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OPEN INNOVATION FOR SUSTAINABLE AGRICULTURE: A TECHNOLOGICAL HUB CASE STUDY.

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Research Proposal

Master's in Innovation and Technological Entrepreneurship

Supervised by

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2023

Honor Pledge

I declare that the present research proposal for my master dissertation is of my own authorship and has not been previously used in another course or curricular unit of this or any other institution. References to other authors (statements, ideas, thoughts) scrupulously respect the rules of attribution and are duly indicated in the text and the bibliographical references, in accordance with the referencing rules. I am aware that the practice of plagiarism and self-plagiarism constitute an academic offense.

Acknowledgements

I am deeply grateful to my supervisor, Cristina Machado Guimaraes, for her unwavering belief in me, endless patience, and valuable feedback. Her genuine enthusiasm and positive outlook have been a constant source of inspiration during the most challenging moments of my life. I am also indebted to my professor, João José Pinto Ferreira, for generously sharing his knowledge and expertise, which have been instrumental in shaping my journey.

None of this would have been possible without the unwavering support of my family, who have always been there for me, even from a distance. Their unwavering belief in me has kept my spirits high and my motivation strong throughout this process. My parents have made my dreams come true by providing me with the best educational opportunities and teaching me the true essence of life's journey. My sisters have been a constant source of inspiration, helping me navigate life's challenges with their unwavering support. I want to express my heartfelt gratitude to my daughter, Maya, whose presence on this journey has propelled me forward. Thank you for attending classes with me and for your adaptability and easy-going nature during the times I needed it most. You have been the best partner I could have asked for during this experience in Portugal. I would also like to extend my thanks to my friends from Brazil and around the world for their emotional support and motivation. Your presence has made a significant difference in my life. Lastly, I am grateful to my classmates for the meaningful conversations, moments of exchange, empathy, and the lighthearted and relaxing times we shared together. Your friendship has brought joy and camaraderie to this journey.

Abstract

According to the United Nations Department of Economic and Social Affairs (UNDESA), the global population is projected to reach 9.3 billion by 2050, leading to a substantial increase in crop production demands. In this context, smallholder farmers play a crucial role as they currently produce about one-third of the world's food. However, they face challenges such as limited resources, lack of access to information and markets, and biased research and development towards large-scale producers. These factors create a cycle of poverty and exclusion, preventing small farmers from adopting sustainable practices and technological innovations, which can result in lower productivity, incomes, and environmental degradation.

This research explores the transition towards sustainable agriculture through open and inclusive innovation. The case study focuses on a technological hub that serves as a catalyst for collaboration, knowledge sharing, and technology adoption in the agricultural sector. By fostering partnerships between academia, industry, government, and civil society, the hub aims to address the challenges faced by small rural producers and promote the adoption of sustainable practices and technologies. Through education, training, and the use of cutting-edge technologies, the hub seeks to improve productivity, reduce environmental impact, and enhance the overall sustainability of agricultural systems. The case study highlights the importance of open innovation and technology in driving the transformation towards sustainable agriculture and improving the livelihoods of small rural producers.

Keywords: smallholder farmers, sustainable agriculture, open innovation, technology

Resumo

De acordo com o Departamento de Assuntos Econômicos e Sociais das Nações Unidas, a população global deverá atingir 9,3 bilhões até 2050, o que levará a um aumento substancial na demanda por produção agrícola. Nesse contexto, os pequenos agricultores de pequena escala desempenham um papel crucial, uma vez que atualmente produzem cerca de um terço dos alimentos do mundo. No entanto, eles enfrentam desafios como recursos limitados, falta de acesso a informações e mercados, além de pesquisas e desenvolvimento tendenciosos para produtores em larga escala. Esses fatores criam um ciclo de pobreza e exclusão, impedindo que os pequenos agricultores adotem práticas sustentáveis e inovações tecnológicas, o que pode resultar em menor produtividade, renda e degradação ambiental.

Esta pesquisa explora a transição para a agricultura sustentável por meio da inovação aberta e inclusiva. O estudo de caso concentra-se em um hub tecnológico que serve como um catalisador para colaboração, compartilhamento de conhecimento e adoção de tecnologia no setor agrícola. Ao promover parcerias entre academia, indústria, governo e sociedade civil, o hub visa enfrentar os desafios enfrentados pelos pequenos produtores rurais e promover a adoção de práticas e tecnologias sustentáveis. Por meio da educação, treinamento e uso de tecnologias de ponta, o hub busca melhorar a produtividade, reduzir o impacto ambiental e aprimorar a sustentabilidade geral dos sistemas agrícolas. O estudo de caso destaca a importância da inovação aberta e da tecnologia na condução da transformação rumo à agricultura sustentável e na melhoria da subsistência dos pequenos produtores rurais.

Palavras-chave: agricultores de pequena escala, agricultura sustentável, inovação aberta, tecnologia.

List of Acronyms

1. AI - Artificial Intelligence
2. CAB - “Cultivando Água Boa”Project
3. CC- Climate Change
4. CE - Circular Economy
5. EU - European Union
6. FAO - Food and Agriculture Organization
7. FH - “Farm Hack” Project
8. GGE - Greenhouse Gas Emissions
9. GPS - Global Positioning System
10. IoT - Internet of Things
11. LSM - Lean Startup Methodology
12. NGO - Non-Governmental Organization
13. SAH - “Smart Agri Hubs” Project
14. SD - Sustainable Development
15. SDGs - Sustainable Development Goals
16. UN - United Nations
17. UNDESA- United Nations Department of Economic and Social Affairs
18. US - United States

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Chapter 1. Introduction

According to UNDESA, the earth's inhabitants will achieve a total of 9.3 billion by 2050, demanding a 70-100% add in crop production worldwide considering the shift in dietary, the consumption growth and the income increase trends (Bruinsma, 2009; van Wart, Kersebaum, Peng, Milner & Cassman, 2013). Furthermore, evidence from particular and general agricultural censuses, show that most of the world's farms are very small, while are owned by an individual or group of individuals and use mainly household labor (Ruane, 2019). As a result, smallholder farmers produce around a third of the world's food, reported by the Food and Agriculture Organization (FAO) of the United Nations (UN) (Boliko, 2019).

The success of any agricultural technology ultimately rests on the rate of adoption among farmers and smallholder growers, being crucial to understand the quaduple hélix role throughout open innovation process.

The dissertation focuses on quadruple hélix role and its application to small farmers' technological adoption and aims at answering how open innovation enable the small farmer's dynamic and respond to the research question :

- How the quadruple helix throughout open innovation enable digital technologies adoption among small farmers?

This research question was defined as a result of the literature review gap. It is expected to contribute to help different actors to create a better environment to small farmers during the technological adoption innovation process, based on the open innovation principles and supported by the quadruple helix model.

This dissertation includes the literature review analysis, as well as a exploratory case study by conducting semi-structured interviews with different players in the agricultural technological value chain. The main findings refer to a quadruple helix model as a promising approach to create the ideal conditions for small farmers to have access to updated technological innovations and tailored solutions. Also, a very high appreciation of hands-on experiences with the technology before deciding, technical assistance assumed a critical role in technological advancement. Agricultural sustainability, as an important approach to farming that seeks to balance the needs of people, the environment, and the economy, need be reconsidered to keep providing human needs in the long term, especially in the scenario of the strong demand for higher crop production in resource poor nations and their significant inhabitant's growth (Lal, 2008).

Lack of resources, limited access to information and market, policy and institutional barriers and bias in research and development towards the needs of large-scale producers, who have more resources and political power, are some examples of factors that create a cycle of poverty and exclusion of small-scale producers that make them unable to adopt sustainable practices and technological innovations. This can result in lower productivity, lower incomes, and a greater risk of environmental degradation and food insecurity.

To reach the objectives described above, the dissertation is divided into the following chapters: Chapter 2 introduces the literature review, focusing on understanding agricultural sustainability and its importance in the current scenario, open innovation concepts and applictions in agri-food settings and technological innovations in sustainable agriculture for small farmers; Chapter 3 explains the detailed methodology for a qualitative research, and exploratory case study are addressed; in Chapter 4 the InovaTec case study is presented and discussed and Chapter 5 concludes the study.

Chapter 2. Literature review

2.1 Introduction

In this chapter, a literature review is presented on the main topics, pursuing the following process: - to find the suitable sources of the information, a database search was conducted on SCOPUS and Web of Science scientific databases. The key words search combinations were agri-food, food, water and nutrients value, aggrotech, agricultural technology, productivity, open inclusive innovation, sustainability, co-designing (Annex A) shows in detailed the keywords search combinations and outcomes). Additionally, Google Scholar and Supervisor´s suggestions were used as a source of scientific papers. The search was done between the 27th of October and the 3rd of January 2022. After obtaining the biographic database, the seminal papers were obtained through co-citation analysis. "A co-citation is taken to exist if two references or authors appear in the same bibliography. It is interpreted as the measure for similarity of content of the two references or authors" (Gmür, 2003, p. 27). Using the software "R" allowed us to get the co-cited papers that permitted us to obtain "seminal" or "classic" work papers. Annex B shows the list of the seminal papers and their relevance to the research explained). Then, a PRISMA Flow diagram (Moher, Liberati, Tetziaff & Altman, 2009), presented Annex C, was used for the selection of the relevant papers for the further analysis. After removing the duplicates, we were left with 1659 papers. After screening 1405 papers were excluded for not being relevant or related to the research question. 254 papers were selected for the full-text eligibility assessment from the screening phase. The exclusion criteria in this phase were not being relevant for the research question and not having the full text available. After analyzing those papers, the connected ideas were consolidated and revised the different concepts suggested by the authors. We identified the following seven main topics for deeper analysis:

- agricultural sustainability: concept and importance
- small-scale producers and family farmers
- circular economy
- open innovation in agri-food settings
- quadruple helix in the innovation process
- lean startup methodology
- technological innovation for sustainable agriculture

- global panoramas and examples

Each of these topics is presented in detail in the forthcoming sections.

2.2 Agriculture sustainable: what is and why is important.

During recent decades, our society has faced questioning regarding our ability to live without compromising the environmental and biological conditions on which we all depend. The level of human impact and its irreversibility have become particularly concerning (Rockström et al., 2009). The state of our environment and global food production relies heavily on agricultural practices (Tilman, Cassman, Matson, Naylor & Polasky, 2002). Agriculture demands significant inputs, including water (Aivazidou, Tsolakis, Iakovou & Vlachos, 2016), energy (Woods, Williams, Hughes, Black & Murphy, 2010), and nutrients (Dungait et al., 2012). Agriculture globally accounts for 70% of the world's water withdrawals, making it the largest consumer of freshwater resources (du Plessis & du Plessis, 2017). Moreover, agriculture requires more than one-quarter of the energy consumed worldwide, particularly in the context of food production and supply (Dubois, 2011; da Silva, 2017). Unfortunately, many agricultural practices worldwide prioritize short-term productivity over sustainable approaches, relying on inorganic fertilizers and chemicals. As a result, the gap between production and consumption of agricultural commodities has widened over the past decade and poses a serious threat to our environment (Shah & Wu, 2019).

To meet the growing demand for food, projected to increase by 59-98% between 2005 and 2050, crop productivity needs to be increased (Valin et al., 2014). However, this growth must be achieved through a sustainable approach that ensures social, economic, and environmental security (Shah & Wu, 2019). Sustainable Development (SD) pathways are crucial for addressing population dynamics and achieving food security for all (da Silva, 2017). The scientific community plays a vital role in developing and promoting innovative practices and methodologies for sustainable crop productivity that optimize input use while safeguarding the environment (Germer et al., 2011). The lack of consensus on agricultural sustainability hinders progress and prolongs the negative impacts of traditional agricultural practices on habitats, societies, and economies (MacRae, Henning & Hill, 1993). Various factors contribute to this lack of consensus, including differing perspectives and values among stakeholders, the complexity and diversity of agricultural systems and practices, and the challenges of balancing social, economic, and environmental goals (Dale, Kline, Kaffka & Langeveld, 2013). Agriculture involves multiple stakeholders, such as farmers, policymakers, researchers, environmental advocates, and consumers (Neef & Neubert, 2011), each with differing priorities and perspectives on sustainable agriculture. For example, some farmers prioritize maximizing yields and profits, while environmental advocates prioritize protecting ecosystems and biodiversity. The complexity and diversity of agricultural systems and practices make it challenging to identify universally applicable sustainability practices (Toensmeier, 2016). Agricultural practices vary based on climate, soil type, crop variety, and cultural practices, further complicating the identification of sustainable approaches. Economic and political factors, such as subsidies and policies favoring conventional farming, as well as the high costs associated with transitioning to more sustainable practices, can hinder their adoption (Piñeiro et al., 2020).

Despite the evolution of sustainability from a conceptualization to improved analytical tools (Xu, Marinova & Guo, 2015), effective governance strategies are essential for its implementation. International agreements such as the "2030 Agenda for Sustainable Development" (Cf, 2015) and the "17 Sustainable Development Goals" (SDGs) (UN, 2016; Biermann, Kanie & Kim, 2017) play a vital role in guiding sustainable agricultural practices.

In the realm of agricultural sustainability, the focus lies on producing crops that are tailored to meet human needs such as dietary and clothing demands, while utilizing resources efficiently and maintaining an environmentally friendly approach within secure environments (Shah & Wu, 2019; Tilman et al., 2002). The concepts of resiliency, which refers to a system's ability to withstand stresses and shocks, and persistence, defined as the ability to remain effective over a long period, are vital for a comprehensive understanding of sustainability (Pretty, 2008). The interaction between social and environmental systems presents numerous challenges and issues (Dell'Angelo, D'Odorico, & Rulli, 2017; Pradhan et al., 2017), making it difficult to predict future trends in agricultural systems (Luedeling, Kindt, Huth, & Koenig, 2014). Key actions related to agricultural sustainability, as identified by Shah & Wu (2019), include: (i) improving productivity not only in terms of per unit time but also per area and inputs; (ii) increasing the adoption of off-farm inputs and enhancing household income through various means such as raising production, trading carbon credits, seeking off-farm employment, and adding value to farm produce; and (iii) enhancing the quality and quantity of freshwater resources at the farm level.

In a broader analysis, the integration of ecological and biological cycles, such as nutrient cycling and nitrogen fixation, is an important aspect of the agricultural sustainability concept (Shah & Wu, 2019; Pretty, 2008). Pretty (2008) also highlights additional elements, including: (i) reducing the use of non-renewable inputs that are harmful to human health and the environment; (ii) better utilizing the knowledge and skills of farmers to increase self-reliance and reduce dependence on costly external inputs; and (iii) fostering collaboration among stakeholders to address common agricultural challenges.

