing the crop, which can influence yield and quality, hence there can be a need for a trade-off between financial returns on best quality and yield compared with outgoings. Discussions indicated that growers prefer to see innovations working in a commercial context, even if they are not scientifically acceptable in terms of repeatability (Ref AS13) because of the variability across different sites. These differences in opinion suggest benefits from having two types of technical information, both scientific and commercial, available when diffusing an innovation of this type to create impactful and persuasive communications.

The relationship with early adopters corresponds with the post-1990s 'subjective' concept put forward by Leeuwis and Aarts (2011) in that successful innovations have inputs from users and intermediaries in addition to the inventor who creates the innovation. This has been particularly successful in the case of Valefresco, and the joint work is continuing; a trial greenhouse has been set-up as a joint venture between the two, with both having technical input (Ref: SB25, SB26). There has been a further benefit too; this venture provides the innovator with the means to sell the produce from the trial helped off-set some of the costs of holding the experiments (Ref: SB21).

This suggests that, if successfully implemented, the relationship can become a long-term as the innovation and services evolve, providing valuable information and a place to demonstrate the innovation. The CEO of Saturn Bioponics has recognised a potential conflict of interest if an innovation offers commercial advantage, so not all early adopters are willing to introduce it to competitors. Although the company still perceives peer influence to be important, it has evolved its strategy more towards making connections during trade shows as it found this was where most sales leads were made (Interview, Ref: SB18). This is because those who are already looking to invest in 3D farming technology are likely to attend such events.

6.4.6.1 Parties active in communications

Key players in Saturn Bioponics' communications strategy are the CEO and the CTO, and early adopters Valefresco. Choice of communicator was based on the ability to be effective, and when Saturn Bioponics was founded, its CEO was not known in the industry. It is not easy for a newcomer to the industry to be perceived as an opinion leader; it takes time to build up a reputation of being knowledgeable in the field, as well as being honest and having integrity and tends to be incremental rather than a series of step changes (Ref: INT01).

The CEO has worked to become an opinion leader in the vertical farming and hydroponics sector, communicating at a number of different events with different target audiences. The CTO, who joined the company in 2015 has also been active in communications, such as Agri-TechE (Ref: AG01). Both communicators are technically adept in reference to the Saturn Bioponics system. Acceptance as industry leaders was demonstrated in March 2020 when the CEO was asked to advise a major certifying entity on the links between hydroponics and sustainability (Ref: LE02). The company has also gained credibility by appearing in the Government's 25-year plan (2018 p36) as a purveyor of equipment for sustainable intensification. This illustrated the effectiveness of communications aimed at building the reputation of the company as an important player in the 3D industry.

Communications received from informal contacts can create social pressures to adopt or reject an innovation which implies the influence of the opinion leader may need to be strong enough to guide the farmer's trusted advisors: agronomist, family, friends and peers. Such ideas are corroborated by the experience of Saturn Bioponics (Ref: SB22) and are broadly aligned with the those of Owen and Mitchell (2015) in the energy technology sector, in which energy reduction scheme advisors were found to play a powerful role in suitability of a particular technology to the location, household and lifestyle.

Other actors with connections to the company, such as some of the early adopters, also played a role in the diffusion process. This was because by having the 3D growing system set up in a farm situation, they offered potential adopters the possibility of viewing the working system. In addition, it provided an opportunity to promote the human element of communication on a peer to peer basis. This highlights that the right choice of early adopter who is capable not only of innovation but also good at communications proved important for promoting Saturn Bioponics' 3D growing equipment. For example, by March 2017, Valefresco had shown more than 50 growers and key industry personnel around the farm; other early adopters had not been so active in this area. As a LEAF Marque certified grower (See Chapter 5, Section 5.4.4), Valefresco has access to the LEAF Innovation programme in which growers within the scheme exchange innovations and knowledge. There may be potential for Valefresco to participate in a LEAF-organised visit to a particular farm as part of its Diffusion of Innovation programme, although so far this has not happened due to time constraints.

While work with early adopters to refine an innovation forms a crucial element within the innovation system, reliance on them as communicators has been observed as not always being so successful because of potential incompatibilities as entrepreneurs themselves. Evidence shows that not all early adopters were enthusiastic about sharing their knowledge about the three-dimensional growing system to their peers. Interviews with other practitioners in the growing and agricultural PR sectors support this view, and the LEAF CEO suggested “Entrepreneurs may not be suitable actors for opinion leaders as they tend not to share” (Ref: LE01). This relates to the desire to benefit from the relative advantage (Interviews, Ref: INT01, IS32); showing direct competitors around within the same commercial sectors has a potential conflict of interest, unless there is an incentive to do so.

The data in Table 16 below was generated from industry observations and discussions with industry specialists with experience in influencing and observing uptake of innovations in the agro-technical and sustainability spheres. These experts all reflected the same, or very similar, ideas on the characteristics needed to be an opinion leader. Analysis of this data leads me to suggest that the ability to comply with these characteristics has been one of the reasons that Saturn Bioponics has been able to build a successful business from its innovation.

Table 16 Relationship between Saturn Bioponics communicators and necessary opinion leader characteristics in fresh produce sector

Characteristics	Peer to peer communications	Saturn Bioponics*
Leadership qualities: good at communications (i.e. speaking to people)	Need for gravitas and/or charisma to speak well in public	Authoritative and charismatic public speaking manner Effective individual person-to-person communications
Innovative	Need to be able to demonstrate scepticism to innovation and how this was overcome	Innovation demonstrated with Saturn Grower and hydroponics consultancy
Available	Busy work schedules may make availability difficult	Always helpful, but busy schedules mean timings have to be cost effective
Thought provoking	This links to charisma and innovative nature	Saturn Bioponics has spoken at thought-leadership events
Clear thinking	Necessary for clear messages	Clear messages for targeted market segments according to audience
Willing to share	Crucial, but may be difficult in competitive environment	Shares data on crop performance and inputs from trials (commercial + company)

Source: Own observations and industry specialists Ref: LE01, IN01, AS16, AS33
*In this table, Saturn Bioponics includes the CEO, CTO and also Valefresco director Nick Mauro

6.4.7 Communications channels and flows

There are a number of methods by which Saturn Bioponics communicates with potential adopters about its value offering, including personal contact from recommendations and introductions, trade press articles, websites, trade shows and conferences, visual, peer to peer communications and blogs. The company works in a highly specialised market with specialised growers with fewer than 5,000 holdings of vegetables, salad and holdings in the UK (Defra report Ref: DEF01), not all of whom grow in the protected environment. The pool of potential adopters is small, so communications channels are targeted to places where specialist growers are likely to look for information.

Communications strategies have evolved as the company has developed its expertise and client base. As the company has grown its networks, communications become more complex; potential adopters may receive communications from the company itself, trade magazines, peers, advisers, and recommendations from its customers as seen in Figure 7 below. The study now looks in more detail at the channels used for such communications.

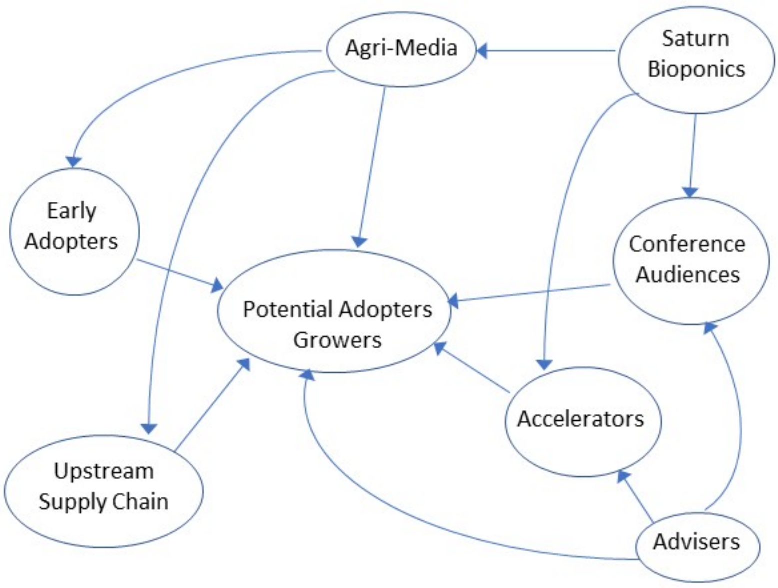

Figure 7: Saturn Bioponics has developed communications flows to target direct customers and also the customers of the customers

Communications made by Saturn Bioponics targeting potential adopters are aimed at stimulating interest in the innovation, rather than social change through the innovation's inherent sustainability elements. Table 17 records the different ways in which Saturn Bioponics initiates personal contact with potential customers. Research on multi-dimensional adoption processes by Pathak et al. (2019) found the importance of such communications was second in importance to the characteristics of an innovation, and the results of this study reflect a similar finding. Methods of wide dissemination such as trade magazines played a useful role in the path of communications because they stimulated discussion among growers and their advisers, and instigated direct contact with the enterprise, and therefore provided a means of initiating value perception. Sales of equipment such as the Saturn Grower are human-intensive processes because of the necessary expertise needed to guide a potential adopter in what is an important investment for a company, which reflects the findings of Wright et al. (2021) when looking at automation in marketing.

Channels used by the company between 2014 and 2019 are shown in Table 17 and show how the company has used them to build relations as a means of communicating the value of the product and services. It shows a learning curve and a willingness to try different channels, particularly since 2018, even though some of them have not been immediately successful. The results from this case study show that social media did not attract customers, which may be a useful indicator for other agri-tech enterprises working in a business-to-business market on limitations of some communications channels.

Table 17 Communications channels used by Saturn Bioponics for influencing potential adopters

Channel	2014	2015	2016	2017	2018	2019	Stimulation of person to person conversations
Trade magazine articles	✓	✓	✓	✓	✓	✓	Yes, contact made by serious potential customers after articles
Personal introductions	✓	✓	✓	✓	✓	✓	Yes, both potential customers and also contacts up and down the supply chain who can influence using a three pronged approach
Peer influence	✓	✓	✓	✓	✓	✓	Yes, in particular on-farm demonstrations and introductions to other parts of the supply chain
Trade conference speech/panel discussions			✓	✓	✓	✓	Results of contact made after these events are unclear for sales but built up networks of contacts and potential investors
Trade fairs					✓	✓	Yes, potential customers come on stand and initiate conversations with the company
Social media					✓	✓	No, social media has not been seen to have results
Website and blog					✓	✓	Unclear results for adoption but have a more broad sphere of influence which may be seen by potential investors or sponsors

Sources: Saturn Bioponics and author observations

Observations and exploration of the collected data have detected a sequence of communications that were aimed at potential adopters to build the human element of its communications. This implies an understanding that personal information plays a critical role in persuasive communications and is similar to results found by Caffaro et al. (2020) about adoption of agri-technical innovations at a more general sector level.

The case study enterprise undertook communications in the form of knowledge transfer activities about the Saturn Grower via technical journals to stimulate interest using carefully chosen information that potential adopters would be likely to be seeking, such as the important characteristics of the innovation. Most of these refer to the important characteristics of the innovation (see for example Commercial Greenhouse Grower article, Ref: M126). On the same day that an article was published, Saturn Bioponics frequently received follow-up enquiries, opening up personal conversations (Ref: SBE01). However, as not all sales enquiries were asked where they had heard about the system, it has been difficult to find reliable data of how such communications are followed through and therefore difficult to generalise from this information.

Choice of events, such as conferences, where the case makes presentations has evolved in stages. In the first phase of the company until 2015, the company accepted invitations to speak at a number of conferences as a means of diffusion of innovation and gain credibility, but found those attending were from an academic rather than commercial backgrounds, thus were not reaching the targeted market. For example for one of the agri-tech conferences attended by Saturn Bioponics, the attendance list provided by the organisers showed there were a high number of vertical farming companies, but very few farmers. The proportions of numbers from each sector is seen in the pie chart in Figure 8 below:

Figure 8 Example of attendee professions at agricultural conference

This list highlights the small number of potential customers attending such conferences and justifies the decision taken by the case to attend more events where the delegates are more targeted.

Decisions to attend some of the conferences were made because of the rationale that the background of the case study company's CEO was academic, supported by the University of Lancaster, and therefore was an attempt to gain credibility of the initial research work. However, by 2018, conferences were chosen more carefully by taking the audience more into account in terms of a market, and this was specified by the CEO of Saturn Bioponics: "The importance of conferences is their delegates; if growers are not there, then it is not worth attending" (Ref: SB18). As the company evolved, it identified where its target market was located, leading to decisions on which were the most effective events to attend, illustrating the experiential nature of its communications strategy.

Trade fairs have played a useful role in diffusing the company's innovation (Ref: SB18, SB21), particularly those which cater for a particular target audience. This is because they are useful for contacting with new potential adopters of the system; and were found to be particularly successful when Saturn Bioponics and Valefresco took a joint stand shared with an established supplier of complementary equipment to the same sector. Such platforms also offer the opportunity to demonstrate the equipment with a crop already growing, which connects to the observability element of the characteristics of the innovation. This was done at large trade fairs in from January 2017 (Ref: TF04). A decision was also taken to exhibit at Fruit Logistica, the biggest fresh produce trade fair in Europe in 2019 (Ref: PR01). Talking about the decision, Saturn Bioponics emphasised that it was based around the show's ability to attract a targeted audience from across the world: "Fruit Logistica will get us out around the world about what we pitch and what we are offering" (Ref: SB24). This illustrates the aim of the company to broaden its target market and when attended by some of the early adopters, provided a means of encouraging communications between them and similar businesses that are non-competitors of their businesses (see Section 6.5.2) and, therefore, driving perceptions of value to potential customers.

By involving early adopters who are willing to use their farms as demonstration units, the case potentially has another important component of communication: an on-farm demonstration, which can help translate data into valuable information. Generating on-farm figures helped potential adopters gain better understanding of what they may be able to achieve on their own farms and helped drive perception of value for potential adopters. This can be referred back to the perception of the characteristics of the innovation and the importance of observability (see 6.4.3 above).

On-farm visits may have been onerous for some of the early adopters, as they can be time consuming, and observations and discussions implied there may be limits to the amount of information about their own farm that they want to impart. In the arable sector, peer-to-peer communication sits alongside the role of the paid opinion leaders, such as agronomists as being a key influence (Rose et al., 2016). This is partly because growers are adept at communicating with their peers about the benefits of the system to peers at the same technical level, and can indicate potential savings in areas such as labour and resource costs. There may be conflict of interest if a potential adopter is a competitor, so there may not be a free flow of information. This is because indoor horticulture, which includes 3D farming, is close to its end markets, and is highly competitive. Although the very early adopters of the Saturn Grower showed potential buyers round their on-farm systems, Saturn Bioponics was aware of potential tensions from doing so, and so this was not a major communications strategy for the company (Ref: SB19).

Using a number of different channels facilitates reaching a wider coverage of the target market in addition to repeating the number of times a potential adopter sees the main message diffused by the company, including if it is slightly adapted according to the media's audience. There are a number of platforms in the UK which stimulate interchanges between innovative farmers and innovators, which the company has used from time to time. This includes speeches at conferences such as those organised by Agri-TechE (Ref: AG01, WW02) which have been specially designed as accelerator events (see Chapter 3) plus a one-off blog on the Innovate UK website. Trade press also often reports on conferences, which increases the potential exposure to targeted audiences.

Other channels include engaging with third parties as mutual distributors. For example, Saturn Bioponics is working closely with Italian company Idromeccanica Lucchini as collaborating agents for each other. The company is dedicated to sales of high-tech greenhouses (for more information see Chapter 3, Policy and Context) and as a well-established company in its sector, it has its own network. Such an agreement can be useful, particularly in building on-farm demonstrations which include the greenhouse and the growing system of towers devised by Saturn Bioponics. There are limitations to the company's ability to answer highly technical questions potential adopters may pose because as a greenhouse company more geared to selling something highly innovative, its staff may not have the same depth of understanding as those from the original enterprise.

The channels used by Saturn Bioponics have been observed to promote the human element of communication to the targeted segments of their particular market. The right choice of communicators, whether it is the innovator or an early adopter, who is capable of promoting the value of an innovation, plays a key role. The next stage in the system is the key messages capable of influencing potential customers.

6.4.7.1 Vision for customers through key messages

The dominant meaning of the message for growers who are potential adopters is focused on increased productivity (see Appendix II for further information on yield per square metre). This is considered by the company to be what the potential customers will interpret as value and therefore it is used to lever adoption of the innovation and services. Environmental sustainability is also important to the company and even though it does not always feature highly in its marketing strategy, it is implicit in its opinion leader pieces (see Chapter 7).

Key messages highlight the characteristics of the innovation and draw attention to potential benefits (such as increased profits) from the technical innovations, thus emphasising any potential relative advantage. This has been evident from features in technical trade magazine articles about the company and its equipment (Refs: AS26b, AS27,AS28, AS29) which have also raised the company profile within its sub-sector of industry.

Topics used in some of the articles are explored in Table 18, and show yield, or yield and quality, to be the most used, implying that these are those to which they are most likely to act as a catalyst and inspire contacts for new trading relationships. These trade magazines are where the company has been profiled and show consistency over the timeline for messages about yield and quality.

Table 18 Trade magazine articles featuring Saturn Bioponics

Headline topic	Platform	Year	Protagonist	Connection with event
Yield	Farm Business	2014	Saturn Bioponics	None
	Horticulture Weekly	2014	Saturn Bioponics	None
	Hortidaily	2016	Saturn Bioponics	None
	Commercial Greenhouse Grower	2014	Saturn Bioponics	None
	Fresh Produce Journal	2019	Saturn Bioponics	None
Yield and quality	Horticulture Weekly	2016	Saturn Bioponics (+others)	GrowQuip
	Hortidaily	2019	Saturn Bioponics	Fruit Logistica
	Farming Monthly National	2019	Saturn Bioponics	Fruit Logistica
	Hortidaily	2020	Saturn Bioponics + Idromeccanica Lucchini	None
Growing strawberries	Fresh Plaza	2020	Saturn Bioponics + Idromeccanica Lucchini	None
Factors limiting controlled environmental growing	Horticulture Weekly	2019	Saturn Bioponics (+others)	AgriTechE
New installations	Farm Business	2020	Saturn Bioponics + Shockingly Fresh	None
	Agronomist and Arable Farmer	2020	Saturn Bioponics + Shockingly Fresh	None
Funding	Fruit Net	2015	Saturn Bioponics	N/A
	AHDB Grower Magazine	2015	Saturn Bioponics	None
	AgriTrade News	2015	Saturn Bioponics	None

Source: Author's data

Figure 9 below depicts the popular words used by the company when it is marketing its innovation to potential adopters and have been taken from articles in the press and presentations made at conferences such as GrowQuip (Refs:SBP01, SBP02, SBP11, PR01, SBC01).

Figure 9: Marketing messages word cloud from words used by Saturn Bioponics in press articles and conference speeches

The emphasis on technical specification leading to financial performance is similar to that of other growers in the agri-food industry, a wide number of observations from trade magazines, trade shows and industry practitioner discussions have shown. This suggests financial gain to be an important driver for adoption, and emphasises the competitive nature of this sub-sector of agriculture and the need for a relative advantage to drive better profitability for a crop: “Profitability is hard for growers; so making farming better is all about profitability” (Ref: SB05). This implies that the company has determined that the most effective message to reflect in its communications has been profitability, or relative advantage to be perceived as value.

The ability to communicate at the right level has been detected as being key to effective communications and the ability to motivate a potential customer to adopt. One early adopter reported that the Saturn Bioponics CEO was able to “speak my language” (Ref:SB26). As a result, he was able to convince his fellow directors to agree to adopt the innovation, and became one of the first adopters to do so. This relationship has developed over the time-span of the study, and has played an important role in communications as noted below in Section 6.5.2, in addition to adding grower expertise to refine the innovation (see Section 6.4).

One of the areas which has not been found to be in use by Saturn Bioponics' diffusion strategy has been social pressure to encourage a more sustainable focus among its adopters. Mills, et.al (2018) found that the willingness of UK farmers to undertake pro-environmental management was strongly affected by social norms and societal pressure and this could be a consideration for driving adoption given the sustainability focus of the Saturn Grower (see chapter on Sustainable Intensification). However, although this was considered the company decided that while it is of interest to some consumers and supply chain members, it was not an important driver for many of their targeted potential adopters. CEO Alex Fisher emphasised: “Normal farmers are not interested in the sustainability features of the Saturn Grower, outsiders and newcomers to the business are more interested” (Ref: SB28), and this view has been maintained over the whole time of the study. This is also reflected by Vertical Farming 2 CEO: “Sustainability is not a big selling point as it needs to be more expensive” (Ref: AS18). These points of view indicate that cost efficiencies and competitiveness are perceived to be of greater value by potential customers. This suggests that if sustainability is also an aim of the company providing technology, it will have to go in tandem with a product the customers demand, and is discussed in more detail in the Chapter 7.

6.4.7.2 Communication flows

Communications made by the company comprise one-way (such as magazine articles or multimedia interviews), two directional (in which a potential adopter speaks to a member of the Saturn Bioponics team) and multidirectional (in which other members of the supply chain and early adopters join the potential adopter and company staff). Channels supporting diffusion flows include social media, events, seminars, trade press, machinery salespeople, trade shows (e.g. Fruit Logistica), and accelerator events (AgriTechE), amongst others. Interviews and observations have shown the initial communication to be often by one-way, such as an article in a technical journal which features the main innovator, or the chief technical officer and is followed because it helps diffuse ideas about the innovation to a wide audience. The aim is to inspire interest which may then be followed up by contacting the company and establishing two-way conversations using the different channels.

The case established two-way communications with early adopters - technically adept growers - who were then able to play a key role by offering technical feedback on the system. These flows between the innovator and the early users helped refine the innovation, but went further as there was also engagement with the down-stream supply chain, to ensure the product grown in three-dimensional methods also met specified criteria, such as shape, size and quality (Interview Ref: SB13). The importance of two-way communications during development of the innovation is echoed by practitioner views: “Ideally it [communication] is bi-directional, from innovator to user and back again to help influence the shape and direction of the innovation, that's very much our mantra, to get that bi-directional dialogue, rather than one-way linear flow of information. The research community still struggle with that a little, but it is improving” (Ref: AS16). In the case of Saturn Bioponics, some of the early adopters provided technical information on inputs and yield that was then used in other communications. This reinforces the importance of choice of early adopters who can – and are willing to – collaborate across different parts within the innovation system and its diffusion.

By listening to feedback to understand underlying demand, the company was able to determine potential markets beyond sales of its hardware Saturn Grower. These are discussed in Chapter 7.

6.5 Discussion

This discussion reflects on the findings from the research into diffusion of innovation in the 3D sector and puts them in the context of wider literature to illustrate their potential contribution to theory development. It shows how the case study enterprise, as part of a collective process with early adopters, refined its innovation and operationalised its communications strategy through the development of different diffusion networks. These findings are based on the close to market, high value 3D farming sector, although there are some similarities with precision technology in agriculture, hence the findings can be used to assess other agricultural sectors.

In addressing the key questions of diffusion of innovation of 3D farming equipment studied in this thesis, areas of general consensus across academic agricultural literature with regard to diffusion of innovation for precision farming equipment and 3D farming have been found. Both sectors are relatively young, dynamic, innovative and there is fierce competition between equipment suppliers and there are similarities in that both types of equipment help refine growers’ production techniques, which offer both co-benefits. But there are important point of divergence because the fresh produce sector is more competitive than that of cereal farming, thus comparisons are limited in scope.

6.5.1 Evolution of diffusion and communications

The path taken by Saturn Bioponics shows an experiential pathway as its actors adjust their communications strategy and behaviour according to experience, learning which are the most effective messages for raising perception of value of the company's technology and services. The ways in which Saturn Bioponics communicates and scrutinises information from potential adopters of innovation can be conceptualised as the application of understanding of customer perceived value to determine leverage points which influence adopter intentions. This was established to be key to bridging the gap between intentions and adoption because it identified the value perception criteria relevant to the case's customers.

In this instance, the leverage works to provide a number of messages drawing on customer value perception, and capitalises on these to drive further adoption of the system. This reflects findings by Rojo-Gimeno et al. (2019) about building information into a value path that will resonate with a potential adopter. The important characteristics identified are similar to those found by Hochman and Carberry (2011) and Rose et al. (2016), and provide growing consensus about their importance in adoption agri-tech in the broader agricultural sphere across different countries. In the context of this case study, such leverage points could be used to transition a move out of the niche, but as a limitation of this growing method is the breadth of crops which can be grown in this system (it is not currently suitable for arable crops) and thus would need input from crop breeders. As an example of this, there may be potential for further expansion towards seed crops, such as mini-tubers (used as a seed potato).

The adopter's perception of how characteristics of the innovation can create benefits has been shown to play a key role in decision-making. The limitation of the information collected implies a remaining a gulf between information about an innovation collected by the potential customer and the decision to implement a change which implies a leap of faith. To address this, all the different channels of communication used by Saturn Bioponics have been observed to be based around the key messages developed from the characteristics of the innovation viewed as the most important to demonstrate the value of the innovation.

Communications messages have been observed to feed into a number of functions which ultimately provide value for the adopter. Similarities have been found to the caveat observed by Lowenberg-DeBoer and Erickson (2019) who explored uptake of digital technology in farming, in that that technology has to solve a problem. The observations from the case study, while agreeing with this in principle, take this theory a little further because adopter response has been shown to depend on what is perceived to be the most urgent problem to solve within the farm budget parameters. The order of precedence has been seen to change over the time period, with trigger events (Sutherland et al., 2012), such as withdrawal from the EU, impacting on grower decisions. For example, potential customers' perception that other problems – such as labour – are more pressing may slow the expansion of the 3D sector and a subsequent move towards more sustainable practices.

Evidence has shown different visions reflected in communications messages targeting different audiences. Sustainability communications by the company were not undertaken on platforms frequented by the target market for sales of the innovation, but on those likely to be frequented by persons from other areas of the supply chain, such as potential investors or facilitators of grants. This adds to the development of a broader understanding of cross-sector similarities in which the supply chain collaboration has been found to be important for driving sales; such as those in the pig-meat sector as found by van der Heijden and Cramer (2017). Klerkx et al. (2010) suggests the need to support such initiatives in the private sector, and while the case study company presented on platforms such as Agri-TechE, which was designed for this purpose, it also explored and analysed other platforms with a more international commercial appeal to broaden the diffusion of its innovation.

The empirical data collected shows that the company's learning evolution about how to undertake targeted dissemination according to the particular audience has been one of the foundations for its ongoing communications strategy. Communications were not limited to potential adopters, but also potential investors and grant-awarding authorities; demonstrating a strategy which also has implications for the business model and discussed in Chapter 7.

6.5.2 Parties involved in communications and diffusion networks

Stakeholders have been observed to drive the performance of the case study company, with many of them taking on more than role. To some extent, this reflects the findings of Knierim et al. (2015), whose core interest of research was interactions and linkages between actors engaging in communications and sharing of trusted information. Reflections have revealed potential limitations to actor engagement because of the competitive element, which adds nuance to current understanding.

Empirical evidence shows that innovators and entrepreneurs can be communicators, which is not unusual in the case of micro companies currently prevalent in the three-dimensional farming sector (See Refs: SB01, AP01, VFC01, VFC02, VFC03). This suggests that effectiveness may depend more on the characteristics of each influencer, and departs from the views of Rogers (2003), who suggests that the innovators themselves tend not to make good opinion leaders because they are too change-oriented. For the case study enterprise, the innovator and CEO of Saturn Bioponics developed into an effective communicator with an overlap of roles. Because of the importance of person-to-person communications and personal information sources (Caffaro et al., 2020), this opens the debate on the actors most suited to undertaking communications in the context of 3D farming and the wider agri-tech sectors.

Technical expertise was considered to be more important than communications expertise (Ref: SB19) for driving adoption. This is different from observations made by Labarthe et al. (2018) who found communications experts to play a role in driving towards adoption. Although the technical aspects may be considered as necessary background information (Eastwood et al., 2017), they were considered of prime importance by the CEO of Saturn Bioponics. This is because in a competitive situation accuracy of information plays a key role in customer decision making, and complies with observations by Rojo-Gimeno et al. (2019). At empirical level, this was one of challenges when working with representatives from other companies whose primary understanding was another field rather than the Saturn system, and suggests this could be due to the competency gap referred to by Labarthe et al. (2018). It can be argued, therefore, that communications need to be done by agents with good technical knowledge of the innovation, and not merely good communicators when providing support to farmers in the decision-making process, thus adding to academic debate on the most effective communicators.

Analysis found advantages from the ability of the CEO of Saturn Bioponics, who has been the main entrepreneur/innovator, to metamorphose into an effective communicator. Such a person has more in-depth knowledge of the innovation, and can respond to technical questions appropriately, rather than a communications specialist needing to relay such questions back for help with technical expertise. It has effectively facilitated the bypassing of professional communications enterprises, and allowed the case study company to control its messaging itself. The implication of this is that the correct platform with the right audience for such exchanges needs to be identified and exploited, and used in conjunction with messages which convey information around the perceived area of interest of the customers.

