Achieving Sustainable Performance in Agri-food Supply Chains Through Digitalization

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Abstract Sustainability is a prosperous field of research for the agri-food supply chain domain. Agri-food supply chain management is currently focused in achieving higher performance of agri-food supply chains. At the same time, sustainability is being promoted as a factor affecting the total effectiveness of agri-food supply chains. The aim of this paper is to examine the practices followed by stakeholders in order to achieve the increase of sustainable performance in the agri-food supply chain domain and proposes ways to implement the existed technology in order to optimize the function of the agri-food supply chains by supporting a holistic framework towards sustainable and efficient agri-food supply chain systems.

Keywords Agri-food supply chains · Sustainability · Sustainable performance · Digitalization

1 Introduction

Sustainability is one of the most important concerns for our planet during the last decades. Meeting the needs of the increased world population has led to radical changes in managing human activities worldwide. In order to manage the environmental, economic, and social crisis, the United Nations have formed the Sustainable Development Goals (SDGs) 2030 Agenda, which includes 17 aspirational objectives with 169 targets about all dimensions of sustainable development [1]. It is estimated that by 2050 food production should increase by 70% in order to cover the world's food demand [2]. For this reason, agri-food supply chain systems play an important role in the worldwide attempts to move towards a more sustainable planet.

Agri-food supply chains are involved in procedures that affect all three pillars of sustainability: environmental, economic, and social. The achievement of the environmental goals of sustainability in agri-food supply chains is an emerging issue that has been set as a target for multiple agri-food supply chain networks. Food

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waste and energy management have been highly implemented in the agri-food supply chains procedures. Companies have started to seek ways to reduce food losses and to upcycle food by-products. Being part of a complex agri-food supply chain network gives them the chance to provide their by-products as ingredients to the production of other products making an important effort to the environmental footprint of the agri-food supply chain systems [3]. At the same time, the reduction of food losses and the good use of food products contributes to the global attempts to reduce hunger, which is a lasting social issue for our planet [4]. The use of new equipment, designed to use less energy and reduce harmful emissions, and the use of alternative energy sources also contribute to environmental protection [5]. The economic dimension of sustainability refers to the costs and profit of the supply chain. The economic growth across the agri-food supply chains should also be enhanced by respecting the individual short-term and long-term objectives of each stakeholder and ensuring the achievement of their economic growth alongside the increase of performance through the whole supply chain network. In terms of sustainability, there has been a new perspective on the economic performance of the agri-food supply chains, as it does not only include the economic profit but also the sustainable outcome. For this reason, the latest research is focused on the sustainable performance of supply chain systems [6].

Achieving sustainable performance in the complex agri-food supply chain systems could be challenging. The evolution of technology has been the key to the modernization of industrial activities, giving companies the chance to produce more and higher-quality products. Even though new technologies have already started to be implemented in various supply chain networks, the agri-food supply chains seem to belong to the late adopters or even laggards in some cases [7].

This paper examines the practices followed by stakeholders in order to achieve the increase of sustainable performance in the agri-food supply chain domain and proposes ways to implement the existed technology in order to optimize the function of the agri-food supply chains by supporting a holistic framework towards sustainable and efficient agri-food supply chain systems.

2 Literature Review

The agri-food supply chains are distinguished from others, mainly due to the products involved in them and the stakeholders participating in the production flow [8]. The agricultural products are characterized by many different properties, such as seasonality and perishability, and their safety and high quality should be assured from all stakeholders through all the stages of the agri-food supply chain [9]. Depending on the end product, agri-food supply chains can be short or long, simple or complex, and include various procedures in all stages [10].

Starting from the field, the agricultural products differ from place to place. Soil fertility, climate conditions, and water availability and quality are some of the factors affecting the quality and quantity of products produced in each area [11]. Not only

do the agricultural products produced in various regions appear to be different from each other, but also the products produced in the same field, depending on the environmental conditions of each cultivation period. As a result, the quality and availability of the primary products of the agri-food supply chains vary from time to time, making the management of the primary production systems challenging. The problems arising in this stage mostly refer to the food losses that occur [12]. The inability to predict the exact weather conditions and the poor forecasting of demand combined with the adoption of outdated cultivation practices leads to an increase in food losses [13]. This leads to a lowered sustainable outcome of the agri-food supply chain together with the decrease of the profit and thus its performance. During the last decades, there have been attempts for the primary production systems to be updated. Precision technologies have started to be applied in the agricultural sector, increasing the efficiency of agricultural activities. As a result, the quality of products is preserved and the production reaches higher levels [7].

