Introduction and adoption of technical innovations

– a study of sustainable production of leafy vegetables in different production systems

Annie Drottberger

Swedish University of Agricultural Sciences, SLU
Faculty of Landscape Architecture, Horticulture and Crop Production Science
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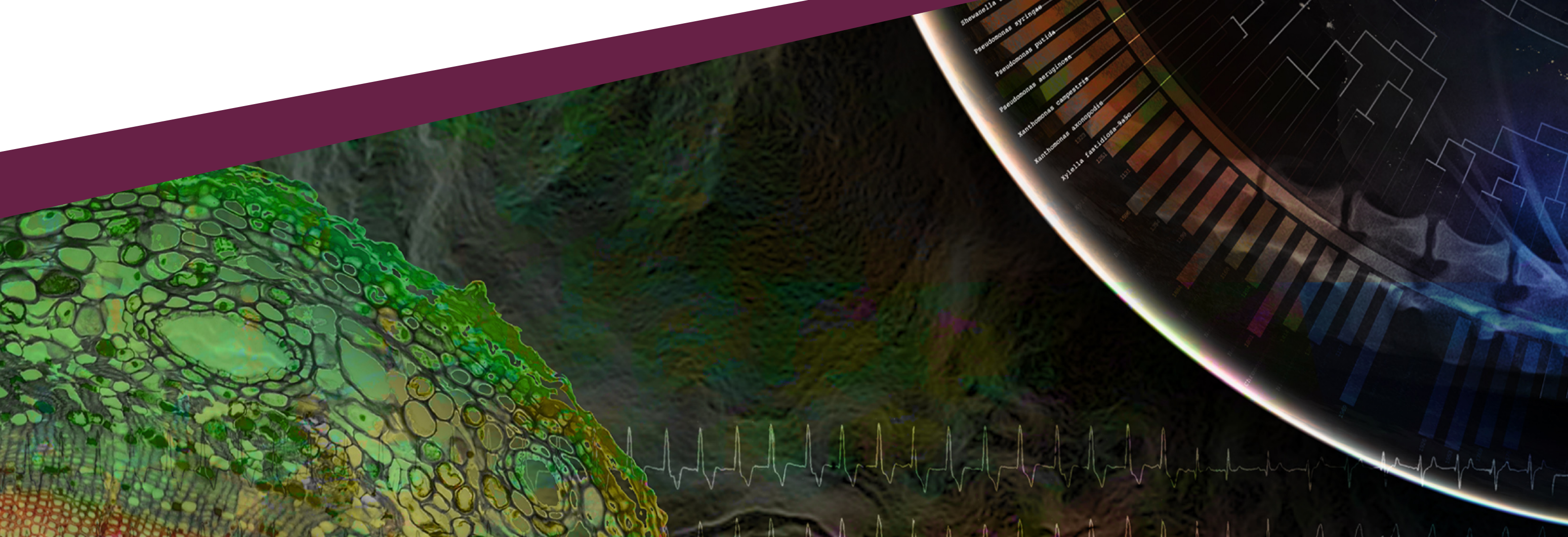

Introduction and adoption of technical innovations – a study of sustainable production of leafy vegetables in different production systems

Annie Drottberger — Swedish University of Agricultural Sciences, Department of Biosystems and Technology

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Abstract

Production of leafy vegetables can take place in a variety of different production systems. Open field and greenhouse production have traditionally been used but alternative production systems with advanced technologies have started to appear lately, e.g. Plant Factories with Artificial Lighting (PFAL). This opens up for new opportunities with increased attention from venture capitalist and investors highlighting food-tech as a new field of interest. At the same time, the technology development can open up for possibilities mainly for firms producing leafy vegetables in greenhouses if they can adopt relevant knowledge and innovations from different production systems. There is also an increased interest for start-up initiatives and businesses in urban settings e.g. urban farming, vertical farming, aquaponics or roof top farms to mention a few models (Thomaier et al., 2015). In contrast, there is furthermore low tech initiatives with market gardening, CSA (community supported agriculture) and small-scale artisan production that can also be important niches for sustainable production of vegetables (Drottberger et al., 2021). These different initiatives can be seen as positive movements influencing society and increasing consumers' awareness when it comes to food production since the producers often use different business models and alternative food networks compared to the traditional value chain (ibid.). But the fact that new actors are entering the market could also create tensions between urban and rural contexts due to the different backgrounds of the grower and sometimes different possibilities for the businesses e.g. depending on support and policies from society.