The role played by early adopters is arguably important; and this study has shown that they can also can act as opinion leaders in peer-to-peer conversations, and may facilitate the diffusion process. This broadly aligns with the work of Mills et al. (2018), as well as being recommended as industry best practice by Caffaro et al. (2020). Analysis has shown peer willingness may be industry sub-sector dependent, as there can be instances where it is not appropriate such as when knowledge emerges as a critical resource for differentiation, by offering competitive advantage. Early adopters may be wary of losing any commercial advantage via peer-to-peer communications, leading to tensions of struggles because of conflict of interest, as found by Turner et al. (2020) and Van Oosten (1998) because peers may be considered as colleagues or competitors in the horticultural sector when differentiation for competitive purposes forms part of an innovation.

This view adds nuance to other academic work which does not differentiate between the different agricultural sectors and industry best practice guides that promote it, such as Rose et al. (2019) and Pretty and Bharucha (2014b). Fruit and vegetable growers are closer to their end markets than arable farmers; thus I suggest that this unwillingness to share information may be more pronounced than in the arable sector where grains such as wheat, barley and oilseed rape are commoditised and processed. This highlights the importance of sector and crop-specific studies as there are important differences between the market contexts in which they function.

There are other factors driving adopter potential willingness to share; for example empirical evidence shows that Valefresco cultivates a diverse number of crops on the farm in addition to those in a greenhouse, and thus, at the time of adoption, thus the crops grown with Saturn Grower was a secondary business to them. Other early adopters who were less willing to diffuse the innovation had businesses that were less diversified. There were also empirical indications that early adopters were more willing to share experiences in a small, niche market with buyers from a different country who are not direct competitors either. These lessons are similar to those discovered by Frattini et al. (2014) across competitive industrial innovations and offer important indications for diffusion innovation systems in agriculture. Despite the relation between proficiency of diffusion techniques and market success, seeking such contacts may not be the main focus of start-up outlier start-up companies who have narrow networks and find it difficult to find early adopters with the right requisites to help them foster innovation management.

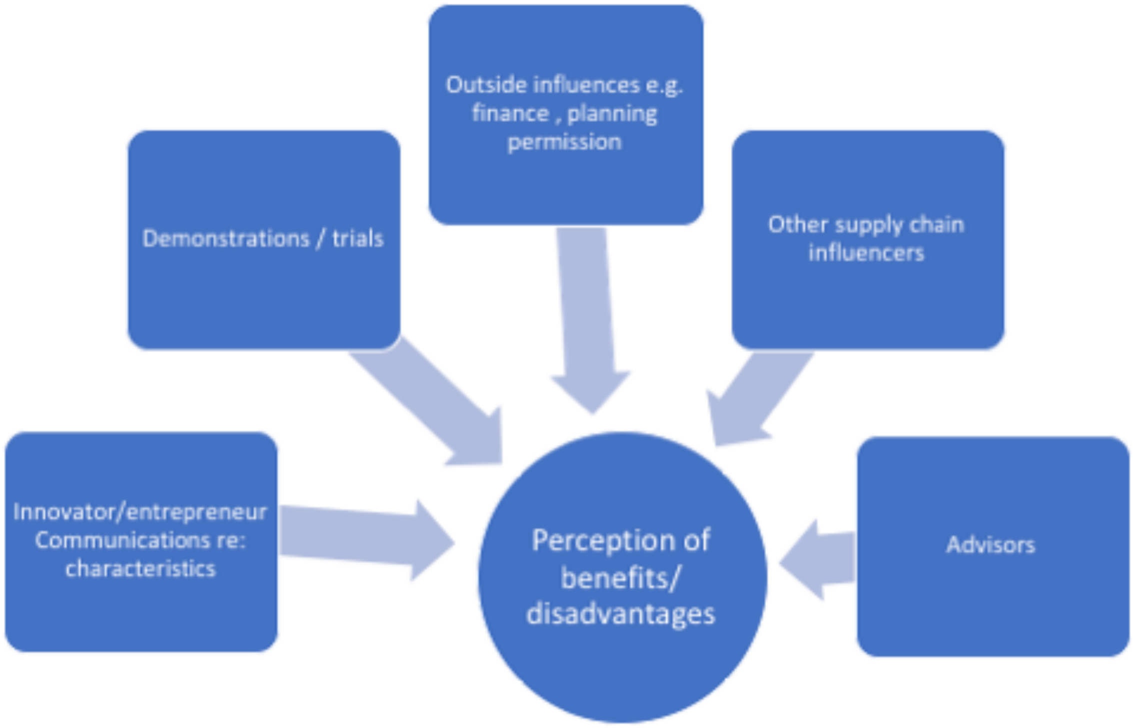

Figure 10 Differing paths of information sources and adoption influences

Strategic use of networks has played a central role by combining actor roles in the diffusion role to drive perception of value. Benefits of the grower knowledge and understanding were utilised for important introductions up and down the supply chain, widening the network of contacts. These actors have been observed to be from different nodes of the supply chain (see Figure 10 above), and either have networks of growers to whom they sell, or, if situated further up the supply chain, they are able to advocate to a particular technology to their suppliers, hence influencing the potential growers from different angles. This strategy was observed to help drive adoption when these actors perceived a benefit to their own business. It can be deduced from the data collected over the time frame of this study that it was not the size of the network pool, the most important outcome was the ability of the pool to provide relevant contacts. If viewed from within the systems approach as recorded by Klerkx et al. (2012), this has worked because Saturn Bioponics was observed to have developed a shared vision with Valefresco and there was good coordination between these actors.

6.5.3 Communication channel evolution and information to value path

This study found better understanding of where customers are likely to be in this particular sector is key to finding the appropriate communication channels. By providing a means of understanding the most effective channels to diffuse information for agri-tech product awareness, the empirical data provides information contributing more breadth to the work done by Klerkx et al. (2012) on finding the best fit framework for diffusion within a systems approach to agricultural innovation.

Observations and interviews suggest a link between time and message conduit; those used for media (radio, TV, articles in press), trade shows and conferences are designed to stimulate interest in their offering. Once that has been achieved other channels, such as observations of the innovation at the company headquarters or in a commercial setting at the site of early adopters (see Table 19 below) are used to build the perception of value. Thus it can be deduced that the company moves from an 'objective' initial transfer of knowledge and information, to a more 'subjective' (receiver-friendly) strategy, as defined by Leeuwis and Aarts (2011) in which they then establish two-way communications with potential adopters so they can better understand their frames of reference and terms of understanding. These two-way, person-to-person communications helped Saturn Bioponics create better adopter knowledge about the innovation, so decisions could be made on whether more precise – and farm specific – information was required to help the decision process. This echoes the findings of Rojo-Gimeno et al. (2019) on the level of information necessary for farmer decisions on adopting or rejecting a treatment or change in the way of working.

Table 19 below illustrates different stages of communications as progress is made towards adoption, which has been put together after scrutinising information about the channels used to diffuse an innovation. Data was annotated by channel on where the first information about an innovation is heard or read by a potential adopter, and these were found to be diffusion event which sends the message to a wider (although targeted), audience. Of course, rejection of the innovation could occur at any of the stages below, taken. Using the analogy of leverage, valuable information is passed to the adopter at each of these stages, helping to build sufficient weight behind the argument to adopt and therefore break any path dependency.

Table 19 Saturn Bioponics' use of communications channels to stimulate move towards adoption

<table>
<tr><td colspan="8">Use of Saturn Bioponics' communications channels to offer information of value to potential adopters during the different stages of the decision process</td></tr>
<tr><td rowspan="4">Initial contact</td><td>Press article</td><td rowspan="4">Stimulate interest:
One direction (objective)</td><td rowspan="4">Contact enterprise and establish human contact</td><td rowspan="4">Discussion(s)</td><td rowspan="4">Observations of demonstrations</td><td rowspan="4">On-farm trial</td><td rowspan="4">Adoption or rejection</td></tr>
<tr><td>Radio article</td></tr>
<tr><td>Speech at conference</td></tr>
<tr><td>Website visit</td></tr>
<tr><td colspan="8">Creating knowledge for leverage</td></tr>
<tr><td>Trials generating data</td><td>Translation of data into information of interest</td><td>Value of information impact on potential adopter attitude</td><td colspan="2">Innovating company ascertains what information is valued by potential customer and responds accordingly</td><td>Observability of the trials legitimising information on perception of usefulness and ease of use</td><td>More intensive information facilitating perception of relative importance of characteristics</td><td>Action: adoption or rejection</td></tr>
</table>

Source: Author's data

Understanding of how messages are perceived by the potential adopter can be better assessed when human contact has been established because of the immediacy of feedback. From there the intensity of the information can be increased to leverage messaging according to the perceived reaction of the recipient. This reaction was observed during conferences and trade events, and there may be opportunities learned from adoption of precision agriculture technologies which are also aimed at improving yield and efficiency with environmental benefits.

Empirical observations of the use of leverage points to encourage adoption were found to comply with the characteristics of the innovation denominated important by growers, such as offering competitive advantage which in turn indicates the farmer's own objectives. Consideration of the attitudes of the adopters has identified that some were clearly ambitious, such as Valefresco, while others, who, despite adopting, did not have the same priority to developing the business. In the longer term, those who chose not to adopt the Saturn Grower, may have elected a similar growing system, or decided not to make changes in their growing methods, but data was not available to analyse on non-adopters. Nevertheless, Labarthe et al. (2018) found the information on innovative systems is likely to be retained and may be used in the future if the farm is subjected to a trigger event, which suggests that such an event could trigger the potential adopter's perception of value. This suggests that policy makers need to take a longer-term view of support offered to innovative agri-tech offerings such as 3D farming.

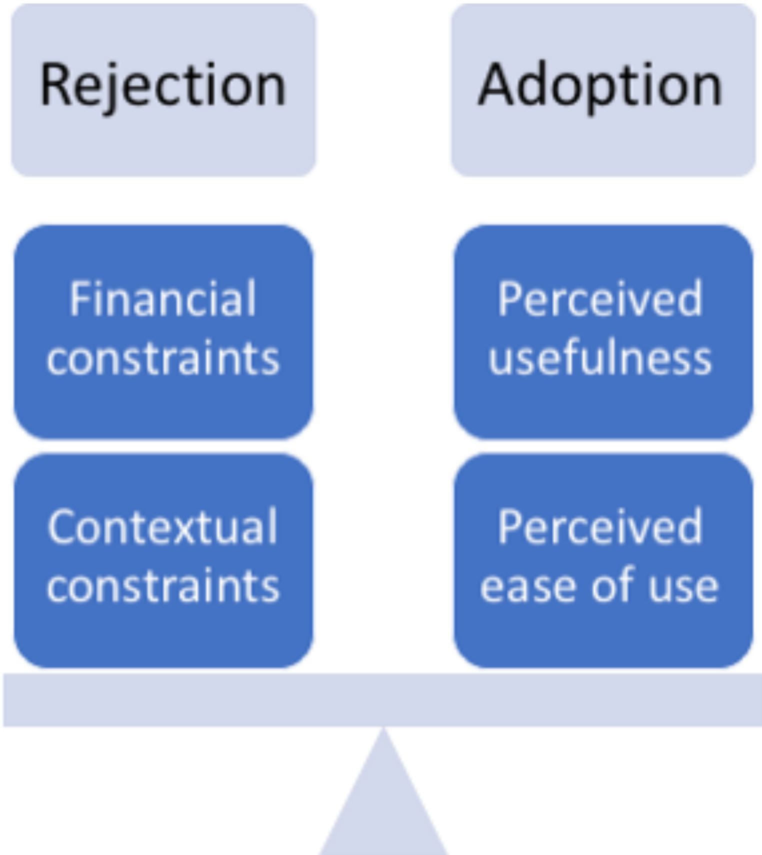

Figure 11: Weighing up the benefits and pitfalls of adoption of a new technology such as 3D farming

The learning curve undertaken by 2017 Saturn Bioponics on the type of adopter investing in the innovation led it to change its focus to targeting fewer, large contracts rather than greater numbers of smaller ones. Although such companies may find it more difficult to change their practices because of rigid working structures than smaller companies (Ref: SB21), they are likely to have a more diversified portfolio of agricultural products which means that the risk undertaken by adopting a new innovation is less than if it is the whole business. This experience reflects that of innovation accelerators Agri-TechE, who have found that it is not so much the size of the enterprise it is the availability of funds for investment and the willingness to take on risk. The change in targeted market impacted on the choice of channels to diffuse the innovation, moving towards large international trade shows attended by big companies. These findings reflect those of Rogers (2003), who suggests that bigger enterprises adopt first, rather than other findings, such as Hockerts and Wüstenhagen (2010), who suggest that in the agricultural industry, small-scale enterprises adopt innovations, and if they are successful, larger ones then embrace the techniques.

6.5.4 Communications messages and sustainability

The main communications messages used by the company are based around yield and productivity, which reflect perceived private sector needs. As confidence about return on investment (ROI) is often cited as one of the most frequent reasons for not adopting new technology (Caffaro et al., 2020), the case study highlights its evaluations for how long a customer can expect it to take. As such, it uses the short time to achieve ROI as leverage to promote its technologies and services, particularly when allowed to use data generated by early adopters, as this can help legitimise such figures. Observations have identified that when the information is presented in such a way that it facilitates the perception of usefulness of the innovation to potential customers, uptake is more likely.

While economic factors drive rational decisions, they can compromise environmental sustainability, hence there needs to be clever use of eco-efficiencies. For example, promoting the sustainability aspect as a means of achieving compliance with environmental and animal welfare regulations can influence decisions. Studies by Rojo-Gimeno et al. (2019) in the dairy sector found awareness and perception of responsibility and the importance assigned to the problem as central to the decision making process. This work offers an empirical view from the other side of the question; Saturn Bioponics has established a growing method which minimises environmental damage and creates eco-efficiencies but the messages used by the company are based on economic factors. This may be connected with their interpretation of how messages are understood in the context of potential conflicts of interest and/or power struggles around price, quality and the environment, and is discussed in Chapters 5 and 7. Although the case study enterprise was founded with the social aim of sustainable intensification, this is not evident in all its communications. Eastwood et al. (2017) suggests that sustainability is often considered by farmers as belonging to the public domain, hence the communications strategy may have evolved around this premise because of the perception that sustainability involves extra costs.

Evidence has shown different messages targeting different audiences. For example, sustainability communications by the company were undertaken on platforms not frequented by the target market for sales of the innovation. This highlights a break in the sustainability message because many growers still regard addressing environmental concerns beyond those demanded by regulation or their customers, to be a cost rather than a benefit. Nevertheless, the growing system and corresponding hydroponic agronomy methods have embedded sustainability which may be more valued by growers in the future if consumers or legislation demand it. Further longitudinal studies are needed to discover how this develops over time.

6.5.5 Addressing innovation system failures

Infrastructural and institutional failures are outside the control of micro-companies working in a niche, such as the case study company. Other companies working in the 3D sector, such as Plantagon (Ref: VF01, PLA01), were observed to be unable to obtain planning permission and faced bankruptcy. Adopters have also had to address problems in areas such as planning permission for the structures to house the Saturn Grower hardware. In one case, the adopter was lucky enough to have access to other suitable facilities at a nearby site close to other greenhouses, where planning permission was given and the project went ahead. Such problems could disincentivise other potential adopters of the system, thus affecting uptake and the resulting improvements for the environment from the sustainability attributes of the system. This suggests a need for policy makers to towards a more holistic plan to include support for adopters at a number of levels, including financial and institutional levels, and also at local council level concerning planning requirements. Multi-level support to facilitate a transition towards sustainable agricultural practices could help kickstart wider adoption.

One of the key policies of Defra is facilitating innovation to help the industry move towards more sustainable ways of growing food, as expressed in its 25-year plan (2018). This policy expedited the development of the Saturn Grower and funding was made available to Saturn Bioponics as part of the InnovateUK policy. Further funds have played an important role in helping the company develop and refine its innovation and the corresponding hydroponic science. Within the context of the AKIS and analysis of grower needs for investment in an innovation, there is a need to review policies which would create a more enabling atmosphere at grower level, with legislation around contacts with retailers so they have more confidence to invest. To some degree there has been some support with the Groceries Adjudicator Code legislation, but, as noted in Chapter 3, growers have little leverage against large supermarket chains. This is important not only in the competitive context of a micro-company selling 3D equipment, but also at macro-level. For 3D growing methods to become mainstream, and enable a transition towards sustainable intensification, there is a need for policy support for adopters.

6.6 Conclusion

Insights from this case study have indicated the need for an integrated diffusion that includes adopter inputs, choice of message focus and the need for technical ability to build perceived value. This adds empirical data to finding the best fit diffusion framework in its particular context, building on the work of Klerkx et al. (2012) in their evolution of systems approaches.

Some of the key findings of this chapter have been the complexity of the relations between early adopters and the innovator and the evolving elements of value which emerge from the association. The data also provides insights into how information about the characteristics of an innovation can be interpreted to demonstrate value for the customer, and then used for communications purposes. This is a novel addition to diffusion literature in that this work articulates different ways in which early adopters can contribute not only to the technical innovation but also the development of leverage points used in communications.

The time-span of data collection has shown the learning experience of the company, including the translation of the characteristics offered by the innovation into perceived usefulness to the customer, and their relation to social-psychological constructs. This has helped the innovative company leverage a move towards 3D growing and the path towards sustainable intensification in a market economy.

The study illustrates the ability of an entrepreneur/innovator to morph into an effective communicator and opinion leader and create a multifactorial communications strategy. The journey of learning which such an enterprise undertakes could be used as a guide for other innovative enterprises in the agri-tech sector.

Chapter 7 Exploring the business model and its links with sustainability in the context of three-dimensional farming

7.1 Introduction

Through my Literature Review I have found that current literature on sustainable intensification and diffusion of innovation does not make the business case for sustainability. This detected gap is important because food production takes take place in a market economy, hence there is a need to determine how value is determined in this context. In particular, there is a need for better understanding of the significance of value in this empirical context beyond theoretical applications.

This chapter explains how value is generated and communicated to customers via the Saturn Bioponics business model, and how it identifies and 'sells' the business case for the sustainability dimension, and the extent to which this is or is not made explicit in the value offering. It draws on the concept of the business model which, as set out in the Chapter 2, is generally considered to be concerned with creating value for its customers, and value for itself, in terms of revenue (Morris et al., 2005), but can also consider societal or environmental value. This study builds understanding of the business model within the specific commercial context of the companies in the 3D value chain, to fill the gap from what is missing from the literature on sustainable intensification and also on diffusion of innovation.

The objective was to determine the business model being used by this company over the seven years covered by the study, its evolution and the relationship with sustainability as one of its core concepts to better understand the business function in the 3D indoor farming sector. The aim was also to build understanding of on factors influencing its success and assess whether more could be done to encourage adoption through the business model.

Influenced by business model thinking, the questions addressed in this chapter are:

a. How does the firm create value?
b. For whom is the value created?
c. What is the firm's economic model and what are its business aims?
d. How does the business model express the purpose of the company in the context of sustainable intensification?
e. What can we learn about the way in which sustainable value is generated in this context?

Traditionally, it was considered that the role of an enterprise was to maximise profit for the shareholders while the government controlled environmental and societal issues through legislation (Haigh and Hoffman, 2012). However, over the past few decades, the importance of societal values, including sustainability issues, have become more prominent among both enterprise owners and customers (Haigh and Hoffman, 2012, Haigh et al., 2015, Santos et al., 2015, Davies and Doherty, 2019). As a result, Schumperterian disruption (Schumpeter, 1934) may already be taking place if sustainable innovations disrupt conventional products and services in response to rising demand from a change in the perception of 'value' or 'utility', thus it is important to understand where actors may perceive 'value' to be, and its different iterations. The importance of sustainability may vary between companies, and when considered in the context of business models it may only be an after-thought (Schaltegger et al., 2012b) or even a 'spillover' – an unrelated but beneficial activity from commercial activities (Davies and Doherty, 2019, Santos et al., 2015). Research indicates there may be potential for hybrid business model reflecting value from both environmental spillover and commercial activities, although (Davies and Doherty, 2019), writing about lessons learned by Cafedirect, suggest that ethical marketing activities may not lead to market expansion.

Social improvements such as environmental benefits are often seen as constraints to economic performance, yet work undertaken by Porter and Kramer (2011) found that not undertaking such improvements could also create internal costs for companies; arguing that the way to address this is through 'shared value'. They define value as "benefits relative to costs" (Porter and Kramer, 2011 p6) and assert that its aim is to "enhance competitiveness while simultaneously advancing economic and social conditions in the community in which it operates" (Porter and Kramer, 2011 p6).

From these studies I have concluded that sustainability may not always be valued equally within the supply chain, or that it may mean different things at different points, which may influence the path towards sustainable intensification and food security. This chapter explores the evolution of a small business within its market context to better understand the conditions needed for enterprises to make a contribution towards sustainable outcomes.

7.2 Business model concept and entrepreneurism

The Business Model concept has only been considered as a key area for businesses since the 1990s (Morris et al., 2005), and its recent history is reviewed in the Literature Review. The business model is a "structured management tool" (Wirtz et al., 2016 p36) to organise the value creation of a company and to secure profits. The concept may be divided into constituent parts, and Osterwalder et al. (2005) identified components, synthesising them into building blocks. Barth (2017) has drawn on these concepts to create a framework to examine sustainability in the agricultural sector, forming a useful basis to explore the sub-sector of 3D farming. While entrepreneurship is featured in the framework used by Barth et al. (2017), there is little on the role of an innovator/entrepreneur/ecopreneur in a sustainable business model; such a person will have a dominant influence on the business model in a small start-up agri-tech company. This suggests space in literature to build more understanding in this context.

To address this, it has been useful to draw on agricultural economics theory developed by Knudson et al. (2004) on degrees of entrepreneurship/innovativeness, particularly when looking at business models in micro-companies. Given the sustainability focus of the study, and to gain insights into how the innovator/entrepreneur uses ethics and business know-how to drive the business model's interaction with sustainability, there is a need to look further into entrepreneurial attitudes. According to Schaltegger and Wagner (2011), ecopreneurs have a focus on environmental performance while aiming at a large market share in a particular sector, but tend to be more entrepreneurial than innovative. Bringing these different characteristics into a matrix provided a way to look inside the business model and the key role of the entrepreneur and their ability to generate value which will help to better understand the business model's interaction with sustainability.

In this chapter the business model is focused on identifying the perceived value of targeted customers and how the company has worked to create an innovative product for which they perceive value while maintaining its sustainability principles. The innovation may be the value proposition of the company and is referred to by Morris (2006) as being crucial to a business model because it can form a platform around which different elements are combined. This is discussed in more detail in Chapter 2.

Table 20 below portrays some of the building blocks of a business model identified by different academics working across organisation theory, technology and strategic orientation. The table shows that most of these reflect the same basic concepts, and although there are some nuanced differences; for example while Morris has used broad components comprising strategic and operational, others use more targeted elements such as 'value proposition' and 'customer relationships'. Building blocks have proved useful in generating understanding of the business model used by a company selling 3D equipment for growing fruit and vegetables and its connection with sustainable intensification, but one of the limitations has been the difficulty separating the values of each and the effects of market forces to understand the factors promoting or limiting the success of a particular model.

To address these constraints, this study has followed the development of a business model over time, which has subsequently facilitated critical analysis of incremental changes made by the company in response to their customers and the market. Through this critical analysis, the chapter demonstrates how the business model interacts with sustainability and the conditions under which more sustainable outcomes may be achieved.

Table 20 Building blocks of business models identified by academics

<table>
<tr><td>Author(s)</td><td>Morris
(2005)</td><td>Osterwalder (2005) Doganova (2009), Boons (2013)</td><td>Barth(2017)</td><td>Schaltegger (2016)</td></tr>
<tr><td>Building blocks</td><td>Strategic</td><td>Value proposition</td><td>Value proposition</td><td>Value proposition</td></tr>
<tr><td rowspan="3"></td><td rowspan="2">Operational</td><td>Customer interface</td><td>Value creation and delivery</td><td>Customer relationships</td></tr>
<tr><td>Supply chain management</td><td>Value capture</td><td>Business infrastructure</td></tr>
<tr><td>Economic</td><td>Financial model</td><td>Value intentions</td><td>Financial aspects</td></tr>
</table>

Source: Morris (2005), Osterwalder (2005) Doganova (2009), Boons (2013) Barth(2017), Schaltegger (2016)

Understanding the role of sustainability in the business model is challenging because it does not necessarily offer the company – or the client – immediate benefits. Sustainability may be fundamentally important to customers as a result of eco-efficiencies, the regulatory environment or because of ethical policies. As the case study company is promoting sustainable intensification, it is important to understand the implications of the business model on the key features of the business model that may promote sustainable intensification.

The skills necessary for innovation, business operations and communications may be very different and are discussed in more detail in the Business Models section of the Literature Review, Section 2.5. As noted above, Knudson (2004) argues that the bonds between entrepreneurs and innovation depend on entrepreneurial abilities, attitude and business drive, determining different levels of entrepreneurship compared with innovation.

Table 21 below builds on Knudson's (2004) depiction of the characteristics of entrepreneurs and their subsequent dominance of the drive for innovations or entrepreneurship by including the main characteristics of ecopreneurs observed by Schaltegger and Wagner (2011). These observed traits have been found useful but the weakness in these frameworks is that they are static, whereas the degree of entrepreneurship or innovation may fluctuate according to reactions to market conditions at any one time. This can impact on interactions with other key players, particularly if the business is new, nimble and agile. In this study, these fluctuations over time are addressed by its longitudinal design, following a start-up company for seven years. This has helped to drive better understanding of the influence of the entrepreneur/innovator in delivering more sustainable outcomes for businesses in the new 3D sector.

Table 21 Levels of entrepreneurship and innovative drive and the corresponding ecopreneur/sustainable entrepreneur characteristics

Type of entrepreneur	Drive to market produce	Characteristics
Master entrepreneur	Dominant business drive	A person who is good at risk-taking and takes an innovation created by someone else to market – e.g. someone who takes a vertical farming equipment innovation to market
Innovative entrepreneur	Entrepreneurial attitude is secondary to innovation	A person who combines both innovative and entrepreneurial skills, thus is able to market their own innovation, such as vertical farming equipment
Entrepreneurial innovator	Entrepreneurial attitude is less important than innovation	Constantly develops processes and adapting the innovation to customer demands to ensure successful diffusion of the innovation and marketing. Innovator and entrepreneur can be the same person

Type of entrepreneur	Drive to market produce	Characteristics
Master innovator	Innovation is the dominant factor	Highly skilled innovator but without the entrepreneurial ability to take it to market
Ecopreneur/sustainable entrepreneur	Economic ends are the most important but incorporate the environment as a core element of the business	The ability to earn money while solving environmental problems. Ability to foresee future challenges and assesses environmental performance, devising technology to address the environmental problem

Source: Adapted by author, based on Knudson et al. (2004),Schaltegger and Wagner (2011) Filser et al. (2019)

The business model building blocks in Table 20, together with the entrepreneurial characteristics in Table 21 have created a base on which to produce a narrative to conceptualise the value-based venture and the relationship with environmental sustainability as seen in Table 24 below. As observations were made over time it has a dynamic element, rather than being a static view of one moment in time. This has facilitated understanding of how management of a sustainability element has evolved as well as any adjustments to the value proposition in response to customer needs and demand.

7.3 Material and methods

This section details of the construction of the framework for this chapter to answer the principal Business Model questions. The reasons for the choice of case study, methods of reduction and analysis used for this thesis are discussed in detail in the Chapter 4.

7.4 Framework

Due to the diverse, often contradictory, and sometimes highly specific business model literature, the building blocks identified by Osterwalder, supplemented by ideas from Barth who adapted these to bring in sustainability, have been key to putting together a coherent framework. The analysis has been structured by drawing on the understanding of the business model blocks developed in literature by Barth et al. (2017), with input from the works of Osterwalder and Pigneur (2010), Knudson et al. (2004), Parnell et al. (2018), Morris et al. (2006), Amit and Zott (2012) and (Yang et al., 2017). The benefit of the building block analogy is that it lends itself to coding for analysis, but a weakness is that it does not lend itself to sub-themes such as agri-food specific business, or the dynamics of evolution of a business model, hence the need to include the considerations seen in Table 22. Another of the limitations of these literatures is the failure to include the influence of the entrepreneurs in small companies, so to address this, the framework for analysis for this study include ideas based on aspects of innovation and the entrepreneur as depicted by Knudson et al. (2004), plus sustainable entrepreneurism and ecopreneurism, as depicted by Schaltegger and Wagner (2011) and seen in Table 21 above. These components of the framework helped build understanding of entrepreneurial awareness of the business model and how it may affect the value chain as observed by Parnell et al. (2018).

One of the challenges of looking at business models is that they often only show one moment in time, and it is difficult to map the dynamism as they adapt to market conditions; sometimes these changes overlap. Entrepreneurial attitudes may also change during this time in response to events, affecting the development of the business model and its relationship with sustainability; for example, Davies and Doherty (2019) observed an increasing sustainability focus for Cafedirect with a result that greatly reduced sales and sparked a refocus of its business model. This study has followed its main case study over a seven-year period and has observed changes in the model, some of which may have affected the market segment and value proposition.