Primary production management is the key to achieving a higher sustainable performance outcome for the agri-food supply chain, as the producers become the suppliers for the processing, distribution, and retailing sectors. In case where the products are not disposed of for direct consumption, they enter the processing stage. The main factors that affect the sustainable performance of the agri-food supply chain in this stage are food waste and energy consumption. During the processing of the primary products, some parts of them remain unused, as they do not consist an ingredient of the end product. New ways to use the by-products of the processing procedures have started to be researched in order to decrease the environmental footprint of the agri-food supply chains, by creating at the same time an effective supply chain network [14]. In this area, there has also been a lot of progress and research on using advanced packing and processing equipment in order to avoid additional food losses and reduce energy consumption [15]. Considering the stage of transportation and retailing there has been some research for the optimization of the transportation and storage conditions, achieving the highest product quality and at the same time the lowest consumption of energy [16]. The accurate monitoring of the exact condition of the products though is difficult, as there is no developed technology in order to obtain the necessary information and data for each batch of products during their transportation and until they are purchased by the customers and as a result, the agri-food supply chain system cannot be further optimized.

Consumers are also a part of the agri-food supply chain system. They define the demand of products and their requirements may cause changes through all the stages of the agri-food supply chains. Lately, consumers become more interested in organic products which are produced through environmental-friendly procedures and are integrated into a sustainable and moral framework [17]. A lot of the production plans which have started to be developed target to meet the consumers' needs and demands, leading to the adoption of more sustainable practices. ISO accreditations support the application of high safety and quality production systems by promoting the monitoring of the procedures taking place through the agri-food supply chains and setting up preventive and corrective action systems. These systems contain methods to increase the product quality, decrease the environmental footprint and assure the

integrity of the agri-food supply chain systems. Each stakeholder has the chance to enhance his operation systems with the ISO standards that suit and make the end product certified for the relevant safety and quality factors, providing it with added value [18]. Even though the biggest firms have started to apply these kinds of safety and quality systems, small companies rarely invest in them. The results of the corresponding research vary. Studies are indicating that the performance of a firm is positively affected by integrating ISO systems [19, 20], but on the other hand, research shows that the application of an ISO system cannot ensure high performance, especially in the case of small and medium-sized firms [21]. The limitation of the referred research is that it mostly refers to the analysis of the performance of individual firms, applying one safety and quality system, or a combination of them, as there is no system placed that aims to the preservation of the sustainable performance through all the stages of the agri-food supply chains. As a result, there is no enough information on how the integration of safety and quality systems in each stage of the agri-food supply chain affects the sustainable performance of the whole network.

3 Methodology

Based on the critical review of the literature we aim to detect the gaps in the literature considering the sustainable performance of the agri-food supply chains and the role of the digital technology tools in achieving it. Our aim is to gather information on how the concept of sustainable performance is promoted in agri-food supply chains and how the new technological tools support a holistic framework towards sustainable and efficient agri-food supply chain systems.

Apart from the particularities that agricultural products possess, the agri-food supply chain consists of stakeholders from various fields, with different perspectives and targets. To achieve a holistic approach to the sustainable performance of the agri-food supply chain systems we should consider the relations between the stakeholders as an important factor affecting its total outcomes. Agri-food supply chain management includes all the levels of decision-making and planning processes, including strategic, tactical, and operational planning [22]. In terms of sustainability, agri-food supply chain management also refers to the material and information management across the agri-food supply chain by enhancing the cooperation and coordination between the stakeholders, aiming to ensure its sustainable operation and at the same time protecting the interests of all stakeholders [23]. Cooperation refers to the sharing of resources as a means to execute an operation. Coordination refers to integrated resource management by setting common goals for all stakeholders [22]. Cooperation and coordination systems are approached either as horizontal which refers to the relationships between stakeholders involved in the same stage of the agri-food supply chains or vertical which refers to the connection between the different stages of the agri-food supply chains [24].