Achieving long-term global agricultural sustainability is a challenge due to agro-ecological constraints (Shah & Wu, 2019). Sustainability strategies in agri-food supply chains encounter limitations when implemented at scale (Trivellas, Malindretos, & Reklitis, 2020). The impacts of climate change further exacerbate the challenges of agricultural sustainability, with an estimated 120 million people at risk of undernourishment by 2050 (Nciizah, Nciizah, Mubekaphi & Nciizah, 2022; Bruinsma, 2003). Balancing water resources between food and energy systems, known as the 'food-energy-water nexus,' poses a critical challenge, as agriculture consumes a significant amount of freshwater (D'Odorico et al., 2018). Understanding the complex dynamics of multiple abiotic stresses is crucial, and there is no one-size-fits-all solution (Shah & Wu, 2019). The competition for water resources and the globalization of agriculture further complicate the food-water nexus, impacting food and water security (D'Odorico et al., 2018).

The interconnections between food, water, and energy systems offer an opportunity for resilient food, water, and energy security through strategies like the Circular Economy (CE) (D'Odorico et al., 2018). Efficient nutrient use is crucial for sustainable agriculture (Goulding, Jarvis & Whitmore, 2008), minimizing negative environmental impacts, increasing crop yields, and ensuring economic viability. Nutrient use efficiency refers to crops effectively utilizing nutrients from fertilizers and other sources, avoiding resource waste and environmental harm (Kumar, Kumar & Prakash, 2019). Conversely, inefficient nutrient use can lead to issues like waterway eutrophication, soil degradation, and Greenhouse Gas Emissions (GGE) (Savci, 2012). Excessive fertilizer use and inputs are costly for farmers and contribute to soil and water pollution. To tackle these challenges, sustainable agriculture promotes practices enhancing nutrient use efficiency, such as precision fertilization, crop rotation, cover cropping, and the use of organic amendments (Chmelíková, Schmid, Anke & Hülsbergen, 2021)."

Agricultural sustainability refers to the ability of agricultural systems to maintain productivity and ecological integrity over time, while minimizing negative impacts on the environment and ensuring social and economic equity for farmers and rural communities. It is a way of farming that seeks to balance economic viability, environmental health, and social responsibility and is important for several reasons: ,(i) it helps to ensure that agricultural production can continue in the long term, by preserving the natural resources, such as soil, water, and biodiversity, that are essential for agriculture; (ii)it can help to reduce the negative impacts of agriculture on the environment, such as soil erosion, water pollution, and GGE, which can have harmful effects on human health and the natural world; and (iii) it can promote social equity by providing economic opportunities for farmers and rural communities, by ensuring that agricultural practices do not exploit or harm vulnerable groups, such as farm workers or indigenous peoples. Sustainable agriculture is, though, necessary to overcome the key humanity's challenges of producing more food in an efficient way and, at the same time preserving the natural resources (Oecd, F. A. O., 2022).

2.2.1 Small-scale producers and family farmers

Although underestimated, small businesses still represent the foundation of economies for many countries, developed and in developing ones (Taneja, Pryor & Hayek, 2016). According to agricultural census data, there are more than 570 million farms worldwide, being the majority small and family operated (Lowder, Skoet & Raney, 2016). On top of that, small farms (less than 2ha) run around 12% and family farms nearly 75% of the agricultural land on the planet (Lowder et al., 2016). So, globally, smallholder farmers constitute about 85% of the world's farmers (Harvey et al., 2014) assuming the position of the major employers on the planet and natural entrepreneurs in a broad sense (Lowder, Skoet, & Singh, 2014; Hazell, Poulton, Wiggins, & Dorward, 2010; Saith, 2011). In the US, according to the 2017 and 2012 Census of Agriculture reports, 96% of the 2.04 million farms (and ranches) are family-owned and 88% of all U.S. farms are small family farms (Kurland & McCaffrey, 2020). In Brazil, according to the last Agricultural Census (2017) of the Instituto Brasileiro de Geografia e Estatística, the country has roughly 4 million enterprises of smallholder producers (77% of the total), employing more than 10 million human beings in different sectors and segments.

According to FAO website[1]under the "Smallholders and family farmers" section, small-scale farmers are those "farmers who operate on small plots of land and with limited resources, usually relying on family labor." Family farmers, on the other hand, are those who own or manage the farm as a family business, and who are directly involved in the production process. In many cases, small-scale farmers are also family farmers, as they rely on their farm for their livelihoods and often involve their family members in the work, being estimated that most of the world's small-scale farmers are also family farmers. Therefore, family farmers produce most of the food we eat, specifically healthy and nutritious food (Ruane, 2019). Particularly regarding the agri-food sector, the world's smallholder farmers produce around a third of the world's food, according to detailed research by the FAO of the UN (FAO, 2019). In value terms, smallholder farmers or family farming, are responsible for about 80% of the world's food (Lowder et al., 2014), still representing the most important way of agricultural production on the planet (Rodrigues Fortes, Ferreira, Barbosa Simões, Baptista, Grando, & Sequeira, 2020).

[1] Food and Agriculture Organization (FAO) website: www.fao.org

There is a lack of global consensus regarding family farms definition, despite many initiatives of different actors either for government programs implementation or rational purposes. The International Steering Committee for the 2014 International Year of Family Farming defined it as follows: "Family farming (which includes all family-based agricultural activities) is a means of organizing agricultural, forestry, fisheries, pastoral and aquaculture production which is managed and operated by a family and predominantly reliant on family labor, including both women's and men's". The family and the farm are linked, co-evolve, and combine economic, environmental, social, and cultural functions (Roa-Ortiz, Forero Camacho, Bautista Cubillos & Zabala Perilla, 2022). According to most of the usually used definitions, family farms are likely to be, by far, the mainly frequent form of farming in most nations and contexts (Lowder et al., 2014).

Small-scale family farmers are highly vulnerable to the impacts of climate change, including higher temperatures, unpredictable weather patterns, desertification, water scarcity, pests, and diseases (Ruane, 2019). Despite their crucial role in global food security, smallholders are often ignored by development policies, and they constitute the majority of the world's poor and hungry (Fan & Rue, 2020). Climate change adaptation has gained prominence, requiring adjustments in social, economic, and ecological systems (Karki, Burton & Mackey, 2020; Smit, Burton, Klein, & Wandel, 2000). However, there is no one-size-fits-all framework for adaptation, and farmers need access to local, updated knowledge for effective response (Žurovec & Vedeld, 2019). Smallholders face challenges such as low education levels, limited resources, and lack of knowledge on food safety laws, hindering their ability to build value-added businesses (Debela et al., 2015; Chen et al., 2021).

Considering that most of the world's farms are owned and operated by families (Lowder et al., 2014), smallholders are crucial players to ensure the preservation of the environment and biodiversity globally as well. However, farm size is negatively related to fertilizer use, as small farms are more pushed to apply inorganic fertilizer and intensive production techniques (Wubeneh & Sanders, 2006). More broadly, smallholders perform a key function in the new global development agenda supporting the SDGs, particularly if well-integrated into a diversified rural economy and agri-food value chains, enhancing a more inclusive development and employment generation (Fan & Rue, 2020). In this regard, small-scale producers and family farmers face several key challenges in achieving agricultural sustainability, including::

- **Limited access to resources**: small-scale producers frequently lack access to resources such as land, water, seeds, credit, and technology, which can make it arduous for them to follow sustainable farming practices (Mizik, 2021).

- **Lack of knowledge and skills**: many small-scale producers lack the knowledge and skills required to apply sustainable farming practices, such as agroecology, crop rotation, intercropping, and conservation agriculture (Mizik, 2021).

- **CC and environmental degradation:** small-scale producers are often the most vulnerable to the impacts of CC, such as droughts, floods, and extreme weather events. Environmental degradation, such as soil erosion and water pollution, can also make it challenging for small-scale farmers to keep sustainable farming practices (Altieri, Nicholls, Henao & Lana,2015).

- **Market access**: small-scale producers frequently face challenges in accessing markets and getting fair prices for their products, which can make it ambitious for them to commit to sustainable farming practices (Jouzi et al., 2017).

- **Policy and institutional barriers**: small-scale producers may face policy and institutional barriers that make it hard for them to access resources, get help for sustainable farming practices, and participate in decision-making processes that affect their sustenance (Saarikoski et al.,2018).

2.2.2 Circular Economy

Circular Economy (CE) has emerged as a nonlinear regenerative framework with the aim of reducing emissions, promoting the use of renewable energy as the default option, eliminating waste through the design of closed-loop systems, and fostering the recycling and reuse of inputs, materials, and natural resources (MacArthur, 2013). The concept and strategy of CE have gained significant attention and traction in various contexts and perspectives, including government, business, and academia (Geissdoerfer, Savaget, Bocken & Hultink, 2017; Velenturf, Archer, Gomes, Christgen, Lag-Brotons & Purnell, 2019). Initially introduced by regulators for practitioners (Murray, Skene & Haynes, 2017), CE has recently garnered even more attention from a European standpoint due to the development of the CE Action Plan, which aligns with the goals of the European Green Deal for Sustainable Growth (Fetting, 2020). Established by the EU in 2015 and updated in 2020, the CE Action Plan highlights the European Union's recognition of the continuous evolution of this concept and strategy (European Commission, 2020). Considering this challenge, companies should adopt innovative CE business models that emphasize the design of closed-loop supply chains and the development of sustainable products and goods, replacing the traditional linear models as depicted in Figure 1 (D'Odorico et al., 2018; Geissdoerfer, Morioka, de Carvalho & Evans, 2018).

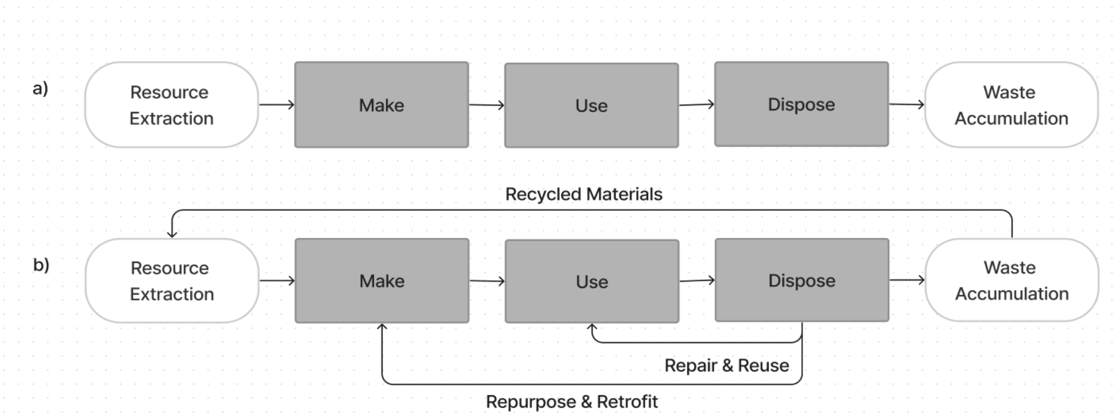

Figure 1: Schematic diagram of (a) linear model of production and (b) toward a CE Source: based on D'Odorico et al., 2018.

Literature's findings also propose the circular business model as an operational tool to foment the competitiveness of businesses (Puglieri et al., 2022). When comparing the developed concepts, Murray et al. (2017) argue that the Circular Economy (CE) represents an updated and successful approach to integrating economic activity and environmental well-being in a sustainable manner. While CE focuses on process redesign and material cycling, which contribute to sustainable practices, it does have limitations, such as the absence of the social dimension inherent in Sustainable Development (SD), which restricts its ethical scope (Murray et al., 2017). As a result, other authors redefine CE as "an economic model in which planning, resourcing, procurement, production, and reprocessing are designed and managed, as both processes and outputs, to maximize ecosystem functioning and human well-being" (Murray et al., 2017). However, the literature reveals a lack of a standardized CE definition (Kirchherr, Reike & Hekkert, 2017) and a conceptual framework for integrating CE and sustainability (D'Amato et al., 2017).

The adoption of CE strategies in agriculture extends beyond minimizing environmental footprints and becomes increasingly necessary to meet future food demand. To minimize the negative impacts of conventional linear agri-food systems on the environment, CE principles for agriculture involve: (i) reducing water and energy consumption and optimizing the use of primary natural resources throughout crop production and animal farming processes, (ii) minimizing the use of synthetic fertilizers and other polluting activities, and (iii) promoting the production of bioenergy, nutrients, and biofertilizers through the recycling, transformation, and reuse of agricultural waste (Cities, 2018). However, the practical implementation of an integrated CE strategy within the agri-food sector, based on a theoretical framework, remains challenging (Del

Borghi, Moreschi & Gallo, 2020), emphasizing that agribusiness still requires assistance and guidance to achieve better outcomes in terms of sustainable development (Ulvenblad, Ulvenblad & Tell, 2019). Recently, bioeconomy, which involves the production of renewable biological resources and their transformation into nutrients, bio-based products, and bioenergy (Bioeconomy, 2012), has been recognized as "circular by nature" (Schoenmakere, Hoogeveen, Gillabel & Manshoven, 2018) and as "the renewable segment of the CE" (Caudet & von Hammerstein-Gesmold, 2018). Currently, agriculture accounts for approximately 62% of the total biomass supply in the EU (Gurria et al., 2017). Within the realm of agriculture, a CE approach entails designing farming systems that mimic natural ecosystems, where waste is minimized, resources are conserved, and nutrients are cycled back into the soil. Below are examples illustrating how CE principles can contribute to agricultural sustainability:

- **Closing nutrient loops:** Instead of relying on synthetic fertilizers, circular agriculture seeks to recycle nutrients within the farming system, using practices such as composting, cover cropping, and intercropping (Giller, Hijbeek, Andersson & Sumberg, 2021).
- **Reducing waste**: Circular agriculture seeks to minimize waste by reducing the use of pesticides and other chemicals, reducing food waste, and recycling farm waste into valuable products, such as bioenergy and bioplastics (Ashokkumar et al., 2022).
- **Promoting biodiversity**: Circular agriculture promotes biodiversity by encouraging the use of diverse crop rotations, intercropping, and agroforestry systems, which can help to improve soil health and reduce the need for pesticides and fertilizers (Altieri, Nicholls & Montalba, 2017).
- **Supporting local economies**: Circular agriculture can support local economies by promoting short food supply chains, reducing food miles, and creating opportunities for farmers to sell their products locally (Kiss, Ruszkai & Takács-György, 2019). Furthermore, the CE strategy can assist to overcome the issues of resource scarcity and environmental degradation by key synergies, such as:
- **Water-Energy Synergies:** The CE can help to reduce the energy and water footprints of food production by promoting practices such as water recycling, renewable energy production, and energy-efficient irrigation systems; e.g, wastewater from food processing plants can be treated and reused for irrigation, reducing the need for freshwater and the energy required to pump and treat water (Radin et al., 2021).
- **Food-Energy Synergies**: The CE can also promote the production of renewable energy from food waste and other organic materials, e.g. anaerobic digestion can be used to

convert food waste into biogas, which can be used to generate electricity or heat (Peng, & Pivato, 2019).