Table 22 below, shows the conceptual framework developed for the study and has been designed to drive better understanding of the context, in particular the role of the entrepreneur/innovator in driving the model. It provides a way of bringing together the building blocks of a business model together with those for sustainable practices, entrepreneurialism and innovation. The building block detailed below formed the starting point for categories for coding and qualitative analysis through coding the data, making it easier to understand the complexities of the business model.

Table 22 Conceptual framework, key questions for innovation and sustainability and other considerations

Building Blocks	Description	Key questions for degree of Innovation	Key questions for sustainability	Key questions for ecopreneurial role	Other considerations
Value proposition	Product/Service, customer segments, and relationships	Does it offer 'more of the same' transforming old products into more sustainable ones, or something new to the firm/world? Is it targeting existing or new markets?	Do the product/service customer segments, and relationships enhance sustainability? For example, does it include eco-efficiencies? Does the customer pay a premium for eco-services?	What is the entrepreneur/innovator's recognition of the problem? What is the commitment to sustainability ? What processes have been undertaken to ensure an eco-friendly outcome from the product?	Schaltegger (2016) asks whether integrated sustainability is expressly included Doganova (2009) suggests the importance of sources of value creation and delivery of this value to customers, noting the influence of where it is situated in the value chain Osterwalder (2010) suggests innovative business models may adopt different formats to fit different audiences

Building Blocks	Description	Key questions for degree of Innovation	Key questions for sustainability	Key questions for ecopreneurial role	Other considerations
Value creation and delivery	Key activities, resources, channels, partners, and technologies	Improvements of existing channels or new relationships? Familiar (fixed) networks or new (dynamic) networks (e.g., alliances, joint ventures)? Improvements of existing technologies or new emerging technologies?	Do key activities, resources, channels, partners, and technologies focus on sustainability aspects? For example, ecological sustainability, social justice, and animal welfare	On perception of problem, how does the ecopreneur create the means to address the problem (for the customer and the environment)?	Amit and Zott (2012) use complementary activities, bundles of activities Customer retention Morris (2006) highlights the importance of positioning in the supply chain

Building Blocks	**Description**	**Key questions for degree of Innovation**	**Key questions for sustainability**	**Key questions for ecopreneurial role**	**Other considerations**
Value capture	Cost structure and revenue streams	Incremental cost cutting in existing processes or new processes that generate revenues?	Do cost structures and revenue streams include sustainability considerations? For example, eco-efficiencies within sustainable food systems based on eco-environmental, social, and economic aspects	How does the product generate economic benefits for the company and capture environmental benefits?	Yang et al. (2017) The benefits of seeking out as-yet uncaptured value Inter-connectedness of value and value assigned to each of the different aspects
Value intention	Mind-set of owner-manager	Attitudes to change and innovation	Is sustainability a means, a goal, or something else? Is sustainability enhancing or limiting the BM?	Knudson (2004): Degree of entrepreneurship/innovativeness	Parnell and Stone (2018): How leaders manage their business models using information Schaltegger and Wagner (2011): Ecopreneurial considerations

So using the building block approach to understanding the business model, this study explores one individual node of the food supply chain, between the innovator (Saturn Bioponics) and the customer who then uses the hardware and corresponding software to grow vegetables which are then sold to processors and packers. The data collection methods and analysis used for studying the business model are discussed in more detail in Chapter 4.

7.5 Findings

This sector follows the evolution of the business model aim of the case study company over seven years, including key resources, innovation, economic model and the relationship with sustainable intensification.

7.5.1 Timeline of the business model – the sequence of events and adaptation

The company was founded in 2011, and has developed through distinct stages of evolution in relation to the value offering, which in turn has driven the customer segments targeted by the company (see Table 23 below). However, although these are shown as time-defined, periods of overlap occurred as the innovation was fine-tuned and the business networks have grown (for more about networks see Chapter 6, Diffusion of Innovation).

The company has been built around the Saturn Grower, its innovative tower system for growing fresh fruit and vegetables described in Chapter 3. The aim of the business has always been targeted to providing commercial growers in the protected crop sector (cultivating in greenhouses and polytunnels) with a way of growing which would help them to minimise inputs while increasing outputs. The development of the modular hardware and the corresponding software (hydroponic science) took over five years to build and test. Support, through funding from Innovate UK, proved crucial by providing the company with funds to develop its innovation to a market-ready stage and is related in more detail in Chapter 3. In 2014 two people worked in the business, the owner and a biologist, and the plan was for "the company to become commercially viable towards the end of 2014, selling their technology to various subsectors of the horticultural industry, such as strawberry and leafy green producers" (CEO, 24 June 2014, Ref: SB01).

A clear distinction between Saturn Bioponics and vertical/urban farming enterprises, has developed which is partly driven by the different markets for the output of vertical farming, the scale of production and possibly by the company's management objectives. Saturn Bioponics has exploited this difference by distinguishing itself from this confusion of vertical/urban farming and in 2016 changed the terminology it used from vertical farming to ‘3D’ or ‘three-dimensional’ (CEO, 20 February 2017, Ref: VFC3). This new terminology is more accurate as vertical farming suggests just growing on the vertical plane, whereas 3D farming implies that crop production is on both horizontal and vertical planes. The company considered its value offering to be totally different from urban farming, as it is undertaken in a different market consisting of professional, commercial fruit and vegetable growers who have established supply chains. Underground farming was dismissed as not being a competitor because of the high energy costs (CEO, 21 November 2018, Ref: SB25). Similar views were expressed by Tom Webster (Harper Adams Conference, Ref: HA02) who found the value offering possible from such enterprises (micro-greens) to be of limited interest in a small niche market consisting mainly of up-market restaurants. These factors influenced the rationale for choosing to analyse a company which has broader scope for commercial success.

Table 23 below tracks the development of the company, dividing it into four key stages. The towers are depicted as hardware, whereas the hydroponic agronomy knowledge needed for growing the crop is known as hydroponic science (also explained in Chapter 3) is considered as being comparable to software, and these comprise the key value offering for customers. Stage one is the early development stage, and driven very much by the motivation of the ecopreneur and innovator of Saturn Bioponics to provide a means of growing food with minimum cost to the environment. The business moves into trials with early adopters from 2015, which may have been partly driven by the recruitment of a hydroponic specialist who has been able to develop this specialism. This was a major milestone (Ref: SB24) as it broadened the value offering and facilitated the move to the second stage.

Increased contact with early adopters provided important input into the value of the innovation, yielding information and feedback for innovative development of value that provided enhanced solutions from better perception of their customers’ problems. These findings are similar to those by Tolkamp et al. (2018) when looking at user centred business model designs in the energy sector. The close contact with some of the early adopters continued into the marketing phase of the business model discussed in more detail in Chapter 6. Development of such relationships played a key role in defining the business model of Saturn Bioponics, and were notable where a supplementary value offering in the form of hydroponic consultancy was created. The partnership with early adopters, which is depicted in Table 23 as Stage Two of the company’s development, is explored in more detail below in section 7.5.5.

The success or limitations of the Saturn Bioponics business model to provide perceived value to customers can be observed from Stage Three (see Table 23, below), when the product is taken to market. From this stage, the company has been seen to develop within a niche for indoor production of fruit and vegetables, following an experiential path as it discovers where best to target its potential customers at national and international levels (see Chapter 6).

Alongside the value creation, Table 23 also charts the focus of environmental aims and measures which subsequently form part of the business case. It starts with value opportunities in stages One and Two, and then as the value offering of Saturn Bioponics matures, there are a number of micro-environmental values which can be added together and thus can create a wider effect. Purchasers of the complete package from Saturn Bioponics benefit from the eco-efficiencies whether or not they are trying to improve their environmental footprint, but the land-saving concept needs more proactive engagement from the purchaser to take effect.

Table 23 Development stages of the company between 2011 and 2020

Value offering	Pre-company stage	Stage One		Stage Two	Stage Three	Stage Four
	2010	2011	2014	2016	2018	2019-2020
Hardware 'Saturn Grower'	Market opportunity for high density growing	Development of the Saturn Grower prototype	Research trials	Trials with growers Market sales	Market sales	Growth in sales
Environmental aspect	Perception of need to produce more food with less environmental damage	Concept of higher density planting leaving more area for environmental services	Development of elements connected with eco-efficiency	Refinement of agronomic inputs and knowledge to reduce waste	Initial market growth in environmental benefits within a niche	
Hydroponic science	n/a	Initial development	Further development	Initial sales	Growth in sales	Growth in sales
Number of employees	n/a	1	1	3	3	4

Source: Interviews with Saturn Bioponics (SB01, SB04, SB05, SB17, SB18, SB21, SB25, SB28)

7.5.2 Key resources and activities

One of the key resources is the entrepreneur and CEO, Alex Fisher, who is the original innovator and who directs the firm. Prior to establishing the company, in 2010 he saw a market opportunity for growing fruit and vegetables using the vertical dimension as well as the horizontal in the protected (indoor) crop market. He then drove to devise and commercialise a product which would not only promote better quality and yields but also minimise damage to the environment and thus be sustainable. This needed technical resource and capability, which developed into better understanding of agronomic strategy for hydroponic (soilless) crop growing, which has a wider reach across different sectors and is not limited only to vertical farming. "It is about me, and where we put our energy and resources" (CEO, 22 November 2018, Ref: SB24). The evolution of the company is about his vision as an entrepreneur/ecopreneur/innovator, his determination to guide the company towards producing food within a more sustainable environment, and those who have decided to accompany him on the journey. It provides a context-rich detail on how a start-up company can contribute towards sustainable intensification. Understanding this case has enabled me to identify some of the conditions influencing business success which may also help other start-ups plan their development either in this sector or similar sectors.

Self-described as 'an opportunist' (Ref: SB21, SB24, SB25), the CEO's characteristics appear to fluctuate between being an 'innovative entrepreneur' and an 'entrepreneurial innovator' as depicted by Knudson (2004 p1333) and also ecopreneur, depending on the circumstances. By following a longitudinal model it has been possible to observe different iterations of how he has adapted his stance to successfully innovate and market his own innovation, creating and building a company around it. For example, it was as an ecopreneur that Alex Fisher, CEO of Saturn Bioponics, first perceived a need to produce more food without damaging the environment, and this developed into an entrepreneur who perceived a market opportunity for 3D farming, and took that forward as an innovator. Once the initial format of this value offering had been designed, the need was to build a network of early adopters who would help to refine and ensure it would effectively provide value to growers, which was arguably entrepreneurial innovator activity. As the business model developed, nuanced oscillations between the characteristics of innovator, ecopreneur and entrepreneur were observed, particularly when evolutions such as joint ventures were assessed and adopted or rejected. These reflect the idea of value opportunities, which either evolve into value capture or are dismissed.

This ability to interpret the situation and create value either from further innovation or exploitation is a key characteristic of the CEO of Saturn Bioponics. In many cases, innovations are given to a third party entrepreneur to exploit rather than the innovator marketing their own innovations, as is discussed in Chapter 6. From a business model point of view, how the company is run also affects governance, as the innovation is developed and adapted according to the concepts laid down by the CEO. In the case of the privately-owned Saturn Bioponics, governance is centred around the CEO who drives the company's sustainability policy with a theme of about 'producing more with less' (CEO Saturn Bioponics Ref: SB05) and the corresponding eco-efficiencies.

The company's resources include physical and intellectual aspects of the CEO and staff. These range from those who are involved in production design and delivery, technical understanding of how to grow certain fruit and vegetables in a high-density system, with understanding of how and when to apply nutrition. These emerge as crucial resources and are perceived as valuable by customers. Other resources are competence in business administration and marketing activities involving diffusion of innovation.

New employees bring their own skills and expertise and add to the firm's internal resources in the quest to build perceived value throughout the company's networks. By instigating division of labour, the company is following classic Organisation Theory (Chakrabarti and Hauschildt, 1989) in its response to growth. During the first innovation process, there was one employee with technical understanding of biology, working alongside the entrepreneur. The second phase was refining the innovation and ensuring it provided a solution to customer problems, with a hydroponic specialist and early adopters (who were not employees but who worked closely with the company). The newer recruits work alongside the technical sales manager, who has been tasked with increasing sales, to ensure continuation of the link between the value proposition, the customer, and the value realised for the company through sales. The element of value is seen in Figure 12 below to remain at the nucleus of the organisation, as the innovation is built around specialist expertise. The newer members of staff have a supporting role; for example a supply chain manager works to ensure smoothness of the transactions, so that customers and innovators receive the parts they need, while ensuring the 'green' status of the operation. This shows a movement of the start-up company towards process and service as it matures. Figure 12, below, illustrates the innovator and technical developers of the Saturn Grower and the hydroponic consultancy as being at the heart of the value proposition. Management of the supply chain feeds in to this by building relations to ensure the smooth running of the supplies, focusing on the environment and the customer.

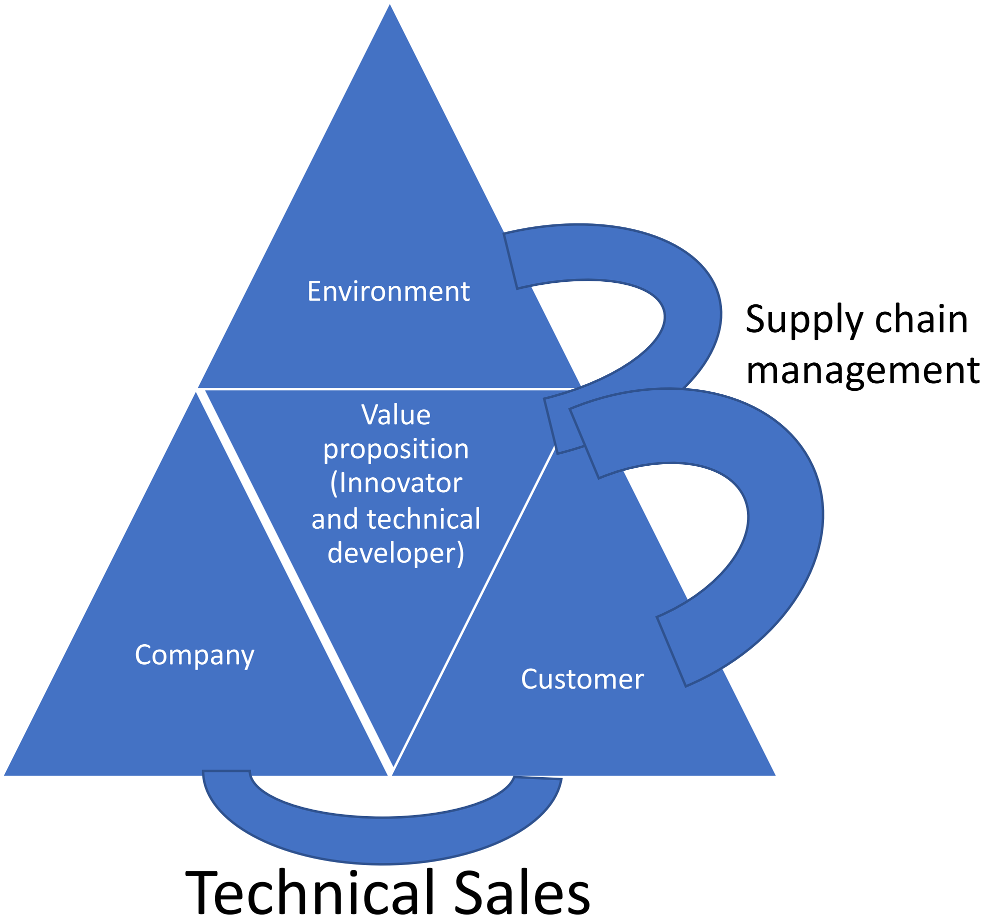

Figure 12 Organisational development of Saturn Bioponics

Some of company's resources have been derived from external sources, as it won grants from KTN and Innovate UK which enabled it to focus on R&D for five years before approaching the market. This permitted the entrepreneur to develop the Saturn Grower and also recruit early adopters who helped to refine the innovation (see Chapter 6) and helped the entrepreneur better understand the players further down the supply chain, such as packers, processors and retailers to understand the customer's customer needs and specifications. This has been an iterative process which has resulted in ongoing innovation of the business model as it constantly adapts as networks of potential customers are developed to ensure the value offering is the right one within the context of the market at that particular time.

7.5.3 Creation of the innovation and the driving role of the innovator/entrepreneur

Financial resources and support proved crucial while the Saturn Grower was being designed and the company was building its agronomic expertise. These commenced in 2012 after winning an Innovate UK For Growth competition, from which the company received £25,000 to develop an initial prototype. Following on from this, in 2013, Saturn Bioponics secured further grants which allowed them to explore how the innovation could be modified to enhance the production of yield, health and quality of plants. The CEO Saturn Bioponics said: “We also conducted a lot of research around different substrates, different nutrients, and were able to engage farmers and potential end-customers about the technology” (Ref: GOV2). This demonstrates that the company, while testing technical feasibility and the ability to produce the technical product, also tested desirability and whether the potential customers wanted the product. It also highlights one of the intersections with Chapter 6, where the benefits of involving early adopters before an innovation is complete are discussed.

Consideration was given to demand for the innovation and customer willingness to pay for sustainability aspects. Discussions showed little interest from customers for environmental considerations beyond those which are required by regulation, (Ref: SB05), hence the need for the innovation to be sold at a competitive price and offer comparable or more benefits than other systems of growing. This highlights how the company listened and reacted to customer perceptions of what constitutes the potential value of the innovation, possibly because of the consequential implications for the viability of its business model. The company’s response to this challenge was to innovate to deliver eco-efficiencies which benefit both grower and the environment in different ways. This included reducing inputs to provide “a safe food supply with lower chemical inputs” (CEO Saturn Bioponics Ref: SB05) from a nutrient supply applied with precision technology, improving phytosanitary standards to reduce waste, and providing the growers with improved crop quality and yields. This illustrates the interplay between the different characteristics of entrepreneur, ecopreneur and innovator, in the determination to create a value offering which is valued by the customer.

The company has demonstrated a positive approach towards continuous innovation, with “more research and refining” as a key objective (Alex Fisher, Ref: SB24), implying it is seeking to increase its value to customers and deliver revenue to Saturn Bioponics. Ongoing innovation has also played a key role in developing a software system to operate the hydroponics remotely. This has a number of benefits;

protecting the company's technical knowledge while delivering high quality crops and delivering the services by a more cost-effective means. This is because working remotely saves time as there is less need to visit the customers' premises (Ref: SB27), and therefore reduces company expense. Innovation is a continuous process, and customers currently walk the crops to assess crop health, combining automation with hydroponics is under consideration, and "future innovation may enable the company to do so remotely using cameras" (Ref: SB28). Such an approach is closely linked with the attitude of the CEO and major shareholder Alex Fisher, an opportunist (Ref: SB21, SB24, SB25) who oscillates between innovator and entrepreneur as determined by Knudson et al. (2004). Here he is using his ability for innovation to drive entrepreneurial benefits in the form of value captured. Undertaking a longitudinal study observation over time has revealed how the CEO interprets a given situation and reacts to secure value, either from technical development or commercial exploitation. These twin characteristics, together with the agility of a small company to react to different circumstances and opportunities, are arguably the key drivers of Saturn Bioponics' commercial success to date. At times business appears to have been taking place in parallel to his ecopreneurial characteristics, and actions to benefit the environment have often been realised under the radar of the marketed value proposition. While literature suggests that innovators are not necessarily entrepreneurs or ecopreneurs (Knudson et al., 2004, Schaltegger and Wagner, 2011), this personal ability to move between the three categories could be one of the contributing factors to the evolution of this business model and its approach to creating value.

7.5.3.1 Degree of Innovation

The main innovation is based around technology; the Saturn Grower and the hydroponic science technology have built on already-established technology to make it more effective at providing the best possible conditions for crop yield and quality. It started with hardware, but, reacting to market perceptions, the company has evolved its value creation and the hydroponic science has now become an important focus as a consultancy service, attracting customers across different continents, including Europe, Asia and even Africa.

The company remains willing to continue to adapt its value offering and innovate for clients according to market demands, therefore maintaining a dynamic, innovation-based aspect to its business model. "If it is hydroponic science, we would consider any new work" – (CEO, 21 November 2018, Ref: SB25). This focus was corroborated at Agri-Tech East in which a presentation by Saturn Bioponics introduced the company as a hydroponics specialist, rather than a vertical (or 3D) farming company (Ref: AG01), showing the ability of the company to metamorphose its key competence according to what it believes the customer will value.

7.5.4 How does the company create value?

Saturn Bioponics creates value by providing its customers, growers of fruit and vegetables produced in polytunnels and greenhouses, with a method of "Growing tasty food which is provides a sustainable and safe food supply with fewer chemicals" (CEO, Saturn Bioponics,12 April 2016, Ref: SB05) with higher yields (see Chapter 5). This value is created by three means of enhancing crop productivity for its customers: sales of 'hardware' (the innovation that is the Saturn Grower, 'consumables' (crop nutrition) and 'software' (consultancy on hydroponic science, the knowledge of agronomy for growing the crops hydroponically).

Customer needs are perceived to be crucial to the value creation, and the company makes use of its technical expertise and small size to be agile and respond to what it learns that customers perceive as value. This has been evident since its conception where "work was slow at the beginning to get things right for the growers and the environment" (CEO, 12 April 2016, Ref: SB05). There are a number of references made by practitioners concerning the tight profit margins of fresh produce growers in the UK. This is corroborated by Farm Business Consultants Andersons who estimate that in the vegetable sector, profits are under two per cent of turnover (Andersons Outlook Ref: FIN1). Thus, liquidity and profitability are major factors in decisions on uptake or rejection of new technology.

There are indications that the company is aware of these difficulties in achieving profitability in the agricultural industry, and this is why the value offering has been aimed at helping them achieve better financial sustainability and profitability. This can be done by providing the means to deliver higher commercial yields with a crop that is of uniform size and quality (which reduces the amount of crop rejected by the next node in the supply chain, in this case, packers or processors). To that end, the company recruited early adopters to help fine-tune the growing methods and ensure it was able to achieve these criteria at a commercial level, and hence of value to other potential customers. Costs of production are also perceived to be important to the company to achieve a sustainable profit margin both for Saturn Bioponics and its customers. However, the time needed for technical development of the value offering needs both time and finance. This is where innovative micro-companies could flounder if not supported by start-up incubators, such as Innovate UK (Ref: WW03), in their early stages while they have low income sources.

7.5.4.1 Processes used for sustainability considerations

For Saturn Bioponics, sustainability is considered in commercial terms, as growers need to be economically sustainable to be able to maintain ecological sustainability, and hence the idea of helping growers to increase their yield per hectare by growing vertically as well as horizontally (Saturn Bioponics Meeting 24 June 201, Ref: SB01). However, unless individual actions for sustainability are considered (such as those considered eco-efficiencies), as documented in Chapter 5, an overall sustainability element of the value creation is difficult to ascertain at macro-level, as they can be more than the sum of the micro-efficiencies. This is because while sustainability is central to the company's *modus operandi,* it is not marketed directly to the customers except as a means of making business more efficient by using crop nutrients more precisely to improve yields while reducing waste, creating eco-efficiencies that are perceived as delivering value.

The importance of eco-efficiencies was highlighted by one of the early adopters as being important to the business. Nick Mauro, director of Valefresco, said: "We are producing nearly 100 per cent clean, saleable crop year round and doing our best to keep it completely chemical free. We sell to some of the UK's biggest processors and retailers and they absolutely love it – in fact we're negotiating a new contract off the back of it. We are looking at rolling it out for all our pak choi production and are trialling it for our premium lettuce too. We are really happy with the payback figures; it makes the investment much more attractive" (Valefresco, 3 March 2017, Ref: SB13). Although this is mainly an economic decision made because of quality considerations of the fresh produce, because of the embedded sustainability aspect of this method of growing, this is an important step which can lead to expansion of the business and the resulting impact on sustainability and the environment.

Table 24 below explores how Saturn Bioponics positions its value offering to the customer needs and demands, and charts potential environmental benefits from the use of the 3D growing system, with direct and indirect benefits for customers.

Table 24 Positioning the proposition from the customer perspective, direct and indirect benefits

	Customer perspective	Direct customer benefit (value) from using Saturn Grower	Environmental perspective	Indirect customer benefit/Eco efficiency environmental benefits
What problem needs solving?	If grown outdoors, yields at risk from climate and inconsistent fruit/vegetable quality due to weather, pests and disease. If grown indoors crops not achieving potential yields without increasing the growing area	N/A	Increased land use for growing food crops Outdoor growing: Threat of leaching nutrients and plant protection products Products grown using valuable resources wasted if damaged by pests/disease/weather	N/A

	Customer perspective	**Direct customer benefit (value) from using Saturn Grower**	**Environmental perspective**	**Indirect customer benefit/Eco efficiency environmental benefits**
What are the bundles of activity:	Sales of hardware, consumables (nutrition) and hydroponic consultancy Potential turn-key service with distributor of commercial greenhouses	Precision applied nutrition and hydroponic consultancy helps secure yields and quality, and prevents too much being applied, and which therefore affects profits	Precision application of nutrients, so less use of resources	Activities leading to Eco-efficiency

	Customer perspective	Direct customer benefit (value) from using Saturn Grower	Environmental perspective	Indirect customer benefit/Eco efficiency environmental benefits
What is the potential value from use of the innovation?		Potential increase in customer income Higher yields from using the vertical plane, better crop consistency and quality and less waste	Better use of resources resulting in lower waste levels of phosphates/nitrogen	Use of technical innovation to increase produce from a given area of land, using the whole farm perspective as per LEAF*, can give more land over to environmental services (weak sustainability) Reduction in crop waste, leaching of fertiliser/plant protection products into the wider environment, with corresponding savings on inputs

	Customer perspective	**Direct customer benefit (value) from using Saturn Grower**	**Environmental perspective**	**Indirect customer benefit/Eco efficiency environmental benefits**
What value does the company deliver?	Multi-sided, creates value in two main areas; hydroponic science and the Saturn Grower hardware. Service based consultancy, with targeted and timely use of nutrients and crop protection products; optimising customers' costs of production	Yield Input cost optimisation Quality and reliability (consistency) Lower maximum residue limits (MRLs) Ease of planting/harvesting	Optimum use of resources creating less waste Quality of produce resulting in less commercial rejections and less waste	Reduced probability of leaching of plant protection and nutrient products not taken up by the plant into the environment (important for legal reasons)

*See Chapter 5, Sustainable Intensification

Source: Data collected by author

As fresh produce such as that grown using this method is near-market (unlike, for example, flour from wheat), sensitivity to maximum residue levels (MRLs) of chemical plant protection products is much higher (CEO LEAF, Ref: OB01). While there are legal limits on chemical residues, retailers tend to specify lower chemical inputs (see Chapter 3). Supermarkets and processors have high expectations of quality and there are a number of Food Assurance audited certification schemes which growers have to comply with, depending on their contract. According to Valefresco director Nick Mauro: “There are 10-12 inspections each year for the different schemes; these schemes are 80 per cent the same but each customer wants an individual inspection” (Ref: SB20).

There is another element to how the company treats sustainability: through Innovate UK there is a policy of supporting and incubating sustainable projects in the agricultural sector, so the sustainability element of the Saturn Bioponics business model has been used when applying for grants (Ref: GOV 2). This demonstrates the ability of the entrepreneur to adapt the language used according to context.

7.5.4.2 The Value Offering

Value has to be created in two nodes of the supply chain; creating a source of profit for Saturn Bioponics and also one for the customer, so identifying a problem to which growers are seeking a solution is key to ensuring relevance to an innovation. As expressed by their CEO: “You have to find where growers need assistance” (Ref: SB24). The first value offering was through the Saturn Grower, a series of towers which take up to 75 plants per sq.m, with initial marketing messages promoting benefits of yield, quality of the fruit and vegetables produced by this method. This, together with relevant crop nutrition products, was initially planned to be the main source of value (Saturn Bioponics, Ref: SB09), but the longitudinal study has shown how the company’s understanding of customer perceived value evolved and new sources of value were introduced into the model.

From early on in the company, there was understanding that the ultimate aim in business to business sales is to create an opportunity for the customer; “Growers need profitability” (Alex Fisher, 2016, Ref: SB05). These criteria have been evident in the activities undertaken and communications at different events attended by Saturn Bioponics (as examined in chapter 6). In addition, within the concept of the value offering, it is clear that, whilst aiming to be competitive and keeping costs down, good quality products and service form an important part of the value.

The initial value proposition offered by Saturn Bioponics was means of providing reliable quality vegetables and increased yields from the use of the Saturn Grower (hardware) which permits higher density growing of leafy vegetables, plus crop nutrients and hydroponics expertise. This was aimed at fulfilling a perceived gap in the market because “Customers are looking for resilience of leaf, longer shelf-life a more robust plant to better withstand transport; good colour and good taste - there is a market in the UK for tasty vegetables” (Ref: SB05).