Keywords: greenhouse, horticulture, hydroponics, innovation, LED lighting, vertical farming

Preface

The adoption of technical innovations in leafy vegetables is a topic of importance to increase the competiveness of Swedish production on the European market. However, there is a need to look into the economic perspective, but also to consider environmental and social issues to be able to find alternative technological innovations and further develop the production systems in an efficient way. Investments in technological innovations such as solid-state (LED) lighting, energy solutions, automation, packaging, hydroponics, artificial intelligence (AI), vertical farming, water recirculation, and climate control can lead to competitive advantages for the horticulture firms, but there could also be reasons for non-adoption for various reasons. This literature review will connect key concepts in innovation theory and sustainability science for vegetable production for an increased understanding about the relation between innovations and production of leafy vegetables. The purpose is to describe the literature in the area of adoption of innovations in agri-food firms focusing on sustainable horticulture and from there, elaborate on the development for this research.

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1. Introduction

Society is facing serious challenges such as e.g. destruction of natural ecosystems, loss of biodiversity, and climate change (IPCC, 2019). This is occurring in combination with an increasing population and urbanization, which puts pressure for increased food production and a transformation of the food system to more sustainable production. One of the solutions to these challenges could be an increased adoption of knowledge and technical innovations in firms producing food.

The diffusion and adoption of innovation in agriculture represents a topic in the literature which will be the main focus of this literature review. The theory on diffusion of innovation was put forward by Rogers (1962) and built on studies of agriculture in the US. It explains how an innovation spreads through a population or social system, where the result is that the innovation is adopted (Rogers, 2003). The primary aim of this study has been to describe the framework behind the model of diffusion of innovations in agri-food firms based on Rogers (2003) and his theory. The results may be used to identify knowledge gaps for future research on particular topics related to the diffusion and adoption of innovations. Some of the preliminary results of this PhD project will also be presented, which has the overall aim to understand adoption of knowledge and technological innovations in horticultural production systems and explore attitudes to new technologies among producers employing the systems.

The review begins with an introduction to diffusion and adoption of innovations followed by a description of various key concepts related to innovation theory. This is followed by a description of the horticultural sector in Sweden mainly focusing on production of leafy vegetables in three different production systems (open field, greenhouse and PFAL), focusing on technology adoption. Finally the concept of sustainability in agriculture and horticulture and how economic, environmental and social concerns can be aligned will also be briefly covered. This will give a broad definition to the adoption of technical innovations in leafy vegetables for an improved understanding of the opportunities and challenges for the firms in a transforming society and food system.

2. Innovation theory

In the following sections, key concepts related to diffusion and adoption of innovations are explained.

2.1. Diffusion of innovations

There are four main elements in the diffusion of innovations and it is defined as the process by which (1) an innovation (2) is communicated through certain channels (3) over time (4) among the members of a social system (Rogers, 2003). An innovation is defined as an idea, practice or object that is perceived as new by an individual or other unit of adoption. The perceived newness of the idea for the individual determines his or her reaction to it. If the idea seems new to an individual it is an innovation (ibid.). Focusing on technological innovations, the definition of a technology is a design for instrumental action reducing the uncertainty in the cause-effect relationships involved in achieving a desired outcome (ibid.). The social system has structure or patterned arrangements of the units in the system, and is engaged in joint problem solving to accomplish a common goal. One aspect of social structure is norms seen as the established behaviour patterns for the members of the social system (ibid.).

When describing the adoption of innovations the population can be categorized in different adoption categories according to Rogers (2003):

- *Innovators* are the first farmers in their market to use a certain innovation.
- *Early adopters* are those farmers who indicate to belong to the first quarter of adopters of a certain innovation, relative to the full range of potential adopters.
- *Late adopters* are those farmers who adopted an innovation, but did not belong to the first quarter of potential users.
- *Non-adopters* are farmers who did not introduce any kind of new technology.