- **Food-Water Synergies:** The CE can promote the use of wastewater for irrigation and other agricultural purposes. In addition, the use of drought-resistant crops and water-efficient irrigation systems can help to reduce water use in food production (Smol, Adam & Preisner, 2020).
- **Multi-sectoral Synergies:** The CE approach can promote collaboration among different sectors, such as agriculture, energy, and water, to find synergies and create more integrated and efficient systems; e.g.food waste from restaurants can be collected and used to produce biogas for energy production, which can then be used to power the restaurant itself (Nika, Vasilaki, Expósito, & Katsou, 2020).

2. 3 Open innovation in agri-food settings

More and more, innovation is perceived as one of the key drivers of business success, high performance, and company longevity, despite its size or market segment (Bigliardi & Galati, 2013; Torres, Ibarra & Arenas, 2015). The need to connect innovations to SD challenges become a serious priority only in the 1990s (Rasiah, 2019) being relatively recent the theory that suggests the population can push the innovation process to design sustainable strategies to accomplish social innovations in a green economy (Carayannis, Acikdilli & Ziemnowicz, 2020).

Innovation enhances research and development (R&D) initiatives, especially those accomplished among industrial players (Ale Ebrahim & Bong, 2017; Bhattacharya & Bloch, 2004). For that reason, to understand the key determinants or the more important drivers of innovation and their effect on business results and on society is crucial and has aroused greater attention of leaders and managers (Hussain, Shahzad & Hassan, 2020). During the industrial era of the 20th century, most knowledge and innovation were created and developed inside companies (Machado & Winter, 2023). Nowadays, the context is quite different, being rare and very challenging for businesses to sustain their competitiveness relying on internal innovation sources only (Kruse, 2012). Since the end of the 20th century, the effectiveness of classical innovation management standards has been questioned essentially due to the meaningful boost in quantity and mobility of very skilled labor, making businesses struggle to manage their expertise and command the specialized intelligence (Chesbrough, 2006; Ale Ebrahim & Bong, 2017). Moreover, in recent decades, innovation has undergone a reshaping, requiring not just more and more collaboration between internal and external players for the generation of new ideas, but also knowledge networks, information flows, and social interaction (Zoll, Specht & Siebert, 2016). Within this framework, the theory of open innovation was originally proposed by Henry Chesbrough as "the use of internal and external flows of knowledge to accelerate internal innovation and expand markets for external use of that innovation" (Chesbrough, 2006; Medeiros, Binotto, Caleman & Florindo, 2016). Although former evidence presented that only big players adopted the new process of open innovation, studies showed that small and medium-sized companies can also achieve potential changes (Chetan, 2021 & 2019; Weiblen T & Chesbrough, 2015).

Very different from the usual model of integrated vertical innovation where all knowledge is internalized and manage by the business (Tennent, 2020), in open innovation systems, business limits are penetrable, making possible for not just a single person but also for organized groups and companies to connect skills and resources by assisting with outside work force (Rasiah, 2019). The open innovation approach is also defined by the strong interaction between the business and its environment (Grimaldi, Corvello, De Mauro & Scarmozzino, 2017) as a company can and must use both outside and inside ideas to boost its own innovation process (Della Corte, Del Gaudio & Sepe, 2018; Bogers, Chesbrough, & Moedas, 2018).

With the open innovation concept popularization, individuals start deliberately sharing and evolving knowledge flows across the business outer limit, through escalating connections with systemic knowledge nodes important to the innovation process (Rasiah, 2019). The development and appropriation of such knowledge has evolved very fast with technology and the propagation of deep networks making possible a singular person up to entire business today, to join it and to help innovations openly across innovation systems (Chesbrough, 2003).

The open innovation approach quickly gained space and recognition in the academic field and its strategies has been applied by different segments, where it is seen as a research and development approach that enable the variety of the client requirement, company competitiveness, and demand for regular innovation (Bogers et al., 2018; Jeon, Kim, & Koh, 2015). From the research point of view, this model offers strong advantages to business, such as: (i) smaller time for launch new products, (ii) reduction of innovation costs, (iii) more effectiveness related to consumer requirements, and (iv) co-responsibility and shared risk during the process of development of products and services (Torres, Ibarra & Arenas, 2015). There is a special attention on going beyond the business boundaries to create new products through open innovation (Chesbrough, 2003). Additionally, business in general apply three different approaches regarding open innovation (Solarte-Montufar, Zartha-Sossa & Osorio-Mora, 2021):

- the “**inside-out approach**”, that pursuit for knowledge and technologies abroad to use them inside (Solarte-Montufar et al., 2021). It is exemplified as the external use of ideas in several markets, selling intellectual property and multiplying technology by channeling ideas to the outdoor environment (Gassmann & Enkel, 2004).
- the “**outside-in approach”**, that requires the outsourcing and commercialization of internal innovations (Solarte-Montufar et al., 2021). Aim to enhance a company’s own expertise base through the integration of suppliers, consumers, and outside knowledge sourcing can boost a business's innovativeness (Gassmann & Enkel, 2004).
- the “**coupled or mixed approach”** that connects outside-in and inside-out by working in partnerships with matching businesses during which give, and take are vital for accomplishment (Gassmann & Enkel, 2004; Solarte-Montufar et al., 2021).

All approaches mentioned above go beyond business borders and encourage collaboration with outside players to connect and balance between external and external capacities to add real value in the business (Iglesias-Sánchez, Jambrino-Maldonado & de las Heras-Pedrosa, 2019; Moreno‐Mondéjar, Triguero, & Sáez‐Martínez, 2020). A different approach, which removes the frontiers between government, community, academia, industry, and business, is the updated concept of “Open Innovation 2.0” (Solarte-Montufar et al., 2021). This version of open innovation emerged in the early 2010s and focused on the use of digital platforms and social media to facilitate collaboration and co-creation, emphasizing the role of communities and crowdsourcing in generating and evaluating new ideas. “Open Innovation 3.0”, coined by Henry Chesbrough, emerged as a response to the evolving landscape of innovation, characterized by increasing connectivity, globalization, and digitalization.

The concept built on the previous versions and expanded the scope to include societal challenges and global issues such as sustainability and public health, emphasizing the importance of involving a diverse range of stakeholders in the innovation process, including governments, NGOs, and citizens (Pacifico Silva, Lehoux, Miller & Denis, 2018). Moving forward, the concept of “Open Innovation 4.0” strongly comes up. “Open Innovation 4.0” reflects the ongoing digital transformation and the emergence of new technologies such as Artificial Intelligence (AI), blockchain, and the IoT. Open Innovation 4.0 involves the use of these technologies to enable more efficient and effective collaboration and innovation across boundaries. In a broader sense, the open innovation 4.0 concept integrates firms, institutions, government, civil society, end users and machines through organizing and cooperative actions of different players in the food system and beyond in co-creative and co-sharing innovation processes (Costa & Matias, 2020). It is also in line with the implementation of long-term perspective oriented to close, slow, intensify, dematerialize, and narrow resource loops and in that sense achieves circular business model goals (Tunn, Bocken, van den Hende & Schoormans, 2019).

The food value chain consists of four main phases: input, production, processing, and output (Humphrey & Memedovic, 2006). Innovation starts with agricultural input producers and extends to growers, processors, and distributors, each contributing to the impact and outcome of innovation (Chen, Joshi, Cheng & Birthal, 2015). Collaboration and alignment among all players are crucial drivers of technological innovation effectiveness (Fertő, Molnar, & Tóth, 2016). Building collaborative models requires strategic actions and investments by chain players in partnership with others (Della Corte et al., 2018; Kastelli, Tsakanikas & Caloghirou, 2018). Innovation in the agri-food chain relies on the relationships and synergy among multiple players to add value to environmental, social, and economic processes (Faure, Blundo-Canto, Dabat & Devaux-Spatarakis, 2018). While opportunities for technological advances in the agri-food sector exist, the implementation and adoption of collaborative innovation processes are increasingly recognized as essential(Meynard, Jeuffroy, Le Bail, Lefèvre, Magrini, & Michon, 2017). However, there is a knowledge gap in understanding the synergies between open innovation practices and the food value chain (Misra & Mention, 2022).

Open innovation practices have gained prominence in the food and water chains due to the diverse demands and technologies involved(Leitão, Pereira & Brito, 2020). Information technology has enabled open innovation strategies in the agri-food field, leading to benefits such as competitiveness, cohesion, and technological advancements(Cillo, Rialti, Bertoldi, & Ciampi, 2019). Cooperation with external actors has shown a positive correlation with companies' innovation abilities in the agri-food sector (Solarte-Montufar et al., 2021). The concept implementation of open innovation in the Agri-sector has also shown a geographic dominance.

Studies highlighted a notable European supremacy, essentially Western Europe, in the Agri-sector (Solarte-Montufar et al., 2021). Italy, the Netherlands, and Spain occupied top positions regarding number of publications in higher impact journals. One of the reasons of European leadership and advantage in this field is the renowned research centers in agribusiness consolidated in Europe as well as the strong leadership in agricultural innovation and technology transfer models that link universities with agri-businesses in a sustainable way (Toth & Ferto, 2017; Fitiu, 2017). On top of that, European authors represented 90% of the articles related to open innovation in the agri-business published between 2006 and 2015. However, the US still appears in first position as the most productive country, confirming that the North American nation, pioneers in the concept, still is a powerful center for similar research (Solarte-Montufar et al., 2021). Lastly, it is important to highlight that a European cross-country assessment of open innovation has stressed the need to take context dependencies into consideration, revealing that the level of technological development of an economy as an important factor (Arbussã & Llach, 2018), endorsing the European supremacy mentioned previously.

According to recent research, intellectual property rights and communication problems between actors are the main issues regarding putting in place an open innovation process (Solarte-Montufar et al., 2021). Other authors also consider the product co-creation, eco-innovation, and bioeconomy are key challenges to implementation (Solarte-Montufar et al., 2021). The last two points highlight the current situation in the agri-food sector, which goes against global trends towards a more sustainable economy. Additionally, it is evident that businesses can gain benefits by collaborating with other stakeholders in their production chain.

This collaboration can be facilitated through approaches like open innovation (Della Corte et al., 2018). As such, open inclusive innovation has been implemented in agri-food settings through a variety of approaches and initiatives. Here are some examples:

- **Innovation networks**: Innovation networks are collaborative platforms that bring together stakeholders from different sectors to co-create and share knowledge and ideas. In the agri-food sector, innovation networks can involve farmers, researchers, businesses, Non-Governmental Organizations (NGOs), and policymakers working together to develop and implement sustainable farming practices, improve food safety, and create new value chains (Reypens, Lievens & Blazevic, 2016).
- **Open-source technology**: Open-source technology refers to software or hardware that is freely accessible, modifiable, and distributable by anyone. In the agri-food sector, open-source technology can include tools for precision agriculture, such as drones and sensors, as well as software for data analytics and decision-making (Pearce, 2012).
- **Hackathons and innovation challenges**: Hackathons and innovation challenges are events where individuals or teams come together to develop innovative solutions to specific challenges. In the agri-food sector, these events can focus on developing new products, improving supply chain efficiency, or addressing food waste (Bertello, Bogers & De Bernardi, 2022).
- **Citizen science:** Citizen science involves engaging members of the public in scientific research and data collection. In the agri-food sector, citizen science can involve farmers and consumers working together to monitor soil health, track food safety, or test new products (Donnelly, Crowe, Regan, Begley & Caffarra, 2014).

2.3.1 The role of the quadruple helix in the open innovation process

The quadruple helix model and open innovation are intimately related concepts that can influence each other in driving innovation. The concept of the "quadruple helix" for innovation is an extension of the "triple helix" model of innovation (Leydesdorff & Smith, 2022). The quadruple helix model expresses the interaction between four key actors in the innovation process: academia, industry, government, and civil society (Cai & Lattu, 2022) as illustrated by the figure below:

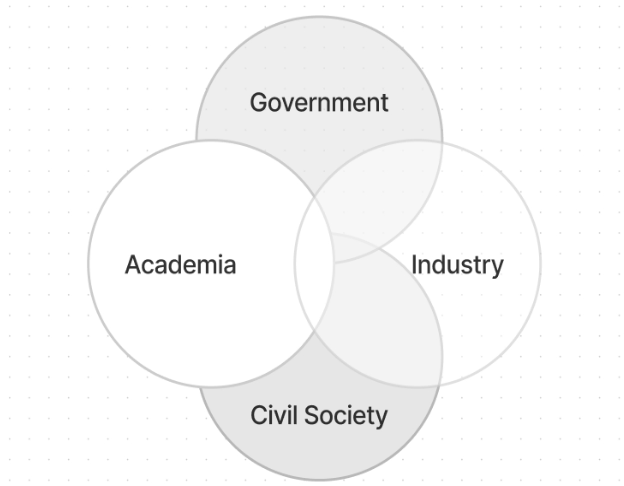

Figure 2: Quadruple Hélix Source: GRRIP[2] (2020).

This means that in addition to academia, industry, and government, civil society actors such as NGOs, citizen groups, and other community organizations are also seen as key players in the innovation process (Cai & Lattu, 2022).

From this perspective, the quadruple helix model highlights the value of collaboration and co-creation between all four actors' groups in driving innovation (Morawska-Jancelewicz, 2022). By including civil society in the model, it recognizes the role of citizens and community organizations in shaping innovation agendas and ensuring that the benefits of innovation are shared more widely. In this sense, the quadruple helix model builds on the open innovation concept by emphasizing the importance of collaboration, not just between firms and external partners, but also between academia, government, and civil society (Gascó, 2017). By bringing together a wider range of actors, the quadruple helix model can create more diverse and inclusive

[2] GRRIP website: https://grrip.eu/why-is-quadruple-helix-engagement-so-important/ accessed on April 11, 2023.

innovation ecosystems that are better able to respond to complex social and environmental challenges (Grundel & Dahlström, 2016).

Therefore, the quadruple helix model and open innovation can support each other in several ways. First, the quadruple helix model can provide a framework for open innovation activities, by mapping key stakeholders and enabling to create an environment that supports collaboration and co-creation (Yun & Liu,2019). Second, open innovation can help to drive innovation within the quadruple helix by providing means for actors to share knowledge, expertise, and resources (Parveen, Senin & Arslan, 2015).

As such, the quadruple helix model is seen as a journey to encourage more inclusive and sustainable innovation ecosystems, by ensuring that a broad range of perspectives and interests are considered in the innovation process (Carayannis & Rakhmatullin, 2014). At the same time, the quadruple helix and open innovation concepts symbolize complementary approaches to driving innovation and can be used in tandem to create more collaborative, inclusive, and sustainable innovation ecosystems (Carayannis, Grigoroudis, Campbell, Meissner & Stamati, 2018).

2. 3.2 The Lean startup methodology

The Lean Startup Methodology (LSM) is an entrepreneurial approach that emphasizes fast experimentation, customer feedback, and iterative product development (York & Danes, 2014). It was popularized by Eric Ries, an entrepreneur and author, in his book "The Lean Startup: How Today's Entrepreneurs Use Continuous Innovation to Create Radically Successful Businesses" (2011).