The perceived value for the initial customers of Saturn Bioponics, the growers, depends on the impact of the Saturn Grower and the hydroponic system on an array of crop attributes. These include visual aspects of the produce, such as size, colour and dimensions, in addition to providing a form of growing which results in lower waste than crops grown outside or by other traditional greenhouse table-top methods. To ensure that the innovative system was something which would be valued, time was taken over the development of the initial innovation. *“The three dimensional systems developed by Saturn Bioponics has taken five years to get on-farm, as work has been slow at the beginning to get things right for the growers and the environment”* (CEO Saturn Bioponics, Ref: SB05).

The main value of this proposition is the higher yield per sq. m of floor space in a polytunnel/greenhouse (Ref: SBC01) through the exploitation of the vertical plane. Thematic analysis of benefits for growers using the 3D growing system has identified a number of areas in which there are benefits to the business which have parallel benefits for the environment. Table 25 looks at them from a different lens from the perspective of Chapter 5, as it shows the consideration of the business benefits customers can expect to achieve from adoption of the system and parallel environmental gain. These benefits have been summarised from those discussed in Chapter 5, and those highlighted below have been drawn from a number of different sources, including discussions with Saturn Bioponics and Valefresco (Refs: SB01, SB05, SB13), conference speeches (Ref: SBC01) and independent technical articles (Refs AS26b, AS27). From the growers’ perspective these environmental benefits may considered as spillover, but they are of interest to financiers, as commented by CEO Alex Fisher “Sustainability is of huge importance for financiers” (Ref SB01) and also discussed in Section 7.5.7. This implies that although customer demand can be interpreted to have played a key role in the innovation to ensure functionality, the environmental benefits attract a different audience who are also stakeholders in the enterprise. This in turn, suggests the interaction of ecopreneurial characteristics of the CEO with those of innovator as work was undertaken to create a growing system which would appeal to different parts of its stakeholder network.

Table 25 Factors characterising the innovation and their environmental value

Factors	**Perceived opportunity value to customer***	**Economic value to customer**	**Environmental Spillover**
Ease and costs of installation	Not a complex system, can be operated remotely, potential labour benefits	Modules not expensive to install	N/A
Precision nutrient and irrigation applications	Optimising input: output ratio	Cost benefit	Less environmental damage from resource use and less waste
Optimal use of daylight	Optimising free natural resource use	Cost benefit	Lower carbon footprint from not using lighting
Optimal land use	Increased yield per land area of indoor cultivation	Potential increase in productivity and profit	Other parts of the farm can be used to provide environmental services
Crop health and consistency	Higher saleable yield	Less waste, with corresponding impact on profits	Less waste from resources used to grow the crop

Sources: See Appendix I, references AG01, AS 26a, AS27, PR02, and Saturn Bioponics (SB01), adapted by author

The perceived opportunity described by the entrepreneur, when collated with, economic and environmental factors shown in Table 25 above, suggest eco-efficiencies from changing to an alternative system such as the Saturn Grower and its corresponding hydroponic agronomics, and to some extent depend on the previous system which was used by the grower. Nevertheless, making such a move implies potential reduction in environmental damage from growing equivalent amounts of fruit and vegetables in a different system, and therefore illustrates an important interaction of the business model building block of the value offering with the environment.

The value offering has the potential to provide benefits further down the supply chain too (see Figure 13, below) because of its impact on the next stage in the value chain, for example, a packer or processor. For example, if the innovation produces a crop is already clean (i.e. no soil deposits), it takes less time to go through the washing and sorting system and therefore can be popular with packers (Ref: PR02) – which is the next node down in the supply chain. “A premium product is better than a soil-grown crop – or has the ability to be better than it” (Ref: SB05). Such patterns show greater alignment with eco-efficiency. This, together with more uniformity in size (Ref: SB13, implies that food grown in this manner is likely to become popular with processors and packers, as found by Valefresco (Ref: SB13). These characteristics suggest potential for scaling up within the context of indoor horticultural crops, particularly as similar companies and competitors are reporting similar messages. For instance, one vertical farming equipment company reported increasing its business volume with one of the firm’s first customers, and has also contracted to receive produce from a similar system (AgriTechE 2019, Ref: AG01).

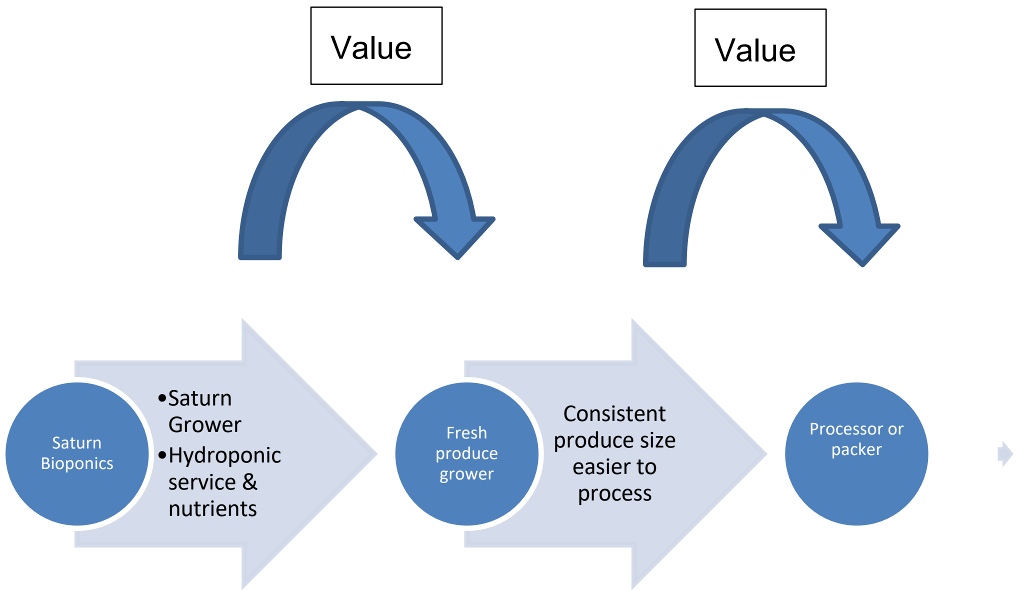

Figure 13 Movement of value through the different stages of the chain

Following a longitudinal approach has facilitated studying the company's response to indications of demand from potential customers over time, and the differing streams of the value offering which has been developed. The company has adapted its value offering, going from selling vertical farming equipment to selling hydroponic expertise which enables the quality of the crops to be enhanced through consultancy (Ref: GOV2). Thus the company has increased its sources of revenue from one-off sales of hardware to combining it with ongoing consultancy which provides software and crop knowhow to ensure the crops achieve the best quality and yield possible. The CEO of Saturn Bioponics specified: “The hardware is just the platform; to provide hydroponic science it does not necessarily have to be our hardware. However to achieve the desired quality and yield result the customer needs to have access to a good-quality hardware platform” (Ref: SB25). This demonstrates the ability of the CEO to adapt the value offering according to the perception of market demand and his interpretation of potential but as yet uncaptured value which may not be immediately visible, and amend the business model accordingly.

7.5.5 For whom is the value created?

This section focuses on the nature and scope of the target market, building understanding of where it sits within the value chain. A learning curve has been detected as decisions were made in response to interest and uptake of its innovation, firstly narrowing its target market and then amplifying it again. These adjustments came from lessons learned about value perception by those who were likely to become customers who would provide revenue for the company. This illustrates the CEO’s innovative and entrepreneurial qualities driving the business model through his ability to perceive how to adapt the innovation to firstly better target the market through the value offering and then broaden it.

In the early iteration of the company, it targeted growers in the UK and other parts of Europe; these were principally growers of fresh fruit and/or vegetables (Farm business award entry, Ref: AW1). The company’s perception of its target market has evolved; in 2015 and 2016 the company considered that “most people are potential customers” (Ref: SB01, SB02, SB03, SB05), which included small customers, and even market gardeners with facilities such as small greenhouses or polytunnels. A decision was made in the second stage of the company to target large commercial growers: “It is not so much the number of sales but the size of the customer which is important” (Saturn Bioponics CEO Alex Fisher, Ref: SB18). A similar view was seen to be held by Tom Webster of Grow-Up, who said at a conference held at Harper Adams University: “To create value there need to be large scale farms… set in a rural location” (Ref: HA02). This reference to large farming enterprises in a rural location is an indication of the importance of targeting commercial businesses dedicated to food production, and observations have underpinned the importance paid by the company to ensuring the value offering yields a competitive advantage or at least is competitive with other methods of growing the same crops. This highlights the combined interaction of the innovator and ecopreneurial characteristics of the CEO in devising a system with mutual benefits to the customer and the environment.

Table 26 Focusing and amplifying market segments for whom the value is created

2012 - 2014	2016	2018	2020 (projected)
Commercial indoor fruit and vegetable growers, market gardeners, anyone with a polytunnel	Commercial indoor fruit and vegetable growers	Commercial indoor fruit and vegetable growers	Commercial indoor fruit and vegetable growers
		Commercial growers using hydroponics	Commercial growers using hydroponics
			Botanical herb purchasers

Source: Author from interviews with Saturn Bioponics

Many indoor systems target either high value low volume crops (such as herbs), which are often labour intensive and difficult to market, or close-to-market high volume leafy greens and salad crops (Ref: NU01), which have a very small target market. While Saturn Bioponics' value offering still targets commercial indoor fruit and vegetable growers, which is a very small and highly specialised sector, the company has also explored the potential of undertaking projects with large multi-nationals cultivating some non-food crops (Saturn Bioponics, Ref: SB18, Ref: SB24, SB25), thereby making potentially broader use of the Saturn Grower to widen the target market, but remaining in the commercial arena rather than selling to consumers.

7.5.5.1 Using indirect target market influence to drive value perception

The company has shown the ability to strategically use other nodes of the supply chain for their ability to drive perceptions of the benefits of the Saturn Grower and the company's hydroponic consultancy to put pressure on their suppliers (See Figure 14 below). This is because benefits are accrued further down the supply chain, and therefore the company has also targeted communications towards groups, packers, processors and even retailers. This is because consistent, clean, good quality produce is faster to process, saving the processor time and waste (Ref: PR02) and provides value in different nodes of the supply chain. The case study company has been using that knowledge to create pressure from on potential purchasers of their system, creating a market-led pull. "Promotion needs to be market led as there are problems with perception of value" (Saturn Bioponics visit, 2 February 2018, Ref: SB18). Therefore, by demonstrating the value offering to processors, and showing how it may benefit their operations, the processor can put its suppliers under pressure to provide fresh produce of the same quality and consistency. However, as yet, such relationships have not been formalised.

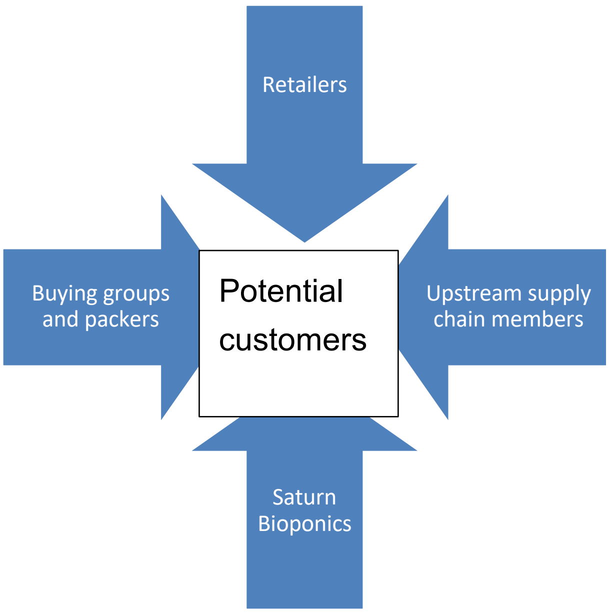

Figure 14 Using influence from up and down the supply chain to help customers perceive value

The motivation for the changes in target markets and the value offering is a reflection of indications of demand from potential customers which help identify a gap in the market that Saturn Bioponics has the potential to fulfil. This appears to be an iterative process, as Saturn Bioponics becomes more familiar with the sector, it is able to benefit from being a micro-company and amend its value offering within a short time frame of a few years.

7.5.6 Evolution of economic aims and revenue streams

Table 28 below highlights the development of the company pre- and post-2016, when the decision to engage a hydroponics specialist was taken; prior to this the economic model was more based on sales of the Saturn Grower. While in the initial stage there was more of a reliance on one-off sales, from 2016 the company separated its revenue streams into single and recurring transactions. For instance, sales of the equipment, the Saturn Grower, are one-off, whereas the sale of nutrients and hydroponics consultancy offer the company a regular revenue stream as on-going customer care. This is because they continue throughout the growing season each year with growers receiving eight days of visits to their site in addition to nutrient and water applications being controlled by computer.

In 2017-2018 the company considered making the consultancy its principal focus: “The main business aim is to create a sustainable profit margin… and the hardware is a platform to deliver hydroponic science” (CEO 22 November 2018, Ref: SB24). This was partly because of its potential to appeal to a broader the target audience to include growers using other hydroponic systems. A decision was taken to continue the main focus on the hardware and in 2019/2020 the hardware remains the most important revenue stream, providing approximately 80 per cent (Ref: SB27). On the other hand, the hydroponics consultancy has remained important because it has provided regular income. The two streams are interlinked because purchasers of the Saturn Grower often use the consultancy service to ensure enhanced crop quality and yields. This is thanks to the growing reputation of the chief technical officer (CTO) in the field of hydroponics whose specialised enhanced understanding of hydroponics has increased its appeal to potential adopters. These developments of the value offering and their contribution to the company’s economic model reflect the entrepreneur’s opportunism as the company continually adapts according to market demands.

Over the time of this study, the company’s attitude towards the environment and sustainability has not changed (see Tables 27-28 below); it remains very much an intrinsic value of the company which is promoted to certain sectors. From Stage Two the company has shown parallel profit and non-profit (environmental) aims of the business model, with profit returns from customer investment in both hardware and consultancy services. Charting sustainability intentions and outcomes, reveals that while outcomes are close to intentions, there is an element of pragmatism as well. This is illustrated in this quote: “We are adapting and dealing with the market as it stands… we are not working in a perfect world” (CEO Saturn Bioponics Ref: SB05). It highlights the entrepreneurial ability of the CEO and his company to modify activities according to need, but at the same time maintaining the sustainability element, which may be considered as spillover from the perspective of the customer whilst remaining a core value for Saturn Bioponics.

Table 27 Building better understanding of Saturn Bioponics pre-2016

Building block	Description	Innovation	Customer benefit	Sustainability intentions
Value proposition	Product/service: Development and sale of Saturn Grower, consumables (crop nutrients) and hydroponic expertise	New growing hardware: the Saturn Grower	Cost effectiveness of fewer inputs, increases in saleable yield from higher density growing	Intentions to innovate to create eco-efficiency benefits from fewer inputs (water, fertiliser, crop protection products); reduced crop waste
Value creation and delivery	Activities: Assistance with set-up and delivery of agronomic assistance	Use of the Saturn Grower for high yielding good quality crops	Saturn Bioponics always uses ethical sources for its inputs; early adopter Valefresco is Leaf Marque certified	Innovations aimed at delivery of eco-efficiencies which create value for the customer and the environment

Building block	Description	Innovation	Customer benefit	Sustainability intentions
Value capture	Revenue: Sales of Saturn Grower and ongoing hydroponics/nutrient sales	Resource use efficiency	Related to cost cutting as the customer has the potential to decrease costs and boost profit margin	Sustainability – while it is a goal and is promoted when applying for grants – but it is not emphasised when selling to growers. Therefore, value capture is received indirectly from sustainability
Value intentions	Mind-set of owner-manager; oscillates between entrepreneur, ecopreneur and innovator	Works to understand what customers are looking for and then innovates for better functions	n/a	Sustainability is a core value of the CEO, and products are sustainable whether or not promoted as being so

Source: Author’s data

Table 28 Building better understanding of Saturn Bioponics post-2016

Building block	Description post-2016	Innovation post-2016	Customer benefit post-2016	Sustainability outcomes
Value proposition	Refined Saturn Grower, consumables and hydroponic consultancy	Improvement of hydroponics expertise	Further enhanced quality and higher saleable yield, improved cost effectiveness	Delivery of eco-efficiency benefits from fewer inputs (water, fertiliser, crop protection products); reduced crop waste
Value creation and delivery	Partners: Other enterprises supplying equipment to the vertical farming industry e.g. greenhouses	Improved yield and quality crops using Hydroponic science for purchasers of the hardware and for other platforms Distribution: greenhouse growers.	No change	Delivery of eco-efficiencies creating value for the customer and the environment

Building block	Description post-2016	Innovation post-2016	Customer benefit post-2016	Sustainability outcomes
Value capture	As pre-2016 with hydroponic consultancy sales and income from joint ventures	Cost cutting : moved manufacture of hardware for Saturn Grower to Eastern Europe	As before, but more efficient	Value capture is from sales but there is no product differentiation from the sustainability characteristics of the innovation
Value intentions	No change	More specialisms within the company facilitate more innovative refinements of the system	Enhanced eco-efficiencies	Sustainability is a core value of CEO, and products are sustainable, and create sustainability benefits for customers, whether or not these are promoted

Source: Author’s data

7.5.6.1 Secondary model

Extra activities, supplementary to the main focus of the company, provide an additional revenue stream. Since 2016, further development of the company's specialism of hydroponic science as part of its value offering has provided an advisory service for growers who use other hydroponic platforms beside the Saturn Grower. This service develops the agronomic (nutrition and plant health) strategies for the customers, selling the appropriate consumables and knowledge, and also forms a basis for ensuring eco-efficiencies are achieved for customers.

Mutually beneficial relationships have been developed and play a small, but important part of the firm's economic model. Potential arrangements have been explored concerning joint ventures with other companies, with synergies such as those in the hydroponic sector, with Saturn Bioponics taking a small stake so that the level of risk is relatively low (Ref: SB25). An example of this has been the decision, which was taken after two years of negotiations, to develop a joint venture with Shockingly Fresh, a company which develops sites for hydroponic farming; with plans to develop 40 sites between 2019 and 2024 (Ref: SBSF01, WW04). Saturn Bioponics will be providing the hydroponic equipment for these sites, and, assuming these site developments go ahead, the project is expected to provide an important revenue for the company from sales of the Saturn Grower over this period.

The main business of the company remains the Saturn Grower, which comprises 80 percent of the activity and benefits (Ref: SB27). However, these amendments indicate the willingness of the CEO to adapt and innovate to reach similar markets if demand is perceived.

7.5.7 Expression in the context of sustainable intensification

The potential of the company's innovation to provide a sustainable method of growing is discussed in Chapter 5, Sustainable Intensification. Expression of sustainable intensification is embedded in its model, not only because of the CEO's personal beliefs (Meeting 2 February 2018, Ref: SB18) but also because it makes good business sense as precision application of inputs such as water, energy and nutrients result in lower usage and thus economic savings (eco-efficiencies). As such, these eco-efficiencies are seen as offering competitive advantage (Ref: SB11). Thus, although it does not play an overt role in defining the value proposition, it is an consistent underlying feature that has not changed throughout the duration of the study. There is an opportunity to increase the sustainability offering if it is able to co-deliver with its customers, as discussed in 7.6.5.2 above. This is also discussed in Chapter 5 and Chapter 8.

However, sustainability is important to other audiences, such as investors, and CEO Alex Fisher emphasised that: ”Sustainability is of huge importance for financiers” Ref SB05). The company has effectively developed into two different messages for the different audiences; while communications targeting potential growers are focused on the potential advantages from the characteristics of the innovation, those expressed at thought leadership discussions, on blogs and aimed at other audiences, have more of a focus on the company’s embedded environmental sustainability focus.

7.6 The evolution of the Saturn Bioponics business model

A new business strategy commenced in 2016, which involved using the expertise of different actors in refining and broadening the value offering is seen in Tables 27-28 which chart the business model of Saturn Bioponics, making a distinction between the stages pre- and post- 2016. It is notable that the sustainability intentions became outcomes, arguably because although the potential customers are not looking for sustainability, there is a connection with eco-effectiveness as a customer benefit. As a result the innovation adopters can still “benefit financially and ethically” (Ref: SB01) even if the latter is not their objective and is therefore a spillover. However, the sustainability message is perceived by customers as being of less importance than efficiency and potential competitive advantage (SB28), hence it is not emphasised in marketing materials.

Entrepreneurial opportunism has also been detected as the company has amended its business model, including the exploration of joint ventures to target specific markets with a potential for growth and high income (such as botanical herbs used to flavour and/or add nutrition to food products). This could have been in response to fomenting contacts in this sector, which is expected to grow by an annual compound grow rate of eight per cent between 2019 and 2023 (Ref: MAKT01). These explorations take place concurrently with the other components of the business model which continue to function, adding complexity which the entrepreneur has to manage. Saturn Bioponics reported approximately 25 percent of the joint ventures explored go ahead following consideration over cultural and technical compatibility. Saturn Bioponics CEO specified: “It has to be the right partnership” (Ref: SB27). Nevertheless, the willingness to adapt the value offering and explore partnerships has shown dynamic ability of the entrepreneur to adjust the business model according to opportunities as they occur.

7.7 Discussion

The basic premise of the Saturn Bioponics business model has been developed around what is needed to supply a good which will solve a problem (and therefore create value) for the customer, and shows a willingness to adapt the business model. It strives to understand evolving customer perceptions of value and ensure the value proposition fits accordingly. To achieve this alongside its environmental criteria, the company uses eco-efficiencies to provide benefits for the customer and the environment and provide a revenue stream. This relationship between value for customer, environment and innovative company is the keystone to this business model.

Identification of the role of the ecopreneur/innovator has helped understand how the company addresses challenges by undertaking activities to drive value perception of their goods and services. An overt/covert relationship with sustainability was detected. For example, refinement of the hardware and software (the value offering), creation of joint ventures and mutually beneficial relationships with suppliers of complementary equipment are all components of the dynamic business model; yet part of the innovation is assigned to preserving environmental benefits. This objective, through the delivery of eco-efficiencies, has been seen to remain constant. This implies the importance of such eco-efficiencies to the business model; while the lack of perception of value from these efficiencies by customers has resulted in them remaining as spillover.

7.7.1 Interactions between business, the environment and sustainability – what are the potential pathways beyond spillover?

The Saturn Bioponics business model has developed from interactions between the environment, the innovation and the entrepreneur, which reflects similarities to research done by Knudson et al. (2004). Findings show that improving economic productivity is key for customer value perception, therefore the value proposition is at the heart of the business model. Using eco-efficiency as part of the value proposition creates business benefits. This adds empirical data which underpins the findings of Biloslavo et al. (2018), who view the value proposition as being at the heart of a business model and the over-riding importance of economics as a means to drive value perception.

Figure 15 below, which has been developed from the idea of a value triangle developed by Biloslavo et al. (2018), depicts Saturn Bioponics' business model which has been observed to have evolved around the basic concepts of innovation and cost effectiveness, with sustainability embedded in the value offering, as set out by Barth (2017). There is also a link with sustainability in the next node of the value chain, the grower, as there are environmental benefits afforded by precision farming with hydroponics.

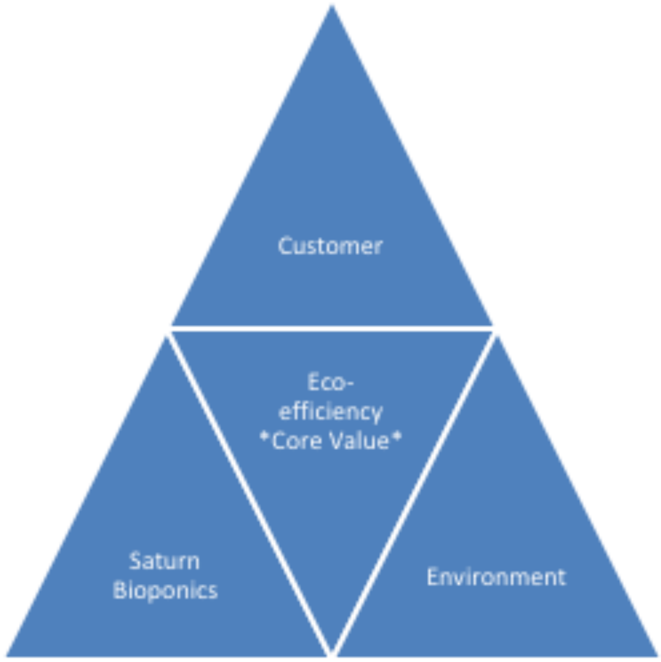

Figure 15 Placing eco-efficiency in the value offering

Not everyone agrees about the benefits of eco-efficiency; it is viewed as low-hanging fruit by Young and Tilley (2006) and an excuse for business as usual, but it is arguably a way to entice customers into working methods that will be better for the environment, and both will benefit. This is because the customer gains from eco-efficiencies in terms of costs, there is less damage to the environment, and the innovator/entrepreneur receives a source of income.

The challenge is to move beyond this to generate and sustain further change as there is a limit to eco- efficiencies that can be achieved within the market; a certain amount of inputs, such as water and nutrition, will always be necessary for crop production. The function of the innovation is also dependent on the genetics of the crop being grown and although the crop breeding houses are working to improve crop water and nutrition use efficiency, this is a long process, hence there are currently limits on the species of crops grown.

One shortcoming is that eco-efficiency refers only to some aspects of sustainability. There remain other limitations to the sustainability of using such systems; for example, although the output per unit area will be higher, higher productivity from intensification means there will be environmental costs from putting up polytunnels or greenhouses, and more pressure on water supply and disposal because more plants are being grown in the same area, thus there are limits to the benefits the innovation can provide within a market context. Other aspects of sustainability, including the relationship with the land saving paradigm are discussed in Chapters 5 and 8.

Conditions for greater change depend on the alignment of both the business to business (B2B) customer and the purveyors' sustainability aspect of their business models. If demanded, these criteria may be in response to another node in the supply chain, the retailer. Collaboration and dialogue between the various nodes of the supply chain facilitate waste minimisation and optimal resource use to maximise the potential environmental benefits. Any substantive changes will require a more holistic campaign to shift perceived environmental values. I suggest that to move beyond the lowest common denominator of environmental standards will entail political will to ensure targeted regulation and consumer education to raise market demand for ethical goods.

If underpinned by both regulation and government-backed incentives, initiatives like the Saturn Bioponics system and other agri-tech innovations would have the potential to provide some real protection to the environment for the relevant indoor crops. For example, policy instruments currently used by the EU target different areas of support, seeking to improve returns from sustainability. These include encouraging consumer awareness through labelling and marketing, which may help drive collaboration alongside legally binding targets for waste, and economic support for research and innovation from the Horizon Europe scheme (Ref: POL01, POL02). A limitation of using incentives to drive uptake may be economic and environmental costs, for instance encouraging the retirement of less environmentally friendly growing facilities to invest in new systems may result in waste of capital goods which are not yet worn out and the resulting environmental impact.

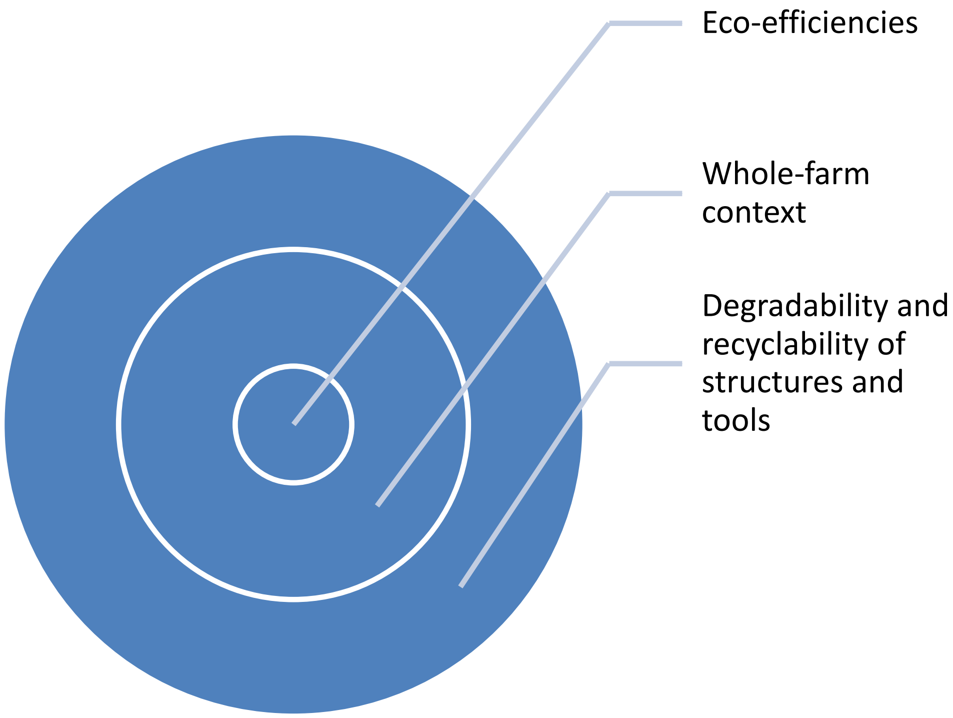

Figure 16 Building sustainability across business models of purveyor and customer

From analysis of the evolution of the business model of the case study, it appears that sustainability is not a driver of uptake. For example, as shown in Chapter 6, the most popular words used in marketing materials are ‘yield’ and ‘quality’ because these are the key words that their markets respond to once the regulatory food standards have been adhered too. In the UK, Food Assurance Schemes such as Red Tractor, BRC or GlobalGAP stipulate basic sustainability criteria, and the expectation of due diligence; once these are satisfied, depending on the customer, higher compensation is not always available.