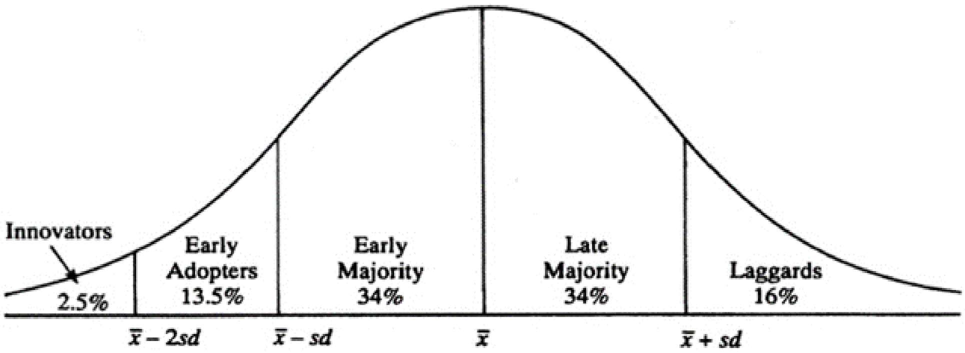

Figure 1. Adopter categorization based on the adoption of innovations (Rogers, 2003).

2.2. Innovation decision process

The innovation decision process according to Rogers (2003) describes the process through which an individual passes from gaining initial knowledge of an innovation, to forming an attitude toward the innovation, to making a decision to adopt or reject, to implementation of the new idea, and to confirmation of the decision.

Technology transfer is another phenomenon that is important to understand correctly and there are three possible levels of technology transfer (ibid.):

1. Knowledge where the receptor knows about the technological innovation

2. Use where the receptor has put the technology into use in his or her organization. This level of technology transfer is much more complex than just knowing about the technology. The difference is equivalent to the knowledge stage in the innovation decision process.

3. Commercialization – receptor has commercialized the technology into a product that is sold in the market place.

Technology transfer often fails and is difficult because we have underestimated just how much effort is required for such transfer to occur effectively. For example when it comes to commercialization, the packaging of research results need to be ready to be adopted by users (ibid.). Here change agents defined as the individuals that attempt to influence clients' innovation-decisions in a way that is deemed as desirable by a change agency could be of main importance.

However the ”adoption and diffusion of innovations perspective” has been criticized theoretically for the intervention practices it has inspired (Leeuwis, 2013). One example is the pro-innovation bias which is the assumption that the innovations studied are considered worthwhile, and that it would make sense for most farmers to adopt them (Roling, 1988). In practice however, many innovations are proposed which do not make sense for many farmers. Conventional adoption and diffusion research tended not to correct for relevance when calculating adoption indexes (Leeuwis, 2013).

2.3. The firm and surrounding innovation ecosystem

Different firms have chosen different strategies when it comes to innovation processes. According to Porter's common competition theory there are three general strategies for improving the competition capacity; low price, differentiation and focusing (Porter, 1998). To gain competition advantages, the firm must make strategical choices to position oneself so its capabilities provide the best defence against competitors. It is important to predict changes in factors and underlying forces to make it possible to respond to industry's needs (ibid.).

A value network is the context where a firm competes and solves customers' problems (Christensen and Rosenbloom, 1995). But another alternative could be to focus on technological capabilities and organizational dynamics to become competitive (Lam, 2005). The absorptive capacity is the ability of a firm to recognize the value of new, external information, assimilate it and apply it to commercial ends, which is critical to its innovative capabilities (Cohen and Levinthal, 1990). These skills and capabilities will affect the firms´ strategies and innovation processes concerning decision-making when it comes to adoption of innovations.

