Costs and benefits of sustainability-oriented innovation in the agri-food industry: A review

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DOI: 10.30682/nm2303b
JEL codes: Q18, Q56, Q58

Abstract

In light of the increasing demand for sustainable development, the agri-food industry is under pressure to make the transition towards sustainability. Innovation has been identified as a key driver for this transformation. However, the agri-food industry, which in many countries is dominated by small and medium-sized enterprises, is highly sensitive to the benefits, costs and potential risks of sustainability-oriented innovation. At the same time, because of the low propensity of countries in the Mediterranean region to innovate, an in-depth exploration of innovation is necessary. This paper presents a review of the costs and benefits of specific sustainability-oriented innovations, not only economic but also social and environmental, to provide a guide for researchers and adopters of sustainability-oriented innovations in the Mediterranean region. To achieve this goal, this paper classifies the elements being reviewed according to the nature of the innovation and stages of the product life cycle it covers. This paper has implications for farmers, business managers, regulators and policy makers in the Mediterranean region.

Keywords: *Sustainability-oriented innovation, Agri-food industry, Benefits, Costs.*

1. Introduction

The need for sustainable development is growing since it can address a range of worsening global issues such as wasted resources, environmental degradation and social inequality. Brundtland (1987) defines the concept of sustainability as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". Sustainable development requires companies to consider the overall development of the economy, environment and society, which is the "triple bottom line" (Elkington, 1994). The agri-food industry is one of the most valuable and influential industries in any country, contributing to national welfare, gross domestic product and social life. The agri-food industry is closely linked to the natural environment. Not only does it directly participate in the use and consumption of natural resources such as water and soil, which have a huge impact on the natural environment (De Luca *et al.*, 2018), but it also suffers from

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the ill effects of the deterioration of the natural environment and therefore has an extremely high demand for environmental improvement. For example, the Mediterranean region, which is one of the regions where food systems are most affected by climate change, is facing a number of problems, such as water scarcity, degradation of arable land and desertification, and loss of biodiversity (Capone *et al.*, 2021). At the same time, the agri-food industry plays a role in food security and human health issues and is hence an industry of significant social importance. Therefore, to create a sustainable food system there is a need for transformation in sustainability in the agri-food industry. Ikerd (1990) defines sustainable agriculture as "farming systems that are capable of maintaining their productivity and utility indefinitely," and that are "resource-conserving, environmentally compatible, socially supportive, and commercially competitive."

The role of innovation in helping firms transition to sustainability has received considerable attention from academics, regulators and policymakers. In particular, in the agri-food industry, innovation is considered to be an extremely critical link in the transition to sustainable agriculture. Bedeau *et al.* (2021) identify technological innovation as one of four critical levers – multiparty collaboration, data and evidence, technological innovation, and coherent policies and investments – to address the challenges faced by food systems in the Mediterranean region. Hansen and Grosse-Dunker (2013) define sustainability-oriented innovation (SOI) as "the commercial introduction of a new (or improved) product (service), product-service system, or pure service which – based on a traceable (qualitative or quantitative) comparative analysis – leads to environmental and (or) social benefits over the prior version's physical life cycle ('from cradle to grave')." As a result of market and consumer needs, companies in the agri-food industry must innovate sustainably in the product, production and packaging phases to strengthen their corporate image and gain consumer recognition.

It has been highlighted in the literature that sustainability and SOI are beneficial for companies and that there is a positive relationship between the social orientation of companies and their economic and financial performance (Marotta *et al.*, 2017). SOI is also considered to increase the productivity and economic efficiency of agricultural farming, enhancing economic performance for companies and further promoting employment and fair compensation (Iofrida *et al.*, 2018). However, such a positive correlation is not immediately apparent. Ponta *et al.* (2022) perform a study on the relationship between the output of SOI and the economic performance of firms in the agri-food industry and the results show that the output of SOI is positively correlated with economic performance, but the impact occurs years later. Therefore, companies must consider the financial cost and return on investment period when developing and adopting SOI. SOI is also associated with "directional risk". The adoption of SOI possesses technical, commercial, organisational, and social acceptance uncertainties. For example, in terms of social acceptance uncertainties, innovation may bring about issues such as widening socio-economic gaps and gender inequality, especially in developing countries (Bedeau *et al.*, 2021). On the Mediterranean coast, except for the north and west, the region is mostly made up of developing countries, so the social acceptance of innovation is more uncertain. Hence, companies should consider not only the economic aspects when adopting SOI, but also the potential environmental and social impacts of SOI. This is especially the case in the agri-food industry, which is a highly competitive industry where most companies are small and medium-sized enterprises. Both upstream suppliers (especially farmers) and downstream producers and sellers have weak bargaining power and limited ability to differentiate (Cagliano *et al.*, 2016), and are highly sensitive to cost and risk.

Consequently, when agri-food companies undertake research and development and adopt SOI, they must weigh up the costs and benefits, including the economic, environmental, and social aspects. Costs include the capital required for technological development and adoption, yield uncertainty, environmental pollution due to technological shortcomings, negative social benefits and potential future risks; benefits include potential increases in economic performance, positive environmental impacts, and social performance, such as an improved agri-food supply chain and employment environment. The costs and benefits of SOI vary across sustainability practices. Several scholars currently provide fragmented accounts of the costs and benefits of specific SOIs. Nevertheless, academics have yet to produce a systematic generalisation and summary on this topic. This paper, therefore, provides an up-to-date review of the literature on the costs and benefits of specific SOI in the agri-food industry, to provide guidance on the adoption of different categories of SOI by companies in the agri-food industry. It is worth emphasising, as mentioned above, that the benefits and costs defined in this paper are economic, environmental and social based, not just economic. Nor does this paper provide any specific numerical evidence of benefits and costs at the economic level. Therefore, no specific contribution is made to the economic or financial balance sheet-based assessment. The aim of this paper is to provide an identification and description of the main initiatives and potential returns and costs for firms to implement different types of innovation to improve their sustainability conditions.

The paper is structured as follows:

In section two, different classification categories for SOI in the agri-food industry are established, drawing on the existing SOI classification and the product life cycle stages in which SOI plays a role. In section three of this paper, we collect and screen the kinds of literature about SOI in the agri-food industry through the Scopus database and then classify each SOI according to the groups established in section two. Section four of the paper contains a summary and discussion of the costs and benefits of each SOI. The conclusions are set out in section five.

2. Framework: designing the classification of SOI in the agri-food industry

In this section, we build a framework to categorise specific SOIs in the agri-food industry covered in the literature. The purpose of the classification is to provide a clearer picture of the types of SOI and the different stages in which they function, as well as to provide a more systematic guide to the adoption of different SOIs by companies in the industry. In this paper, we will classify SOI using two dimensions: the type of SOI and the stage of the product life cycle.