Talking about ‘green’ values of companies undergoing auditing for LEAF Marque, LEAF CEO said: “From Waitrose through to Unilever, really important work is being done; the driver has been fresh produce, but oilseed rape and cereals are also following. Adoption of environmental measures is push-pull, but the real driver is the market place” (Ref: OB01). This implies that supply chain leverage and dynamics can result in firms changing their environmental practices when they are subjected to pressure (Hall et al., 2010), hence there may yet be potential for the business model used by Saturn Bioponics to encourage customers to adopt it innovation because sustainable practices have already been embedded.

Sustainability business model literature suggests a supply side endeavour to encourage customers to act more sustainably (Long et al., 2018), but I argue that, especially in the context of such a small, specialised market, a start-up is unlikely to try and influence a customer to change, as it may result in the new product being ignored. However, by informing the customer’s customers of the sustainability aspect, this becomes part of the industry-level debate and by attempting to inform thinking in the sector, illustrating credentials of the CEO as an ecopreneur. In addition, informing agents in the supply chain of the eco-efficiencies at the different nodes, and the potential business benefits for their company, leverage may be brought to bear on the growers. Such activities also arguably build the company’s reputation and the CEO’s credibility as an influencer.

Analysis of the evidence has led me to suggest that the company has integrated the environmental spillover from the eco-efficiencies deriving from its innovation into a holistic value offering. Data collected around sustainability as part of this study show that there is always a pro-active approach towards value for the environment and the company appears so far not to have decreased its environmental value offering as a pragmatic trade-off. However, as it does not confer competitive advantage for Saturn Bioponics and therefore it is not promoted in marketing materials; thus adds more evidence to the ‘spillover’ theory. This is reiterated by CEO Alex Fisher who said: “Sustainability points have great value to us, but they generally seem of minor importance to the grower” (Ref: SB29) and this point of view has remained constant throughout the time of the study. While the service offered by the case study company generally concurs with the findings of Lüdeke-Freund and Dembek (2017) concerning the provision of value with environmental benefits to a customer, there is a suggestion that there may be tensions between the combinations of the different elements of value. Those conferring eco-benefits which directly benefit the customer, and therefore can be viewed as perceived value, may carry more weight than other environmental benefits which are less tangible to the customer because of the perception that business needs to make economic sense. Creating an innovation which confers such benefits can result in hybrid tensions as observed by Davies and Doherty (2019) and the evidence from Saturn Bioponics leads me to concur with their hypothesis that making customers into beneficiaries can help drive social (or environmental) benefits. Where this study goes further has been in the detection of an audience comprising potential investors and grants authorities that are interested in the spillover environmental benefits, and therefore the sustainability message part of the hybrid can bring business benefits to the innovative enterprise.

Overall the findings on messaging reflect those of Davies and Doherty (2019), leading me to suggest that communications should be tailored according to the audience. This work highlights some of the significant challenges involved in getting sustainable technology taken up more widely because of the limits of relying on private companies to innovate and disseminate sustainable technology. Because of this difficulty, sustainability may become just one strand of a business, or a side-line, albeit one that embodies its values, which reflects the findings of Davies and Doherty (2019). Such factors draw attention to the need for policy makers to support not only the innovators in their quest for more efficient ways of growing with environmental benefits but also to support the adopters. This is because of the domination of price in the agri-food market and insecurity of supply contracts (See chapter 4). At the time of writing, it is as yet unknown what will be supported under the new system in the UK that has been designed to replace the EU's Common Agricultural Policy.

7.7.2 Conditions for delivery of more sustainable outcomes

Key factors identified in this longitudinal study as delivering more sustainable outcomes include the aspiration and determination of key stakeholders, such as the CEO of the innovating enterprise, and the use of innovation to generate competitive advantage alongside protection of the natural environment. Eco-efficiencies are central to providing customers with a means of growing crops with a lower environmental footprint without compromising on profit margins, and I also suggest that the use of the same area of land for a higher volume of production (see Chapter 5) are quintessential conditions for delivery of more sustainable business outcomes.

7.7.2.1 Leadership and sustainability aspirations

The driver of the sustainability aspect of the company is the founding entrepreneur who perceived an economic business opportunity alongside an environmental need, and has worked to create value by innovating and embedding sustainability throughout each element of the business model canvas. In many ways this complies with the theory of creative destruction developed by Schumpeter (1934) because of the potential of 3D farming to destabilise current ways of producing fruit and vegetables indoors, although because of the size of the sector, it may be considered as niche.

The qualities of the entrepreneur go further than identifying risks and opportunities and exploiting them to feed the aspirations of the company. The relationships built by the CEO of Saturn Bioponics and the commercial success from his ability to undertake organisational factors and processes to more eco-friendly outcomes, have built a reputation as an opinion leader in the sector. For example, Saturn Bioponics' CEO has shown pro-active leadership which has led the company but also resulted in recognition as an industry expert, which may help drive his vision for future developments of the business model.

As a privately-owned micro-company, with a single owner who chooses and invites people to be shareholders, observations of Saturn Bioponics have led to the identification of the entrepreneur's ability to seize opportunities as a crucial element for business. This is similar to the findings of Sosna et al. (2010) who highlighted that in a micro-company the perception of opportunities and risks is crucial when making decisions. In the context of sustainability, the entrepreneur is arguably the key player in ensuring sustainability in a commercial enterprise which is not publicly funded.

The moral compass of the CEO of Saturn Bioponics arguably complies with the definition of eco-entrepreneur identified by Schaltegger and Wagner (2011). This is because critical analysis of the attitudes and evolution of the company show recognition that economic benefits remain at the forefront of the business, especially for customers, and that in order for them to be 'green' the companies need to be in the 'black' i.e. that the business has to be economically profitable. There is no consensus, however, at academic level, about the weighting given to profitability (Filser et al., 2019), but this study shows empirical evidence that without economic benefits, if Saturn Bioponics offered only environmentally sustainable benefits, it would be unlikely to achieve success in gaining adoption, and the business would have collapsed. This suggests the importance of having a value offering which will offer competitive advantage; while this may be through eco-efficiencies as spillover, it is the value benefit to the customer which is a driver of adoption.

The business strategy of the company has been built on value creation for customers by providing goods and services to offer competitive advantage at B2B level. It does not, however, use the sustainability element to differentiate its services. This could be because these elements are not difficult to imitate by competitors, and therefore, as further down the supply chain there is a drive to build more sustainable practices in farming, it is likely to become accepted practice at retailer level. This suggests that, such a development, while being beneficial to the environment, would not create competitive advantage to Saturn Bioponics.

Interesting comparisons can be made with other start-up vertical farming companies. For example, Swedish-based Plantagon had a vision of using multi-storey city buildings to grow fresh produce, reducing the carbon footprint of transport of food (Ref: VF01). One of the reasons this company struggled was that the main consideration was not the quality of the produce and the resulting value for its customers (retailers and consumers), indicating failure of its business model to effectively design value capture and delivery strategy. As a result, it was hard to find a market for the produce in the highly competitive and mature markets in Sweden. This may have been partly because of failure to understand the complex connections within the supply chain, which is highlighted by Sage (2012) as being one of the key issues for connecting sustainable growing methods with consumers. The failure of that business model design appears to have impacted on the recruitment and retention of financiers, which, given the high investment costs of this sort of farming (Specht et al., 2013), is likely to have contributed to the company going into liquidation (Refs: PLA01, PLA02). Such failures also contribute information to the academic debate referred to by Connor and Mínguez (2012) on whether revolution or evolution can best contribute to sustainable food production. One of the lessons learned from this study is that when companies try and create value for the environment within a market economy, there needs to be primary consideration of what the customer perceives as value. This supports the argument for building a robust business case through careful consideration of different sub-sectors of the building blocks to be able to deliver more sustainable outcomes. It also indicates why some companies may prefer to keep the environmental benefits of their value offering as ‘spillover’ when it is not perceived as being a driver of adoption.

7.7.2.2 Policy and incentives

To encourage a faster rate of adoption and a more sustained transition towards sustainable intensification, policy makers should consider changes to regulate and improve contracts between growers and retailers to facilitate the market environment, and also some positive incentives to invest (i.e. subsidies). This may involve regulating minimum terms for length of contract so that growers have the confidence they will have the necessary time to receive payback on their investment. Other policies encouraging and rewarding more sustainable ways of growing which could help break away from the environmental benefits being relegated to being spillover, include public payment for public goods. This would compensate growers who do not receive payment for efforts toward more sustainable growing.

7.7.3 Value and its changing perspective within the 3D market

The value referred to in this study is within the specific commercial context of research and innovation in the UK and its significance is the need to ‘sell’ the business case for sustainability. I argue that the ability of the CEO to understand this need is critical and highlight the importance of entrepreneurial ability for those driving the business model.

Revision of the different perceptions of value between the ecopreneur and customers has led me to consider potential benefits if these values were perceived the same way. For example, mutual development of shared value would pave the way to building coordination between actors. This would then facilitate formation of a path towards resolving some of the externalities caused to the natural environment when growing food crops. However, as suggested by Davies and Doherty (2019) from lessons learned by Cafedirect, the value offering still needs to prioritise the utility demanded by the customer.

One of the key findings has been the acuity shown by the CEO of Saturn Bioponics by reacting in both an innovative and entrepreneurial capacity as more was learned about customer value perception of value. This included innovating to ensure economic efficiency from different strands of value offering, yet maintaining the environmental aspects. I suggest that this ability to adapt the business model is one of the key factors for success in a small, agile start-up company.

Part of the value of the innovation was its ability to provide eco-efficiencies alongside customer benefits with no additional costs for the environmental benefits. I suggest this has been an important factor because the customers were seeking to achieve their own aims in competition with others in the market, and not looking to improve their environmental performance which already met regulatory standards and customer expectations. This implies that such an approach with the use of eco-efficiencies is helpful in the path towards sustainability.

7.7.4 Continuous adaption of business model and interactions with sustainability

When reviewing the business model evolution, a central theme has emerged: the importance of the entrepreneur's awareness of the need to adapt the business model according to customer demand and value perception to exploit emerging opportunities. This highlights the need for an entrepreneur to understand value in the specific context of the commercial context within which it is working.

Although literature reviewed by Barth et al. (2017) suggests there are two main stages of a business model, exploration followed by exploitation, the empirical evidence from this case study illustrates that the two can run in parallel and inform each other. Taken together, being able to adapt according to customer demand while the company is functioning may be important to the long-term financial success of a company. This business model fluidity suggests a connection with the inherent uncertainty of innovation and transaction cost economics, similar to that described by Amit and Zott (2001) for e-business, as the company strives to provide what potential customers are demanding by demonstrating both feasibility and worth of its value offerings.

In this case, the enterprise has a fluid business model which allows it to take on innovative and opportunistic ventures and forms of business in response to the changing market as it attempts to generate value and profits not just for the present but also the future. The services offered ensure eco-efficiencies are achieved with the corresponding benefits for the customer and environment, in addition to creating a continuous revenue stream for the case study company.

Analysis of findings indicates the importance of stakeholder inclusion in the innovation to ensure the value proposition meets needs of the end user. The decisions to amend and adapt the business model are also similar those found by Sosna et al. (2010) who found evidence of business model innovation being stimulated through trial and error in reaction to market demands. The company has to evaluate the implications of internalising eco-costs, as if it is unable to offer a competitive advantage to its direct customers, this might threaten the existence of the company. In a situation of no economic return, there is no value for the environment, either. This tension highlights the interaction between the innovative and entrepreneurial characteristics of the CEO; in this case it is the entrepreneur who is driving the innovator, which suggests this relationship to be key to sustainable outcomes. This is because innovation is used to balance the factors leading to value offering which has high costs for the environment but offers greater customer advantage and one which gives more profits with less environmental damage and lower returns. This implies trial and error, as the company drivers oscillate between ecopreneurism and innovation, and can be linked to incrementalism as being important given context of the market conditions in which companies such as Saturn Bioponics operate.

The reactions of the company to the needs of the customer shows recognition of the importance of economics for its transactions. This is because it needs to show that despite being eco-friendly, above all, the price of its value offering needs to be competitive. Given the commitment shown by the CEO of Saturn Bioponics to the environment, I argue that it is exploiting innovative ability to use business interest as a means to a more sustainable outcome.

7.7.5 Limitations to scaling up - external factors limiting demand

Understanding the business model of the potential customer and the finance available to invest in a new system emerges as being important to success, and may play a crucial role in customer demand for a product which provides eco-efficiency benefits for environmental sustainability. Through the use of eco-efficiencies as part of its business model, Saturn Bioponics is arguably making a micro-contribution towards sustainable intensification, and by scaling up, this would make a more important step.

One of the challenges is how to scale up this way of growing fruit and vegetables. Although this study has been focused within the indoor fruit and vegetable context, there may be some parallels with other sub-sectors of broad-acre arable crops. Precision farming technology can also provide eco-efficiencies on a wider scale; yet reflection on work undertaken by Rose and Chilvers (2018) has indicated that the rate of change is not consistent or sure. The implication is that scaling up either 3D farming or precision agriculture is likely to be an evolution as businesses seek to improve their competitiveness without taking on too much risk, and would therefore depend on the existence of a robust business model and the convergence of benefits at different levels of the supply chain.

However, there are limitations to the eco-efficiencies, and there will come a point when no further gains will be able to be made, which is likely to be driven by achieving maximum genetic efficiency from the lowest possible inputs.

There are also limits on the impact of this technology because the sector is relatively small (fresh fruit and vegetables) and not cereal staples such as wheat. Although the sector size may limit a transformation, there are lessons which may be learned by larger farming companies and their multi-national suppliers, for instance by bringing together activities of small and large enterprises to promote a transformation towards sustainability, and referred to by Hockerts and Wüstenhagen (2010).

7.8 Conclusion

This framework of this chapter has helped me to identify important implications about how the evolution of the Saturn Bioponics business model has created benefits for the environment, for the customers, and also a revenue stream through the integration of eco-efficiencies. In this case study, what is important about the value offering is how it is perceived by the different parties, and how the ecopreneur unites these perceptions of value within the business model to drive a relationship with sustainability.

The implication from understanding of modifications in customer perception of value in this context is the need for a fluid business model, with commercial success being underwritten by an iterative attitude of the entrepreneur who adapts key resources, activities and the value offering in response to demand and perceived opportunities. The key relationship with the environment is from eco-efficiencies created by the value offering as a means for attracting customers. Limitations of the strategy have been determined to be external factors beyond the control of the innovating company which work against adoption, such as the price competition of the fresh produce market and the short term contracts in the industry. These discourage investment in technology and new systems by adopters because of lack of security.

Analysis of this case over the time period has shown that the CEO has the ability to move between the categories of innovator, entrepreneur and ecopreneur, and this suggests a key condition for better interactions between the business in this new agricultural sector and the environment. A number of areas which link with Diffusion of Innovation, such as the close relationship with early adopters, have also been identified and are reviewed in Chapter 8.

Chapter 8 Bridging the chasm – 3D farming as part of a transition towards sustainable intensification in a market economy

8.1 Introduction

Achieving sustainable intensification in a market economy is a complex challenge because it requires social and commercial input from companies. This thesis has critically examined how the socio-economic phenomenon of commercially undertaken 3D farming is contributing to sustainable intensification. My focus is on the innovative technology and the knowhow of a company which has designed a system to work at commercial scale in indoor growing areas (such as greenhouses and polytunnels), how the diffusion of innovation takes place and the evolution of the business model in addition to the mutual influences between these paradigms.

The principal challenges for achieving a sustainable business outcome from 3D farming are:

1. To ensure that the innovation creates value by providing a solution to a perceived problem.
2. To innovate to minimise environmental damage from growing fruit and vegetables where possible (value for the environment).
3. To create a source of revenue for the innovating company (value from business activities).

This study is placed within the context of the UK market economy that is driven by an oligopoly of food retailers (Finger et al., 2018). The setting is important because the supply chain is unbalanced, with retailers dominating and demanding efficiencies from their suppliers (Hingley and Lindgreen, 2010). There are other pressures for growers, too, as they are expected to minimise any environmental effects; these benefits are not visible to the consumer (Carolan, 2006), which makes it difficult for consumers to value them. As supermarkets are highly competitive in their objective to achieve continual profits (Finger et al., 2018), their suppliers of fresh fruit and vegetables also respond to calls for cheaper foods, which often means they are more intensively-grown. 3D farming methods provide clean, sustainably grown food, but as yet this is not a means of differentiation; as found in fruit and vegetables with ‘organic’ classification, which earns a premium. The UK government supports sustainable intensification with initiatives accessed through competitive funding from entities such as Innovate UK (see Chapter 4), but do not currently support it at consumer level as well, for example with consumer-facing campaigns. Improved academic understanding of the business model canvas of a company within this commercial context, its evolution and the relationship with sustainability, plus improved support at grower and consumer level would increase its contribution towards sustainable intensification of the UK food system.

A gap has been identified in empirical literature concerning the multiple components and actions necessary in the indoor 3D (vertical) farming industry to take the concept of sustainable intensification through to delivery of higher crop yields within a commercial environment. For example, Despommier (2010) advocates advantages of vertical farming but does not indicate a business pathway towards them. Others have typically drawn on single, technical issues such as energy efficiency (Daniel, 2014) or urban agriculture (Specht et al., 2013) as pathways to sustainable intensification. In contrast, this study has undertaken a multi-disciplinary evaluation of the relationships between the business model, diffusion of innovation and sustainable intensification practices to drive a more holistic understanding of how an innovative agri-tech company can contribute towards sustainable intensification.

This chapter integrates the findings within the concepts of sustainable intensification in agriculture, diffusion of innovation and business models and then synthesises them to explore the intersections between theories. I developed this integrated framework to help understand how growing fresh fruit and vegetables in 3D can contribute to sustainable intensification in a competitive market.

The key questions addressed include how the enterprise Saturn Bioponics has been using the potential of new knowledge in the 3D farming sector as a base for its entrepreneurial activities, its relationship with sustainable intensification, how it diffused its innovation and its business model evolution. Following a seven-year timeline facilitated perception of what was at the 'heart' of the case study company's ethos, and the interactions between the three paradigms driving its development within the broader UK food system.

8.1.1 Positioning of the work

As agribusiness across the world adapts to meet growing global demand for food, there are different sources of innovation across technology, agronomics and genomics. This study has followed the path of an innovative start-up company, and therefore it sits under the general umbrella of innovation theory, as expounded by Schumpeter (1934). The research framework interacts with the literatures of sustainable intensification, diffusion of innovation and the components of the business model, revealing important interfaces which are discussed below.

By using the three different lenses of sustainable intensification, diffusion of innovation and business model, this study has sought to identify key insights from the case study and then explore similarities and divergences with current literature and adding new knowledge gained from analysis of the interaction between the literatures. Bringing these concepts together has helped to create a holistic view of how the different processes of this new sector fit together to drive sustainability and has created a novel contribution to academic literature. The findings from the study have also drawn on theory in other areas, including agricultural and ecological economics, such as research done by Knudson et al. (2004), and Figge and Hahn (2013), in addition to co-evolution literature centred around transitions towards sustainability, such as those explored by Smith (2010). It also brings in altruistic elements of corporate responsibility literature which have converged across industry sectors over time (Ioannou and Serafeim, 2019).

For this thesis, I have developed a practical framework which has considered the practitioner and the academic points of view to gain a holistic vision of the first years of a start-up agri-tech enterprise. Development of this framework helped address the primary research question, and in the course of empirical research links to other literatures were explored and led to modification of this framework.

8.1.2 Evolution of a company and factors influencing the success of the process

Opportunities and constraints play an important role in the evolution of a company in the agri-tech sector (such as suppliers of 3D growing equipment), and reflections made during this study have highlighted it is the decisions made in response to these factors that facilitate or impede sustainable outcomes. This is illustrated in Figure 17, which shows decisions and activities building into a conceptual ‘river of life’ (Moussa, 2009) of a commercial enterprise. The principal player in the company is the CEO, who uses managerial abilities which may be entrepreneurial and/or innovative, or fluctuate between the two (see Chapter 7), to manipulate the different scenarios to benefit three core elements: perceived value for customers, a source of revenue and environmental benefits.

The aim of the river of life diagram is to guide understanding of where support may be needed or best targeted, either from stakeholders or government policies, to support sustainable intensification. The analogy has been chosen because some of the developments may happen very quickly yet others may be very slow, giving the impression of being becalmed, or even stagnant, and in need of an injection or new outlet to move on.

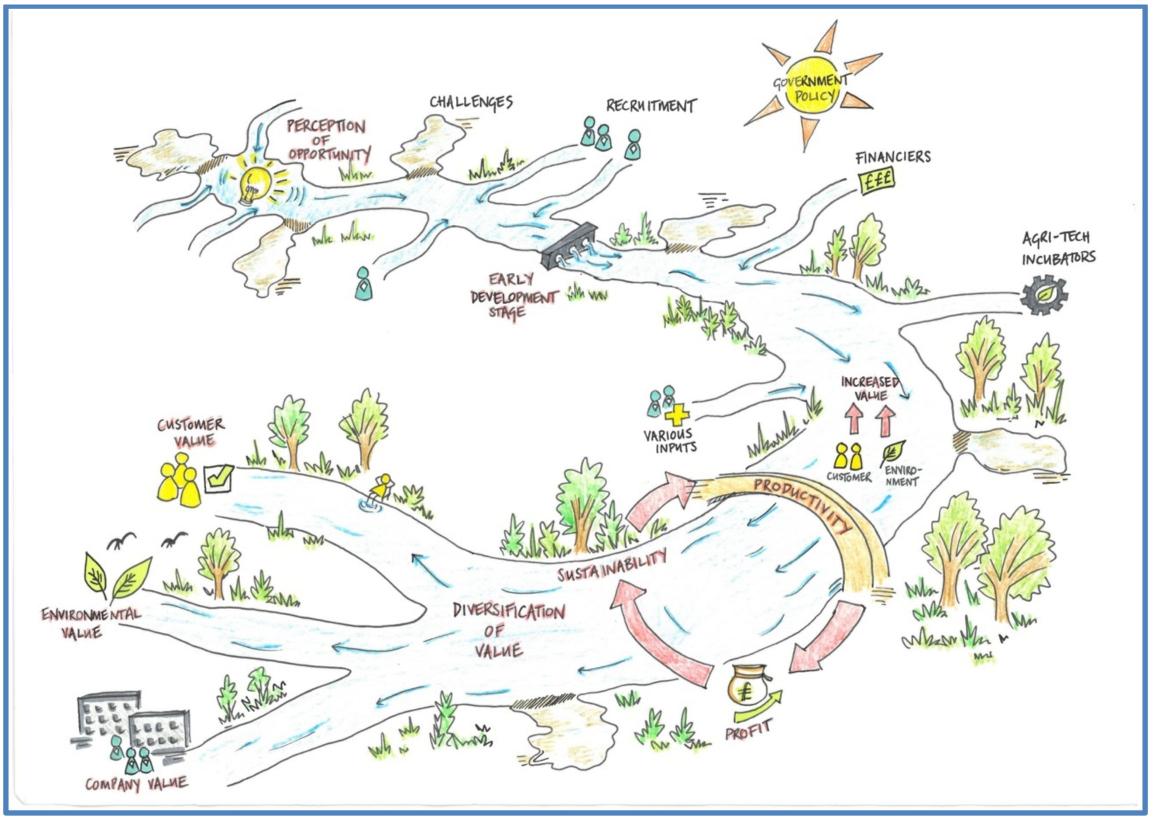

Figure 17 River of life conceptual evolution of a company
Credit: EnviroVisuals

There are pinch points which appear as part of a sequence of activities followed to create perceived value for the customer, with the potential of minimising environmental damage, whilst providing a means of revenue for the company. Typical constraints identified from studying Figure 17 include lack of staff (hence the need to recruit and train new staff), cash flow during the time taken to create and refine the innovation, (hence the need for financial services and/or grants). These are followed by the challenges of diffusing information about the innovation and services (part of the solution can be through the use of company incubators and/or accelerators).

Government policy, which is a constant influence, is portrayed as the sun. Some government policies may be used as incentives, either as support for work on the innovation (such as grants received from InnovateUK), or the creation of an environment in which customers are incentivised to uptake such innovation. One of the challenges in this area is compatibility of national and local policies; for example, if the potential customer wishes to install new greenhouses or polytunnels to use with the 3D equipment, planning permission is necessary (granted at local level). This may be denied if neighbours object to new installations, reflecting the differing opinions of the definition of sustainability, and whether the construction of buildings can be considered as part of a move towards sustainability even if they provide eco-efficiencies and lower waste. Such problems highlight a need for consistency in policy making across national and local government.

Analysis of possibilities for scaling up the technology has determined limitations in that the type of crops which can be grown in this way constrains the market size. The model does not take into account any wider consequences of a move towards more sustainable growing, such as regional effects on employment.

8.1.3 Summary of data chapters findings

This section reviews the summary of findings and conclusions from each of the data chapters.

8.1.3.1 Sustainable intensification in practice; benefits and limitations

In the context of 3D farming, innovation has been identified as a key element for creating the means for both the business case and the environmental case when practical sustainable intensification is considered from a practitioner's point of view. The case study analysis has shown that in this context, sustainability is mainly based on eco-efficiency benefits from the high density growing systems, which has created a business case that is the basis of this study.

Producing higher density crops with precision use of inputs is, arguably, contributing towards sustainable intensification at micro level because of the productivity gains, in addition to creating cost efficiencies. The case has shown that by increasing growing density of suitable fruit and vegetable crops, better use can be made of land by increasing the output per unit of area, as illustrated by the case in interviews and presentations undertaken by the company (see Appendix II). Moreover, it complies with the views of Pretty (2008) that the focus should be on achieving better productivity. This also suggests compatibility as an important connection between productivity and the business model. However, there are theories that such cost efficiencies may not really provide benefits to the environment, suggesting that the production of higher yields may be considered the continuation of a regime seeking continuous productivity improvements and growth (Maye, 2018) and providing an easy route to its continuation (Young and Tilley, 2006).

There are limitations to the potential for innovation to provide a sustainability element through building eco-efficiencies as a business case because inputs (nutrition, water etc.) will still be needed for growing fruit and vegetables.

Another controversial issue for some environmentalists is that high output farming systems are not normally considered as being sustainable, particularly as sustainability tends to be thought of as being connected to land sharing rather than land-saving (Tscharntke et al., 2012). This premise has more recently been challenged (Balmford et al., 2018) and the evidence from this case study suggests different areas of sustainability can be achieved from 3D technology, including both eco-efficiency and land saving potential, both of which have relevance for the business case. This is because the technology makes it possible to obtain higher yields from a unit area of land (leading to profit) and use fewer resources, so there is less waste in addition to having an effect on input costs thus affecting profit margins. There is also a possibility to set land aside for environmental benefits, which further increases the potential for better environmental sustainability.

8.1.3.2 Bringing under-utilised space into production

Compromises in productivity to benefit the environment have the potential to lead to an increase in the total area dedicated to agriculture. However, indoor sites, such as those used for 3D crop growing, can be constructed on previously abandoned sites, such as disused underground stations in cities. The main case study has not followed this route, but others, such as Growing Underground (Ref: VF4, GU01), who were interviewed as part of a scoping study have established businesses in such sites, which can create other challenges. As greenhouses for indoor crops can be placed in areas unsuitable for outdoor cropping, this fits with the suggestion made by Weltin (2018) on increasing returns from under-utilised lands. This use of land could also feed in to the debate about maintaining the integrity of other areas of natural capital for environmental services (see Section 8.2.2, Weak sustainability below).

8.1.3.3 Diffusion of innovation

One of the key findings of analysis of the case study's diffusion of innovation activities was the number of areas which interconnect with value and diffusion of innovation. Embedded understanding of farmer needs was found to be key to a successful business strategy, driving not only communications strategies but also the 3D technologies. In the case of Saturn Bioponics, empirical evidence shows such strategies evolved through an experiential process of trial and error.

Customer perceptions, intentions and goals were identified as drivers of adoption or rejection, and the study found that success depended on the ability to pinpoint which were the most important at a particular moment in time for a specific audience and adapt communications accordingly. Understanding value, and value perception were detected to be fundamental concepts for the case study company. This is illustrated by their activities, for instance, once the initial prototype technology had been designed, value was extended thanks to the effectiveness of the role of early adopters who provided feedback about the innovation, which was then subsequently adjusted to better fit with customer needs. The implication of this has been the realisation of the importance of recruiting early actors capable of playing a key role in both refining the innovation and creating relevant information for diffusion strategies. They played an important role in transforming the technical innovation and the function of marketing strategies by building technical value and also the potential customer perception of value. The case study company recruited early adopters, including Valefresco, as the CEO was able to articulate his vision effectively and build networks with similar-minded company representatives.