The LSM is based on principles that aim to minimize waste and maximize value in the context of product development within the Lean Startup framework (Frederiksen & Brem, 2017). It focuses on creating and managing new businesses that can adapt to changing market conditions and customer needs by encouraging rapid experimentation and prototyping to test and validate assumptions (Bland & Osterwalder, 2019).

The LSM involves three key stages: (i) build, (ii) measure, and (iii) learn (de Faria, Santos & Zaidan, 2021):

> **(i)** In the build stage, entrepreneurs create a Minimum Viable Product (MVP) to test their assumptions about the market and customer needs.

(ii) In the measure stage, entrepreneurs gather feedback from customers and stakeholders to evaluate the viability of their product and identify areas for improvement.

(iii) In the learn stage, entrepreneurs use the feedback and data gathered in the measure stage to make iterative improvements to their product and business model.

The LSM has gained widespread adoption among entrepreneurs and startup companies globally and has influenced the approach to product development and innovation in many organizations (Ries, 2011). It has also led to the development of related concepts and tools such as Lean Canvas, a visual tool for developing and testing business models, and Lean Analytics, a framework for measuring and analyzing product or business success (Humble, Molesky & O'Reilly, 2020).

The LSM and rapid prototyping are closely linked concepts that can be connected to Living Labs, which promote innovation and the creation of user-centric products and services (Äyväri & Jyrämä, 2017). Rapid prototyping involves quickly creating and testing prototypes to validate ideas and assumptions about user needs and preferences (McElroy, 2016). It is commonly used in product development to gather feedback and validate key assumptions. Rapid prototyping can be combined with the LSM to create an MVP that tests assumptions and gathers user feedback (Olsen, 2015).

Living Labs, on the other hand, are real-world environments where users and stakeholders can co-create and test new products, services, and technologies collaboratively and iteratively. Living Labs provide a way to validate and refine products and services in real-world settings, gathering feedback and insights from users and stakeholders throughout the innovation process (Hossain, Leminen & Westerlund, 2019).

Therefore, the connection and correlation between the LSM, rapid prototyping, and Living Labs lie in their shared focus on experimentation, user feedback, and iterative development (Carlgren, Rauth & Elmquist, 2016).

By using rapid prototyping to create an MVP, entrepreneurs and innovators can quickly test their ideas and assumptions in real-world settings, gathering feedback and insights from users to refine their product and business model. Living Labs offer a collaborative and iterative approach to testing and refining products and services, involving users and stakeholders in the innovation process from the beginning (Ballon, Van Hoed & Schuurman, 2018). The LSM, rapid prototyping, and Living Labs represent complementary approaches to driving innovation that prioritize user-centric products and services through experimentation, iteration, and collaboration (Blank, 2020).

2. 4 Technological innovations in sustainable agriculture

According to a case study conducted in Brazil, the adoption of new cropping systems focused on the market, along with the introduction of mulch technology, has been found to enhance the sustainability of agricultural systems among family farmers (das Chagas Oliveira, Calle Collado & Carvalho Leite, 2012). Research conducted worldwide indicates that the implementation of agricultural technologies, such as water-saving techniques and drought-resistant varieties, can improve the adaptability of agricultural systems to the changing climate (Biagini, Kuhl, Gallagher & Ortiz, 2014). The final report of the European Innovation Partnership's Focus Group on Digital tools for sustainable nutrient management emphasizes the importance of adopting a systems approach to technology optimization and fostering an innovation ecosystem in agriculture. This approach enables the agricultural sector to fulfill its critical societal role of providing food, feed, fiber, and fuel while generating significant environmental benefits (Prandecki, Wrzaszcz & Zieliński, 2021).

In addressing society's pressing challenges, which demand greater awareness, inclusive innovation processes, and up-to-date governance, digital technologies play a central role. They enable organizations to effectively manage data, communicate research findings to a broader community, and inspire actionable responses (Cajaiba-Santana, 2014; Carayannis & Morawska-Jancelewicz, 2022; Faludi, 2023).

These new technologies, under the banner of the Fourth Industrial Revolution or Industry 4.0, hold significant promise for delivering innovative solutions to global challenges such as food traceability and quality (Hassoun et al., 2022). Industry 4.0 represents a transformative shift in global value chains through broad-based innovation that disseminates rapidly and extensively (Piccarozzi et al., 2022; Schwab, 2017; Dionisio et al., 2023). Its distinctiveness lies in its scale, scope, complexity, and transformative power (Schwab, 2017), particularly in terms of reshaping current relationships within different processes (Mhlanga, 2021). The concept is characterized by advanced automation, digitalization processes, and interdisciplinary implementation across nine key pillars: "Big Data," "Autonomous Robots," "System Integration," "IoT," "Cybersecurity," "Cloud Computing," "Additive Manufacturing," "Simulation," and "Augmented Reality" (Dionisio et al., 2023). Recent research highlights four technologies—blockchain, IoT, AI, and autonomous robots—as predominant, accounting for 75% of the frequency in the literature, underscoring their significant untapped potential (Dionisio et al., 2023).

In the agri-food chain, Industry 4.0 encompasses digital innovations and advanced technologies such as blockchain, AI, big data, IoT, smart sensors, robotics, 3D printing, cloud computing, and digital twins (Hassoun et al., 2022). There are ongoing efforts to leverage emerging digital technologies to enable farmers to enhance productivity in a sustainable manner (Fielke et al., 2021; Klerkx & Begemann, 2020). Agriculture is undergoing a technological revolution known as "Agriculture 4.0," with farming and the food sector being profoundly impacted by digital innovations (Kaloxylos et al., 2012; Poppe et al., 2013; Poppe et al., 2015; Wolfer et al., 2017).

Investment and data forecasts in information and communication technologies (ICTs) within the agricultural sector demonstrate consistent growth (Sagarna Garcia & Pereira Jerez, 2020). Tech startups focused on the farming segment attracted $4.6 billion in funds, reflecting a 63 percent increase from 2010 to 2015 (Laugerette & Stöckel, 2016). In Europe, various governmental strategies aim to enhance the digitalization of the farming sector, including initiatives such as the Cork 2.0 declaration "A better life in rural areas," the EU Commission proposal for the Common Agricultural Policy beyond 2020, the EU Communication "Digitizing Europe Industry," and the Digital Single Market (Sagarna Garcia & Pereira Jerez, 2020).

However, the adoption of innovative technologies remains limited to only a few smallholders. Currently available applications are fragmented and primarily used by early adopters. An example of precision farming adoption is the use of Global Positioning System (GPS) technology for agricultural production or the adjustment of management operations and agrochemical applications based on satellite-derived weather forecasts (Sagarna Garcia & Pereira Jerez, 2020). In the UK, the implementation rates on farms reached 22 percent for GPS-based machinery steering, 20 percent for soil mapping in fertilization management, 16 percent for variable rate application of agrochemicals, and only 11 percent for crop yield mapping (DEFRA, 2013). This situation is not significantly different worldwide, indicating that the reasons behind the limited dissemination of precision farming appear to be universal (Sagarna Garcia & Pereira Jerez, 2020).

While developed nations drive scientific knowledge, addressing the sustainability of our society requires technological and green strategies that are accessible to all stakeholders, including economic support for those in disadvantaged or underprivileged situations, which presents a significant challenge (Lorek & Spangenberg, 2014).

To support family farmers in overcoming these challenges and enhancing the resilience of the agricultural sector, accelerating innovation is seen as crucial (Ruane, 2019). However, the implementation of technological changes driven by digitalization also raises concerns about human skills and social learning necessary to sustain the transformation (Fielke et al., 2021). It is important not to overlook the anthropological perspective and the broader social and financial benefits associated with the technological revolution (Rose, Wheeler, Winter, Lobley & Chivers, 2021).

The vulnerability of farmers should also be taken into account when assessing the success of technological implementation. Increases in productivity can be accompanied by rising production costs (Bukchin & Kerret, 2020), leading to stagnant or declining real revenue for farmers due to credit repayment or missed opportunities for labor utilization, further contributing to low implementation levels (Anderzén et al., 2020).

New technologies for the recovery of agricultural waste from cereal crops have been developed worldwide, including in the US, India, and China (Duque-Acevedo, Belmonte-Urena, Cortés-García & Camacho-Ferre, 2020; Chiranjeevi, Dahiya & Kumar, 2018). Agricultural residues, such as livestock waste, hold significant potential for producing bio-based products (Caruso et al., 2019). To enhance resource efficiency and create value-added products, the adoption of circular bio-based business models is imperative (Donner, Gohier & de Vries, 2020). However, the demand for bio-based materials is often overlooked and underestimated, despite projected increases in agricultural productivity to meet the growing food demand (Bos & Broeze, 2020).

The farming technology market is attracting various stakeholders beyond traditional agricultural corporations and technology providers. Foreign tech companies, venture capital firms, universities, research centers, and tech start-ups are all seeking to participate in this ecosystem (Wolfert et al., 2017). Governments are encouraging public institutions, universities, and technological centers to play a role in this process, resulting in a diverse range of digital products and services in agriculture (Sagarna Garcia & Pereira Jerez, 2020). While this diversity can be enriching, it also poses challenges. Inappropriate methods can hinder precision agriculture and broader digital transformation initiatives (Sagarna Garcia & Pereira Jerez, 2020). The effectiveness of digital transformation in agriculture depends on various factors, including the participatory support of agribusinesses and governmental institutions (Sagarna Garcia & Pereira Jerez, 2020).

The digital transformation in agriculture typically involves three stages: (i) the initial stage, which involves the collection of vast amounts of data using sensors like drones or satellites; (ii) the transformation of data into valuable operational information for farmers' decision-making through algorithms and artificial intelligence; and (iii) the use of actuators to automate and control operations, such as indoor management (Sagarna Garcia & Pereira Jerez, 2020).

In agriculture and food systems, innovation involves implementing new ideas across different contexts and throughout the entire food system. In the following pages, we will examine successful real-life cases and notable advancements. Various technological innovations offer practicality for sustainable agriculture.

Here are some examples (Aubert, Schroeder & Grimaudo, 2012; Bohra, Chand Jha, Godwin & Kumar Varshney, 2020):

1. **Precision agriculture:** Precision agriculture utilizes sensors, GPS, and other technologies to collect and analyze data on soil health, crop growth, and weather conditions. This helps farmers optimize resource usage, reduce waste, and improve crop yields.
2. **Biological control:** Biological control involves the use of natural predators and parasites to manage pests and diseases in crops, replacing reliance on chemical pesticides. This reduces the environmental impact of agriculture while promoting biodiversity.
3. **Agroforestry:** Agroforestry integrates trees into farming systems, offering benefits such as soil conservation, carbon sequestration, and biodiversity preservation. Additionally, it provides farmers with additional income sources, including timber and non-timber forest products.
4. **Vertical farming:** Vertical farming entails growing crops in stacked layers using artificial lighting and controlled environments. This reduces the need for land, water, and pesticides while enabling the production of fresh produce in urban areas.
5. **Biotechnology:** Biotechnology involves using genetic engineering and other techniques to enhance crop productivity and resilience. For example, genetically modified crops can be engineered to resist pests and diseases, tolerate drought and environmental stresses, and possess improved nutritional qualities.

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2.4.1 Global panorama and examples

This section explores cases around the world for technology, sustainability, and open innovation with a particular emphasis in Agri settings, which look for knowledge transfer for small farmers.

2.4.2 "Farm Hack": a global community of open technological innovation

Farm Hack (FH) is a great example of cooperation between producers from the point of view of open technological innovation (Rotz et al., 2019). FH is a global community of farmers, engineers, designers, and open-source advocates who collaborate to develop and share knowledge and tools that can help farmers improve their operations and sustainability practices (Giotitsas & Giotitsas, 2019). The movement started in the US in 2010 and has since expanded to other countries. FH aims to promote open-source technology in agriculture, making it more accessible and affordable for small farmers (Rotz et al., 2019).

Through their website, FH provides a platform for farmers to share their knowledge, experiences, and ideas (Zhang, Wang & Duan, 2016). They also organize events, workshops, and hackathons, where farmers and designers can work together to develop and improve tools for farming. Some examples of the tools developed by FH include a pedal-powered washing machine, a solar-powered seed dryer, and a low-cost greenhouse (Giotitsas & Giotitsas, 2019).

These tools are designed to be easily replicable, using locally available materials and technologies, and to help farmers increase their productivity while reducing their environmental impact (Toensmeier, 2016).

FH has been successful in promoting collaboration and innovation among farmers, designers, and engineers. The movement has inspired similar initiatives in other countries, such as FH Brazil and FH Ireland, and has contributed to the growth of the open-source movement in agriculture (Klerkx, Jakku & Labarthe, 2019). Furthermore, sustainability is a key theme in the FH project. The platform promotes the development of open-source technology for sustainable agriculture, including tools and practices that reduce environmental impact and increase resilience. The website has a section dedicated to sustainable agriculture that includes resources on agroecology, regenerative agriculture, and permaculture (Menozzi, Fioravanzi & Donati, 2015).

The FH community also emphasizes the importance of sharing knowledge and collaborating with others to achieve sustainability goals. By providing a platform for farmers, researchers, and others to connect and exchange ideas, FH aims to foster a culture of innovation and sustainability in agriculture (Menozzi, Fioravanzi & Donati, 2015). Additionally, the platform encourages the use of locally sourced materials and the development of technology that is appropriate for small-scale and sustainable farming practices.

2.4.3 “Cultivando Água Boa”: a knowledge transfer project to small farmers

The "Cultivando Água Boa" (CAB) project was created by Itaipu Binacional, a Brazilian hydroelectric power plant located on the Paraná River, in partnership with government institutions, NGOs, cooperatives, and rural producers in the region west of Paraná, Brazil (Casale, da Silva Carvalho, Furtado, Barrozo & de Fátima Alberton, 2014).

The project aimed to promote SD in the region, focusing on the conservation of natural resources and the improvement of the living conditions of small rural producers and achieved many of its development goals, reaching over 29 municipalities (Mello, Laurent, Kassam, Marques, Okawa & Monte, 2021). The project started in 2003 and has achieved significant results in terms of knowledge transfer and innovation (Pelfini, Fulquet, Marchegiani & Christel, 2020).

The project's main approach was to involve the rural producers in the decision-making process and promote the exchange of experiences and knowledge among them (Munck & Tomiotto, 2019). One of the key strategies was the formation of "farmer clubs" that brought together small producers to discuss and learn about best practices for soil conservation, water management, and diversification of agricultural production.

The project also invested in the dissemination of new technologies and innovation (Brown, 2018). For example, Itaipu Binacional developed a mobile unit equipped with various agricultural technologies, such as precision agriculture equipment, seedling production, and soil analysis equipment. The mobile unit traveled to rural areas, providing training and technical assistance to small producers (Carvalho & Da Cunha, 2021).

Another successful initiative was the implementation of agroforestry systems, which combine the cultivation of food crops and trees in the same area. This system helps to reduce soil erosion, increase soil fertility, and provide additional income for small producers (Koncagül, 2015). The project also supported the implementation of small-scale fish farming and beekeeping, providing technical assistance and training to the producers (Carvalho & Da Cunha, 2021).