The Innovation Ecosystems thinking involves transitions to more sustainable agriculture and requires the formation of innovation niches (Elzen et al., 2012, Meynard et al., 2017). This conceptualizes the need for cross-sector interactions to facilitate transboundary innovation (Walrave et al., 2018) and therefore may make a contribution in expanding the scope of traditional Agricultural Innovation System thinking (Pigford et al., 2018). As an example, this is recognized in agroecology which has sought to integrate multiple scales to advance innovation and scaling of novel agroecological systems (Dalgaard et al., 2003). Innovation Ecosystems thinking may offer a useful umbrella concept that is suitable for the wider multi-functionality of agricultural systems, with the potential to better support development of transboundary innovation niches designed to realize innovation in support of sustainability (Pigford et al., 2018).

3. Production of leafy vegetables

The production of leafy vegetables is increasing and in 2018, the production was 8 200 tonnes in Sweden (Swedish Board of Agriculture, 2020a). The Swedish production of iceberg lettuce (including leafy vegetables and baby leaves) has been around 25 000–30 000 tonnes during the last years, with yearly variations. The cultivation of leafy vegetables in greenhouses and frames was as presented in Table 1 during 2008-2017 (Swedish Board of Agriculture, 2018):

Table 1. Overview of production of leafy vegetables in various production systems during 2008-2017 (Swedish board of Agriculture).

Production system	**Product**	**2008** Area (m^2)	**2011** Area (m^2)	**2014** Area (m^2)	**2017** Area (m^2)
Greenhouse	Lettuce grown in pots	44 119	69 909	56 225	47 199
Greenhouse/PFAL	Other salad	57 388	47 455	57 216	46 185
Greenhouse/PFAL	Fresh herbs	90 730	77 075	95 479	99 405
Open field	Iceberg lettuce	1 222	1 128	1 168	968
Open field	Dill	158	156	194	176
Open field	Spinach	161	167	114	39

From a European perspective about 2.2 million hectares of land in the EU was used to produce fresh vegetables in 2017, the equivalent of 1.2% of all the EU's utilised agricultural land. The group of fresh vegetables that comprises leafy and stalked vegetables, such as lettuce, spinach, chicory, endives, asparagus, artichokes, etc., were produced on 18.1% of the EU's fresh vegetables area and brassicas (cabbages, cauliflowers and broccoli) on 12.5%. The areas planted to fresh vegetables in Italy was 17.8% of the EU total, Spain 17.3%, France 11.8% and Poland 10.8%, were considerably more than other Member States and together represented a clear majority of the area planted to fresh vegetables in the EU in 2017 (EUROSTAT, 2018). When looking at the European market, fresh fruits and vegetables were traded mainly within the EU. Three Member States accounted for more than two-thirds of intra-EU exports in value terms; these were Spain (33.3%), the Netherlands (26.8%) and Italy (10.9%). Spain accounted for a majority of the value of intra-EU exports of lettuce and chicory (51.1%) (ibid.).

3.1. Horticultural market

The market for leafy vegetables has been rapidly growing over time and is offering appealing products to consumers (Saini et al., 2017). Alongside a growing market, the consumption of leafy vegetables has increased and is considered to continue doing so according to trading operators (Fernqvist and Göransson, 2021). As an example, Swedish per capita consumption of fresh vegetables increased from approximately 15 kg/person, year since the 1960s to 47.1 kg in 2015 (Swedish Board of Agriculture, 2018).