Other start-up companies reported challenges in recruitment of capable early adopters because of the competitive nature of the fruit and vegetable business. This points to the potential for contribution of early adopters to the business model strategy of a firm, connecting the two literatures (see Section 8.8 below).

The literature review revealed that technical input and peer to peer influence has been well documented, but the input of technical information for marketing purposes has been less well documented in terms of early adopters' impacts on driving company sales in the context of diffusion of innovation. This study contributes to closing the gap by providing a commercial perspective of diffusion of innovation in the highly competitive fruit and vegetable industry. By illustrating how diffusion of innovation can improve uptake of more environmentally friendly technology through using early adopters to refine the technology and create knowledge for persuasive and targeted communications, I have shown how diffusion of innovation approaches can help achieve more sustainable outcomes.

8.1.3.4 Business model

This case study details the fluidity of the company's business model in a new sector, 3D farming, and how the entrepreneur adopts an iterative attitude and adapts the model accordingly. Following a business model over time offered better insights of how it works in an empirical situation, rather than a snapshot at one moment in time, which could be particularly important given that this new crop production sector is still in its early stages of development. Literature reviewed by Barth et al. (2017) suggests there are two main stages of the business model, exploration followed by exploitation, but the empirical evidence from this case study shows the two can run in parallel. It also suggests the importance of entrepreneurial awareness as noted by Parnell et al. (2018) and how to adapt according to customer demand is important to the long-term financial success of a company. Overcoming this potential cognitive gap of what potential customers are likely to want or need through collecting and analysing feedback from early adopters is arguably one of the key factors in the success of the company's business model.

The case study company supplying equipment has learned to successfully make a clear case for its innovation to be taken up by others and this has been an important mechanism for its business growth. This has been based on the company's understanding of the need for perceived value in a number of areas, creating overlaps between the three main concepts of the study. Study of the company revealed perception of sustainability as a core value of the innovator/entrepreneur, but it did not always promote its sustainability value, targeting its communications messages according to its audience. There are similarities to the evolution of the Fairtrade mark/labelling approach (Davies et al., 2010) as it tried to enter the mainstream market. A decision on the emphasis of marketing communications about sustainability commitments can be difficult to make, and may depend on the customer's willingness to pay a premium, which could be financial or non-financial (Ioannou and Serafeim, 2019). The case illustrated that there can be pressure from bodies providing financial assistance to start-up companies as they can also insist on a sustainability focus.

My study demonstrates that while there is potential for sustainable intensification to form a key part of the *raison d'être* of enterprises supplying vertical farming equipment, and as such play an important part of the chosen business model, this is not necessarily the message that companies selling within the agricultural sector wish to highlight. Indeed, empirical evidence collected over seven years from the case and narrative emerging from trade conferences (see Appendix I) indicates that the connection between the business model and the sustainability aspect of the company is not always overt and depends on the particular audience. Recent literature suggests that sustainability issues have become more prominent among both enterprise owners and customers (Haigh and Hoffman, 2012, 2015, Santos et al., 2015, Davies and Doherty, 2019). The case study has illustrated that such information may be used only for particular audiences, which aligns with the opinions of scholars such as Peattie and Belz (2010), Moore (2010) and Bostrom et al. (2013) in addition to reflecting personal experience in public relations work with farmers.

The case has also demonstrated an attempt to broaden its impact by diversifying its value offering from just one area to seek appeal in a wider market. This has parallels with the findings of Hockerts (2010) when looking at the differences between incremental and disruptive innovation and the categorisation of sustainable entrepreneurism. The current momentum of travel has been to develop expertise in hydroponic science that has the capability of challenging the incumbents in the sector as part of its bundle of services as a means of creating value.

8.2 3D farming - building a path towards sustainable intensification in a market economy

This section critically assesses the different elements of this study, and their implications for the 3D farming industry. These assessments have then been used to seek the linkages between the different literatures discussed in Section 8.8 below.

8.2.1 Innovation creating value for sustainable intensification

Smart farming technologies have the potential to solve a problem (Caffaro et al., 2020), and also to have a positive effect on the environment. To make a transition onto the path towards sustainable intensification there needs to be innovation and this invites the connection between two concepts; sustainable intensification and innovation.

The technical innovation is central to the business case as it provides efficiency which is not only linked to the value added for economic return but also the environment. The case study has illustrated that an innovation can internalise the effects on the environment, for example through the use of eco-efficiencies, and create competitive advantage perceived by potential customers as ‘value’.

A fundamental question such companies have to overcome with their innovation is to ensure the savings from eco-efficiency justify the investment. This reflects findings of Lüdeke-Freund (2020) on customer willingness to pay for sustainable goods, and the importance of bundles of value-creating activity as part of the business model as they can broaden the value offering to encourage customer willingness to pay. I suggest that such a strategy can have an important impact on driving company growth, and play an important role in delivering sustainable outcomes.

8.2.2 Mechanisation, IT and labour considerations

Companies using the Saturn Grower system still use labour for planting and harvesting; despite advances in agri-tech robots, there is not yet sufficient convincing data of the benefits of automated harvesting. This is because not only are soft fruit and vegetables such as lettuce very susceptible to damage, but also the picker has to assess ripeness before picking. As such, this is not a topic promoted by the company at the moment. However, by using powerful software which is operated remotely to automate operations such as irrigation and nutrition application, there is potential for other levels of middle-management labour may be replaced. This could potentially save the grower some of the more expensive labour costs. There are also social implications of this which are outside the scope of this project.

8.2.3 Weak sustainability

3D farming technology is aligned to weak sustainability within the ecological economics concept as discussed in Chapter 5. Data collected as part of the study details how 3D farming systems comply with sustainability markers from farm assurance initiatives such as LEAF Marque Standard Certification, which take a whole farm perspective towards sustainability (Perales et al., 2019). Given the complexity of the topic and difficulties in measuring well-being and utility from natural capital, and despite claims that some of the components of natural capital are critical or non-negotiable (Brand, 2009), there are arguments for a trade-off between the two extremes of weak and strong sustainability to develop a pragmatic, achievable sustainability.

As natural capital is considered irretrievable once gone, ecological economic theory suggests stocks cannot be rebuilt and therefore technology may not be considered as being able to contribute to strong sustainability (Dietz and Neumayer, 2007, Brand, 2009). However, following environmental economics theory and the weak sustainability argument, trade-offs using technology to minimise environmental degradation can be acceptable, as noted by Biely et al. (2018). Building on this premise, and using observations made in this study, I argue that by maintaining crops within a smaller area through the use of 3D growing, more natural capital can be maintained in other areas. This implies there is the potential for maintaining other ecosystem integrity of the areas which have either been saved from being brought into production or have been taken out of production.

This complies with land saving literature as discussed by Loos et al. (2014), while the grower does not have to compromise on yield or lose out on profit.

The land-saving benefit can be seen as a partial spillover, although for the maximum environmental benefit from the ‘saved’ land, there will need to be input from the grower and the will to use it for environmental services. Projecting from this observation, I assert that there may be a continuation of the productivist regime, with an increased risk that the extra land will be kept in production to further increase output and profits (Young and Tilley, 2006, Blignaut et al., 2014, Weltin et al., 2018). In particular, I argue that when growers are having problems in achieving sufficient profits to remain in business, they may be enticed to increase overall outputs, hence such benefits cannot be considered as being certain, but their potential is there.

Although assessment of weak and strong sustainability is not a focus of this study, in view of the increased productivity per unit of land, I have made an empirical contribution to this academic debate because of the potential for 3D farming to make a micro-contribution to strong sustainability (land saving) despite being closely allied to weak sustainability because of the use of technology in minimising environmental damage. This is because data collected on productivity per unit area suggest elements of natural capital can be maintained through the technology’s land-saving potential, which helps maintain the overall stock of natural capital. Insights from this study suggest that 3D technology and the corresponding hydroponic agronomy promotes the use of precision techniques and raises the potential to reduce resource consumption and waste disposal, while lower land usage from growing in 3D all contribute to the functional integrity of environmental sustainability as part of the weak sustainability argument.

8.3 Eco-efficiency; more than spillover?

It is arguably the value proposition and *modus operandi* which make a difference as commercial entities such as providers of smart agricultural technology can have social objectives as well as commercial ones. The company adapted its value offering according to customer demand, seeking to ensure that the customer is offered something for which it will perceive value through enhancing the competitive capability of its customers, commercial growers.

Eco-efficiency, as a driver of sustainability in the market in which the case study operates, has emerged as one of the major drivers of a move towards a more sustainable approach to growing indoor crops. This is because of the tangible benefits from lower input costs and reduced waste when 3D farming is adopted, but is often considered as ‘spillover’ (see Chapter 7).

The reason behind the company's reticence to promote the environmental message is due to customer perception of value: potential customers do not always respond to strong environmental messages because the main drivers of uptake of new technologies are profit and income. Therefore, productivity tends to lead the marketing message because that is viewed as a stronger driver of uptake of the innovation. The important connection here is that this productivity is achieved through eco-efficiencies.

But there are further challenges: for example, while productivity is a tangible benefit which can be assessed, services to the environment are often intangible and therefore difficult to calibrate and measure. As a result, if they do not have a monetary value they may not be considered in the context of the full value chain, thereby distorting the overall picture. This corroborates findings from the Public Ecosystem Goods and Services from Agriculture and Forestry Unlocking Synergies (PEGASUS) project which found that environmentally sustainable practices need to be incentivised (Brouwer et al., 2018), although this study does not clarify how financial benefits need to be made clear or the time period for which they would need to be paid. While certification standards help growers achieve a price premium for complying with environmental standards that go beyond those covered by legislation there is still a need to account for sustainability throughout the value supply chain (Perales et al., 2019). This suggests that unless the sustainability is supported by government policy, such as regulation or stewardship schemes, it is unlikely to be integrated into company strategy due to the lack of a business case (Schaltegger et al., 2012a). Sustainability is therefore likely to remain, at best, a niche concept.

Government policy makers and strategists working in the agricultural, food and nutrition sectors should be made aware of possible implications of this and I suggest that these growing methods should be classified as providing a public good. As such, appropriate incentives should be applied to them, for instance being included in future Countryside Stewardship initiatives.

8.3.1 How green is green?

As sustainable intensification may be perceived as a move towards industrial-scale agriculture, there may be a connection with the corporate social responsibility literature, where messages can be perceived as extrinsic, which implies increasing profits, or intrinsic, which show as genuine concern (Du et al., 2010). This highlights the complexity of communications in attaining congruence between social issues and company business. The case illustrates a dichotomy between sustainability marketing which is often viewed at point of sale for consumers, and promotion of goods and services at a business to business level in which the language is focused on input costs and yield. This concurs with the findings of Belz et al. (2009) who note that resolving environmental problems can be seen as a constraint and a cost factor and that indicators of greenness are hard to measure for competitive advantage. Such factors may affect decisions on uptake, but empirical studies by Owen et al. (2014) on the uptake of energy technology have indicated that rational economic decisions do not always drive acceptance of energy conservation technologies. Nevertheless, at the level of communications undertaken by the case for InnovateUK, the public good benefit of sustainable ways of working illustrates the difference in communications according to the target market, and hence a connection with corporate social responsibility.

8.3.2 Categories of fresh produce

While this study has found 3D farming to be able to provide a more environmentally friendly means of producing fresh fruit and vegetables, and provides a form of differentiation, there is no bonus in prices received by the growers from supermarkets. There is polarisation between organic and conventional sectors, with the latter often described as ‘industrial’ agriculture, and nothing in-between. Critical appraisal of the data collected as part of this study has led me to suggest that there is space for the promotion of sustainably-produced fruit and vegetables, and the producers should be rewarded accordingly. This would either mean higher supermarket prices, such as a similar premium already received by organic producers. Initiatives would also be necessary to help consumers understand what really is sustainable so they could make more informed choices. Such an initiative could be led by an organisation such as LEAF, which already has experience in auditing grower’s environmental sustainability and organising consumer-facing events such as Open Farm Sunday to help bridge the gulf between farming and consumers. Such policies would need to be put in place at national level to support and finance such an initiative.

8.4 Diffusion of innovation

The empirical evidence collected from the case has found diffusion of innovation starts before commercial release of the innovative value offering, demonstrating an important relationship between these concepts. This illustrates the mutual influence between innovator and early adopter growers, thanks to the feedback from the latter. It also corroborates the arguments proposed by Douthwaite et al. (2001) that stakeholders, such as potential users, can be a major factor in successfully launching innovations because they provide an opportunity to create common understanding between parties.

Due to their potential for putting peer pressure on non-adopters, early adopters are considered effective opinion leaders in some sectors (Frattini et al., 2014) and as such should be considered within the business model. An important limitation of this theory is that if the aim of early adopters in purchasing the new equipment is to gain competitive advantage, there could be conflict of interest. This could be relevant to peer-to-peer communications; while they are considered an important influence on adoption decisions, particularly in the agricultural industry (Pathak et al., 2019), competitors would not want to give away any commercial advantage. Industry observations have indicated that this may be sector dependent; producers of commodities such as wheat and barley do not compete with each other in the way that the nearer-consumer markets such as vegetable producers do, and this may impact on the willingness of early adopters to advocate the advantages of a new system if it gives them commercial advantage

By following a case study within the commercial agriculture sector, this thesis has added to understanding of diffusion of innovation and how it can influence evolution of a business model of a company supplying new agricultural technologies such as 3D farming equipment. The implication is that such a business model needs to be able to respond to modifications suggested by targeted communications with multiple stakeholder groups to help define customer needs as part of the company's diffusion of innovation, which supports my argument that it should be considered as a pre-building block. Further implications of the connection between the two literatures are discussed in Section 8.7 below.

8.5 The challenge of scale: moving out from the niche

Companies such as Saturn Bioponics may yet find scaling up to be challenging, which will impact on their ability to deliver sustainable outcomes across a wider sector of agriculture. This is because of the currently limited number of crops grown by this system, and whilst this is being expanded there is a need for time to develop and grow organically. The niche in which it is located has proved to be important as it provides an area in which agricultural innovation could be developed. This reflects the views of Pigford et al. (2018), thereby supporting technologies and knowledge transfer that facilitate a move towards more sustainable agricultural practices. To scale up, there will be a need for the support of a number of actors across the different boundaries of the chain, such as finance, to facilitate the company replicating the efficiency of the innovative growing system across more agricultural sub-systems and crops. In this area, innovation platforms such as Agri-Tech East and Innovate UK may play a further role by extending support.

One of the challenges of allowing commercial growth to happen organically (i.e. not buying other companies) is how much influence small companies can have on a sector compared with large corporations (Hockerts and Wüstenhagen, 2010). This raises the question of whether smart agronomic systems could become more of a mainstream activity. Smith (2007) asserts that niches are more likely to make such a transition if they are compatible with current systems, which suggests that if a company is be able to demonstrate superior performance to potential adopters who are already using similar techniques, they are more likely to adopt the new system.

As such as system becomes mainstream, a potential subsequent challenge has been detected because of the price competition between the retailers and their asymmetric power over their suppliers (Hingley and Lindgreen, 2010). On detecting lower costs of their suppliers, I suggest there is the possibility that the retailers would aim to benefit from the cost savings made by their suppliers, the growers, thus leading to erosion of the growers' potential profit margins. This loss of value for the growers is likely to result in continuation of the spiralling race towards the lowest price, with low perception of value. I argue there is a need for policy makers to support transformative innovations which will lead to benefits for the environment, rather than leaving it to market forces.

8.6 Creating perceived value for sustainability attributes

From analysis of the empirical data collected and the discussion above in the subsector 8.8.4, I suggest that on a more general level, the innovating company needs to ensure that the innovation is capable of effectively creating value for both the customer and the environment; i.e. the sustainability value element needs to enable profitable business. For conversion to sales, targeted customers (in this case fresh produce growers) need to perceive its value – including relative advantage to provide return on investment – which in turn provides the motivation for them to invest in a new way of producing their crops. This underlines the role of the ecopreneur and a pragmatic management plan to encourage people to respond to financial incentives of eco-benefits and higher productivity and release more land for environmental services, thus driving towards a more sustainable future.

One of the implications is that a potential weakness for such companies has been detected; although they are responding to drivers such as environmental legislation, market demand for the product may be slow, leaving it as technology in search of a market unless there is a cycle as the innovation and business model are adjusted as the company learns more about customer needs and values. To move towards sustainable intensification, adoption of green technologies will need to move out of the niche, scale up and become accepted at a wider scale, but to do so in a commercial situation, they still need to offer the growers a business benefit.

8.7 Potential for sustainable outcomes from 3D farming innovation

My analysis has led to better understanding of factors behind the sequence of events from perception of an opportunity to driving adoption of an agri-tech innovation such as 3D farming. As discussed in Chapter 5, I suggest higher density farming can make a micro-contribution towards sustainable intensification. One of the challenges is context; farms are run as commercial activities within a supply chain, thus the identification of a business case and the implementation of a sustainable business model is crucial to outcomes.

Bringing together and reflecting on the analysis from the data chapters has led me to suggest that in the context of business in practice, sustainable intensification is a function of the sum of a number of activities: eco-efficiencies, land-use savings, innovation, business model and diffusion of innovation.

The path towards growing higher yielding and sustainable food crops draws on different themes. The three main conceptual literatures of this study are shown with the basic intersections in Figure 18 below.

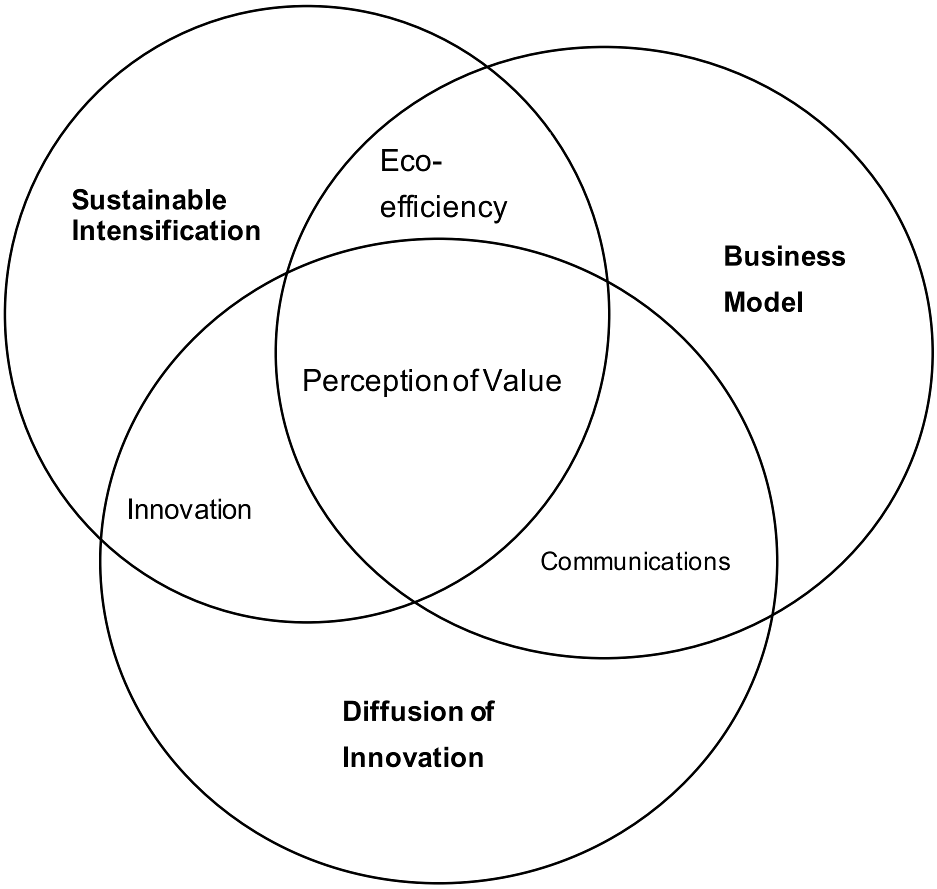

Figure 18 Exploring how value creates overlaps between the concepts of sustainable intensification, diffusion of innovation and business model

The central theme that connects all three literatures is the creation, articulation and perception of value (Figure 18). Sustainable intensification creates environmental values; diffusion of innovation is about presenting and communicating value, while the business model is centred on creating and capturing this value. I argue that the innovating company has to provide and receive value from its activity (return on investment as value capture), the customer has to perceive a value (utility) from the company's offering, and there has to be a value generated for the benefit of the environment. The value articulated in this study includes both utility and exchange concepts which are underpinned in neoclassical economic theory and the Law of Value as developed by Ricardo and developed from Smith's Wealth of Nations (Hollander, 1904). Within economics, theories of value have been refined, and so, for example, Chesbrough et al. (2018) argue that value is derived from deployment of resources and is ultimately determined by the customer and willingness to pay, when the environment is taken into consideration, it can become more complicated. Pretty (2008) notes that when value is monetised, it can be moved between different resources, but nature cannot respond in a similar way. Researchers from the ecological and environmental economics schools of thought have raised some challenges; for example, according to

Figge (2005), environmental management aims to create value based on corporate value models (which infers returns to shareholders), with the creation of a sustainable value added beyond eco-efficiency (Figge and Hahn, 2004), implying the need for effectiveness to achieve desired outcomes. They argue that to ensure enterprise value over the medium to longer term, companies need to be able to withstand both environmental and social shocks, assessing risks of options such as aiming for higher sales income from promoting green credentials. Understanding how to achieve resilience to such shocks can be challenging because different actors may not have the same objectives, and Hahn et al. (2010) point out that gains in one area, such as environmental sustainability may compromise economic gains and vice versa. Creating and then measuring shared value (Porter and Kramer, 2011, Kramer and Pfitzer, 2016) may help inspire adoption of social aims, particularly when applied to cross-sector partnerships, to work around "trade-offs and conflicts [that] are the rule rather the exception" (Hahn et al., 2010 p 217). The ability to ensure social and environmental aims are taken from conception to fulfilment, despite any necessary trade-offs, depends on personal perceptions (Hahn et al., 2010) and from the perspective of this case study, is discussed in more detail in Sections 7.7.1, 7.7.2 and 7.7.3.

From these conceptual underpinnings, I suggest that the central point is the innovation which is aimed at creating something able to satisfy these different forms of value and minimising any potential loss from trade-offs between the environment and the economic aims of the innovating company and its customers. From seeking the linkages between value and the different literatures in the context of the case study, this research contributes to the ongoing debate referred to by Figge and Hahn (2013) around difficulties in reconciling demand for value for different factors such as the environment, the customer and the innovating company. One of the challenges they point out is that eco-efficiency may not always create economic value; thus it is crucial that the innovation is capable of creating sustainable economic value for the innovating company and their customers. Mapping such value is complex, and a review by Bocken et al. (2015) found that the need for economic return can make it difficult to embed sustainability in the business model, and hence the need for innovation to facilitate its uptake.

Although neoclassical theory suggests no technology is perfect and actors have to make "the best choice amongst confessedly imperfect measures" (Hollander, 1904 p.489), actors in the business sector often try to provide goods and/or services which help make their services rare and difficult to substitute, to provide competitive advantage (Bowman and Ambrosini, 2000). This relates back to resource-based theory (Bowman and Ambrosini, 2000) and it entails adjusting the business model according to customer perception of need and value. These considerations are brought into play because actors are seeking short or, at best, medium term value when they consider they receive the maximum satisfaction (Bowman and Ambrosini, 2000). However for sustainable outcomes to achieve real utility from the innovation, the environment needs to benefit from long term consideration of value. Such value may not be articulated in monetary terms, and there could be challenges as preferences may change in response to future opportunities, hence from an *ecological* economics point of view there are certain ambiguities. Nevertheless, I argue that the key implication of the connections between the literatures is a drive to stack the different benefits, or utility, from the different types of 'value' created by the innovation.

This study makes a contribution to the debate explored by Figge and Hahn (2013) on the limits to relying on eco-efficiency to drive sustainability. The information analysed from this case study leads me to suggest that despite its limitations, eco-efficiency remains as one of the ways to address the challenges of minimising environmental damage because the efficiency element can provide economic benefits. As such, this study has illustrated an important link between sustainable intensification and the business model because, despite its limitations, it presents a business pathway which may have some potential to create benefits for all three areas of value. However, care needs to be taken as the extent of the wins and any proportion of benefits may not be the same for all parties. Hahn et al. (2010) found that decisions on whether a business should follow this path can be taken down to individual levels of value perception and motivation, and this is also reflected by the activities of actors in this case study.

As the customer may not share the same perception of sustainability from eco-efficiencies, there is a link back to the discussion in Sections 7.5.4, 7.5.6, 7.6 and 7.7.4 on the importance of economics in sustainability, the role of eco-effectiveness and the overt/covert business relationship with sustainability. This is because from a sales and marketing perspective, the case study has illustrated the need to reduce the risk of negative perception towards sustainability from the customer.

From the perspective of the purchasers, as observed by Chesbrough et al. (2018), value is arguably the price they are willing to pay and the utility they obtain from a value offering. Based on analysis of the evidence collected in this study, the implication is that the promotion of the value of eco-efficiencies can be used to motivate actors such as customers, because they gain better profit margins from lower input costs and less waste. These roads to cost effectiveness provide an important source of value (Bowman and Ambrosini,

2000) and this study has found that driving customer perception of company-specific benefits is helpful in addressing fears that eco-friendly systems result in increased costs and lower profits. I suggest that despite concerns about eco-efficiency being a means to continue business as normal, this study illustrates that eco-efficiency provides a first step towards stimulating change, particularly in the context of emerging technologies such as 3D agriculture.

When taken from the ecological economics perspective, efficiency is the derived difference between the costs and opportunity costs which are not linked to the environment (Figge and Hahn, 2013), hence the strategic use by the entrepreneur/innovator of eco-efficiency has proved a useful means of incentivising a move towards sustainability. However, as Pretty (2008) reported, when goods assigned a monetary value are then lost, funds from other resources can be brought in, however, this is not the same for the environment, and if natural resources are lost, they are not so easy to replace. I suggest, therefore, that over the longer term there is still a need to incentivise change through better understanding of the value of the environment and its fragility as part of a broader spectrum of benefits. Further studies could explore in more detail the magnitude of such wins, and any trade-offs which may need to be made, which is advocated by Hahn et al. (2010).

The holistic framework used in this study contributes to a rounded understanding which stretches from the need to move towards sustainable intensification through to the user of the technology. It starts with an innovation which offers technical advantages in addition to sustainability, and then passes through a stage of diffusion of innovation. It is during this stage that, through two-way communications, early adopters can be used help to refine the innovation into a value offering, according to more precise customer needs. This is the time that the innovation passes into the value chain, and it is then enveloped into the business model, which may be adjusted to adapt to the needs of the customer. The implication of these findings is that they demonstrate the need to effectively pass value through each of these stages to get the best business results and outcomes for the environment.

Through unpacking the different understandings of value, this study has found that achieving perceived value at each stage relies on key actors working within key relationships. The principal actor (such as a CEO) has been identified as playing a key role throughout all the different stages of the system, from the original innovation and the apportionment of value, to each stakeholder, to resolving conflicts, refinements and marketing of the product. The ecopreneur needs to demonstrate the ability to take on multiple roles, create networks across different parts of the supply chain, direct business strategy and listen to useful feedback that will eventually drive the business forward. Such feedback can inform decisions on how to motivate other actors in the sector to accelerate change towards sustainable intensification, which is through the commercialisation of something for which the customer perceives value and also has other beneficiaries.

Analysis has shown that the agent who decides on how and where the innovation can create value and then operationalise this by aligning the innovation with its diffusion and the enveloping business model, is the entrepreneur. Business success is dependent on the decisions of this actor, who can incentivise others, particularly if there is a powerful motivation to drive the firm forward. The same actor is also responsible for driving sustainable outcomes, which implies an entrepreneur with the ability to undertake multiple roles is better able to drive sustainable business outcomes.

I argue that business models approaches can be improved by adding more about diffusion of innovation to inform decisions about the value offering. Part of the innovator/entrepreneurial role is to listen and act on the opinions of other stakeholders whose knowledge inputs are added to the innovation to create a unified value as seen at the centre of Figure 19. This value then becomes the entry point for the business, and it can continue to dynamically evolve as part of the business's survival strategy.

This is partly because awareness of the innovation must be able to cut through the inertia of potential adopters, creating awareness of benefits for their business through investment in the innovation.