These initiatives helped to diversify the production of small rural properties, increasing their resilience to market fluctuations and CC (Pelfini, Fulquet, Marchegiani & Christel, 2020). Furthermore, the project has been successful in improving the quality of life of local communities, by promoting social inclusion, environmental education, and sustainable production systems.

The project's main achievements were the promotion of SD in the region, the improvement of the living conditions of small rural producers, and the conservation of natural resources, been recognized nationally and internationally as a successful case of knowledge transfer and innovation to small rural producers winning several awards, including the UN-Water "Water for Life" Best Practices Award in Category 1, "Best water management practices", in 2015 (Mello, Laurent, Kassam, Marques, Okawa & Monte, 2021).

2.4.4 "Smart Agri Hubs" Project: a quadruple helix model of large-scale innovation

Smart Agri Hubs (SAH)[3] is a large-scale innovation project funded by the EU's Horizon 2020 program. The project that began in November 2018 and concluded in October 2021, aimed to promote the digital transformation of the European agri-food sector by creating a network of regional innovation hubs, each focusing on specific agri-food areas and regions across Europe.

The SAH project is designed to support the development and deployment of digital technologies in agriculture and food production, by connecting farmers, food producers, researchers, and other stakeholders across Europe. The project is structured around a hub-and-spoke model, with each regional hub acting as a central point of contact for local stakeholders and serving as a gateway to the wider European network.

The project is focused on six main areas of activity:

- **Innovation experiments:** SAH supports the development and implementation of digital innovation experiments in agriculture and food production, aimed at improving productivity, sustainability, and profitability.
- **Digital innovation hubs:** SAH establishes a network of digital innovation hubs across Europe, each focusing on specific agri-food areas and regions and providing support and expertise to local stakeholders.
- **Community building:** SAH brings together stakeholders from across the agri-food sector, including farmers, food producers, researchers, and technology providers, to promote collaboration and knowledge sharing.
- **Skills development:** SAH provides training and support to help stakeholders develop the digital skills needed to adopt and implement new technologies.

[3] Available at https://www.smartagrihubs.eu/ . Accessed on March 5, 2023.

- **Data management:** SAH promotes the use of data management tools and technologies to improve the efficiency and sustainability of agricultural production.
- **Policy and regulation:** SAH engage with policymakers and regulators to promote the adoption of digital technologies in agriculture and food production, and to support the development of policies that promote sustainability and innovation in the sector.

The need for an interconnected ecosystem of digital innovation hubs is driven by the desire to accelerate the digital transformation of the European agri-food sector. While there are many innovative technologies and digital solutions available, their impact can be limited if they are not effectively integrated and adopted by stakeholders across the value chain.

An interconnected ecosystem of digital innovation hubs can help to overcome this challenge by creating a network of expertise and support that connects stakeholders across different regions and sectors and helps to promote the adoption of digital solutions.

The goals of an interconnected ecosystem of digital innovation hubs include:

- Facilitating the adoption of digital technologies and solutions across the agri-food sector.
- Supporting the development of new business models and value chains based on digital technologies.
- Promoting collaboration and knowledge sharing across different regions and sectors.
- Addressing the digital skills gap by providing training and support to stakeholders.
- Encouraging innovation and entrepreneurship by providing access to funding and other resources.

But how is sustainability presented in the SAH Project? Sustainability is a key focus of the SAH project funded by the EU's Horizon 2020 program. The project recognizes that the agricultural sector is facing significant challenges, including the need to produce more food to feed a growing global population, while minimizing the impact on the environment and natural resources.

The SAH project aims to promote sustainability in several ways, including (Eitel, Weltzine, Riechmann, 2021; Visser, Contiero, Dequidt, 2021; Bacigalupo, Re, Massa, 2020):

- **Digital technologies for sustainable agriculture:** The project supports the development and deployment of digital technologies in agriculture and food production, aimed at improving productivity, sustainability, and profitability. These technologies include precision agriculture, IoT devices, and big data analytics.
- **Sustainable food production:** The SAH project promotes sustainable food production practices, including organic farming, agroforestry, and other approaches that minimize the use of chemicals and fertilizers and protect soil health.
- **CE and resource efficiency:** The project supports the development of CE models in agriculture and food production, aimed at reducing waste and optimizing the use of resources. This includes initiatives such as farm-to-fork supply chains, food waste reduction programs, and the use of renewable energy sources.
- **CC mitigation and adaptation:** The SAH project recognizes the impact of CC on agriculture and food production and promotes measures to mitigate its effects. This includes the development of climate-smart agriculture practices, such as conservation agriculture, and the promotion of agroforestry and other approaches that can help to sequester carbon.

Chapter 3. Methodology

3.1. Introduction

This chapter intends to provide justification of the methodology adopted in the approach to the problem under study and response to the research questions.

Thus, it is structured in main parts: (i) the first section presents the method chosen as a response to the research problem, highlighting its advantages, limitations, and addressing aspects related to the quality of the research design, (ii) the second section describes the selected unit of analysis and discusses the factors that influenced its choice, (iii) next, the section outlines the data collection techniques employed in the case study, (iv) the following section presents the empirical data, and finally, (v) the section analyzes the empirical data, providing insights and interpretations based on the findings.

This research aims to understand how open innovation, namely through quadruple helix models, can promote sustainability, making it possible for small farmers to benefit from digital technologies and overcome challenges and limitations.

3.2 Method – Case Study

This dissertation has the characteristics of qualitative research that are consistent with the approach used in the case study as a research strategy (Yin, 2018).

To gain an in-depth understanding of complex phenomena, case study research is a powerful method (Merriam & Tisdell, 2015) often used in the analysis of the complex social phenomena (Stake, 1995), namely in sustainability issues (Gregar, 1994) and factors that shape the development and use of technology (Avgerou, Ciborra, & Land, 2004).

Aiming to create a research design that not only comprehensively understands a single case but also provides a thorough analysis, a case study "type 1" methodology was defined (Yin, 2018). The case study "type 1" is a combination of two factors: single-case design and unit of analysis. Single-case design refers to the research design used in the study, which involves examining a single case in detail.

This means that the study focuses on a single unit of analysis, rather than multiple cases or units of analysis. Holistic approach to analysis refers to the way in which the researcher examines the case. The Type 1 case study is the methodology selected considering the need for a holistic approach to analysis. This approach emphasizes the interconnectedness of different aspects of the case and seeks to understand the case as a complex system and allows for a detailed and comprehensive examination of the case, which can provide insights and understanding that would not be possible with other research designs.

This method is recommended when the main research questions are “how” or “why”, and the researcher has little or no control over behavioral events (Yin, 2018).

Aiming to capture the circumstances and conditions of an everyday situation while lessons are provided about the social processes related to theoretical interest, the common case rationale was chosen.

In this sense, the method fits to the research question of this dissertation aims to investigate:

- How can quadruple helix throughout open innovation enable digital technologies adoption among small farmers?

3.3 Unit of Analysis

Merriam and Tisdell (2015) suggest that the unit of analysis in case study research should be carefully defined to match the research questions and goals of the study, and could involve a single individual, a group, an organization, or a specific event.

Considering that the choice of method adopted was conditioned by the problem under study and the type of question to be answered, the selection of the unit of analysis took into account the following inclusion criteria:

- The analysis unit should be an academic science and technology organization with an entrepreneurial mission.
- The quadruple helix and open innovation approaches should be present in this organization's governance and strategy.
- The unit would have a focus on agribusiness, and
- The unit impacts should include small farmers.

3.4 Data Collection

Merriam, and Tisdell (2015) emphasize the importance of collecting data from multiple sources and using multiple methods of analysis to establish a chain of evidence that supports the conclusions drawn from the case study.

Therefore, data collection was conducted by utilizing semi-structured interviews and documentary analysis, with the respective data collection instruments constructed specifically for this purpose. Further, the importance of establishing a chain of evidence in case study research, which involves collecting and analyzing data from multiple sources to support the validity and reliability of the findings is emphasized by several authors (Merriam & Tisdell, 2015; Yin, 2018; Gregar, 1994).

3.4.1 Semi-structured interviews

Semi-structured interviews are a commonly used data collection method in case study research. They are characterized by a flexible structure that allows the interviewer to ask follow-up questions and probe deeper into the participant's responses, while still adhering to a general set of questions or topics (Yin, 2018; Gregar, 1994).

Semi-structured interviews are a flexible and adaptable method of data collection in case study research, allowing the researcher to gain detailed insights into the participant's experiences and perspectives while still adhering to a general structure (Merriam & Tisdell, 2015; Yin, 2018). As part of the protocol followed in the study of case, an interview guide was created and is available in Annex D.

To organize and optimize the data collection, the transcription and recording software named Tactiq were used. Seventeen interviews were conducted with an average of time of ninety minutes.Basically, the research had nine different profiles of interviewees, namely and detailed in the table1 following below.

The core business of companies and startups listed in the table are machinery manufacturing, high-tech equipment solutions for furrow and ridge planting, bioinsecticides and others biological agents, and operations centers (digital tools).

Table 1. Interviewees' Profile Grouping.

Interview number	Profile Category	Role and Current Job
1	Exclusive Academia	InovaTec Manager
2	Hybrid - Academia and Startups	InovaTec Professor Startup Shareholder
3	Hybrid - Academia and Startups	InovaTec Professor Startup Shareholder
4	Hybrid - Academia and Startups	InovaTec Professor Startup Shareholder
5	Hybrid - Student and Startups	Scholarship holder Startup Shareholder
6	Hybrid - Student and Startups	Scholarship holder Startup Shareholder
7	Hybrid - Student and Startups	Scholarship holder Startup Shareholder
8	Hybrid - Alumini and Startups	Startup Shareholder
9	Hybrid - Alumini and Market Leader	Machinery Manufacturing - Integrated Solutions Consultant
10	Hybrid - Alumini and Farmer	Small Farmer Owner
11	Hybrid - Alumini and Farmer	Small Farmer Owner
12	Exclusive - University Industry Affiliate	Mechanization Solutions Technology Manager
13	Exclusive - University Industry Affiliate	Machinery Manufacturing - Senior Strategic Consultant
14	Exclusive Cooperative	Field Technician Consultant
15	Exclusive Cooperative	Communication and Press Advisor
16	Exclusive Cooperative	Field Technician Consultant
17	Hybrid - Academia and Farmer	Small Farmer Owner University Professor

3.4.2 Documental analysis

The use of several types of data source such as documentation, as outlined in table 2, were considered in the data analyses process. Part of the interviewed profiles also shared presentations related to the business, such as, mission, goal and technological solution offered, totaling six different documents from 5 sources. Although, mainly of the information accessed are public data and it is published in the respective websites. In total, twelve websites were reviewed as outlined in Annex E.

Table 2. Types of Data Sources.

Type	Description	Number	Profile Provider
Interviews	Semi-structured interviews	17	InovaTec, University, Cooperatives, Companies and Farmers
Documents	Websites contents	12	InovaTec, University, Cooperatives and Companies
	Videos contents	2	Globo Rural Channel
	Institutional presentations	3	InovaTec and Startups
	Technical description of projects	3	InovaTec and Startups

3.5 Data Analysis

The data collected was analyzed using a variety of techniques such as pattern-matching and explanation-building. The analysis should identify the key themes and patterns in the data, as well as any unique characteristics of the case (Ridder, 2017). From the analysis of the transcription of each of the interviews, an attempt was made to highlight what was most significant from the point of view of the objectives that guided the conduction of the interviews. Answers to semi-structured interviews, documentary content and notes of the observations were subjected to categorization.

The categorization followed three steps: (i) data were grouped into categories, by concepts identified by their properties and dimensions (such as ideas, events coded and reassembled into subcategories): (ii) data were reordered to connect categories; (iii) selective coding of core categories and those related to them (Yin, 2018). In order to provide a range of features to facilitate the process of coding, organizing, and interpreting qualitative data, Quirkos, as qualitative data analysis software designed to assist researchers in analyzing and exploring textual data was used.

The list of codes,was built based on the concepts enunciated in the previously carried out bibliographic review and presented in the previous chapters,is detailed in the table 3,the results of their analysis is described in section 4.1 . After encoding only relevant data, data reduction was performed, following the recommendations of Yin (2018). Patterns can be identified and compared with the theoretical support of reference and are presented in the next section.

Table 3. Codes Summary.

Code	Sub-Code
4Helix	Academy Role
4Helix	FarmersTraining Gap
Barriers to adoption	Financial Constraints
Barriers to adoption	Planning and Control
Barriers to adoption	Technological Skills
Barriers to adoption	Internet Connectivity
Enablers	Technical Assistance
Enablers	Technological Early Adopters
Benefits to adopt	Productivity Increase
Sustainability	Circular Economy
Sustainability	Biofertilizers
Sustainability	Environmental Laws
Open Innovation	Fairs and field days
Lean Startup Methodology	Small Test Areas
Lean Startup Methodology	MVP
Lean Startup Methodology	Rapid Prototyping

Chapter 4. Case study - InovaTec

The case was selected based on its unique features and characteristics that helped address the research question. In Brazil, InovaTec, Innovation, Science, and Technology Park located in Santa Maria (geographic location an Inovatec logo avaiable in the annex F), was selected as the single-case study. One of the three technology parks that have verticals focused on Agri-technology, out of sixty-two existing technology parks in Brazil. Furthermore, InovaTec has been recognized as one of the most successful innovation parks in Brazil, and it has played an important role in promoting technological development and economic growth in the region.

InovaTec was created in 2006 with the objective of fostering technological development and innovation in the region. Some of the main features and initiatives of InovaTec include:

1. Incubation and acceleration of startups: InovaTec offers a space for the incubation and acceleration of startups, providing support for the development of new businesses in the region.

"TechLaunch Incubator Program" is one example of that. It aims to support early-stage technology startups by providing them with a dedicated space, resources, mentorship, and access to a network of industry experts. Startups accepted into the program receive assistance in refining their business models, developing their products or services, and accessing funding opportunities. This comprehensive initiative is designed to nurture and support early-stage technology startups and provides selected startups with a dedicated workspace equipped with the necessary infrastructure and resources to foster their growth and development. This includes access to state-of-the-art facilities, advanced technology equipment, and software tools. In addition to the physical space, the incubator program offers a wide range of support services. Startups benefit from mentorship and guidance from experienced professionals who provide valuable insights and advice on various aspects of business development, technology implementation, and market strategy. The program also facilitates access to a network of industry experts, entrepreneurs, and potential investors who can offer further guidance, partnerships, and funding opportunities. Throughout their incubation period, accepted startups receive assistance in refining their business models, identifying target markets, and validating their ideas.

2. Collaboration with universities and research institutions: InovaTec works in partnership with local universities and research institutions to promote research and development in areas such as biotechnology, agribusiness, and information technology.