There are different classification criteria for innovation. According to the type of innovation, Gaudig *et al.* (2021) classify innovation into technological innovation, marketing innovation, product innovation and service innovation; Klewitz and Hansen (2014) classify innovation into three categories: process innovation, organisational innovation and product innovation. According to the degree of innovation, innovation can be classified as radical, incremental or reapplied (El Bilali, 2019); Adams *et al.* (2016) classify innovation into three levels: operational optimisation, organisational transformation and system building. When categorising innovation according to its drivers, innovation is classified as technology-driven, market-pull, design-driven, regulatory-driven/pull or value-driven (Cagliano *et al.*, 2016). Most of the literature classify SOI based on only one criterion as listed, with only a small amount of literature using two dimensions to classify SOI, for example Hansen and Grosse-Dunker (2013) classify SOI according to the goal dimension and the lifecycle dimension. It's because that they don't discuss a large number of specific SOIs. However, the subsequent part of this paper deals with a large number of specific SOIs and it would be difficult to organise the article clearly by following only a single criterion. Therefore, we choose to classify SOI using a two-dimensional classification.

In this paper, in the first dimension, the classification is made according to the type of innovation as Gaudig *et al.* (2021), Klewitz and Hansen (2014). Combining the work of different scholars, the types of innovation mainly include product and service innovation, process innovation, organisational innovation, marketing, and market innovation, etc. However, according to research on the characteristics of sustainable development in the agri-food industry and based on the results of the literature review below, the current SOIs in this industry are focused on three types, namely process innovation, product

Table 1 - Classification of SOI according to its nature.

Process innovation	*Product innovation*	*Organisational innovation*
Innovative practices in the production process of products or services to reduce environmental impacts and improve eco-efficiency and sustainability. Mainly includes clean production, waste recycling, efficient logistics and other related technologies.	The elimination or improvement of old products or services that have a significant impact on the environment, making improvements or discovering a completely new product or service. The main directions include sustainable products, sustainable labels, packaging and other related innovations.	The reorganisation of the internal systems of the company at the organisational level to promote sustainable development, or to propose new forms of management and new thinking about business operations, to transform old business operation models that are not in line with the concept of sustainable development. The main directions include the establishment of systematic innovation models, supply chain management and stakeholder management.

Source: own elaboration.

innovation and organisational innovation. Therefore, in this paper, according to the classification of Klewitz and Hansen (2014), SOIs are divided into above three groups in Table 1.

In order to give companies in the agri-food supply chain a more direct view of the SOI in their own sector, in the second dimension, we classify SOI according to the 'cradle-to-cradle' (Hansen and Grosse-Dunker, 2013) life cycle stages of the products in which it plays a role. There are five life cycle stages of a product that are important and where the main sustainability impacts occur: supply chain, production, packaging or distribution, use and end of life (Hansen and Grosse-Dunker, 2012). Cagliano *et al.* (2016) argue that companies in the agri-food industry can be divided into three main sectors: agriculture, food processing and distribution. De Luca *et al.* (2018) divide the life cycle of agriculture into the planting sector, the growing sector, the production sector and the end of life. On this basis, this paper divides the life cycle of products in the agri-food industry into one 'cornerstone' and four stages, as shown in Table 2.

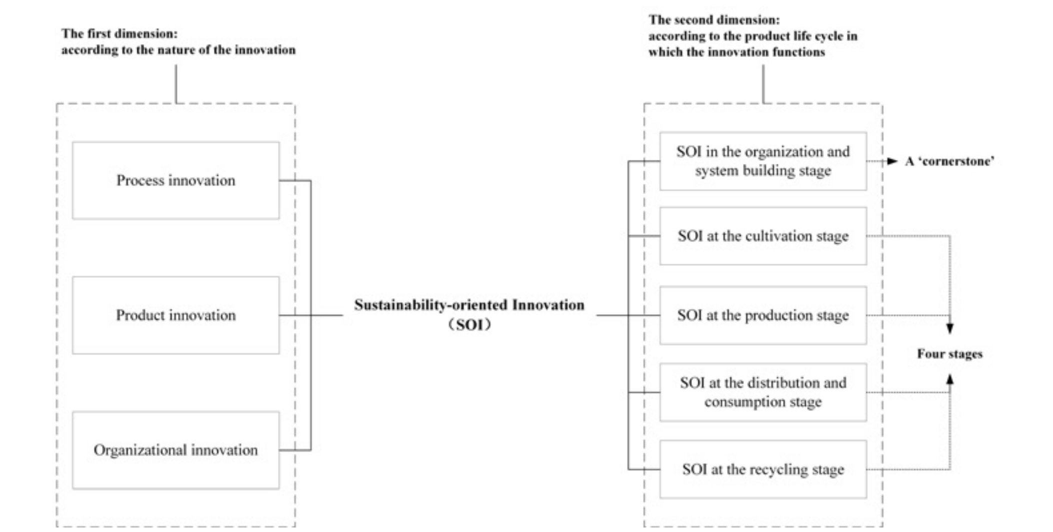
Here, while the decision-making in technology development strategy (TDS) and system building stage is not part of any product life cycle, the com-

Table 2 - Classification of SOI according to the product life cycle stages in which it functions.

Stage	*Definition*
Cornerstone: Decision-making in technology development strategy (TDS) and system building	In this stage, the strategic decisions of the company regarding sustainability are determined.
Stage 1: Cultivation	In this stage, the raw materials for the agri-food products are obtained through cultivation.
Stage 2: Production	In this stage, the raw agricultural products are transformed into agri-food through processing.
Stage 3: Distribution and consumption	In this stage, the agri-food products are packaged and shipped to various distributors or hotels, restaurants, etc., after which they are purchased and used by consumers.
Stage 4: Recycling	This stage actually runs through all three of the previous stages, as any one of them can produce waste or wastewater or greenhouse gases that have an impact on the environment. In the recycling stage, the waste and wastewater are transformed into new raw materials or energy through the recycling system.

Source: own elaboration.

Figure 1 - The classification of sustainability-oriented innovation in agri-food industry.



Source: own elaboration.

pany's strategic decisions about sustainability determine the technological direction of production and the subsequent adoption of SOI. At the same time, sustainability is seen as a system-level issue (Adams *et al.*, 2016) that is not only achievable by one technology or one individual organisation, but rather requires the whole supply chain system to innovate towards sustainability. This stage is therefore defined in this paper as a 'cornerstone'.

This paper, therefore, divides SOI in the second dimension into five groups according to the life cycle of the product: SOI at the cultivation stage, SOI at the production stage, SOI at the distribution and consumption stage, SOI at the recycling stage, and SOI at the decision-making in technology development strategy (TDS) and system building stage.

Combining these two dimensions, we believe that such a classification provides a main line of analysis for the subsequent literature study in this paper and facilitates a categorical discussion in the discussion section to understand the strengths and barriers to SOI adoption within the different segments. It will also help the relevant adopters of each SOI to understand more directly the different types of SOI within the different segments. The classification of SOI in the agri-food industry is shown in Figure 1.

3. Methodology

This paper is a compendium and review of current research on the costs and benefits of SOI in the agri-food industry. In accordance with standard literature research methods, this paper chooses to collect the relevant literature through the Scopus database. The specific method is shown in the Figure 2.