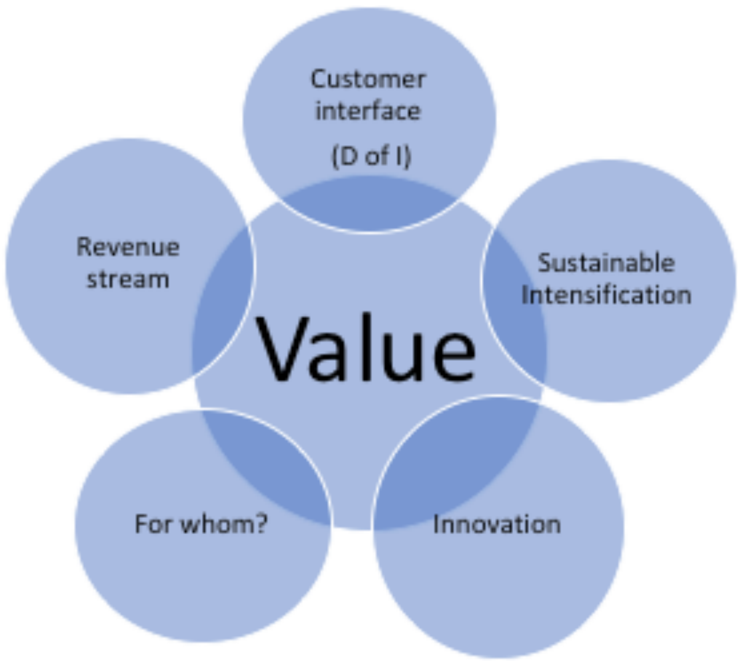

Figure 19 Considering elements interconnecting with the concept of value

One of the critical factors behind the success of a company is the learning process it undergoes on how to build value for the different stakeholders in the value chain. This is reflected in Figure 19 which illustrates the different areas interacting with value and which comprise key areas which need to be fulfilled for sustainable business outcomes; if the potential purchaser does not perceive value from investing in a new system, no purchase will be made, hence the innovation needs to create something of value to solve a particular problem experienced by the customer. This needs to be tacitly understood by the company, and each of these elements of value may need to receive some adjustment, suggesting the importance of learning and then taking the appropriate decisions forward.

This study illustrates that it more than just the architecture of the innovation that dictates the success of the enterprise which corroborates with the work of Timmers (1998) and Kuratko et al. (2015). What drives business success is the role the innovation plays in creating perceived value because it drives uptake. Analysis of the findings from this study show that adapting the value offering according to demand is critical to perception of value assigned by potential adopters, who may also value usefulness and even symbolism of the product, which are similar to findings of Owen et al. (2014), By connecting the business model with diffusion of innovation I argue that early adopters need to be able to generate economic value from the innovation. Such value is likely to help build confidence in the innovation, and therefore stimulate business from the value offering, which entails communications to diffuse the innovation. Interactions between the business model literature and that diffusion of innovation are further discussed in Section 8.8.

This study found the positioning of the value offering to be critical to commercial success, and at B2B level, this depends on relationships with suppliers, partners and customers, reflecting the views of Morris et al. (2006). A limitation of business model literature is that actors' and stakeholders' perception of value can change over time according to changing circumstances. For example a trigger event means that what is ranked as having been of very high importance today, can quickly become of little importance. This may be due to a certain stage in a company's lifecycle, or events outside the control of the company, such as extreme weather or changes in a political regime. This research demonstrates the importance of continually assessing feedback and evolving not only value creation but also how, and to whom, the value is articulated and the resulting changes in the business model.

The implication from better understanding of value in its different forms is that for adoption of an innovation to take place the adopter has to perceive value before taking a leap of faith, which suggests the need for an effective interface with customers and convincing communications to build their confidence in the ability of the innovation to provide solutions. If there is no confidence, it can result in low demand and innovations can become solutions in need of a problem, leading to limited business success. This was observed with some of the companies originally designated to be part of this study (e.g. Plantagon, Ref: VF1), which focused on marketing the sustainability aspects of its value offering, but did not include short or medium term benefits to the user in their understanding of sustainability of the innovation and ultimately stopped trading. The suggestion, therefore, is that for sustainable business outcomes, the responsibility is with the entrepreneur to guide activities which are covered by the binding of the three literatures and ensure seamless interaction to build the multiple elements of value.

8.8 Bringing the three concepts together as a contribution to theory

By linking together the three concepts, and their individual contributions to theory of Diffusion of Innovation and Business Models, this thesis provides an integrated conceptual framework that can be applied particularly to agri-tech innovations in commercial agriculture and has relevance for policy makers seeking to facilitate a transition towards sustainable intensification in the agricultural sector.

Figure 20 highlights the articulation of connections between diffusion of innovation and business model in the quest to achieve sustainable intensification. This is a process because once the need for sustainability has been identified, utilising user-driven innovation helps build a value offering which has business validity, thus it is the diffusion feeding into the business model that improves performance. Pivotal to commercial success is that the innovation needs to be considered as the main source of value by potential adopters. One of the key findings is that the value offering always needs to deliver economic value or business benefit, even while offering benefits to the environment. In the context of innovation for sustainability, strategic use of the new knowledge developed from the company’s diffusion of innovation to build and/or refine the value offering has been perceived to play an important contribution to the development of the overall business model. The key insight from analysis of the explanatory figure below is that innovation validity is generated through knowledge interaction from the interface between diffusion of innovation and the business model.

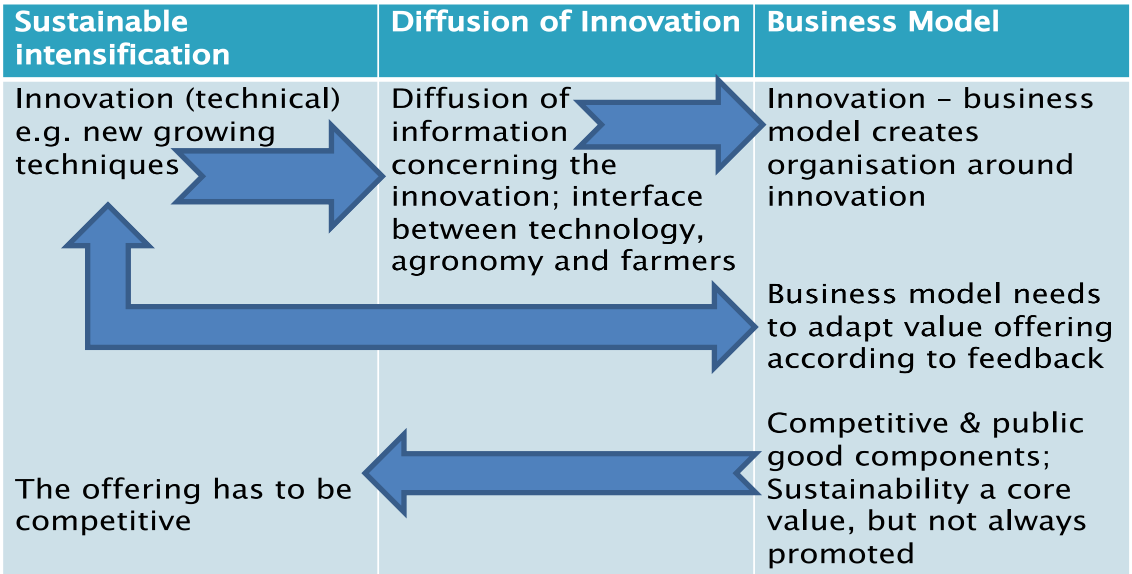

Figure 20 Key connections of the interfaces between Sustainable Intensification, Diffusion of Innovation and Business Model

Consideration of Figure 20 has led me to suggest that diffusion of innovation is key to effective innovation as it facilitates enhanced understanding of where value lies for each stakeholder group. The implication of this is recognition of the need for the creation of an integrated approach with learning from diffusion of innovation about perceived value being used to drive decisions on the business model.

The business model canvas is made up of resources and competencies often termed building blocks (see Tables 20 and 22), including value proposition, value creation and delivery, value capture and value intention (see Section 7.2). The findings of this study reflect those of Biloslavo et al. (2018) in that the critical component threading through the components is value. However, business model literature does not engage with how these elements of value are created and the activities and functions of the innovating actors (Hermans et al., 2013, Klerkx et al., 2010). Empirical evidence collected for this study about the activities used in diffusion of innovation has shown them to centre around raising the perception of value (see Section 6.5.1). This was seen to be fine-tuning the innovation to ensure its robustness, the production of knowledge and choice of diffusion networks and channels and messages.

The company’s use of early adopters suggests that they can be effective co-creators of value, particularly when they are used to fine-tune innovation and create knowledge which can be exploited by the innovating company (see Sections 6.4.5, 6.4.6, 7.5.3, 7.5.4). Farmers and innovators can, therefore, become partners within an agricultural system, creating mutual learning between them to strengthen their knowledge and improve the innovation which provides the source of value in the business. For example, because of their understanding of their peers in the sector and what is likely to be important to them, early adopter farmers can play a role in the development and the refinement of the innovation which is the value proposition and delivery of value to the customer. As such, through diffusion of innovation, activity from the different skillsets possessed by growers can contribute to the design of the business model canvas and shape the business model building blocks. This has led me to propose that diffusion of innovation theory should be considered as a pre-building block of the business model where a new agricultural technology linked to sustainability is being disseminated. This is because in such a situation it can be used to provide relevant knowledge which about the value offering and effective communications for marketing activities and shown in Table 29.

Table 29 Using Diffusion of Innovation as a pre-building block

Diffusion of innovation	**Business model building block**	**Contribution of diffusion to building block**
• Technical input from early adopters on the value offering • Technical and knowledge information inputs from growers, communicated to the innovators	• Value proposition and value offering • Value creation and delivery • Value capture	• Recruitment of the right adopters to refine the technology, creating a more effective value offering • Early adopters can enhance knowledge about what customers will value, thus how to more effectively market the value offering. The refined value offering improves potential customer perception of value • The consequent value capture can be enhanced from the inputs of diffusion of innovation

Knowledge exchange between stakeholders and actors contributes to the business model architecture, and provides an addition to the debate around the importance of the mutually influential relationship between the business model and technological innovation (Boons and Lüdeke-Freund, 2013, Chesbrough, 2010, Doganova and Eyquem-Renault, 2009, Zott et al., 2011). The experiential process of finding an effective form of diffusing the innovation to the targeted customers has been seen to be crucial to the concept and evolution of a sustainable business model. At small company level, this highlights the contribution of actor interactions, and the importance of awareness and ability to listen and learn to optimise the development and exploitation of the value offering. The business model and its interactions with diffusion of innovation, which facilitate or constrain uptake of innovations contribute to better understanding of the socio-technical system of 3D farming and how it helps lead to more sustainable outcomes. As decisions are made by the entrepreneur, their effectiveness is dependent on personal ability to decide where value is perceived and adapt the business accordingly.

Looking further down the supply chain, one of the key challenges for the fresh produce sector is the changing nature of value because customer demand at different stages in the food chain tends to be dynamic, evolving according to conditions such as over or under-supply and its highly competitive nature (Menary et al., 2019). Pressures can also be due to government policies or retailer response to consumer demand, hence there is a constant need to re-evaluate and adjust goods and services. This implies the need for an inherent flexibility in the business model which enables the firm to embed a number of sustainability principles alongside the drive for competitiveness. Such potential may not be available to incumbent suppliers of equipment to growers who may prefer to proceed with more caution and minimise risks rather than enter into the new sector of 3D farming.

Product differentiation remains driven by efficiency rather than environmental benefits but this may change with market demand. In this case, innovation for precision in growing strategies has increased the efficiency of production process to increase efficiency and created space for the ecosystem services – and therefore provides the key to sustainable intensification in this micro-context.

Figure 21 below illustrates actions taken by businesses working towards a path towards achieving sustainable intensification, with an initial innovation and early business model design, which, following two-way communications is then adjusted according to the crucial nature consumer demand.

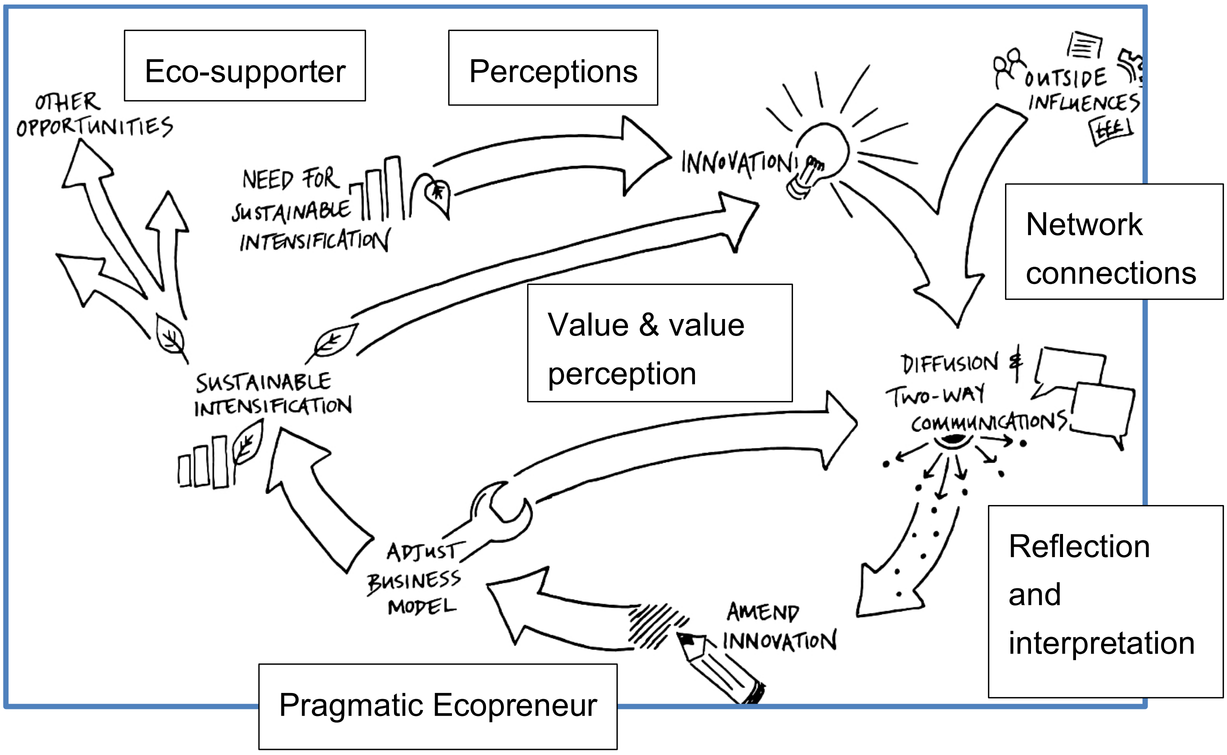

Figure 21 Evolution of a business: showing the perpetual need for feedback and amendments of the value offering

Credit: EnviroVisuals

My insights from this analysis suggest a circular systems approach is used as part of an overall business strategy in its quest towards sustainable intensification using 3D farming and is depicted in Figure 21. Traditionally, supply chains are often described in literature as being linear (Christopher, 1999, De Angelis et al., 2018), but the processes can be circular as they adapt to changing demands (Genovese et al., 2017). These changes may be to reduce risk exposure, and may also be linked to organisational trial and error, which result in a change in part of the architecture, or the addition of a new branch, such as product service innovation to harness knowledge. Adaptability and responsiveness to the market have been observed to be key factors driving market success, and are closely tied with entrepreneurial ability and the processes of maturation of the innovator. The development of this actor is depicted in boxes on the outside of the model. Value perception and the other boxed elements are key to delivering more sustainable outcomes.

Start-up entrepreneurs have the potential to leverage the flexibility of a small company in different ways. Their role is central to commercial success, because it is this actor who is responsible for setting achievable goals, assigning the value to each category, devising strategies to ensure each aspect of value is met, and establishing ways of amending or refining the value offering as needed. The experiential journey of the principal actor is portrayed in text boxes around the circular system, and helps to show how activities at each stage relate to the development of the system. For example, engaging in problem solving activity needs a connection with networks, creating interactions with heterogenous actors. Such connections help to identify a value offering which will work for the customer, and provide profitability alongside sustainability. Incumbents with multiple stakeholders to please may have more difficulty in achieving the same amount of flexibility.

At conceptual level the interactions between the different literatures are seen as crucial to building the elements of value illustrated in Figure 21, demonstrating the dynamics of a move towards sustainable intensification. Each part of the diagram has a connection to value; the need to maximise production while minimising environmental externalities; building and refining the value and subsequently communicating it, and the dynamics of a business model which can respond to changing value perceptions. All these elements need to be driven and managed, and at the heart of the business is the entrepreneur/innovator. This diagram shows key connections of the activities necessary to build a company with these values, the organisational ability to exploit evolving demand of customers, and the ability to move and create value to secure such exploitation.

Consideration of the importance of diffusion alongside the business model building blocks referred to in Chapter 7, has led me to consider whether diffusion of innovation is a pre-building block or forms part of a building block, such as value creation and delivery.

Figure 21 shows how the business adapts to have a strong focus on efficiency and competitiveness; the ability to be competitive despite offering value to a third party (the environment) is a key focus of the case study company and arguably a driver of business success to date. Insights suggest that this is derived from the company’s understanding of the need to prove the value of the innovation and demonstrate it, alongside the ability to articulate economic value. These characteristics depend on the ability and moral compass of the CEO of the company to ensure that all the elements work together seamlessly.

The evidence from this case study suggests a pathway to sustainability which is linked to the competitivity derived from the innovation and the relative advantage received by customers from adopting it. Crucial to success is the ability to offer something that offers articulates value in the form of relative advantage for customers which is better than any competitors, hence the need to actively review and revise the business strategy according to the evolution of value. The revisions are incremental rather than radical and build on the evolution of customer demand from the market already targeted and those with a close connection (such as vegetables grown for food and botanical herbs.)

When considering diffusion of innovation in the context of sustainable intensification technology and understanding, I argue that there is a need to define a boundary between diffusion of innovation at pre-competitive and competitive stages. This is because there are collective benefits of public goods, which, in economic theory, are non-rival goods such as those considering climate and the environment. Private goods, such as agri-food products, timber and tourist attractions, work within a competitive environment. Thus improvements in productivity alongside environmental protection and supported by social awareness, such as those connected with three-dimensional farming which generate public and private goods simultaneously, need to be eligible for extra support. This highlights an interdependence of natural and socio-economic spheres and the complex relationship of farming (De Groot et al., 2012) and the need for better academic understanding of how to drive increasing demand for ecologically sustainable goods, through a connection with environmental and agricultural economics literature because of the need for farmers to make a profit.

There is room for this theory to be further advanced by exploring the steps alongside the adopter perceptions of the characteristics of the innovation which are discussed in Chapter 6. This research provides a framework to drive better understanding of the effects of adapting messages according to perceived value and subsequent links to the company's business model. Further research is required to build empirical evidence on instruments which effectively facilitate or impede more widespread adoption, and their interaction with elements of value.

8.9 Summary

Using the combined framework which has been synthesised from the three literatures, analysis on how the case study company works has revealed the use of a circular systems-based approach that comprises intersectional areas in the search for value. The fluidity of intersections works to create flexibility in the business model, which is important because the critical factor for success has been identified as how the ecopreneur gains knowledge and interprets it in the context of value, and then uses this understanding to benefit the different stakeholders.

Insights from this study have determined value to be the crucial leverage point driving more sustainable ways of growing crops as it drives uptake and benefits for the environment. Thus the first step in driving sustainable outcomes from commercial agri-tech innovations is to establish what such values constitute for each stakeholder, and ensure the innovation makes an important contribution to them and provides a means for internalising externalities (such as environmental damage).

I argue that to deliver of sustainable outcomes, a business model needs to be developed to maximise resource efficiency and deliver commercial functionality, creating a value proposition that is attractive not only at the immediate point of sale, but also further down the value chain. Activities undertaken to drive perceived value have been identified as an important factor in uptake of 3D farming, providing the means for potential customers to test the validity of the innovation. Such building of communications has been a key element driving commercial success for the ecopreneur and the grower, and therefore also benefitting the environment. This can be arguably be described as providing competitive eco-efficiency leadership.

The value offering presents a novel opportunity for association between sustainable intensification and business models through the potential of eco-efficiency, when both the environment and business may benefit. The improved resource efficiency from 3D farming contributes to the debate on assertions of higher costs from enhanced sustainability by building evidence of cost savings and eco-efficiencies, combining different elements of sustainability where possible rather than just taking advantage of low hanging fruit and continuing business as usual. Context is important, and resource-intensive industries such as the fresh produce sector where competition is tight and profit margins declining, are more susceptible to external shocks which influence investment. By developing an integrated framework this study provides a novel addition to academic literature from better understanding of the advantages of a step by step approach of how the diffusion of an innovation drives business model evolution while seeking to maintain benefits for the environment.

Chapter 9 Conclusion

Three dimensions of value need to be achieved to move onto the path towards sustainable intensification in a market economy, the findings from this thesis have shown. These are value for the environment, value for the grower, and value for the innovator/entrepreneur. Providing innovative equipment and hydroponic science for growing high-density indoor crops (3D crops) can play an important role in the path towards sustainable intensification when the three dimensions of value are achieved.

The principal research question addressed in this study was to understand whether suppliers of 3D farming equipment can contribute towards the pathway to sustainable intensification within the context of a market economy and the evolution of the entrepreneurial activities undertaken along the way. An integrative framework was developed to evaluate the relationship between sustainable intensification and 3D farming in terms of a case study company supplying equipment for protected cropping systems, its diffusion of innovation strategies and its business model. Following the progress of a start-up company over seven years, this thesis has built empirical understanding of how an agri-food business with an ingrained sustainability ethic can contribute to sustainable intensification when providing the three dimensions of value mentioned above. This approach could be transferable to agri-tech innovations in other sub-sectors of agriculture and the food chain where companies are looking to improve sustainability while building effective relationships with their customers.

9.1 Theoretical, empirical and practical contributions

In this thesis, a contribution to knowledge has been made in two ways: theoretical and empirical. The theoretical contribution is the conceptual bridge between the frameworks of sustainable intensification, diffusion of innovation and business model literatures, with value at the core of each. Using these three lenses contributed to a more holistic view of how sustainable intensification can be achieved and provides a framework which can be used to study explore contributions to sustainability achieved at different points along the agri-food chain.

Empirical evidence is provided of a micro-company's evolution and contribution to sustainable intensification, and at practitioner level, it indicates the need to evolve the value offering according to customer perception of value. This has a practical implication in that companies may require a longer lead-in time for their innovations before taking them to market and therefore policy makers and financial investors should take this into account.

One of the important conclusions reached from the analysis of the empirical evidence is that innovation is not just the technology, it is how the technology creates value for the customer, the environment and the innovator/entrepreneur. As the creation of such value needs to be adjusted and re-adjusted to ensure it complies with the necessary criteria for perceived value, one of the important insights from this study has been that diffusion of innovation should be considered as a pre-building block. This facilitates the integration of the three concepts of Sustainable Intensification, Diffusion of Innovation and Business Models because the innovation is developed and then adjusted according to early adopter feedback, which the feeds into the business model which is also adjusted in turn.

9.2 Reflections for future research

This framework connects the concepts of Diffusion of Innovation and Business Model with Sustainable Intensification. The connection of three concepts creates better understanding of how the private sector may contribute to a transition towards sustainable intensification of agriculture. There are opportunities to use this framework in conjunction with other facets of sustainability, such as social responsibility, to evaluate how they interact.

There is a need to unpack the multi-faceted role of adopters in creating the business models, and conditions necessary for effective peer-to-peer communications. This should include research into where and when they are willing to collaborate and improve understanding of when their activities are pre-competitive. This would help future initiatives optimise strategies and target communications more effectively.

Further studies using this framework could be made in the sectors connecting food production, the retailer and the consumer from a different point in the supply chain to gain a more holistic view and identify trade-offs. For example, exploration of the up-stream and down-stream supply chain to understand what might constitute value and the two way dialogue needed between innovator and the customer, as part of a life cycle analysis, including eco-efficiency over time.

Better understanding of how to leverage the potential of agri-tech innovation to contribute to business resilience within the agri-food business and how to overcome limitations could make an important contribution towards sustainability. Not all crops are suitable for growing by this method, hence there may be a need to explore how business models for traditional, outdoor cropping can complement those of 3D systems. There is also a need for better understanding of the effects on willingness and ability of the fresh produce sector to invest in sustainable practices during political and health crises, the importance of which has been highlighted by the twin challenges of the COVID-19 virus and the withdrawal from the European Union.

9.3 Considerations for policy makers

This study has identified important areas for consideration for future policies on support for public-private sector partnerships, particularly those working towards sustainable intensification. For example, the need to create something which will be perceived as having a value for the customer is key to uptake, hence there may be a need to better support agri-tech development which takes customer demand into consideration. Evaluation of the data collected in this study has highlighted the importance of input at farm level to ensure that an agri-tech innovation addresses real industry concerns and therefore provides value to the industry. Consideration of how best to support and facilitate farmer input and co-development of the product is necessary to help reduce the risk of designing solutions that are looking for a problem to solve and consequently failed product launches. In addition, adopters need to be better supported with legislation ensuring fairer contracts which will provide them with better financial security to adopt more environmentally friendly growing methods (see Sections 6.1, 7.7.2.2, 7.7.1 and 8.5). What has been learned from this research is also relevant to policy makers in different geographies and levels of development. This is because innovations – whether or not they are agri-tech based – need to provide environmental, economic and/or social improvements and also reduce the adopter's risk exposure when adopting them.

The research findings also provide useful insights for decisions when there is a need to balance sustainability aspects of growing fresh fruit and vegetables and land use policies when there is a need to raise the appropriate greenhouse or polytunnel structure (see Section 3.2.4). There needs to be a consistent policy that includes national and local government, and councils, which at present does not exist in many countries (see Section 6.5.5). There is a further consideration too; when a natural event such as a volcano has taken ground normally used for growing fruit and/or vegetables out of production, emergency planning policies for such events could take 3D farming into account. For example, the structures could help local communities produce food for themselves quite quickly on land not suitable for growing crops, although there would still be a need to provide means of irrigation. This could provide a means of growing valuable food at critical times.

The factors influencing the evolution of the business model detected in this study could also provide insights to policy makers when devising mechanisms for supporting successful agri-tech businesses with a sustainability focus to help them start to move out of the niche. Food policy considerations to create a third retail category to give consumers more choice; for example a ‘sustainably grown’ product which has been produced to a set standard (see Section 8.3.2). This would need to be promoted to ‘socially conscious’ consumers as an alternative to organically certified produce and also through education about what sustainability is about. By offering support at innovator, grower level and then promoting it to consumers, such policies would support a better business case for sustainability and thus increase momentum towards sustainable intensification.

9.4 Interactions with other literatures

Part of the academic contribution is the interdisciplinary nature of sustainable intensification because of how these different literatures, which all play a defined role in the quest for environmental sustainability while pursuing commercial activities, are interacting, emphasising a need for a holistic, interdisciplinary view. This research has illustrated that pathways towards sustainable intensification need not only interaction between the business model, diffusion of innovation and sustainability, but also with other academic literatures, such as agricultural and ecological economics, in addition to corporate social responsibility.

The discussion about weak and strong sustainability is one of the principal links with ecological economics in this study (see Sections 1.2, 2.2.3, 5.6.3 and 8.5.3), and has played a key role in building better understanding of how 3D farming can contribute to sustainability through the use of the whole-farm method advocated by LEAF. Agricultural and ecological economics literature has also provided important information for the study, particularly the literature on understanding the supply chain (see Section 2.3) and when considering the role of an agri-business entrepreneur (see Sections 2.4 and 7.4).While based on agri-food production sector, the findings could also relate to corporate social responsibility literature on entrepreneurial attitudes, as suggested in sections 2.4.1, 3.2.2 and 8.4).

Further studies using these relationships with the different literatures will help improve understanding of the need for interaction between social and technological elements to achieve better results for the environment in a commercial situation. For example, entrepreneurs in the agri-food industry may not want to save the world but survive in a market and earn sufficient profit to stay in business while minimising effects on the environment. Better understanding of the perceived value of an innovation by the different actors in the supply chain may contribute to facilitating further movement towards sustainable intensification.