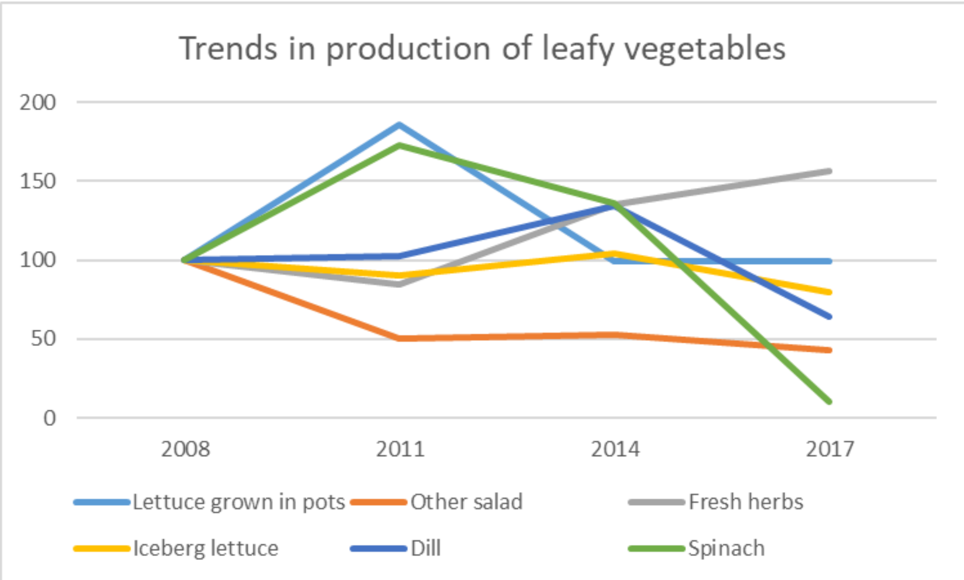

Figure 2. Trends in production of leafy vegetables between 2008-2017, based on statistics from Swedish board of Agriculture.

The Swedish production of leafy vegetables (excluding Iceberg lettuce) was 8 200 tonnes in 2018 (Swedish Board of Agriculture, 2020a). However, the production of leafy vegetables and baby leaves is significantly smaller than the production of iceberg lettuce which was estimated to around 25 000 tonnes in 2017, although the production has declined in recent years as shown in Figure 3 based on statistics from the Swedish Board of Agriculture (2020a). The production of fresh herbs grown in greenhouses (including PFALs) is the only studied crop which has increased from 2011 until 2017 (Fig 3).

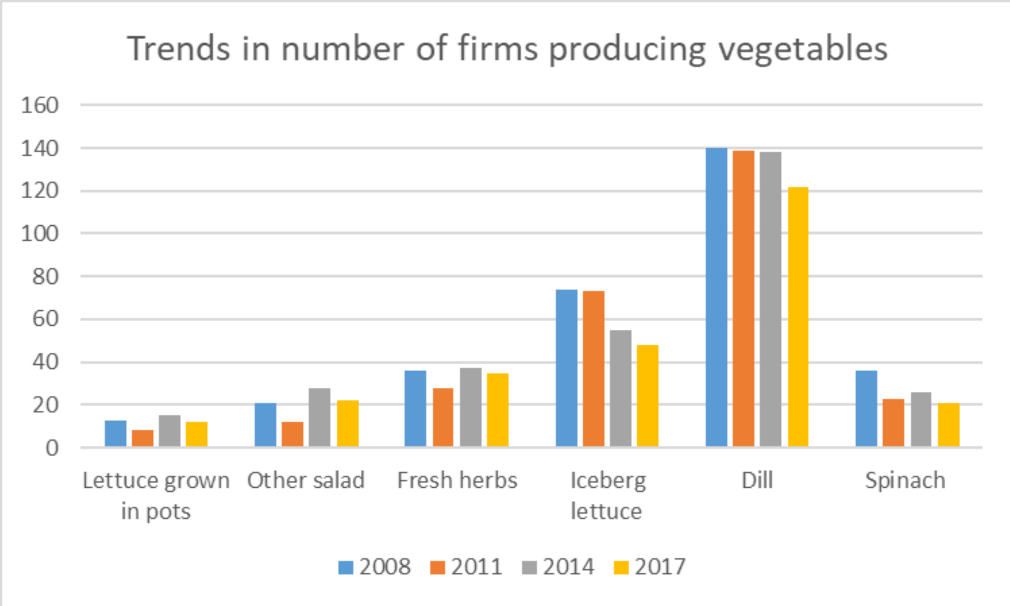

Figure 3. Trends in number of firms producing vegetables in Sweden between 2008-2017 based on statistics from Swedish board of Agriculture.