The first step was to obtain research material by searching through the Scopus academic database. The keywords selected for this paper are divided into two parts. The first part is about the description of the agri-food industry. Since the agri-food industry involves many related keywords, we chose "agri*" as the search term, which can cover many keywords related to agriculture, including agriculture, agri-food and so on. In a broad sense, agriculture includes farming, animal husbandry, aquaculture, forestry, etc., while in a narrow sense, agriculture refers specifically to farming. In this paper, we focus our attention on agri-food production in the narrow sense and therefore do not consider agriculture in the broad sense. The second part is about the keywords for sustainability-oriented innovation. The terms used most commonly in academia are "sustainability-oriented innovation", "sustainability-driven innovation" and

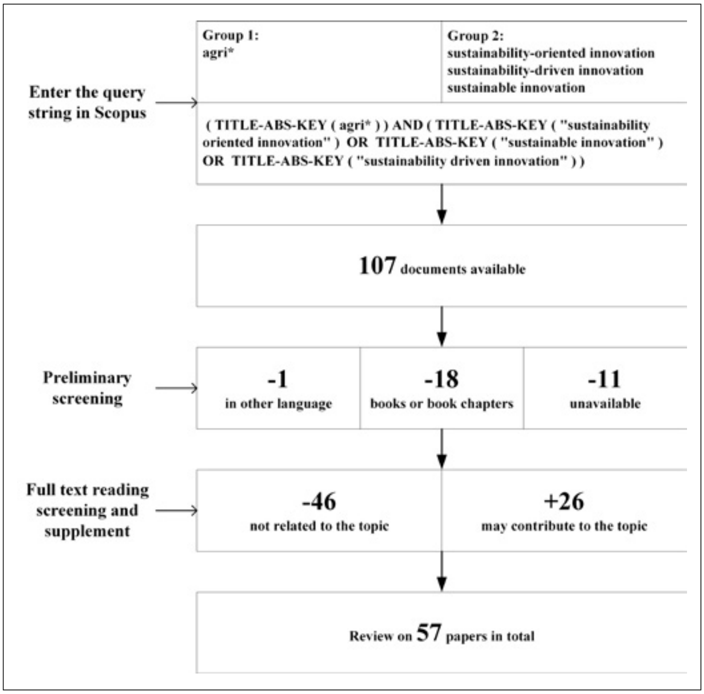


Figure 2. Methodology for literature search and screening.

Source: own elaboration.

"sustainable innovation", so this paper chose these three phrases as search terms. In addition, there are fairly narrow definitions of sustainable innovation, such as eco-innovation, ecological innovation, environmental innovation, frugal innovation, green innovation, inclusive innovation and social innovation which focus on innovation that improves a single aspect of the environment or society. This paper believes that according to the "triple bottom line" theory (Elkington, 1994), sustainable development must be comprehensive and balance the economic, environmental and social benefits. Innovations that focus on a single aspect do not meet this criterion, so the above keywords were excluded from consideration. After completing this step, the result was 107 relevant papers (as of 27 August 2022).

The second step was the preliminary screening of the above literature. In order to make the screening more accurate, this paper did not use the automatic filter in the database and instead screened the 107 papers manually. The screening criteria are divided into three parts. The first part is language, and English was chosen as the only allowed language for this paper. One document was removed under this criterion. The second part was that the target literature should be journal articles, so 18 books or book chapters were excluded. The third part was availability, and the remaining literature was searched through major databases, of which 11 could not be sourced and were therefore excluded. After screening, the remaining 77 articles were available for the next step of the reading and screening.

The third step was to read the full text for screening. In screening methods used by other authors, there may be a step of reading the abstract for screening. However, after reading through this paper it was found that there are few studies directly on the costs and benefits of SOI in the agri-food industry and a large number of descriptions of this topic are scattered in some seemingly irrelevant literature through the abstract. Therefore, this paper considers that filtering through abstracts may result in some important information being missed, so we skipped this step and read the full text directly for screening. The selection criteria for this paper were that the paper must include a description of the costs and benefits of a specific SOI technology, or a study of how a specific organisational innovation has improved the diffusion and adoption of SOI, as such an improvement is itself a potential benefit that contributes directly to the SOI technology while indirectly contributing to sustainable development. Meanwhile, in the process of reading the full text, this paper found that the literature mentioned or cited in the text was also related to the research topic of this paper. In particular, articles about some specific artificial intelligence, biological and chemical technologies, whose article titles, abstracts and keywords do not explicitly contain keywords related to sustainability-oriented innovation, had been excluded from the scope of this paper. However, these articles do describe the costs and benefits of the technology and can be of great reference value to this paper. Therefore, this paper used the "snowball" (Adams *et al.*, 2016) method and included these articles in this review as well. After this screening and supplementation stage, 46 irrelevant papers were removed and 26 relevant papers were added, meaning that finally 57 papers were obtained as the review material for this paper.

Table 3 - The result of classification.

	Classification according to nature			*Classification according to the product life cycle*				
	Process innovation	*Product innovation*	*Organisational innovation*	*Decision-making in TDS and system building*	*Cultivation*	*Production*	*Distribution and Consumption*	*Recycling*
Aljaafreh, 2017	√					√		
Awada & Phillips, 2021	√				√			
Bigliardi 2022	√				√			
Butler & Holloway, 2016	√			Across all stages				
Cagliano *et al.*, 2016		√			√			
Cappelli & Cini, 2021	√				√			
Cappelli, Canessa, & Cini, 2020	√					√		
Cappelli, Guerrini, Parenti, *et al.*, 2020	√					√		
Cappelli, Oliva, & Cini, 2020	√					√		
Cappelli, Oliva, Bonaccorsi, *et al.*, 2020	√					√		
De Boni *et al.*, 2019		√			√			
De Luca *et al.*, 2018	√				√			
Delmas & Gergaud, 2021		√					√	
Dobbs *et al.*, 2011	√				√			
Dyck & Silvestre, 2019			√	√				
Fam & Mitchell, 2013	√				√			
Fargione *et al.*, 2008	√							√
Gao *et al.*, 2020	√				√			
Gaudig *et al.*, 2021	√		√	√				√
Geissdoerfer *et al.*, 2017	√							√
Giller *et al.*, 2009	√				√			
Giua *et al.*, 2022	√			Across all stages				
Greenland *et al.*, 2018	√				√			

	Classification according to nature			*Classification according to the product life cycle*				
	Process innovation	*Product innovation*	*Organisational innovation*	*Decision-making in TDS and system building*	*Cultivation*	*Production*	*Distribution and Consumption*	*Recycling*
Heyes *et al.*, 2020		√					√	
Klewitz & Hansen, 2014			√	√				
Kopytko, 2019	√				√			
Li *et al.*, 2020	√				√			
Long & Blok, 2021			√	√				
Long *et al.*, 2017	√		√	√	√			
Lubell, 2011			√	√				
Marotta *et al.*, 2017		√				√		
Martin-Rios *et al.*, 2021	√		√	√			√	
Meisch & Stark, 2019	√						√	
Orjuela-Garzon *et al.*, 2021			√	√				
Pancino *et al.*, 2019			√	√				
Patrício & Rieder, 2018	√			Across all stages				
Pelse *et al.*, 2018			√	√				
Philippi *et al.*, 2015	√		√	√	√			
Pilloni *et al.*, 2020	√		√	√				√
Ponta *et al.*, 2022			√	√				
Pontieri *et al.*, 2022		√			√			
Raman & Mohr, 2014	√							√
Rana *et al.*, 2021	√						√	
Rejeb & Rejeb, 2020	√						√	
Saberi *et al.*, 2019	√						√	
Sanders *et al.*, 2021	√			Across all stages				
Schoenke *et al.*, 2021			√	√				
Seghieri *et al.*, 2021			√	√				
Sellitto *et al.*, 2021	√				√			
Sparrow & Howard, 2021	√			Across all stages				
Stanco *et al.*, 2020	√		√	√	Across all stages			
Su *et al.*, 2019	√					√		√
Troise *et al.*, 2021			√	√				
Vecchio *et al.*, 2020			√	√				
Wu *et al.*, 2014	√					√		
Yamoah *et al.*, 2021	√				√			
Zhang *et al.*, 2021	√			Across all stages				

Source: own elaboration.