Appendix I

Resource References

Table_Appdx 1: Interviews with case study informants

Date	Speaker	Company	Data collection	Code
01/08/13	Farmer 1	Farm Business	Interview for article	AS01
24/06/14	CEO	Saturn Bioponics	Visit Edgbaston, Birmingham	SB01
28/07/2014	Head of Horticulture	Soil Association	Email	ORG01
07/10/14	CEO	Saturn Bioponics	Email	SBE01
12/11/14	CEO	Saturn Bioponics	Telephone call	SB02
01/01/15	Grower 1	n/a	Telephone call	AS02
19/08/15	CEO	Saturn Bioponics	Email	SB03
17/12/15	CEO	Saturn Bioponics	Email	SB04
10/01/16	Grower 1	n/a	Interview	AS06
12/04/16	CEO	Saturn Bioponics	Stratford on Avon	SB05
23/04/16	CEO	Saturn Bioponics	Telephone call	SB06
01/06/16	Grower 2	N/A	Interview	AS10

Date	Speaker	Company	Data collection	Code
01/09/16	Knowledge Exchange Intermediary 3	n/a	Telephone call	SB07
11/10/16	CEO	Saturn Bioponics	Email	SB08
13/12/16	CEO	Saturn Bioponics	On-site visit, Stratford on Avon	SB09
12/01/17	CEO	Saturn Bioponics	Email	SB10
17/01/17	CEO	Saturn Bioponics	Interview	SB11
23/01/17	CEO	Aponic	On-site visit, Cambridge	AP01
30/01/17	Marketing Director	Vertical Farming Company 1	Skype call	VFC1
27/01/17	CEO	Vertical Farming Company 2	Skype call	VFC2
27/01/17	CEO	Saturn Bioponics	Email	SB12
20/02/17	CEO	Vertical Farming Company 3	Telephone call	VFC3
03/03/17	Director	Valefresco	Stratford on Avon	SB13
31/03/17	CEO	LEAF	Telephone call	IS01
01/06/17	Vegetable Grower	n/a	Interview	AS11

Date	Speaker	Company	Data collection	Code
01/07/17	Grower 1	n/a	Interview	AS09
28/07/17	Grower 2	n/a	Interview	AS12
07/09/17	CEO	Saturn Bioponics	Telephone call	SB15
19/09/17	CEO	Saturn Bioponics	Email	SB16
22/11/17	CEO	Saturn Bioponics	Telephone call	SB17
06/12/17	Scientific Speaker	n/a	Discussion at agronomists Conference	AS13
14/12/17	Intermediary 1	Knowledge Transfer Network	Telephone call	AS14
15/12/17	Intermediary 2	Knowledge Transfer Network	Telephone call	AS15
19/12/17	Innovation Intermediary 1	AgriTechE	Email reply to questions	AS16
10/01/18	Knowledge Exchange Intermediary 1	n/a	Interview	INT01
02/02/18	CEO	Saturn Bioponics	Saturn Bioponics visit	SB18
10/04/18	Fresh Produce Processor	n/a	Interview	INT02

Date	Speaker	Company	Data collection	Code
13/04/18	Vertical Farming Technologist 1	n/a	Telephone call	TE01
06/06/18	Knowledge Exchange Intermediary	n/a	Telephone call	TE02
19/06/18	CEO	Saturn Bioponics	Email	SB19
19/06/18	Knowledge Exchange Intermediary 2	n/a	Meeting	M15
27/06/18	Vertical Farming agronomy consultant	Harper Adams Conference	Conversation	HA01
08/08/18	Knowledge Exchange Intermediary 3	n/a	Interview, Dundee Scotland	AS17
12/08/18	Strategy Director	AHDB	Meeting	ME16
29/08/18	CEO	Vertical Farming Company 2	Telephone call	AS18
13/9/18	Representative	Valefresco	Email	SB201
14/09/18	Director	Valefresco	Telephone call	SB20
03/10/18	Grower 3	Farm Manager	Telephone call	AS27
12/10/18	Agronomist	British Crop Protection Council Conference	Interview	AS20

Date	Speaker	Company	Data collection	Code
21/11/18	CEO	Saturn Bioponics	Telephone call	SB25
22/11/18	CEO	Saturn Bioponics	Meeting	SB24
13/12/18	CEO	Saturn Bioponics	Visit: Harborne, Birmingham	SB21
15/12/18	CEO	Saturn Bioponics	Telephone Call	SB23
24/01/19	Processor 2	Packhouse procurement specialist	Interview	PR02
06/02/19	CEO	Saturn Bioponics	Meeting	SB24
03/10/19	CEO	Saturn Bioponics	Meeting	SB25
12/02/20	Grower 1	n/a	Telephone conversation	AS31
13/02/20	Agronomist	n/a	Telephone conversation	AS32
20/02/20	Director	Valefresco	Telephone conversation	SB26
25/02/20	CEO	Saturn Bioponics	Telephone conversation	SB27
27/02/20	Technical Coordinator	LEAF	Telephone conversation	IS02
28/07/20	Editor	Vegetable Farmer	Email	ED01

Date	Speaker	Company	Data collection	Code
28/07/20	Editor	Commercial Greenhouse Grower	Email	ED02
29/07/20	Agricultural researcher	n/a	Telephone conversation	AS33
03/08/20	Head of Marketing	H.L. Hutchinsons Ltd	Telephone conversation	AS34
04/08/20	CEO	Saturn Bioponics	Telephone conversation	SB27
05/08/20	CEO	Saturn Bioponics	Telephone conversation	SB28
03/09/2020	CEO	Saturn Bioponics	Email	SB29

Table_Appdx 2: Other sources

Date	Protagonist/Topic	Media outlet	Data type	Code
01/05/14	Saturn Bioponics	Commercial Greenhouse Grower p8	News article (no by-line)	SBP01
01/08/14	Farmer 1	Food and farming entry form	Competition entry	AS03
07/10/14	Saturn Bioponics	Horticulture Weekly	News article (no by-line)	SBP02
07/10/14	Saturn Bioponics	Fresh Plaza	News Article (no by-line)	FP01
15/12/14	Saturn Bioponics	Horticulture Weekly	News article (no by-line)	SBP03
01/01/15	Overbury Farm	Shropshire Star	News article (no by-line)	AS04
01/02/15	Food supply chain facing crisis	HortNews	Online article (no by-line)	SC01
15/05/15	Saturn Bioponics	BBC Radio 4 Farming Today	Radio	SBM01
01/09/15	Saturn Bioponics: Case study commercial hydroponics	Commercial Hydroponics	Online article	HP01
30/10/15	Saturn Bioponics	Fruitnet		SBP04
31/10/15	Saturn Bioponics	Agritrade News		SBP05
06/11/15	Guy Poskitt (NFU Horticulture Board)	Produce Business UK	Gill McShane	PB01
19/07/16	Saturn Bioponics	BBC Midlands Today https://www.youtube.com/watch?v=6a0J6Zd-R_c&feature=youtu.be	TV	SBM02
29/07/16	Saturn Bioponics	BBC Radio 4 Farming Today	Radio	SBM03

Date	Protagonist/Topic	Media outlet	Data type	Code
10/10/16	Overbury Farm	Farmers Guardian	No by-line	AS07
21/10/16	Saturn Bioponics	Hortidaily https://www.hortidaily.com/article/6029709/uk-commercial-pak-soi-grower-increases-yield-with-tower-system/	Internet article (no by-line)	SBP07
16/11/16	Saturn Bioponics	Horticulture Weekly	No by-line	SBP08
30/11/16	Andersons Centre Outlook 2017	Farm Business Consultants	Report	AC01
06/01/17	Underground farm hidden 30m below ground	Farmers' Guardian	By-line Olivia Midgely	GU01
01/02/17	Saturn Bioponics, Robbes, Urban Crops, Urban Produce & Aponic	Countrystore	By-line Heather Briggs	SBP09
01/03/17	LEAF	LEAF Global Impacts Report	Report	AS08
01/05/17	Saturn Bioponics	Greenhouse Grower	Trade Magazine	SBP11
01/06/17	Wantisden Farm	Potato Review	Trade Magazine	AS10
02/06/17	Aponic	Farmers Guardian pp26-27	Clemmie Gleeson	AS19
13/06/17	Valefresco	https://www.worcesternews.co.uk/news/15344595.students-discover-state-of-the-art-salad-growing/	Online journal	SBPVF01
20/06/2017	LEAF evaluation	https://www.ccri.ac.uk/evaluation-leaf-marque/	Report	LME01
01/07/2017	Elveden Estate	Vegetable Grower	Trade Magazine	AS20

Date	Protagonist/Topic	Media outlet	Data type	Code
01/08/2017	Seasonal worker shortage/labour	The Vegetable Farmer (p8)	No by-line	LAB01
01/09/2017	Grower 1	Food and farming Entry Award	Competition entry	AS21
06/10/2017	Farmer 2	Industry Award	Competition Entry	AS22
01/11/2017	Sustainability key to feed growing population	Arable Technology Guide p14	Article: no by-line	AS23
01/01/2018	Take cover in intensive rotations	Commercial Greenhouse Grower Pp 27-29	Article: no by-line	AS25
01/01/2018	Life cycle assessment	Commercial Greenhouse Grower p30	Article: No by-line	AS26
11/01/2018	Government 25 year plan	Horticulture Weekly online	By-line: Gavin McEwan	HW01
01/04/2018	Growing to new heights	Better farming	By-line: Lauren Arva	BF01
30/04/20018	Optimising the modern farm	Blog: Philips Growise website	By-line: Olga Kotsova	PG01
01/07/2018	Mini-revolution	Commercial Greenhouse Grower pp13-15	By-line: Adrian Tatum	AS26a
22/01/2018	Innovate UK Blog	https://innovateuk.blog.gov.uk/2018/01/22/changing-how-the-world-eats-saturn-bioponics-growing-revolution/	Blog	SBB1

Date	Protagonist/Topic	Media outlet	Data type	Code
01/07/2018	Solutions for the Future	Vegetable Farmer July 2018 p24	By-line: Rachel Anderson	VF02
08/08/18	Potatoes in Practice	Syngenta spray nozzles	Trade Fair Demonstration	TF03
31/07/18	Vertical Farming – does the economic model work	Nuffield Scholarship	Sarah Hughes	NU01
01/09/18	Crop Lighting – the next generation pp9-12 (Interview Rhydian Beynon-Davies)	Commercial Greenhouse Grower	By-line: Spence Gunn	AS26b
01/09/18	How low can we grow	Commercial Greenhouse Grower September 2018 Pp 31-33	By-line: Adrian Tatum	AS27
28/10/18	Opening doors to new growing technologies	Farmers Guardian p34	Article: Marianne Curtis	AS29
01/11/18	STC Vertical Farming development	Commercial Greenhouse Grower p8	No by-line	AS26c
28/11/18	Crop Tec	Sencrop field weather station	Trade fair demonstration	TF06
28/11/18	Crop Tec	Rothamsted pathogen/aphid monitoring	Trade fair demonstration	TF05
12/12/18	Alex Fisher - Prosperity UK Conference	https://www.youtube.com/watch?v=I3gDO5RIH0k	Conference YouTube	AS30
15/01/19	Agri-tech company	Press release	n/a	TF07

Date	Protagonist/Topic	Media outlet	Data type	Code
25/01/19	Valefresco	Sustainable Food Trust https://sustainablefoodtrust.org/articles/grower-nick-mauro-of-valefresco-reflects-on-brexit/	Online article	SBPVF01
25/01/19	Fruit Logistica Press release	https://www.fruitlogistica.com/Press/PressReleases/	Press release	PR01
28/01/19	Farming Monthly National	https://www.farmingmonthly.co.uk/news/shows-events/11188-saturn-bioponics-at-fruit-logistica/	Online article	FMN01
14/02/19	What is holding back controlled environment growing	Horticulture Weekly online	By-line: Gavin McEwan	PB02
26/02/2019	Sad days for Plantagon	Floral Daily	By-line: Arlette Sijmosma	PLA01
01/03/2019	What Plantagon's bankruptcy could tell us	The Spoon	By-line: Jennifer Marston	PLA02
10/03/19	CTO Saturn Bioponics	Arnoud Witteeven, LinkedIn profile. https://www.linkedin.com/in/arnoud-witteveen-027711a9/	LinkedIn account	LI01
12/03/19	Virginia smart farming conference report: Controlled environment agriculture on the rise	https://www.morningagclips.com/controlled-environment-agriculture-on-the-rise/	By-line: Virginia Farm Bureau Federation	GP1

Date	Protagonist/Topic	Media outlet	Data type	Code
12/03/19	SmartHort 2019 Farming conference: Horticulture on cusp of technological revolution	Press release	By-line: Lauren Colagiovanni, AHDB	GP2
14/03/19	Product launch	Rhiza precision agriculture system	Attendance at press launch	RH01
18/03/19	Alex Fisher	https://www.thetimes.co.uk/article/maserati-top-100-profiles-a-f-s2t3kfkg0	Inclusion in the Maserati Top 100 Profiles	PL01
19/03/19	Rhydian Beynon-Davies Head of novel growing systems	Stockbridge Technology Centre (STC)	Conference	STC1
19/03/19	AgriTech East	Conference: Bringing the Outside In	Conference	AG01
01/04/19	Growing to new heights	Better Farming	Trade magazine, no by-line	BF01
17/04/19	Optimising the modern farm	https://innovationorigins.com/optimising-the-modern-farm-with-leds-at-philips-growwise/	Online article, journalistic platform. By-line: Olga Koltsova	OMF01
24/04/2019	Saturn Bioponics + Valefresco	BBC Radio 4 Costing the Earth	Radio	SBM04
01/09/2019	Editorial	Vegetable Farmer p3	No by-line	VF03

Date	Protagonist/Topic	Media outlet	Data type	Code
07/10/2019	Plans unveiled for 40 vertical farms	Farm Business	Shockingly Fresh	SBSF01
24/02/2020	Midland vertical farm gets green light	Agronomist and Arable Farmer	Shockingly Fresh	SBSF02
03/06/2020	Step forward in growing strawberries	Fresh Plaza	Saturn Bioponics & Idromeccanica Lucchini SpA	SBIL01
05/05/2015	Defra Farm Statistics Report	Produced by Farming Statistics on request	Personal email	DEF01
07/08/2016	Defra Statistics	Agri-tech industrial strategy 2016	Personal email	DEF02
27/02/2018	Defra Press Office	See www.gov.uk/government/news/once-in-a-generation-opportunity-to-shape-future-farming-policy	Press release	DEF03
01/01/2009	Defra	https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/268691/pb13558-cogap-131223.pdf	Code of Good Agricultural Practice	DEF04
05/11/2020	Alex Fisher: Planning permission	https://www.forbes.com/sites/philipsalter/2020/11/03/seven-businesses-helping-britain-build-back-greener/amp/	Online report	FOR01

Table_Appdx 3: Selection of some of the Trade Fairs attended by Saturn Bioponics

Date	Name	Details/website	Attendance/ discussion/speech	Code
13/12/16	GrowQuip conference	Organised by Commercial Horticultural Association https://www.cha-hort.com	Conference speech by Alex Fisher, CEO of Saturn Bioponics	SBC01
03/11/16	World AgriTech Investment	https://worldagritechinnovation.com/about-us/	Conference speech Saturn Bioponics	SBC02
15/11/17	InnovateUK conference 'Feeding the World'	https://www.youtube.com/watch?v=BGr-2FjYZck	Speech by Arnaud Witween CTO of Saturn Bioponics	WW02
31/01/18	Fieragricola in Verona	http://www.fieragricola.it/it/la-113-edizione-di-fieragricola-di-verona-nel-2018	Trade Fair: Stand taken by Saturn Bioponics and Lucchini Idromeccanica	SBTF01
06/02/19 – 08/02/19	Fruit Logistica	https://www.messe-berlin.de/en/Organizers/EventCalendar/Event_25602.html	Trade Fair: Stand taken by Saturn Bioponics and Lucchini Idromeccanica	SBTF02
07/02 –09/02/20	Fruit Logistica	https://www.fruitlogistica.com	Trade Fair attended: stand taken by Saturn Bioponics and Lucchini Idromeccanica	SBTF03

Table_Appdx 4: Other vertical farming companies

Date	Name	Country	Basic business model	Contact	Code
2014-2019	Plantagon	Sweden	Growing crops and selling vertical farming (VF) equipment for urban farming (no longer trading)	Website, news and interviews	VF1
2017	Robbes	Finland	Growing fruit crops for Finnish market	Website, news and interviews	VF2
2017	Urban Crops	Belgium	Selling VF equipment	Website, news and interviews	VF3
2014-2019	Growing Underground	UK	Growing for restaurants & supermarkets; tourism	Website, news and interviews, conference speeches	VF4
2014-2019	Aponic	UK	Selling VF equipment	Website, news and interviews, conference speeches	VF5
2014-2018	Grow-up	UK	Selling VF equipment	Website, news and interviews, conference speeches	VF6
2019	Veloya	Germany	Grow-lights for VF	Website, news and third party interview	VF7
2019	Current by GE	UK	Grow-lights for VF	Website, news and third party interview	VF8

Date	**Name**	**Country**	**Basic business model**	**Contact**	**Code**
2019	Hydrogarden	UK	Hydroponic equipment	Website, news and third party interview	VF9
2019	Lettus Grow	UK	VF equipment	Website, news and third party interview	VF10
2019	Signify	Nether-lands	Growers	Website, news and third party interview	VF11
06/11/19	Jones Food Group	UK	Herb growers	Website, news and Agri-TechE conference speech	VF12
06/11/19	Phytoponics	UK	Aeroponic growing systems (using only water and nutrients)	Website, news and conference	VF13
06/11/19	Cambridge HOK	UK	Growing indoor baby-leaf salads	Agri-TechE Conference	VF14

Table_Apdx 5: Further information – Other trade events/ conferences

Date	Speaker and/or Innovation	Event name	Event type	Code
09/09/14 – 10/09/14	Presentations and discussions	International Conference on Vertical Farming and Urban Agriculture	Conference	NOT01
10/01/16	Jake Freestone, Overbury Farm	Oxford Real Farming Conference	Conference	AS05
06/12/17	Scientific Speaker	Agronomists Conference	Trade conference	AS13
08/08/17	Crop Systems' retro ventilation system	Sutton Bridge Crop Storage Research	Trade demonstrations	TF01
10/08/17	Agrovista's Crop app	Potatoes in Practice	Trade Fair demonstration	TF02
08/12/17	Presentations and discussions	Agronomists' Conference	Trade Conference	AS24
13/12/17	Presentations and discussions	Cambridge University Potato Growers Research Association	Trade Conference	CUP01
12/10/18	Presentation, speaker	British Crop Protection Council (BCPC) conference	Trade conference presentation	AS28
27/06/18	Harper Adams Urban Farming Conference	Vertical Farming Adviser	Personal discussion	HA04
28/06/18	Harper Adams Vertical Farming Conference	Presentation: Jonathan Lodge, City Farm Systems	Conference	HA01
28/06/18	Harper Adams Vertical Farming Conference	Presentation: Tom Webster, Grow Up Box	Conference	HA02
28/06/18	Harper Adams Vertical Farming Conference	Presentation: John Coppalonga	Conference	HA03

Date	Speaker and/or Innovation	Event name	Event type	Code
06/11/19	Presentations and discussions	Agri-Tech E Realising Economic Agricultural Potential	Trade Conference	AG02
05/02/20	Presentations and discussions	Advancing the use of biopesticides and IPM in field vegetables	Event/ Conference	AG03

Table_Appdx 6: Websites, online reports and webinars

Date	Platform/company	Website	Platform	Ref
08/12/17	Sustainable Intensification Research Platform	https://www.benchmarkmyfarm.co.uk/About	Webinar	SIRP1
n/a	European Innovation Partnerships (EIP AGRI)	https://ec.europa.eu/eip/agriculture/sites/agri-eip/files/eip-agri_brochure_knowledge_systems_2018_en_web.pdf	Website	M13
n/a	Peer-to-peer Learning: Accessing Innovation through Demonstration Peer to Peer	https://ec.europa.eu/eip/agriculture/en/find-connect/projects/peer-peer-learningaccessing-innovation-through	Website	M14
n/a	Idromeccanica Lucchini	https://www.lucchiniidromeccanica.it/en/company.php	Website	WW01
19/02/18	Sustainable Intensification Research	sipplatform.org.uk	Website	SIRP2

Date	Platform/company	Website	Platform	Ref
n/a	Innovate UK	https://www.gov.uk/government/organisations/innovate-uk	Website	WW03
n/a	Shockingly Fresh	https://www.shockinglyfresh.co.uk	Developers of sites for hydroponic farming	WW04
n/a	Knowledge Transfer Network	https://ktn-uk.co.uk	Website	WW05
n/a	Government’s 25-year Environment Plan (2018) P26	https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/693158/25-year-environment-plan.pdf	Report	GOV1
n/a	Innovate UK (on Government website)	https://www.gov.uk/government/case-studies/saturn-bioponics-uk-success-just-the-start-for-3d-crop-grower	Article	GOV2
05/11/19	Botanical herb extracts market 2019 - 2023	https://www.businesswire.com/news/home/20191105005585/en/Global-Botanical-Extracts-Market-2019-2023-Evolving-Opportunities	Market Report	MAKT 01

Date	Platform/company	Website	Platform	Ref
10/10/18	UK becoming a global leader in agri-tech	https://agfundernews.com/how-the-uk-is-becoming-a-global-leader-in-agritech.html	Market Report	AGT01
23/04/18	UK agri-tech companies on the rise	https://www.fgsagri.co.uk/uk-agritech-companies-on-the-rise/	Market Report	AGT02
01/06/19	Where next for soft fruit in the UK	https://d7tti9vs6rqbf.cloudfront.net/documents/188-8046-richard-harrison-where-next-for-soft-fruit-in-the-uk-3-.pdf	Nuffield Farming Scholarship Report by Dr Richard Harrison	NU02
06/10/20	Connecting Farmers with Technology	Agri-EPI Centre Annual Conference - Agri-tech	Webinar	EPI01

Table_Appdx 7: General trade conferences and shows attended

Years attended	Name	Type of event	Code
2014, 2015, 2016, 2017,2018, 2019	CropTec	Trade Show/ Exhibition/Discussions General/whole show	CR01
2014, 2015, 2016, 2017, 2018,2019	Cereals Events	Arable Event General/whole show	CER01
2015, 2016, 2017, 2018,2019	Agronomists' Conference	Conference General/discussions and speeches	AG01
2014, 2015, 2016, 2017, 2018, 2019	Potatoes in Practice	Event/ Conference General/discussions and speeches	POT01

Appendix II
Yield differences

Saturn Bioponics' business case is looking at cost savings and profit margins:

Gain in yield per square metre + Reduced costs of production = Increased profitability

Table AppdxII_1 Yield differences between conventionally grown crops and 3D grown crops using the Saturn Grower

Crop	Normal yield	Yield using 3D Growing technology	Increase in productio n	Potential other benefits
Pak Choi (Based on 200,000 plants)	3 kg/m2	Yield 11.5 kg/m2	Increase of 8.5 kg per m2 = 380 per cent	Reduced labour costs, No down time between crops + Faster growth rate = Additional 2 to 2.5 crop cycles per annum Reduced labour costs; 100% saleable yield; 0% root disease; Reduced pesticides; No ground preparation
Strawberries June bearer variety Elsanta Light	1.6 kg/m² @ 6. plants per m² in coir bag system 25	6.5 kg/m² @ 29 plants per m²	Gain of 4.9 kg/m² => 4 x yield increase	+ Faster growth rate + Reduced water use by 80 to 85% + Reduced costs of production

Source: Saturn Bioponics' crop data

Appendix III
Information Sheet

The potential of vertical farming to provide sustainable means of food production in Europe

Heather Briggs would like to visit your company premises to gain more in-depth understanding of vertical farming. Before you accept her request, please read the following information concerning the visit. If you would like any further information or clarification, please do not hesitate in asking for it.

1. Purpose of the project

Future population growth will result in challenges for food producers. There is evidence that demand for food will increase as the global population grows, with particular emphasis on the first half of the 21st century. This places a burden on food production that is currently experiencing flat-lining yield increases and a number of environmental concerns and one of the potential means to address this concern is to make use of vertical space to grow high density indoor crops. It is therefore vital to increase understanding the potential role of vertical farming could play in growing fresh produce by sustainable means.

The project is part of a PhD that will look at the case studies in the vertical farming sector to explore what they consider to be their contribution to sustainably obtaining higher yields, how they communicate about their innovation and their business model.

2. Visits to your company

Your enterprise has been chosen because of its relevance to vertical farming. I believe that because you are actively involved in the management and operation of your organization, you are the person best suited to speak to me about various subjects.
These include:

- Your company's business model and your core value offerings
- How your business model is based around your innovation
- Your priorities, and whether moving towards sustainable intensification is one of them
- The networks with which the business engages and the opinion leaders in your sector

- How you communicate information about sustainable information, its practices and your products
- With your permission, views will be sought from yourself and also your key staff about a number of concepts such as sustainable intensification.
- Contribution to sustainable food production with higher yields.

I am also very interested how you have approached technical and agronomic challenges that could lead to greater sustainable intensification.

Participation will involve a number of face-to-face interviews of approximately two hours at your company offices or trials areas, plus time looking round the installations over a time period of three years. Questions will be designed to gain greater understanding of vertical farming, your networks, how you communicate with your customers, and the role of your innovative product to creating value as part of your business model. Information gained from the interview may be used when publishing the results of the research. Any confidentiality requested will be respected and anonymity can be maintained if requested.

3. How the evidence will be used

The research for this PhD is self-funded. It is not linked with or reliant on any other company or third party.

With your permission, the interview will be recorded to facilitate analysis which will become part of the PhD and interviewees will be shown draft articles for their comments in terms of accuracy of what is quoted or attributed to them. The material may be used in press articles and/or peer-reviewed journals. If you request anonymity, this will be respected

Evidence will be collated and used to analyse the relationship between vertical farming, sustainable intensification, diffusion of innovation and business models. Permission will be sought before using any confidential material for public viewing.

4. Participation

Participation is entirely voluntary and the final decision about participation is yours. This study has been reviewed by the Research Ethics Review Board at the University of Leeds and approval granted.

5. Contact details

Researcher: Heather Briggs.

PhD supervisor: Dr Anne Tallontire.

Information sheet received:

Agreement to participate:

Date:

Signed:

Appendix IV

Ethical Review

Performance, Governance and Operations
Research & Innovation Service
Charles Thackrah Building
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UNIVERSITY OF LEEDS

Heather Briggs

School of Earth and Environment

University of Leeds

Leeds, LS2 9JT

ESSL, Environment and LUBS (AREA) Faculty Research Ethics Committee

University of Leeds

19 August 2015

Dear Heather

Title of study:	**The potential of vertical farming to provide a sustainably intensified means of food production in Europe**
Ethics reference:	**AREA 15-003**

I am pleased to inform you that the above research application has been reviewed by the ESSL, Environment and LUBS (AREA) Faculty Research Ethics Committee and following receipt of your response to the Committee's initial comments, I can confirm a favourable ethical opinion as of the date of this letter. The following documentation was considered:

Document	Version	Date
AREA 15-003 Ethical_Review_Form-150801v2.docx	2	17/08/15
AREA 15-003 Case study consent form.doc	1	17/08/15
AREA 15-003 Fieldwork Risk Assessment form+AT.doc	1	05/08/15
AREA 15-003 Consent form company.doc	1	04/08/15
AREA 15-003 Consent form.doc	1	04/08/15
AREA 15-003 Letter Callum Murray Innovate UK.docx	1	04/08/15
AREA 15-003 Letter of confirmation.docx	1	04/08/15
AREA 15-003 Letter of introduction.docx	1	04/08/15
AREA 15-003 Memorandum of participation.docx	1	04/08/15

Committee members made the following comments about your application:

- Should there be any amendments to the anticipated outcome regarding the commercial agreement with the company, you may need to come back to the ethics committee. It sounds as though the commercial agreement is not yet made, and that there is the potential for the companies to insist on outcomes that do not suit the researcher/ research or that change the nature of the researcher/ research.

Please notify the committee if you intend to make any amendments to the original research as submitted at date of this approval, including changes to recruitment methodology. All changes must receive ethical approval prior to implementation. The amendment form is available at http://ris.leeds.ac.uk/EthicsAmendment.

Please note: You are expected to keep a record of all your approved documentation, as well as documents such as sample consent forms, and other documents relating to the study. This should be kept in your study file, which should be readily available for audit purposes. You will be given a two week notice period if your project is to be audited. There is a checklist listing examples of documents to be kept which is available at http://ris.leeds.ac.uk/EthicsAudits.

We welcome feedback on your experience of the ethical review process and suggestions for improvement. Please email any comments to ResearchEthics@leeds.ac.uk.

Yours sincerely

Jennifer Blaikie

Senior Research Ethics Administrator, Research & Innovation Service

On behalf of Dr Andrew Evans, Chair, AREA Faculty Research Ethics Committee

CC: Student’s supervisor(s)

Appendix V
Glossary

Agronomist: Person qualified in agronomy; in the UK they are BASIS and FACTS qualified

Agronomy: The science and technology used for producing crops

Biological plant protection: The use of natural plant defence mechanisms and predation to control pests and disease. They can include bacteria and fungi; beneficial predatory organisms, pheromones and plant extracts

Combinable crops: Crops that are harvested using a combine harvester, including cereals (e.g. oats, wheat, barley) and oilseed rape

Cultivar: Plant variety developed by selective breeding for certain desirable characteristics

GAP: A Code of Good Agricultural Practice published by Defra for protection of water, soil and air

Green Area Index (GAI): The ratio of green leaf area to the ground area. This is important to building yield because to be able to photosynthesise, the leaves have to be green.

Hydroponic: The process of growing crops without soil in sand, gravel or other media such as rockwool or clay balls.

Levy body/board: Non-departmental public body funded by a statutory levy; for example, in agriculture the funding is from producers and the supply chain

Plant protection: Means of managing plant health through the use of natural and synthetic products, physical barriers and the controlled use of predators

Three-dimensional farming: See vertical farming below

Vertical Farming : Use of the vertical plane to grow crops in structures such as towers or on walls. During the time of this study has taken place the terminology 'vertical farming' has become synonymous with urban farming, which is a distinct sub-sector, often run by enthusiastic amateurs with social rather than commercial objectives, rather than the professional operations which have been the target of this work. As a result, this thesis uses the terminology three dimensional or 3D farming.

Appendix V

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