3.2. Adoption of technical innovations in leafy vegetables

Leafy vegetables can be grown in different production systems, such as open field production, greenhouses, and PFAL (Plant factories with Artificial lighting). These different production systems have adopted different technologies that are compatible with the chosen production system e.g. LED lighting, energy solutions, automation, packaging, hydroponics, AI, vertical farming, and water recirculation. In the first exploratory study, the role of adoption of technical innovations in production of leafy vegetables has been investigated. A qualitative study was conducted to investigate the adoption of technical innovations in three different production systems; open field, greenhouse and plant factories with artificial lightning (PFAL). A total of 15 owners/managers (5 from each production system) was interviewed using semi-structured questions. The results from this study will be presented in depth in a future scientific journal article. Therefore I have chosen to not elaborate on this in my introductory paper, but I will present some preliminary results briefly. In figure 1 is a description of how the firms in the different production systems have decided on adopting different innovations and technologies.

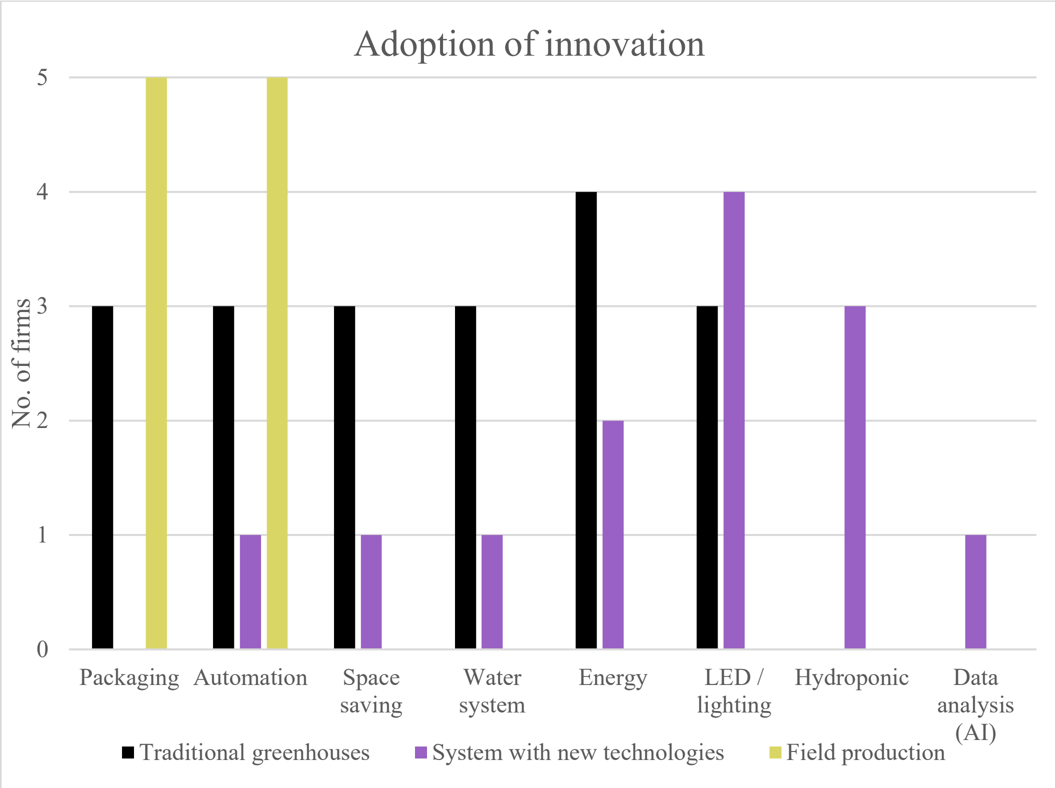

Figure 4. Description of how firms in different production systems are adopting innovations and technologies.

The firms producing leafy vegetables in various production systems have different business strategies to adopt technical innovations. The share of innovative firms is comparably high in the food industry, trade and restaurants, but despite this, the degree of refinement is not increasing. A low level of education and an aging labour makes primary production lagging behind when it comes to adoption of innovations. Less than a third of the agricultural firms have introduced a new or improved product or process between 2016 and 2018, which is considerably less than in other sectors. Knowledge and innovation is of central meaning to the food chain's long-term development. Over time, the level of education in the food chain needs to increase if the firms should be able to assimilate new technologies and research. As the production becomes more high-tech and knowledge-intensive, this influences the need for knowledge to be able to stay competitive. There is a risk of Swedish food production firms to fall behind when it comes to the global development, if this does not change (Swedish Board of Agriculture, 2020b).