After reading these 57 articles, the SOIs covered in these articles were classified according to the classification criteria established in Chapter 2. The results of the classification of literatures are shown in Table 3.

In Chapter 4, SOIs will be discussed under each category separately, according to the classification.

4. Results and discussion

4.1. *Process innovation*

If we consider the product life cycle involved in process innovation, process innovation can occur throughout the product life cycle at the cultivation, production, distribution/packaging and recycling stages. This section will therefore cover these four stages.

4.1.1. *Process innovation across the life cycle*

Digital technologies are currently a hotly discussed topic. Digitisation of agricultural systems cuts across every aspect of the agri-food industry, enables the technological optimisation of every aspect of the whole system and minimises the environmental impact of agriculture (Zhang *et al.*, 2021). For example, smart farming technologies, intelligent devices in cyber-physical systems, can improve farm management and generate a wealth of data that can be used not only on the farm but also throughout the whole supply chain (Giua *et al.*, 2022). The adoption of artificial intelligence technologies (AI), which analyse large amounts of data through intelligent machines or software that automatically identify and respond to the environment they are in and act accordingly, is considered to play an important role in driving technological change and sustainable development. In the area of agricultural production it can also help ensure global food security (Patrício and Rieder, 2018). Across the entire supply chain system of the agri-food industry, artificial intelligence can solve the problem of information asymmetry in the food system, provide traceability of the entire food production process, from planting to consumption, contribute to the transparency of food production management and increase safety, as well as integrating the entire supply chain and greatly reducing transaction costs. In cultivation and production, AI technologies help to overcome the disadvantages of traditional technologies and detect and optimise the use of production materials, thus reducing waste. In addition, AI makes an outstanding contribution to the monitoring and control of carbon and biological footprints (Sanders *et al.*, 2021). The Barilla Pasta Factory has experienced a huge change in terms of improving food production and land and vegetation conservation and reducing energy consumption by creating decision support systems that collect, organise and process soil and weather data to provide farmers with timely information and advice (Stanco *et al.*, 2020). However, AI requires significant funding to develop the technology and associated hardware costs, which may entail a significant amount of money and create uncertainty about the future of the technology. At the same time, the impact of AI on society has been questioned. AI may fundamentally change the employment situation in the agricultural sector, replacing humans and thus impacting on the labour market (Sanders *et al.*, 2021). In addition, the development of AI tends to be uneven globally, with high-income countries having sufficient R&D funding to invest in and benefit from AI development, while low-income countries struggle to master the core technology. AI technology is therefore thought to exacerbate global equity issues and have an impact on the political landscape (Sparrow and Howard, 2021). Furthermore, the spread of AI may change the cultural patterns of traditional rural communities, thus posing a threat to social and mental health (Butler and Holloway, 2016).

4.1.2. *Process innovation in the cultivation stage*

The cultivation stage is one of the most important stages in the agri-food industry and the one with the greatest environmental impact. Considerable attention is paid to issues such as land conservation and the quality of agricultural products. SOI at the cultivation stage is integrated into planting, fertilisation, tillage, irrigation, weed control and pest control. Generally speaking, SOI at the cultivation stage is of great direct benefit to the environment and can also bring significant financial benefits to farmers through improved productivity and quality. Awada and Phillips (2021) use an equilibrium displacement model to assess the profit-sharing consequences of technological innovations that improve the efficiency of land and other inputs in a multi-factor crop production system. They show that the adoption of land-technical innovations provides more lucrative returns to landowners than other technological innovations. However, agribusinesses, including farmers, are mostly small and medium-sized enterprises or farms (Dyck and Silvestre, 2019) with limited cost and risk-taking capacity. For example, in the case of climate-smart agriculture (transforming agri-food systems into green and climate-resilient systems), developers and users of technological innovations in the project have reported that the technologies are too expensive, have long payback periods and are not competitive in terms of ROI (Long *et al.*, 2017), so research on the costs of SOIs is necessary.

In the planting section, Yamoah *et al.* (2021) compare the practice of using the traditional no-shade method and the shade method in cocoa cultivation. The traditional no-shade method (full sun) ensures higher yields in the short term, but yields appear to be difficult to secure in the long term. The no-shade method also leads to negative environmental consequences such as deforestation, carbon loss, increased temperatures, depletion of soil nutrient levels, high inorganic fertiliser use, and loss of above- and below-ground biodiversity (Asare *et al.*, 2017). The shade method, on the other hand, although less productive in the short term than the no-shade method, provides more stable and sustainable cocoa productivity in the long term, and also reduces fertiliser use and pest and disease incidence. Kopytko (2019) summarises the advantages of sustainable seed innovations (both in situ conservation and innovation of new plant varieties through traditional practices). Financially, the innovation is less costly as it reduces the use of pesticides and fertilisers; environmentally, it ensures local ecological stability as the seed varieties are better suited to the local environment and the exchange of seeds between farmers maintains biogenetic diversity. Socially, the exchange of seeds between farmers creates a new social network, and the social status, professional competence and self-confidence of farmers are enhanced.

In the fertiliser application section, many technologies have been developed to replace conventional fertilizers. For example, Li *et al.* (2020) use manure to replace chemical fertilisers and discuss the effects of liquid and solid manure fertilisers separately. Compared to traditional chemical fertilisers, solid manure fertilisers reduce environmental impacts by 24.6% and increase profits by 17.2%, while liquid manure fertilisers are more effective, reducing environmental impacts by 37.9% and increasing profits by 19.1%. In addition to this, Fam and Mitchell (2013) use urine diversion technology to separate urine at source and recover nutrients for use in agriculture. All of these technologies can significantly reduce the environmental impact. However, the problem of high unit costs remains and it is not suitable for intensive production (Cappelli and Cini, 2021).

In the tillage section, Dyck and Silvestre (2019) conduct a study on the adoption of "conservation agriculture" by small-scale farms. "Conservation agriculture" refers to the protection of agricultural land by reducing mechanical disturbances, technical maintenance of the land during periods of downtime and crop rotation. "Conservation agriculture" doubles productivity in relation to financial benefits and reduces financial capital inputs. In terms of environmental benefits, conservation agriculture improves soil quality by facilitating access for the soil to carbon from the atmosphere. In terms of social benefits, "conservation agriculture" can improve the overall quality of life on small-scale farms and improve community health. However, Giller *et al.* (2009) point out that "conservation agriculture" suffers from erratic yields and may lead to increased labour demand, with the increased labour burden shifting to women.