"The Advanced Farm 360" illustrates this collaboration and involves universities and research institutions to explore advanced farming techniques, technologies, or agricultural research. The project uses a variety of advanced technologies such as AI, IoT, and precision agriculture to help farmers optimize their production processes, reduce costs, and increase yields. Some of the specific technologies that the project incorporates include soil sensors, weather stations, drones, and data analytics tools. The project also seeks to foster collaboration between different stakeholders in the agricultural sector, including farmers, researchers, and industry partners. Through this collaborative approach, the project aims to co-create solutions that are tailored to the specific needs of farmers and can help to promote sustainable and environmentally responsible farming practices. Additionally, the objective of the project is to enhance teaching, research, extension, and innovation in agriculture, and to develop and introduce more sustainable farming systems in the agrarian community. The project aims to disseminate technologies compatible with the reality of rural producers in the Central Region, promote training courses for rural producers on crucial topics, and validate new technologies from startups at UFSM business incubators being supported by private companies in the agricultural sector, which provide the latest available technologies. On top of that, to validate new technologies from startups at UFSM business incubators, allows the use of new ones even before they are available on the market. The project's goal is to achieve the SDGs published by the Food and Agriculture Organization (FAO) of the UN.

3. Innovation and entrepreneurship events: InovaTec organizes a variety of events aimed at promoting innovation and entrepreneurship, such as hackathons, workshops, and conferences.

InovaTec organizes an annual event called "Innovation Summit" which serves as a platform to bring together innovators, entrepreneurs, industry experts, and investors. The summit features keynote speakers, panel discussions, workshops, and networking sessions focused on promoting innovation and entrepreneurship. It showcases cutting-edge technologies, emerging trends, and success stories from startup founders. The Innovation Summit provides a valuable opportunity for participants to exchange ideas, foster collaborations, and explore potential business opportunities. It acts as a catalyst for fostering an innovation ecosystem and promoting entrepreneurial culture in the region.

4. Technology transfer: InovaTec promotes the transfer of technology from research institutions to the private sector, facilitating the commercialization of new products and services.

A prominent project at InovaTec is the "TechConnect Program" that aims to facilitate the transfer of technology and knowledge from academic research to practical applications in industries. The TechConnect Program connects researchers, innovators, and industry professionals to collaborate on the development and commercialization of new technologies. It provides support in intellectual property management, technology licensing, industry partnerships, and funding opportunities to bridge the gap between academia and industry. This Program plays a crucial role in fostering technology transfer, promoting innovation-driven growth, and enhancing the competitiveness of businesses in the region. Initially, startups interested in participating in the program can submit their applications, showcasing their innovative technology solutions and business models. A panel of experts reviews the applications and selects promising startups based on their potential for growth, market fit, and technological innovation. The selected startups are then provided with a dedicated space within the InovaTec facility, where they can work on developing and refining their products or services. They also gain access to a range of resources, including mentorship, workshops, and networking opportunities.

5. Sustainability initiatives: InovaTec has implemented a variety of sustainability initiatives, such as the use of renewable energy sources, water conservation, and waste management programs.

The "GreenTech Challenge," is an example of a sustainability-focused program aimed at promoting and supporting green technologies and environmentally friendly practices. The challenge invites startups and innovators working on sustainable solutions to participate in a competition where they can showcase their projects. The selected participants receive mentoring, guidance, and access to resources to further develop their ideas. The program also facilitates connections with potential investors, partners, and customers interested in sustainable innovations. The Program plays a vital role in fostering sustainable entrepreneurship, encouraging the development of environmentally conscious technologies, and addressing pressing environmental challenges in the region.

4.1 Findings and discussions

The following paragrafs present key findings and discussions of this study. Twelve diffrents groups was defined during the codification process considering their relationship to each other and some transciptions were included to better illustrated the content analysed.

Academia role within Quadruple helix model:

- It was observed the establishment of partnerships and the creation of projects that involved the small farmers at the same time of promoting innovation and sustainable initiatives. *"So, we discuss and bring knowledge opportunities to this new generation without a commercial focus." Hybrid Profile Interviewed -* ***University Industry Affiliate***

- Former university students are now small-scale farmers who continue to maintain contact and relationships with InovaTec and the University. *"Surely, this market will grow as soon as we manage to increase the efficiency of farmers in their fields. And for that, there needs to be a continuous exchange of knowledge to accelerate this process. Through this knowledge exchange, along with our commercial partners, cooperatives, and dealerships, we can ensure that the entire supply chain is prepared to meet these new challenges arising from demands such as the use of biological inputs." Hybrid Profile Interviewed -* ***Alumni and Startups.***
- It identified a significant potential for "The Advanced Farm 360" to expand its partnerships. The project should seek partnerships with other government institutions, NGOs, cooperatives, and rural producers to expand its results and impact.
- InovaTec's positive influence on the technological journey of the small rural producer was evident. The University stands out for its neutrality, impartiality, credibility, and technical quality.
- Academia is seen as a safer and more reliable source of information and reading of global contexts. Simultaneously, professors often act as neutral and highly qualified consultants and are often demanded by alumni for guidance. *"I still have contact with the professors, many times I prefer to ask them. The professor gives me an explanation through WhatsApp. They send an audio, they send a message like, 'This thing works like this, according to the professor's explanation.' I take that and forward it, what the professor explained about the product."* ***Hybrid Profile - Alumni and Employee***
- Producers are skeptical and doubtful of salespeople. However, when a professor speaks about a product, the receptiveness is entirely different. They perceive the professor as unbiased and highly qualified, placing much more trust in the information provided about the product. *"It is different when they (producers) listen directly to the professors who, in an unbiased way, will report the results. They are much more open to listen, they interact and questioning without suspecting of veracity of information "* ***Hybrid Profile Interviewed - University Industry Affiliate***
- InovaTec was pointed out as the main agent of training and technical qualification in the region. The training offered by the University stands out in the connection between theory and practice, making it possible to test and apply the knowledge acquired. The technical agriculture course that students can enroll in and be affiliated with InovaTec was mainly mentioned. The course is designed to provide students with comprehensive

training in various aspects of agriculture and equip them with the necessary skills and knowledge to excel in the field. The partnerships established with companies enable experiments that are highly equipped with modern technologies that simulate a complete experience for the students of the cycle of cultivation and harvesting. *"They are graduating much more equipped. They already have the exposure to machinery because the technology is already there. They can use it and even conduct studies and comparisons between different types of technologies and options."* ***Hybrid Profile Interviewed - University Industry Affiliate.***

- It is also true that University´s qualification and training also showed relevance from the company's side to overcome the skeptical attitude of producers regarding salespeople mentioned previously. Further, a common practice among companies in the region is to proactively recruit top-performing university students specializing in agricultural technology even before they graduate, reinforcing the University's reputation in the region as a qualified workforce provider.

Farmers Training Gap :

- The need for more training and qualification appeared as a great pain in the local agriculture, with the university within the context of the quadruple helix allowing the formation of strategic partnerships. InovaTec is the reference to solve this gap and to reduce the distance of technical knowledge between who sells and who buys technology.
- According to the startup owners themselves, the knowledge generated in universities is still inadequately disseminated to farmers in the field. *"There is a big lack of knowledge in the field. The information doesn't reach us, there is a huge gap. A lot of knowledge, research here within the university doesn't make it outside."* ***Hybrid Profile Interviewed - Startup and Student.***
- A very low utilization of machine functionalities, mainly reported by companies and academia, were attributed to the lack of understanding and inadequate training and support. Users are not fully aware of the capabilities and functionalities of the machines and not have a comprehensive understanding of how to utilize them effectively. This led to underutilization and limited exploration of the machines' potential. Further, the more the equipment is used, the greater the return on investment as the cost is diluted in operations. *"It's no use having advanced technology if we don't use it. The professors also mentioned that only 5% - 10% of the farmers who purchase technological machines utilize the embedded technology. So having the technology but not using it doesn't solve anything."* ***Hybrid Profile Interviewed - Alumni and Farmers.***

- Strengthening of rural extension, which is the technical arm responsible for taking the knowledge generated in academia to rural producers was highlighted by startups. It is seen as essential that extensionists are well prepared and available to meet the demands of producers.
- Some farmers profiles interviewed mentioned the difficulty to find and to hire skilled labor in the region that increase the complexity of complicates managing rural properties.
- Many farmers face a reality of limited knowledge, low levels of education, and lack of scientific understanding. *"Proper training and education are necessary for farmers to fully utilize technology. Farmers need to see economic and environmental benefits to justify the investment."* ***Exclusive Profile Interviewed - University Industry Affiliate.***
- While they acquire practical skills through hands-on experience, their formal education and access to scientific knowledge may be limited. Without adequate knowledge, farmers are unaware of available technologies that could address their specific challenges and improve their agricultural practices, heavily relying on traditional practices and inherited knowledge.
- Basic rural management techniques and simple innovations are still largely unknown and poorly implemented.
- According to all profiles interviewed, farmers don't feel comfortable to choose the most appropriate solution for themselves. Farmers shared that they aim to have technical and impartial support to make better decisions. Timing was also reported as crucial in this process, being many times unavailable cooperative technicians and even sellers. *"But they, rural producers, have to know how to sift through and choose what works for them. It is a huge challenge for most of them."* Exclusive ***Profile Interviewed - Cooperatives.***

Lean Startup Methodology Application:

- Several concepts and values of LSM were mentioned by farmers profiles, even without deep knowledge of the theory.
- The concept of MVP applied to new crops was observed in all farmers profiles interviewed. The farmers allocate small test areas on their properties to experiment with new products (biofertilizers) and management techniques (telemetry). By doing so, they can gather real-world data and feedback to validate the viability and potential of these innovations. By starting small and testing in controlled environments, farmers can minimize risks and make informed decisions based on empirical evidence, ultimately

improving their overall agricultural practices. From the perspective of companies, the MVP concept is also observed by companies testing new products and solutions within their own designated areas, as well as through the "The Advanced Farm 360" of InovaTec. *"It's not the same productivity that you get when aligning the altitude on the machine, for example. Each property has to have its testing area for new product issues."* ***Hybrid Profile Interviewed - Alumni and Farmer.***

- Testing of innovative farming techniques was also reported. Small farmers are quickly and cost-effectively validating and iterating on new agricultural methods. Usually advised by technicians, they are implementing small-scale trials or experiments within controlled environments or designated areas to assess their viability and impact. One interviewee was already being able to gather real-time data, analyzed results, and make informed decisions about the adoption and scaling of these techniques.
- Customer discovery for niche markets is an essential aspect of the Lean Startup approach applied to agriculture. When it comes to gathering the needs of small rural producers in the region of study, both cooperatives and startups play important roles. Cooperatives, with their collective approach, often work closely with farmers, gathering feedback and providing tailored support to them. Startups, on the other hand, bring innovation and technology to the table, offering solutions that address their challenges.
- To implement concepts in practice, making a rapid prototype, without adopting expensive technologies, some farmers are making adaptations where free mobile applications were used to attempt to automate the planting line layout. In this manner, the farmer attached the mobile phone to the tractor and, as the tractor operator, managed to follow the line layout (simulation with autopilot).
- More customized and affordable technological solutions are crucial for small farmers. *"It is crucial to tailor the technology to the specific needs of each farm, rather than simply buying the latest, the best, or the cheapest, which is more common in practice."* ***Exclusive Profile Interviewed - Cooperatives.***
- There is an imbalance of solutions and products for different crops. Some already have options, but a significant portion lacks market interest and suitable technological alternatives. *"Depending on the crop, there are few options. For rice, the choices are limited, and many people use other products that are not suitable. There is no specific product, and no one is willing to develop a solution. The market and companies prioritize soybeans which are gaining traction here. This creates an imbalance, leaving many crops unassisted."* ***Hybrid Profile Interviewed - Alumni and Farmer.***

Farmers Financial Constraints:

- The limited financial resources and consequent focus on cost reduction of small farmers appeared in the responses as a factor that prevent to invest in new technologies. *"60% of farmers, who own less than 10 hectares, struggle to invest in technology. They need to think differently, they need to support each other and work together. When we talk about Brazilian agriculture, we often refer to medium-sized and large-scale producers. The small-scale farmer operates in a different world."* ***Hybrid Profile Interviewed - University Industry Affiliate.***
- In Brazil, there are various financing options available to support farmers and agriculture. However, the results showed a negative perception of financing lines, which are increasingly smaller and more restrictive recently. The difficulties in obtaining financing with low interest rates aggravate the situation, generating meaningful financial constraints as well as very low working capital.
- Higher-cost technologies may be perceived as unaffordable or too risky, especially if the return on investment is not expected in the short-term, limiting the exploration of more advanced and sustainable technological options. *"It (technology) is still very expensive. If you look at it, the cost is quite high, and there is also no financing available sometimes. Most of us pay off debts with the proceeds from the harvest of the current year."* ***Hybrid Profile Interviewed - Alumni and Farmer.***
- The focus on low costs in agriculture has detrimental effects as farmers often prioritize price over the technology that best meets their needs. This can result in the selection of technology that may not be the most suitable for their specific requirements. For instance, farmers may choose suppliers based on payment conditions or financing availability rather than considering factors like solution fit, quality, or technical support.

Lack of planning and control:

- The lack of planning indicates low knowledge and control of what happens on the property, making it difficult to understand what is needed in the field and impacting the innovation decision making process. *"What often happens is that the producer wants to skip steps. They are also applying at any time and in any way. However, without doing the basics, it won't work."* ***Hybrid Profile Interviewed - Student and Startup.***
- The majority of interviewees from all backgrounds perceive the lack of planning and control on the farm as a hindrance to the adoption of agricultural technologies. As an example, the adoption of machinery is directly linked to specific periods of use, with the harvest season being the peak time for new machinery demands. *"They (farmers) all go to buy*

last-minute before planting. The majority does not engage in planning and control; they are unaware of what actually happens on the property. There is a lack of professionalism among farmers, a need for a stronger business mindset." ***Hybrid Profile Interviewed - Startup and Student.***

- It directly affects availability of products and prices, which are inflated during harvest periods and create a perception of a culture that is heavily pressured by cost according to the company's profile interviewed.