4. Sustainable horticulture

The concept of sustainable agriculture involves three areas of concern namely, economic, environmental, and public welfare (Weil, 1990); but rarely do these factors hold equal weight in agricultural decisions. The UN sees economic growth as imperative to sustainable development, and believes that it can enable social and economic goals to be met by trickle-down effects (United Nations, 2015). Since the Sustainable Development Goals (SDGs) put forward by the UN in the above cited Agenda 2030 (ibid.) has become a working definition of sustainable development in political contexts, their perspective is very influential in practice. Since sustainability depends on social, political and economic factors, these factors cannot be divorced from the definition of sustainable agriculture (Altieri, 1987).

When it comes to evaluating the sustainability of a production system, it is easier to judge the direction in which a new technology or policy will move an agriculture system than it is to judge the absolute sustainability of a system the way it is (Weil, 1990). Below I have elaborated on the core concepts of sustainability science as a way to further categorize my results from interviews concerning adoption of technical innovations in sustainable production of leafy vegetables.

4.1. Economic concerns

Economic concerns are often in focus when discussing sustainability with growers. If the innovations are expensive, this will limit the possibility to adopt new innovations. The main focus for the firm is to stay competitive and make a profit and this will affect which investments are selected e.g. new technologies such as LED lighting, renewable energy systems, recirculation of water, automation, digitalization and vertical farming. When it comes to the specific innovation of vertical farming, the firms adopting this technology are often start-up initiatives involved with venture capitalists which will affect their possibilities to adopt new technologies in a positive way. In the next step, this affects the market situation and competition between firms from different production systems in various ways.

4.2. Environmental concerns

Environmental concerns are often of importance but different firms are more or less concerned about environmental issues. The growers producing leafy vegetables and herbs in traditional greenhouses are for example organic producers. The firms using hydroponics in vertical farming production systems are however not allowed to label their produce as organic but there are other ways of focusing on environmental values such as not using pesticides and shorter transports of crops due to the location of the firm (for example nearby urban locations). When it comes to the use of energy, however, greenhouses and open field production are using light from the sun whilst this is rare in vertical farming systems. Open field production often needs to use more water and pesticides but the production is more profitable from an economic perspective as there is no need to invest in a greenhouse or a PFAL. To be able to compare the production systems from a sustainability perspective, several factors should be considered.

4.3. Social concerns

Social concerns and the use of networks for knowledge transfer are some of key factors to ensure competitiveness according to the firms. Some firms also highlight that they prioritize social innovations instead of latest technologies. This could for example mean a strategy where they choose to focus on new crop varieties or keeping the labour to produce crops in soil with handcraft instead of in factories in a more industrial way with latest technologies, as expressed by some growers. This could perhaps be more appealing to the consumer as well but this needs to be evaluated further. The use of networks for knowledge uptake such as grower groups, advisors, contacts with representatives from the value chain or university expertise are also mentioned as a way of gaining knowledge and develop the firm.

5. Discussion

The focus of this review is the role of innovation in sustainable horticulture and how different firms are adopting new technologies. The phenomena of adoption of innovations and knowledge is highly important to understand what is really going on when it comes to innovations in horticulture. When adding the perspective of sustainability science, this enhances another layer of inquiry concerning the way firms are making decisions about adoption of innovations. The capabilities and strategy of each firm affects how they decide to relate to sustainability.

Future research of interest would involve additional interviews with firms producing vegetables in different production systems to further understand the differences between traditional greenhouse producers and other newly established initiatives, such as PFALs. This would be interesting to get a deeper understanding of the firms' decision processes and to compare the adoption of innovations and knowledge, as well as attitudes to future technologies. To follow the same firm over a longer time in a longitudinal case study would also give a broader picture and show what happens after the start-up phase in the newly established firms. Another interesting issue is to investigate the development of the political climate and how this will affect the businesses over time. Investigating the adoption of technical innovations in production of leafy vegetables can help the sector to anticipate future improvements, and thereby support stakeholders in their future decisions.

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