In the irrigation section, drip irrigation technology is considered an important innovation in agriculture and offers a solution to the problem of water use. Dobbs *et al.* (2011) suggest that drip irrigation can reduce irrigation water use by between 20% and 60% and increase yields by 15% to 30%. Drip irrigation combined with remote technology can reduce the manual labour associated with irrigation. Greenland *et al.* (2018) argue that drip irrigation technology has a high return on investment in terms of financial benefits and improves farmers' lifestyles in terms of social benefits. However, the equipment is more expensive to install, operate and maintain, and the maintenance and system management is more complex, requiring farmers to have more advanced technical skills.

In the weed control section, De Luca *et al.* (2018) study weed control techniques in olive cultivation. Within the three options: traditional control (involving chemical herbicides), low-dose/no-till (reduced chemical and mechanical use) and zero-chemical weed control (mechanical weed control only): the low-dose/no-till option performed best in the environmental dimension, with the lowest greenhouse gas emissions, ecotoxic emissions and land occupation; from the financial perspective, the low-dose/no-till option is the least costly, providing higher profitability and investment viability for the farm; in the social dimension, the zero-chemical weed control option does not use chemicals, providing greater profitability and investment viability for human health.

In the pest and disease control section, the search for natural alternatives to chemical agents is one of the main directions for SOI. To prevent the formation of caterpillars in crops, the SOI of parasitising a wasp called trichogramma on the eggs of pests has been proposed (Philippi *et al.*, 2015), where the number of applications is reduced from three to one compared to traditional insecticides. Biological control is also usually cheaper than the use of insecticides, thus reducing the cost of acquiring insecticides. The method also reduces local pollution as the spraying of insecticides easily infects people and non-agricultural areas. In terms of social benefits, it provides organic food for consumers and improves consumer health. Sellitto *et al.* (2021) studied the application of microbial biological control strategies in pest management. As an alternative to chemicals, biological control is beneficial in improving crop growth while indirectly reducing the fossil fuel and greenhouse gas emissions used in the chemical manufacturing process. Microbial-based biological tools can be useful in controlling plant diseases and simultaneously reduce contamination of agricultural products. Biological control tools can protect soil and plants before harvest and also after harvest by preventing crop spoilage and reducing waste. Gao *et al.* (2020) proposed the use of wheat straw vinegar, a natural fungicide obtained from the pyrolysis of wheat straw, as an alternative to chemical fungicides for the prevention of Fusarium head blotch, which not only improves fungicidal efficacy but also reduces the cost of fungicide to farmers and increases income.

4.1.3. *Process innovation in the production stage*

Cappelli and Cini (2021) argue that the use of innovative technologies in the wheat handling and product baking production process can both improve product quality and reduce energy and water consumption, which reduces the environmental impact. Cappelli *et al.* (2020d) study traditional stone milling flour technology. Stone milling technology retains more nutrients from the wheat, has a larger consumer market and, with some improvements in stone milling technology, can reduce energy consumption in the milling process, with potential benefits for the environment and production costs. In addition, there are some social benefits, such as improving the landscape and attractiveness of rural areas, thus improving the living environment for farmers; promoting the dissemination of traditional crafts, and thus promoting the transmission of traditional culture. Cappelli *et al.* (2020b) conduct a study on modern rolling mill technology. Rolling milling technology, as the most advanced wheat processing technology, has the advantages of high efficiency, flexibility and low heat generation, and does not affect the functional characteristics of the flour. With improvements in this technology, productivity can be increased and the environmental impact can be reduced through measures such as reuse of by-products and improved water utilisation. In the production of dough, the use of improved technology can increase environmental sustainability (Cappelli and Cini, 2021). Cappelli *et al.* (2020a) investigate the use of snow carbonate as a refrigerant to control dough temperature during the kneading phase, a technology that is less costly and less energy intensive than low temperature retention technology. This technology has better cooling effects and does not contain the same level of chemical or toxic residues as other refrigerants, making it more environmentally efficient. Su *et al.* (2019) investigate the production of organic acids from by-products and waste substrates for use in the dough production process, which is effective in improving dough quality and reducing the environmental impact of by-products. In addition, Aljaafreh (2017) develops an intelligent process control machine for dough kneading, which introduces artificial intelligence into the production process, automates the production equipment and manual management, optimises all the technical specifications of dough kneading, reduces costs and reduces energy consumption and environmental impact.

Protein is the basis for human growth and health, yet the FAO estimates that approximately 1 billion people worldwide have inadequate protein intake. The shortage of protein supply has led to the search for alternative protein sources as an important issue in the production process. Plant foods (mainly cereals and legumes) account for 65% of human protein (Wu *et al.*, 2014) and are the main source of protein for humans. However, the extraction process suffers from inefficiency, waste and environmental impact, so it is necessary to develop more efficient and environmentally friendly plant protein extraction technologies to meet human nutritional needs as well as the requirements of sustainable development. Cappelli *et al.* (2020c) study the combination of chickpeas with cereals. The results show that the combination of chickpeas with cereals creates proteins of high biological value and can have a positive effect on environmental sustainability because chickpeas are grown using a smaller amount of nitrogen fertilisers. Soy protein is an available and relatively high-quality form of vegetable protein and to further improve the sustainability of soy protein production, a sustainable and innovative technology of concentrating and separating raw materials into individual components in the soy protein extraction process has been proposed. This allows the components to be recycled and reduces waste in the production process (Wu *et al.*, 2014).

4.1.4. *Process innovation in the distribution and consumption stage*

In the distribution stage, the adoption of digital technologies can play a role in logistics. Rana *et al.* (2021) suggest that various digital technologies such as barcodes/QR codes, RFID, IoT, ICT and blockchain can improve and simplify the traceability of food products across the supply chain while integrating these technologies can improve their functionality and reduce costs. In terms of blockchain technology, this allows participants in the supply chain to share data, quickly access relevant information and reduce costs (Rejeb and Rejeb, 2020). The technology also helps consumers track food sources, environmental impacts and ethical aspects (Saberi *et al.*, 2019). At the same time, the use of blockchain can help develop quantitative indicators related to sustainability and therefore contribute to a more sustainable agri-food industry (Rana *et al.*, 2021). However, blockchain technology requires a large amount of data to be collected and therefore involves significant funding. The blockchain network requires a lot of computing power, especially when it becomes complex, and therefore a lot of energy, implying an increase in costs and greenhouse gas emissions (Rana *et al.*, 2021).

At present, while there is a shortage of food in some parts of the world, there are also parts of the world where food is being wasted. At the consumption stage, food waste is a very serious problem, especially in hotels, restaurants and catering businesses that account for a significant share of total food waste. Not only does waste lead to inefficient food distribution, but the disposal of waste food also leads to the emission of harmful greenhouse gases. Statistics show that dealing with food waste accounts for 6% of the greenhouse emissions from the food industry (Poore and Nemecek, 2018). Therefore, how to reduce waste in the consumption chain becomes an issue for sustainable development. Martin-Rios *et al.* (2021) examine sustainable solutions that use digitalisation and automation (especially artificial intelligence technologies) in this area, where companies integrate data network connections with waste handlers or build a device that measures the amount of food waste directly from the handling equipment and outputs data or reports directly to help managers develop waste prevention programmes. Such technology helps businesses to gain an insight into their food waste components, volumes, costs and sources, which is expected to lead to a 70% reduction in food waste and can significantly improve a restaurant's food profitability.