Users Lack of Technological skills:

- Small farmers' lack of technological skills occupied a huge relevance in the context being characterized as fear and resistance among farmers towards technology usage. *"There is always that fear of doing something wrong, of not being able to use technology."* ***Hybrid Profile Interviewed - Alumni and Farmer.***
- They need more experience and knowledge in operating and integrating these technologies into their traditional farming practices. Traumatic cases of individuals bankrupt due to over investments in machines that they could not operate were mentioned by farmers and cooperatives.
- Questioning about how "friendly" technology is on a real basis, fearing the "unknown" and distrusting of the "new" was constantly reported by all players as key innovation challenges and barriers. Despite that, after using technology, the perception was defined as friendly, positive, and accessible, being technology usability well evaluated by all parties.
- The user's fear it was overcome with the assistance of a technician. It is worth mentioning that during the interview process, one emblematic case was mentioned of an illiterate person who operate technological panels of harvesters in a very efficient way. The willingness to learn and "open mind" attitude appeared as relevant factors capable of overcoming educational gaps. *"We once had a situation with an illiterate person. He couldn't read or write, but he managed to use the autopilot. He simply memorized the icons on the monitor and followed the sequence correctly. It's very intuitive. Some individuals may still face difficulties, but around 95% learn."* ***Hybrid Profile Interviewed - University Industry Affiliate.***
- Older farmers were constantly characterized as resistant to change, less familiar with digital tools, lower comfort level with technology and harder to adapt to new systems compared to younger generations. *"Here in our region, I think 90% of farmers are over 70 years old or in that age range. They prefer to continue doing what is working for them. They also take a bit longer to catch on and it takes them more time to understand it."* ***Hybrid Profile Interviewed - Alumni and Farmer.***

- The younger generation plays a crucial role in changing the technology adoption scenario in agriculture according to university, companies and farmers profiles interviewed.
- In recent years, it has been observed that descendants of farmers that go out to study are coming back home and implementing what they have learned. According to different interviewees, technology and connectivity were mentioned as the main responsible for this moving back.
- Companies and cooperatives highlighted the influential role of younger individuals in encouraging innovation, even influencing their parents. The younger generation's tech proficiency can bridge the technology-agriculture gap. *"Mainly because there is a generational shift happening - that's what I believe will help. I believe it will greatly facilitate things."* ***Exclusive Profile Interviewed - University Industry Affiliate.***
- The knowledge, skills, and familiarity of the operator with different technologies play a significant role. If the employee is experienced and knowledgeable about advanced machinery and technology, they influence the farmer to invest in more technologically advanced equipment. This scenario was rare, since most rural workers were characterized as having a very low level of education as well.
- Farmers also demonstrated concerns about technical issues or malfunctions and compatibility with existing equipment in a practical sense.
- The local agriculture had deep-rooted traditions, and some farmers are resistant in changing established practices.

Connectivity Role:

- Connectivity plays a crucial role in driving technological innovation in local agriculture. It enables farmers to access and utilize various digital tools, data-driven systems, and smart farming technologies that can enhance productivity, efficiency, and sustainability.
- Connectivity is a crucial prerequisite for the adoption and advancement of technology in agriculture, particularly in rural areas. However, the level of rural connectivity varies significantly in the study region. Internet access is more reliable and accessible in densely populated areas or near urban centers. In contrast, rural and remote areas face limitations in terms of high-speed internet availability, resulting in challenges when it comes to accessing and utilizing technology-driven solutions.

- Although the coverage and reliability of mobile networks can vary depending on the proximity to cellular towers and infrastructure, mobile networks are often relied upon for internet connectivity in rural areas.
- All farmers in the study expressed a favorable view of having an online-connected farm when needed. Despite challenges related to connectivity and accessibility, all respondents found ways to establish connectivity, even if it required additional efforts, investments, or accepting limitations in terms of internet speed and signal capacity.

Technical Assistance Role:

- The availability of reliable technical assistance plays a crucial role in the adoption of technology and was strongly mentioned by all players interviewed. Farmers often seek support from experts and technology providers who can offer guidance and troubleshooting assistance. *"What they value the most is technical support. Being available and present is essential for small rural producers."* ***Hybrid Profile Interviewed - Academia and Startup.***
- According to the interviewed companies, the role of the seller goes beyond simply selling products. Farmers face various challenges, such as financial, technical, and emotional aspects. In this regard, a seller who develops a close relationship with farmers understands their struggles and becomes a trusted confidant. By offering support, the seller increases the farmer's willingness to take risks and adopt new technologies. *“"They need to trust. We need to be close and available. Not to let them down when they need us the most."* ***Hybrid Profile Interviewed - Alumni and Market Leader.***
- It was identified as an opportunity for technical assistance and post-sales support for small rural farmers in the region, considering most of them are not receiving any assistance.
- The region, characterized by a significant number of small-scale farmers, posing challenges for sellers and service providers. The dispersed nature of small farms and their limited purchasing power make it less economically viable for companies to invest in extensive on-the-ground support and dedicated technical assistance for individual farmers.
- Companies mention the farmer's lack of proactivity in seeking technological innovation in agriculture. They actively approach potential customers, while farmers typically seek help only when faced with unsolvable problems.

Technology Early Adopters Influence:

- It was identified farmers in the region considered technology early adopters who are embracing new innovations in local agriculture. These individuals were characterized as open-minded, willing to take risks and exercise influence in the local community. *"We have to take risks, we have to trust that it will work out, and we have to experiment. Otherwise, we will always stay in the same place. We won't move forward. We'll never change."* ***Hybrid Profile Interviewed - Alumni and Farmer.***

- Farmers tend to observe and learn from their peers who have already adopted the technology successfully. A neighbor's farm is seen as neutral and much more believable than a demo in a technology company context being a farmer "influencer" of technology seen as a reference in the geographic region. *"Even if he doesn't get along well or has a close relationship with his neighbor, he will visit the neighbor's property to see the new machine. It becomes an event in the region, and everyone will come to see, ask questions, and discuss the new acquisition."* ***Hybrid Profile Interviewed - Academia and Startup.***

- As a negative effect, the strong influence of neighboring farmers leading to a lack of individualized decision-making and hinder the adoption of technologies that align with the farmers' unique requirement.

- With a much smaller representation, social media were mentioned as a source of awareness of new technologies and innovations - not as decision making. Farmers used it to stay informed about emerging technologies.

Open Innovation at InovaTec:

- Farmers interviewees often appreciate hands-on experiences with the technology before deciding. These practical experiences provide a deeper understanding and confidence in the technology's effectiveness and assess its potential benefits firsthand. Companies also value practical experiences in the sense of differentiation among competitors.
- The "field days" proposed by InovaTec in partnership with technology companies were extremely mentioned by all profiles interviewed. The opportunity to test in practice was perceived as extremely crucial to breaking down barriers to technology adoption.
- InovaTec's "field days" specifically focus on promoting local innovations and solutions. Highlighting local solutions also facilitates collaboration between researchers, technology

providers, and farmers, fostering the development and adoption of technologies tailored to the specific needs of the region.

- The hands-on testing allows farmers to make informed decisions about the equipment's suitability for their specific farming operations and were very highlighted during the interviews.
- "Agribusiness fairs" is a common practice in the sector, with larger-scale characteristics that serve much more as platforms for companies to showcase their latest offerings and brand engagement.
- The poor geographical distribution of testing centers makes it difficult for local farmers to access testing services conveniently. The cost associated with testing pose a financial burden for players of the supply chain, limiting the number of machineries tested. *"Today, we do not have how to certifies that what has been purchased in an agricultural machine is being delivered. It is necessary to involve external parties which is rarely feasible".* ***Hybrid Profile Interviewed - Academia and Startup.***

Productivity Increase:

- Productivity was the factor most mentioned for all profiles as the main benefit of adopting technology in agriculture being defined as significant gains in productivity.
- The gain of productivity was directly associated with mechanization and automation. The use of machinery and automated systems can significantly improve efficiency and productivity on farms.
- Some interviewees associated productivity gains with a more efficient resource management, optimizing the use of resources such as water, fertilizers, and pesticides. Precision agriculture and Internet of Things (IoT) also was related to enhancing productivity considering the revolutionary approach for resource management.
- Mechanization was also related to reduction of human resources, operating independently even with limited human resources available. Few situations were evidenced in which the farmer depended directly on a specific and qualified workforce, and he did not show up.
- Timely and informed decision-making was realized as a key benefit since technology provides access to real-time data and information, enabling small rural producers to make more informed decisions. For instance, weather monitoring systems providing accurate weather forecasts, allowing farmers optimize planting, irrigation, and harvesting.

Sustainability Awareness:

- Many producers tend to view sustainability primarily to reduce costs in their farming operations.
- Brazilian environmental legislation is a positive factor of awareness, mentioned by 90% of the interviewees in this case study. Opportunities to increase farm income due to legal incentives to remunerate farmers for carbon credits were mentioned.
- There is still a lot of subjectivity in relation to agricultural sustainability application, and one of the root causes found is the difficulty of quantifying and measuring gains and/or environmental improvements.
- Farmers intuitively apply circular economy (CE) principles by composting agricultural residues, using them as organic fertilizers, and leaving crop residues on the surface to improve soil health, retain moisture, reduce erosion, and enhance biodiversity, thus promoting sustainable agricultural practices.
- There is a good perception regarding the cost-effectiveness of biofertilizers, offering long-term cost savings. Biofertilizers also was popular in the interviees due to the several advantages over conventional chemical fertilizers, particularly in terms of environmental sustainability and long-term soil health.
- During the interviews, it was observed that the adoption of biologicals was motivated by the search for a solution to a chronic problem on the farm that has not traditionally been resolved. Contradictorily, many farmers reported the use of both, as a perception that the exclusive use of biologicals is not hundred per cent effective.

Chapter 5. Conclusions

Open innovation is of particular importance for small farmers in the context of sustainable agriculture. Small-scale farmers often face numerous challenges, such as limited access to resources, knowledge, and technologies. Throughout the literature review, we were able to conclude that open innovation provides an opportunity for small farmers to overcome these constraints by promoting collaboration and knowledge exchange with other stakeholders, including researchers, experts, and technology developers.

This research was carried out with the aim of understand how can quadruple helix throughout open innovation enables digital technologies adoption among small farmers. A case study was conducted in InnovaTec, a Technology Park with Agri-technology vertical focus. With this purpose, a detailed review of the concepts and their evolution served as a starting point. The case analysis findings , in comparison with the results of the bibliographic review led to the following conclusions:

InovaTec, as an actor with both academia and industrial/entrepreneurial purposes, plays a crucial role as a catalyst for industrial partnerships (affilliates), facilitating the convergence of the economy with academia through the Quadruple Helix approach. Its stakehlders interactions proove that the quadruple helix model is shown to be a promising approach to create the ideal conditions for small farmers in the region to have access to updated technological innovations and tailored solutions. Open innovation, agricultural sustainability, and technology are interconnected concepts that can create a positive feedback loop, where innovation leads to sustainability, and sustainability drives further innovation. By collaborating and leveraging technology, small farmers can improve their productivity and reduce environmental impact.

Open innovation in Agri-settings is intertwined with InovaTec's field days and with the increasing presence of agribusiness startups. These events create an environment of collaboration, knowledge sharing, and technology adoption, fostering innovation and driving advancements in agricultural practices in the region.

Small farmers' knowledge gap harms their ability to adopt and utilize advanced agricultural practices and technologies effectively and limits their ability to make informed decisions harming the potential of technological advancements. The combination of technology early adopters and the potential of succession in the agricultural sector creates a positive outlook for technology adoption.

The availability of reliable technical assistance is crucial for technology adoption. Farmers rely on experts and technology providers for guidance and troubleshooting. Building close relationships and providing support is essential, as it increases farmers' trust and willingness to adopt new technologies. However, small rural farmers often lack assistance, presenting an opportunity for post-sales support.

Although farmers have access to the best agricultural technologies available in the market, they face a challenging context related to: financial constraints, machines at unfordable prices, internet connectivity issues, reduced technical training and support, and lack of planning and control.

In this regard, the research question has been answered in the following way:

- *How the quadruple helix throughout open innovation enable digital technologies adoption among small farmers?*

  The quadruple helix model, in conjunction with open innovation, plays a crucial role in facilitating the adoption of digital technologies among small farmers. By bringing together academia, industry, government, and civil society, this model creates a collaborative environment where knowledge, resources, and expertise can be shared. Through open innovation practices, small farmers can access and integrate digital technologies into their agricultural practices.

  The quadruple helix model encourages partnerships and co-creation, enabling small farmers to collaborate with researchers, technology developers, and other stakeholders to identify the most suitable digital solutions for their specific needs. These collaborative efforts help overcome barriers such as limited resources and technical knowledge that often hinder technology adoption among small farmers. By leveraging the quadruple helix model and open innovation, small farmers can effectively embrace digital technologies, enhancing their productivity, sustainability, and overall competitiveness in the agricultural sector.

5.1 Future directions and research

In the context of future directions and research, studying the role of digital technologies and their integration within the quadruple helix model and open innovation processes could shed light on their potential to drive innovation and collaboration further. Exploring the challenges and opportunities related to data privacy, security, and governance within this framework would also be valuable, considering the increasing importance of data-driven innovations.

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Annex A

Table. The summary of search trials.

Keyword search combination	Source and number of papers found in the search	Date of Search	Name of the file saved in the search
(TITLE-ABS KEY (*"Agri"* AND *food* AND *value* AND *chain*)	Scopus (727)	10/27/2022	AFVCS
(TITLE-ABS-KEY (“*Ag-tech*" OR “*AGROTECH"* OR “*Agricultural technology” AND* food AND supply) AND TITLE-ABS-KEY (productivity))	Scopus (71)	10/27/2022	AAAFSPS
TITLE-ABS KEY (*open* AND *inclusive* AND *innovation* AND *sustainable* AND *value* AND *chain*)	Scopus (04)	11/01/2022	OIISVCS
TITLE-ABS KEY(*open* AND *inclusive* AND *innovation* AND *agriculture*)	Scopus (08)	11/01/2022	OIIAS
TITLE-ABS-KEY (*open* AND *inclusive* AND *innovation* AND *food*)	Scopus (15)	11/02/2022	OIIFS
TITLE-ABS KEY (“*Codesigning"* AND *agriculture*)	Scopus (27)	11/02/2022	CDAS
TITLE-ABS-KEY ("co-designing" AND food AND water)	Scopus (08)	11/03/2022	CDFWS
TITLE-ABS-KEY (social AND innovation and food AND water AND nutrients AND value AND chain)	Scopus (02)	11/03/2022	SIFWNVCS
(ALL=(" Agri" AND food AND value AND chain)	WoS(1,135)	10/27/2022	AFVCW
(ALL=(inclusive AND innovation AND open AND agriculture)	WoS(42)	10/27/2022	IIOAW
(ALL=(inclusive AND innovation AND open AND food)	WoS(36)	10/27/2022	IIOFW
(ALL inclusive AND innovation AND open AND agriculture) AND social)	WoS(18)	11/01/2022	IIOASW
(ALL= (“*Co-designing"* AND *agriculture)*	WoS(50)	11/01/2022	CDAW
(ALL= (“co-designing" AND food AND water)	WoS(13)	11/02/2022	CDFWW
(ALL= “Agricultural technology” AND food AND supply AND productivity)	WoS(15)	11/02/2022	ATFSPW
(ALL= “Agricultural technology” AND food AND supply)	WoS(80)	11/03/2022	ATFSW
(ALL= social AND innovation and food AND water AND nutrients AND value AND chain)	WoS(06)	11/03/2022	SIFWNVCW

Annex B

Table. List of the seminal papers.