4.1.5. *Process innovation in the recycling stage*

Recycling refers to the creation of a regenerative system where waste, wastewater and other environmentally stressful by-products from the production processes (whether industrial or agricultural) are reused through technologies that slow, close and shrink material and energy cycles, minimising resource inputs and waste, emissions and energy leakage (Geissdoerfer *et al.*, 2017). For example, the "aquaponics" shore-based closed-loop production system combines plant cultivation (hydroponics) with fish production (aquaculture), using fish excrement to fertilise plants in the water, reducing stress on the link while providing nutrients for crop growth (Meisch and Stark, 2019). However, the circular economy must be accompanied by a shift in the social structure of the consumption and production system, so this system will be quite costly to establish (Gaudig *et al.*, 2021).

A large number of by-products and residues are generated during the food processing stage and such residues can cause great pressure on the environment, making the reprocessing and recycling of residues extremely important. Many relevant SOIs have been proposed, such as the example of producing organic acids from by-products and waste substrates and using them in dough production, as already mentioned above (Su *et al.*, 2019).

Biofuel technology is one of the more controversial technological innovations combining agriculture and industry. The use of food as biofuel to generate energy is a reality in a number of regions and such behaviour may exacerbate the threat to food security as well as the seizure of agricultural land (Raman and Mohr, 2014). In turn, the introduction of second-generation biofuel technologies using non-edible feedstocks has further contributed to sustainable development. For example, in Jordan and Israel, waste treatment through biogas units in the agricultural waste cycle segment has transformed agricultural waste into renewable energy (Pilloni *et al.*, 2020), avoiding the direct use of food for energy production. This is a good example of using biofuel technology while avoiding food waste. However, there are still potential social and environmental issues with biofuel technologies and Raman and Mohr (2014) argue that there is a spatial imbalance in biofuel technologies in that biofuel energy is not necessarily being produced where the real benefits are, and therefore may exacerbate global inequities. Fargione *et al.* (2008) suggest that the use of large amounts of agricultural land or non-agricultural ecological land such as rainforests for biofuel production could lead to higher food prices and indirectly increase greenhouse gas emissions.

4.2. *Product innovation*

According to the product life cycle involved in product innovation, product innovation is mainly concentrated in the cultivation, production, distribution and consumption stages, so only these three stages will be discussed in this section.

4.2.1. *Product innovation in the cultivation stage*

Currently, "retro-innovation" (designing new products, services and processes by combining past and present methods) for the cultivation of old wheat varieties is being adopted in order to find more health benefits in baked products (Cagliano *et al.*, 2016). This type of wheat produces more suitable nutrients, contributes to biodiversity conservation and simultaneously promotes sustained local microeconomic growth (De Boni *et al.*, 2019). However, older varieties suffer from poorer technical characteristics, with poor dough rheology and smaller bread volumes compared to modern wheat varieties (Cagliano *et al.*, 2016). In addition, sorghum is seen as a product innovation in sustainable agriculture that can be widely used as a health and functional food to replace wheat in a specific range and provide healthier ingredients. Pontieri *et al.* (2022) summarise the characteristics of food-grade white sorghum as (1) low cost to grow, (2) high nutritional value, (3) gluten-free and, for specific consumers, an alternative to wheat, (4) rich in fibre and antioxidants, and (5) suitable for a variety of uses in the agri-food industry.

4.2.2. *Product innovation in the production chain*

Marotta *et al.* (2017) study the sustainability of the Rummo pasta factory, which has paid special attention to sustainability and public health, not only by reducing its environmental impact through sustainable technological innovations in the production process, but also by further proposing a sustainable and innovative product range aimed at improving consumer health, which has not only led to market success, gaining consumer acceptance and greater revenue, but has also improved the company's reputation, resulting in smoother contractual relationships with stakeholders and lower transaction costs. Combining product innovation with production technology innovation, the company has optimised its greenhouse gas emissions, energy use efficiency and production waste recycling, and has improved the quality of its employees' work at a social level, safeguarding their rights and increasing their productivity by making them much more productive.

4.2.3. *Product innovation in the distribution and consumption stage*

Exhibiting a "sustainable" label on commodities is an important product innovation in the consumption stage of the agri-food industry, with the aim of reducing the knowledge asymmetry in the distribution and consumption of sustainable products and increasing market recognition and sales of sustainable commodities. Currently, the more mature labelling systems include the sustainable label, organic label and fair-trade label. To obtain a label, companies need to be certified by a third-party organisation. Such certification provides producers with existing sustainable best practices and reduces the costs associated with producers finding and experimenting with these sustainable practices (Delmas and Gergaud, 2021). Also, because of the high authority and market acceptance of third-party labels, it helps to increase the willingness of consumers to pay a premium price and increases demand for the product (Heyes *et al.*, 2020). At the societal level, the economic benefits of labelling involve encouraging more producers to adopt sustainable practices, while labelling provides consumers with more information and guarantees about the product and increases public interest.

4.3. *Organisational innovation*

Most organisational innovations are made at the decision-making in TDS and system building stage of the company with the aim of improving unsustainability in multiple or even entire life cycle stages. Very few organisational innovations exist in isolation in a certain life cycle stage, so, in this section, the paper only contains a discussion of the enterprise decision-making in TDS and system building stage.

Innovations in technology play a prominent role in sustainable development, but are often affected by socio-economic barriers such as the inability of single technological instruments to address the integration of technological solutions and technology adoption (Sovacool *et al.*, 2015), and focusing only on technological innovation while ignoring the social and institutional dimensions may create new inequalities (Petruzzella *et al.*, 2020). Therefore, new approaches or systems are needed to understand the human dimensions and adoption of technology (Bale *et al.*, 2015). The adoption of innovative business models can facilitate the diffusion of technological innovations and increase their success by developing new value propositions, cost structures, profitability and ways of interacting with customers to address the problems of low initial profitability and uncertainty about the innovation (Long *et al.*, 2017). Adams *et al.* (2016) argue that the development of SOI requires three shifts: from technology- or product-oriented innovation to human-centred innovation; from innovation in an independent sector of the firm to innovation that is widely integrated within the firm; and from innovation in isolation by a single firm to innovation in a system that is widely involved in social collaboration. The success of the urine diversion technology mentioned above (Fam and Mitchell, 2013) is not only due to its technical feasibility, but also to its human-centred social organisation, participation and integration of social knowledge from various stakeholders into the technology adoption process. Pilloni *et al.* (2020), through a socio-technical systems approach (combining technology with economics, ethics, philosophy, political science and sociological theories), summarise the successes and failures of biogas installations in Israel and proposes improvements at the social level (e.g., increasing the participation of women and community members) to generate greater social benefits while promoting the adoption and diffusion of biogas technologies.

The development and marketing of new products requires a lot of time, money and capacity. Therefore, SOI development is risky and usually requires a more collaborative and/or open systems approach (Chesbrough, 2010) since firms are able to solve these problems by collaborating and taking advantage of their partners. Collaboration not only removes some of the uncertainties inherent in SOI and reduces the riskiness of SOI, but also allows the configuration of the entire value chain to be adjusted (Cholez *et al.*, 2021). As a result, collaboration is generally considered to improve the ability of firms to engage in innovative activities (Pelse *et al.*, 2018). In response to this, the concept of open innovation was proposed. Open innovation can be seen as a new knowledge management model that involves an innovation process characterised by openness to the external world, challenging the more traditional closed innovation model that has been used by companies until now (Bigliardi and Filippelli, 2022). Lubell *et al.* (2011) demonstrate, in terms of the role of innovation and collaboration, that innovation can result in financial profits exceeding financial costs, while collaboration can enable social benefits to outweigh social costs. Interaction with third-party technology providers can facilitate a company's ability to innovate in SOI and reduce costs (Klewitz and Hansen, 2014).

Vecchio *et al.* (2020) argue that the creation of an innovation environment in which actors interact within a geographical area reduces innovation uncertainty and triggers innovation adoption, and that a systemic innovation environment is constructed with the joint participation of business, education and research, national institutional and legal frameworks, and finance (Pelse *et al.*, 2018). In the agri-food sector, the full participation of the farm and the interaction of all parties can contribute to the sustainability of the innovations adopted. As in the case of the Barilla pasta factory mentioned above (Stanco *et al.*, 2020), at each stage of the supply chain – agricultural stage, storage stage, production transformation stage and marketing stage – the company has established a "multi-stakeholder partnership", such as establishing agreements or ground rules with partners related to the commitment to sustainability at each stage. It has then established crop rotation systems among farmers for cooperation, which improves soil fertility, reduces costs and improves production efficiency and product quality while reducing market volatility and the financial risks associated with market volatility, providing long-term production security (Pancino *et al.*, 2019). Data show that the collective innovation led by Barilla has resulted in significant improvements in product quality, costs, farmers' income, resource consumption and waste emissions (Stanco *et al.*, 2020).

Collaboration in technology can drive the diffusion and use of SOI. Ponta *et al.* (2022) state that co-patenting can influence economic performance when firms develop SOIs, especially in the short term by reducing development costs, resulting in better economic performance. The Colombian National Federation of Rice Growers has improved sustainability through a large-scale technology transfer programme, resulting in a 23% increase in national average rice yields and a 26% reduction in average production costs (Orjuela-Garzon *et al.*, 2021). Technological collaboration between universities and industry can increase the innovation and technological capacity of enterprises, while also leading to increased social benefits for all parties involved and society (Philippi *et al.*, 2015). Collaboration is made possible through technology transfer, where universities transfer their own developed technologies and knowledge to companies, bringing innovative capabilities and competitive advantages to them while promoting the adoption and diffusion of SOI. New business models of collaboration with research centres allow for lower costs in mass production, and government promotion can make collaboration on technology more successful and facilitate the realisation of expected and potential benefits (Philippi *et al.*, 2015). In the example above regarding AI technology to address food waste (Martin-Rios *et al.*, 2021), although the technology is thought to increase food profitability in restaurants, the restaurants' concerns about the cost of AI technology can affect SOI adoption as most restaurants are small and medium-sized businesses. However, by partnering with third-party technology companies, the restaurants can reduce the cost of technology adoption and reduce waste while not spending additional money. Schoenke *et al.* (2021) propose the concept of an AI and data streaming platform called Gaia-AgStream, which is a platform for technology development and association that is collaborative in nature, bringing together research centres, industry, agricultural start-ups and farmers to help address the costs, knowledge gaps and technical deficiencies of SMEs in the AI rollout process, and to accelerate the adoption of AI. It will help solve the problems related to costs, the knowledge gap and technical deficiencies faced by SMEs in the process of AI diffusion and accelerate the adoption and diffusion of AI.

Innovations in investment and cooperation models can address the uncertainty and risk relating to the future of SOI technology and avoid future costs (Gaudig *et al.*, 2021). A number of scholars have contributed on innovation in investment and cooperation models: Seghieri *et al.* (2021) argue that a participatory approach involving public, private and civil stakeholders combined with a systematic and interdisciplinary approach is beneficial to promote the achievement of sustainable innovation. In order to improve food security in Africa, a large amount of aid such as funding and innovation programmes from Europe has entered African agriculture. However, it has not improved the situation much because it is fragmented between institutions, organisations and sectors, and between disciplines. Through stronger partnerships, especially between sectors and disciplines, the food security situation in Africa has improved, agroforestry landscapes have prospered and regenerated, farmers' poverty levels have been significantly reduced and Africa's out-migration trends have slowed (Seghieri *et al.*, 2021). Dyck and Silvestre (2019) examine the ways in which NGOs and farms or other organisations collaborate on sustainability innovations in the context of "conservation agriculture" practices, using small-scale farms in Nicaragua as a case study, comparing the use of traditional centralist approaches (where NGOs define standardised practices and farmers or other organisations adopt them directly) with new non-centric approaches (where NGOs adopt a more bottom-up, two-way approach to innovation, working with farmers and other organisations) in collaborative work. The findings suggest that non-centrism can address SOI uncertainty and promote SOI efficiency. Troise *et al.* (2021) argue that equity crowdfunding is a valuable way for open innovation to help agri-food companies pursue SOI so that agri-food companies do not use process-related crowd inputs when implementing SOI, and they also use knowledge-based inputs in organisational innovation to promote social sustainability. Long and Blok (2021) point out that the problem of inadequate innovation financing levels is a major barrier to addressing the climate situation, and that collaboration at the niche level, using the non-financial resources of existing actors to transcend asymmetries, can improve climate innovation performance.

4.4. *Discussion*

Process innovation and product innovation reflect technological upgrading and change, the main purpose of which is to optimise the production process and supply chain and reduce pollution by changing technology or finding alternative products or raw materials, all in order to achieve both cost control in terms of financial benefits and sustainable development in terms of environmental benefits. At present, in the agri-food industry, there are three major directions of SOI in terms of technology and product types. Firstly, new technologies and products are being adopted at the planting stage to increase food production and nutritional content while reducing land pollution and resource waste; secondly, at the production stage, technologies and clean energy are being adopted to reduce the generation of waste gas, waste water and waste residue in the production process, or to recycle them; thirdly, in the process of supply chain operation and distribution, new technologies and products are being adopted to reduce waste and pollution in the distribution chain, and increase the transparency of distribution, so that product data can be collected in a timely manner, further analysed through digital technology and reduce waste.

At the planting stage, changes in planting technology have received a great deal of attention because human planting behaviour has a direct and profound impact on the environment. A great deal of SOI in the agri-food industry is focused on this segment and reducing chemical damage to the land and solving the problem of water scarcity have become hot topics. However, the high cost of adopting new technologies and the lack of guaranteed yields continue to hinder the spread of technology. The Mediterranean region has a population of more than 500 million people and a considerable economic imbalance within the region, with the northern and western parts of the region being highly developed and innovative, while the eastern and southern parts are densely populated and economically underdeveloped, facing not only pressure on the food supply but also limited innovation capacity. At the same time, the use of cultivation technologies in different regions can be greatly influenced by objective conditions (e.g. land conditions, hydrological conditions, climatic conditions, etc.), so there is a high degree of uncertainty about the effectiveness of new technologies in practice. Under the double threat of cost and yield uncertainty, it is difficult to popularise SOI in the cultivation segment. For example, in the case of water use, a large number of countries in the region are suffering from water stress, while on the other hand, it is difficult to promote the adoption of new irrigation technologies or water recycling systems due to their cost, which leads to a dilemma. Therefore, in the Mediterranean region, innovation in the cultivation sector requires further financial and food security guarantees to ensure that the process of sustainable development does not lead to a break in the food supply chain.