Article	Author(s) and Publication Year	Relevance to the research topic
1. The era of open innovation	Chesbrough, H. 2003	Application of open innovation concepts to business models; based on technology management.
2. Beyond high tech: Early adopters of open innovation in other industries	Chesbrough H., Crowther, A.K. 2006	Practices of organizations in industries outside "high technology" that are early adopters of open models. Influences that Open Innovation has utility as a paradigm for industrial innovation beyond high tech to more traditional and mature industries, such as agriculture.
3. University-industry relationships and open innovation: Towards a research agenda	Perkmann, M., Wals,h K. 2007	Addresses the research needs of organization and management of collaborative relationships between the universities and firms.
4. Challenges of open innovation: The paradox of firm investment in open-source software	West J., Gallagher, S. 2006	Identifies the fundamental challenges for firms in applying the concept of open innovation. Describes strategies and discusses how to address the key challenges of open innovation.

Annex C

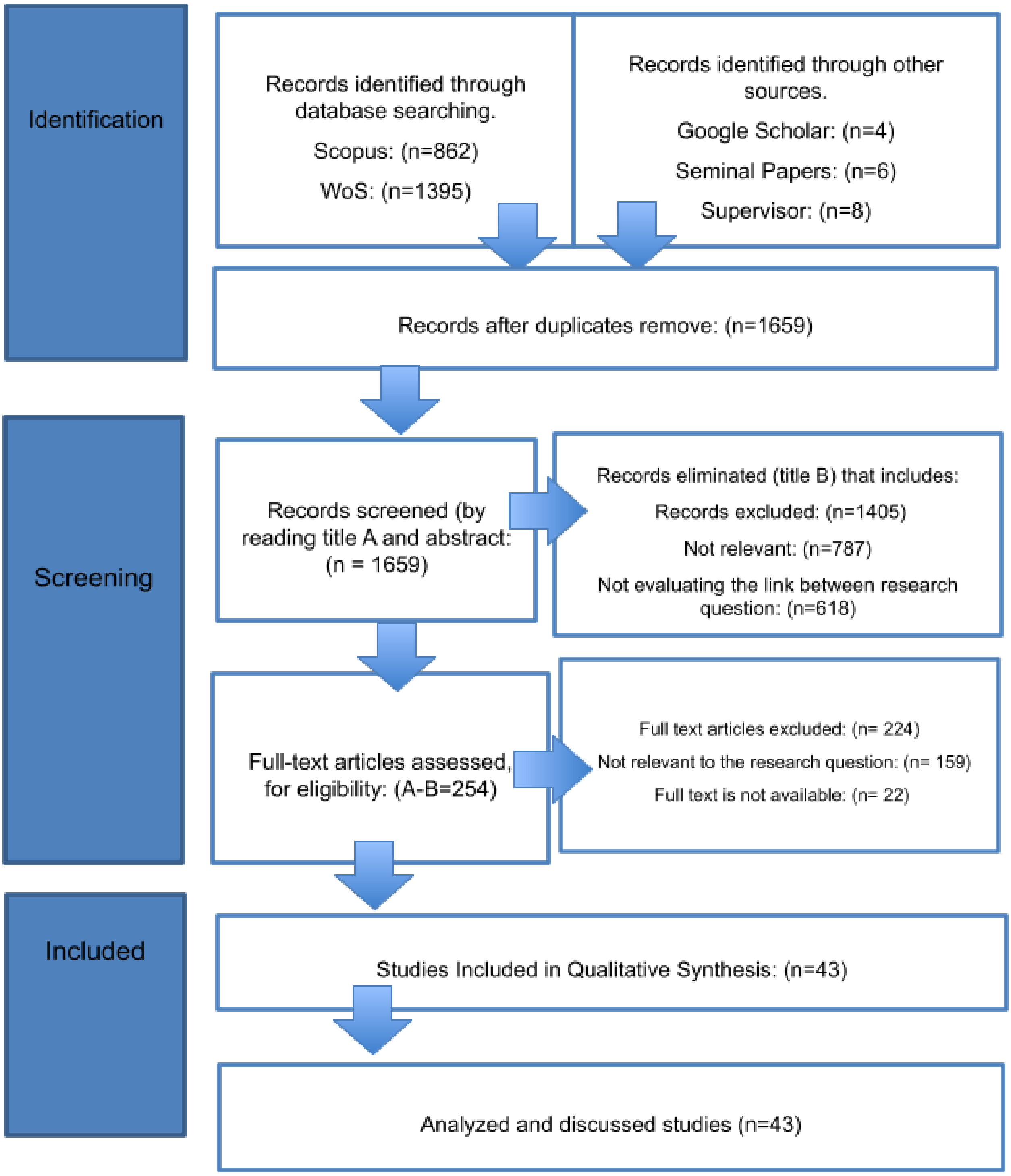

Figure. Prisma flow Diagram.

Annex D

Table. Interview Guide 1(part 1) - Portuguese version.

Guião de entrevistas					
Blocos	**Objetivos específicos**		**Questões Principais**		**Questões Auxiliares**
1.Sustentabilidade agrícola: conceito e importância	Entender como se define o conceito de sustentabilidade agrícola	1	O que é sustentabilidade agrícola na sua visão e/ou de vcs?	1.1	Quais são os pilares que caracterizam a sustentabilidade agrícola?
	Entender a importância da sustentabilidade agrícola	2	Por que a sustentabilidade agrícola é importante na sua visão e/ou de vcs?	2.1	Quais são os fatores que fazem a sustentabilidade agrícola ser tão importante para o InovaTec?
	Entender os benefícios cruzando a definição com os maiores objetivos de longo prazo mapeados na revisão bibliográfica	3	Quais os benefícios da implementação das práticas de sustentabilidade agrícola?	3.1	Ao longo do tempo, o InovaTec observa ou não mudanças na Saúde do Solo, Biodiversidade, Conservação de água, Eficiência Energética e Viabilidade econômica devido às novas práticas adotadas?
	Entender a aplicabilidade do conceito na prática e dentro do contexto dos pequenos produtores rurais	4	O quanto os membros/participantes implementam tais práticas nas suas propriedades rurais?	4.1	Como se mensura a adoção das práticas de sustentabilidade agrícola?
		5	Na sua experiência como professor/gestor, os pequenos produtores possuem barreiras ou maiores dificuldades na implementação dessas práticas?	5.1	Há evidências sobre dificuldades em 1) atingir uma escala maior de produção aplicando as técnicas? 2) Já se sentiu afetado pelas Mudanças Climáticas? 3) Percebe-se ou não uma competição entre os recursos naturais (food-energy-water nexus)? 4) Há desperdício ou não com relação ao uso de nutrientes?
				5.2	Práticas como : 1) Reduzir o uso de pesticidas naturais e produtos químicos que contaminam o solo, ar e água para o controlo de pragas, optando por alternativas naturais disponíveis no mercado; 2) Escolher adubos e fertilizantes orgânicos; 3) Reaproveitar recursos naturais (exemplo: criar sistemas que aproveitem a água da precipitação, utilizando-a para a irrigação do solo); 4) Investir em sistemas que funcionem à base de energias renováveis e limpas, como a solar; 5) Evitar a monocultura através da rotatividade no cultivo de espécies diferentes; 6) Alternar as rações dos animais; 7) Reutilizar as emissões de carbono para produzir energia; já foram implementadas nas propriedades participantes?

Table. Interview Guide 1 (part 2) - Portuguese version.

Guião de entrevistas					
Blocos	**Objetivos específicos**	**Questões Principais**		**Questões Auxiliares**	
2.Inovação aberta e inclusiva no agro	Entender a governança e o processo de inovação aberta dentro do InovaTec na vertical do Agronegócio.	**6**	Como funciona a inovação aberta na vertical do agronegócio ?	**6.1**	Sendo o que caracteriza a inovação aberta a busca no mercado soluções e novos produtos, não dependendo exclusivamente dos esforços de suas equipes internas, como o InovaTec aplica esta abordagem na vertical do agronegócio?
	Mapear se já tiveram ou não alguma experiência com inovação aberta na vertical do agronegócio com resultados tangíveis	**7**	Na sua experiência como professor/gestor do InovaTec, a inovação aberta influencia a tomada de decisão do pequeno produtor rural?	**7.1**	Como se mensura a efetividade da inovação aberta dentro da vertical do agronegócio?
	Entender como enxergam os benefícios cruzando com quádrupla mapeados na revisão bibliográfica	**8**	Na sua experiência como professor/gestor do InovaTec, quais benefícios a quádrupla hélice gera para a inovação aberta?	**8.1**	O modelo de quadrupla hélice representa as inovações como emergentes na cooperação entre universidade, indústria, governo e sociedade civil. Na sua experiência como professor/gestor, quais benefícios a quádrupla hélice gera para a inovação aberta na vertical do agronegócio?
	Entender o como e quando é feito a prototipação/ teste de acordo com a metodologia Startup Lean	**9**	Como é feito o teste/prototipagem do produto no mercado?	**9.1**	Em qual etapa de desenvolvimento do projeto acontece o teste no mercado?
	Entender como enxergam os benefícios cruzando com LeanStarpup mapeados na revisão bibliográfica	**10**	Na sua experiência como professor/gestor do InovaTec,quais benefícios a metodologia Lean Startup gera para a inovação aberta no agronegócio?	**10.1**	Sabemos que a Lean Startup é uma metodologia de criação e gestão de startups que ensina como criar produtos desejados por clientes, gerando ciclos de aprendizado rápidos, em que as mudanças no direcionamento das estratégias da empresa aconteçam visando um crescimento acelerado. Na sua experiência como professor/gestor, quais são os benefícios dessa metodologia para a inovação aberta na vertical do agronegócio?
	Entender a aplicabilidade do conceito na prática e dentro do contexto dos pequenos produtores rurais	**11**	Na sua experiência como professor/gestor, quais barreiras/dificuldades o pequeno produtor enfrenta na implementação da inovação aberta na vertical do agronegócio?	**11.1**	No agronegócio, a inovação inclusiva aberta vendo sendo implementada por diferentes abordagens e iniciativas, tais como : redes de inovação, tecnologia abertas (software ou hardware que é livremente acessível, modificável e distribuível por qualquer pessoa), Hackathons e desafios de inovação, Ciência cidadã que engaja sociedade civil em pesquisas científicas e coleta de dados entre outros.

Table. Interview Guide 1 (part 3) - Portuguese version.

Guião de entrevistas					
Blocos	**Objetivos específicos**	**Questões Principais**		**Questões Auxiliares**	
3.Inovações tecnológicas para sustentabilidade agrícola	Entender a efetividade das tecnologias para uma agricultura mais sustentável no contexto do pequeno produtor	12	Na sua experiência como gestor/professor, como as tecnologias digitais são usadas pelo pequeno produtor?	12.1	Agricultura de precisão? Controle biológico? Agrofloresta? Fazendas verticais? Biotecnologia? são alguns exemplos de inovações tecnológicas que favorecem a sustentabilidade agrícola. Quais são mais populares entres os pequenos produtores?
	Mapear a experiência dos pequenos produtores rurais durante a adoção de tecnologias digitais	13	Como o pequeno agricultor inicialmente se interessa por tecnologias digitais nas suas operações?	13.1	Como se inicia o contato entre o InovaTec e o pequeno produtor?
	Mapear os pontos de contato com o universo de tecnologia digital antes, durante e depois do projeto	14	Qual é a jornada tecnológica do pequeno produtor rural?	14.1	Existe um "padrão" de evolução tecnológica observado nos pequenos produtores rurais?
	Entender os principais fatores de motivação para adoção das tecnologias	15	O que sustenta o interesse dos pequenos produtores no uso de tecnologias para a agricultura?	15.1	Quais são as principais motivações dos pequenos produtores rurais para manter o uso e a aplicação de tecnologias?
	Mapear as principais barreiras para adoção das tecnologias	16	Os pequenos produtores rurais apresentam dificuldades na adoção e manutenção do uso de tecnologias?	16.1	Quais as etapas para um pequeno produtor se tornar participante do projeto/ InovaTec?
	Entender o valor gerado na adoção das tecnologias para o produtor rural	17	Quais são os principais benefícios almejados pelos pequenos produtores na adoção e uso de tecnologias na sua propriedade?	17.1	Há evidências amostrais de mudanças após a implementação das tecnologias ? Como se mede o impacto da adoção das tecnologias?
		18	Em termos de investimento financeiro/ custo, os pequenos produtores acham as tecnologias para a agricultura acessíveis?	18.1	Os valores são baratos, justo ou caro na realidade/contexto dos pequenos?
		19	O quão habilitados os pequenos produtores estão para usar /operar as tecnologias ?	19.1	Os pequenos tiveram/relataram dificuldades em usar/operar as tecnologias?
		20	Qual era a percepção deles antes de usar as tecnologias versus depois de adotá-las?	20.1	O que mudou e o que foi confirmado (preconceitos/ vieses) ?
		21	O quanto é importante para o pequeno produtor atingir melhores resultados financeiros no curto prazo (1 ano)?	21.1	Em geral, os pequenos obteve melhores resultados financeiros no curto prazo (1 ano)?

Annex E

Table. Websites of documental analysis

Number of websites	Website link
1	https://www.ufsm.br/orgaos-suplementares/InovaTec/sobre
2	https://www.g2wsistemas.com/
3	https://www.farm360.com.br/#a-farm
4	https://bioagreen.com.br/
5	https://www.deere.pt/pt/index.html
6	https://itaimbemaquinas.com.br/
7	https://www.ufsm.br/orgaos-suplementares/InovaTec/2023/01/24/ufsm-recebe-comitiva-da-rede-gaucha-de-ambientes-de-inovacao
8	https://www.masseyferguson.com/pt_br.html
9	https://camnpal.com.br/camnpal/1/historia.html
10	https://www.cotriel.com.br/
11	https://afubra.com.br/
12	https://portal.ufsm.br/projetos/publico/projetos/view.html?idProjeto=67766

Annex F

INOVATEC UFSM / PARQUE TECNOLÓGICO

Figure. InovaTec Logo

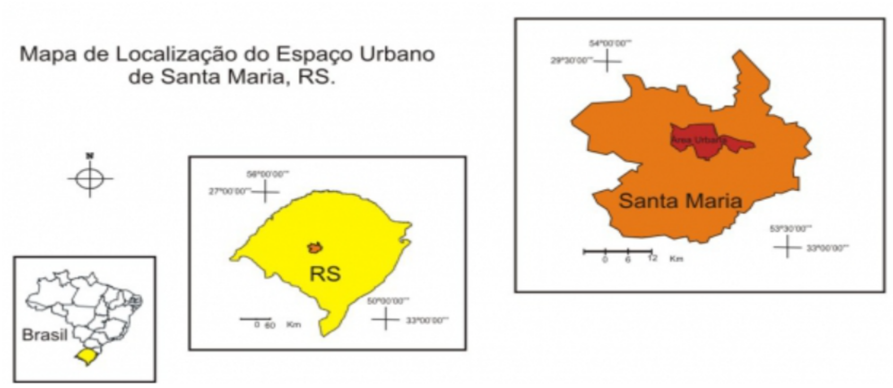

Figure. Santa Maria Geographic Location

Figure. Santa Maria Geographic location