In terms of SOI adoption at the production stage, the ability of new technology to ensure or improve productivity and company profitability is a prerequisite for its widespread adoption. Agri-food production companies have higher cost tolerance and higher brand building requirements than growing farms, and therefore have a greater willingness and ability to be sustainable. Although the adoption of new technologies may mean a change of production equipment for the producer, the production capacity of the equipment is less affected by objective factors and has a higher yield stability and less technology adoption risk compared to new technologies in the planting stage. Therefore, the promotion of SOI adoption in the production phase requires the technology or product to have a high level of yield and stability and the lowest possible technology cost. In the Mediterranean region, where the capacity to develop production technologies is high due to the strong research capacity of the countries in the region, the problem is how to reduce the cost of adoption so that the technology can be more easily adopted.

In the supply chain, the increasing maturity of digital technology has provided strong support for transparency and process optimisation in the agri-food industry. The main forms of inter-organisational cooperation include horizontal, vertical and multi-stakeholder cooperation, with digitisation being considered a horizontal trend in all types of cooperation (Cholez *et al.*, 2021). However, digitisation of the supply chain is a system-wide issue, and digitisation by a single player in isolation makes it difficult to optimise the supply chain and can lead to higher operational costs for companies. At the same time, the new resource waste and pollution (e.g., resource consumption and gas emissions from large-scale computing), cybersecurity and moral risks associated with large-scale digital operations have not been fully practiced and proven, so digitisation faces huge unknown costs. In the agri-food sector in particular, there is a potentially significant risk that the information gap between companies may lead to a "digital divide" and further polarisation between rich and poor. In order to ensure a more equitable and inclusive digitisation of agriculture, farmers need to be further motivated to adopt digital technologies through the role of social influence and improved organisational conditions (Giua *et al.*, 2022).

SOI at the organisational level, especially SOI based on cooperation, can complement and enhance SOI at the technical and product levels. A multi-stakeholder partnership leverages each other's resources and complements each other's shortcomings. Resources are the motivation for cooperation, including internal resources such as entrepreneurship, finance and know-how, and external resources such as external services, market intelligence and public funding (Camanzi and Giua, 2020). Different stakeholders have different roles to play in cooperation and constitute different types of cooperation with each other. Producers (or farmers) are both developers and end-users of SOI technologies throughout the supply chain, and cooperation between individuals is based on technology and knowledge. Technology transfer cooperation, for example, enables innovative technologies to be better disseminated within the industry, reduces the costs and inputs for the introduction of relevant technologies by companies in the industry, and reduces the financial pressure for sustainable development. Another subject of technology-based cooperation is third-party technology companies, which authorise the use of developed technologies to production entities, or production entities outsource technology development to third-party companies, in such a way that reduces the R&D costs and technology risks of production entities. Third party companies are able to leverage their talent by bringing together R&D talent to focus on technology development and consequently improve the technological level and sustainability of the entire supply chain. Funding-based collaborations involve public, private and stakeholder parties. Through investment, the cost of developing and using SOI technology in companies can be addressed, reducing the financial pressure for sustainable development. The issue of investment efficiency is a noteworthy aspect of financial cooperation, which can be effectively improved through the adaptation of public policies and investment cooperation models, thus improving sustainable performance.

Overall, collaboration is one way to effectively improve the sustainability level of the industry. However, the depth and breadth of cooperation can be deepened and expanded. Regions with backward economic development may face the problems of a shortage of funds for technology research and development, a poor production environment due to the quality of the population and a lack of research professionals. The capacity of the backward regions is also needed. Especially in the Mediterranean region, where regional development is highly uneven, more optimisation at the organisational level is needed. On the one hand, in the more developed northern and western regions, there is a need for increased cooperation, especially on a financial basis, to stimulate initiatives of producers or third-party companies to develop SOI technologies. On the other hand, in the less developed southern and eastern regions, the dissemination and diffusion of existing SOI technologies is a major challenge, and therefore technology-based and public service cooperation needs to be deepened and optimised.

5. Conclusions

SOI adoption is restricted due to its cost and the uncertainty about its benefits. This paper provides an overview of the costs and benefits of specific SOIs in the agri-food industry, summarising the costs and benefits of different types of SOI at the different stages. Both process and product innovations are aimed at producing environmental and social benefits, but generating more financial benefits requires organisational innovation to further "innovate for innovation". Organisational innovation can be seen as a complement to process and product innovation and plays a key role in the diffusion and adoption of SOI. Summarising the dimension of the agri-food production cycle, the cultivation and production stages are the most stressful for the environment and therefore a large number of SOIs are focused on these two stages, aiming to guarantee or even increase production while reducing the pressure on the environment. The organisation and system building stage, as a cornerstone, guides the direction of the company on sustainability issues and offers a guarantee for SOIs in other life cycle stages.

As the Mediterranean region has a low propensity to innovate, this review provides guidance on the adoption of innovation in that region, especially for small and medium-sized agri-food companies based there, to help them judge the costs and benefits of SOI when adopting it. In relation to inter-industry cooperation, this paper summarises potential opportunities and ways to collaborate and contribute to improving inter-industry cooperation on sustainability issues. For policy makers and regulators, there is a need to understand the potential costs and risks of different types of SOI and the barriers for companies to develop and use the technology when developing relevant policies to support sustainable development. When policies are developed in isolation from the realities of SOI technology, they can be less effective. The information provided in this paper on the different types of SOI technologies therefore provides them with a direction for policy development, and the SOI at the organisational level provided in this paper helps to advance the continuous innovation and deepening of policies that can stimulate large-scale sustainable industry transformation. For the academic community, the SOI classification framework presented in this paper can be used for future research.

However, since the query terms were not the most extensive when searching the database and there is an excess of literature on specific technologies, it is difficult to include them all in the review. Therefore, there is still a large amount of relevant literature that is not included in the scope of the review, and a large amount of information is ignored as a result. At the same time, the costs and benefits of specific SOIs are not static since they change as technology advances and society evolves. In particular, for technological innovations that generate environmental benefits, the awareness of their potential risks and potential negative impacts on the environment is limited by the current level of human cognition and will only be gradually exposed as that increases.

Finally, the SOIs studied in this paper are designed to reduce the pressure on the environment and society and to slow down environmental and social degradation. Recently, however, the concept of "Sustainability 2.0" has emerged, which aims not only to mitigate environmental and social problems but also to improve our current environment and society. Therefore, based on this paper, future research could take the concept of "sustainability 1.0" to the level of "sustainability 2.0" and conduct more in-depth research.

Acknowledgements

This work was supported by the grant PID2021-123154NB-I00 funded by MCIN/AEI/ 10.13039/501100011033 and "ERDF A way of making Europe", and by the COMPETE (S52_20R) research group funded by Government of Aragón (Spain) and ERDF.

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