The main problem occurring when trying to achieve coordination is that the profit goals of the different stakeholders are not always the same and the level of adoption of new sustainable practices differs between them. Especially in the case of small-sized firms, or firms that use outdated production systems the adoption of new sustainable practices requires a larger investment, which leads to losing short-term profitability [25]. The sustainable management of the agri-food supply chains aims to motivate all stakeholders to align with each other regarding the sustainable procedures that take place in the agri-food supply chain systems, leading to coordination and increasing their sustainable performance.

4 Results and Discussions

The modern agri-food supply chain networks become more and more complex as the demand for food products increases. The recent COVID-19 crisis has indicated that agri-food supply chains have to be quickly adapted to new, and in some cases unpredictable conditions. As a result, agri-food supply chain management should evolve, in order to overcome the new barriers that appear and increase the agri-food supply chains' adaptability. The evolution of new technologies plays an important role in the creation of robust, resilient, and sustainable agri-food supply chain systems.

The recent literature has started to promote the implementation of new technologies as an effective means to achieving sustainable performance in agri-food supply chains. It is highly important that the performance of the agri-food supply chains can be measured from a sustainable point of view. This means that the efficiency outcome of the agri-food supply chain should include more aspects, including profit, environmental footprint, and product safety and quality. The total factor productivity approach, combined with the necessary uncertainty analysis of the factors included is proposed as a means to measure and compare the sustainable performance of the agri-food supply chain systems [26]. With all the necessary information available, the results could be useful in order to shape a more efficient and complete framework towards more sustainable agri-food supply chains.

In the agriculture sector precision technologies and smart agriculture have started to be researched and applied [27]. New technologies in agriculture play an important role in the maximization of the efficiency of agricultural activities, leading to the production of more sustainable and, at the same time, high-quality products, by reducing the food loss that occurs due to bad production practices. Stochastic programming models are also used in order to optimize the production plans by taking into consideration the uncertain parameters involved. Robust optimization systems on the other hand are used in order to reduce the risk and shape a production plan without being affected by the uncertain factors that occur. Stochastic programming and robust optimization systems have also been developed recently in order to manage the uncertainties of the primary production sector [28]. Considering that the agri-food supply chain system's sustainable performance is strongly linked to the management of these unpredictable factors, the research and development of more

stochastic models are necessary in order to shape an optimized framework for the agri-food supply chain system management.

Even though the agricultural sector has evolved lately, it is still difficult for small-scale farmers to invest in new technological equipment. The lack of knowledge on the use of these new technologies alongside the lack of motivation from the government makes their implementation even more difficult. In order to overcome this barrier, there has been some research on the establishment of knowledge networks through the development of knowledge-sharing models and systems in order for all stakeholders to adapt to the new era of digitalization and be part of an updated agri-food supply chain system [29]. A proposed framework that promotes the knowledge sharing across the agri-food supply chains as a means of achieving a higher sustainable performance is the lean K-Mob conceptual framework [10] which was created by taking into consideration an expert's team prioritization considering the lean objectives of the agri-food supply chains. Even though knowledge management tools have started to be implemented in the agri-food supply chains in order to optimize the procedures taking place, less attention is given to parallel support of their sustainable management through them.

The use of simulation models also gives useful information, as the data from this kind of research are used to develop new models and frameworks to optimize the procedures that take place in agri-food supply chains. Moreover, simulation models have started to replace the use of mathematical models in agri-food supply chain studies, as they can process more data and take into consideration the complex factors affecting the performance of the agri-food supply chains [30]. Simulation models are also combined with optimization models in order to shape analytical frameworks towards more efficient and sustainable agri-food supply chain systems [22]. Taking into consideration multiple factors such as safety and quality of products, cost, and environmental footprint of the agri-food supply chains, these models propose alternatives in order to achieve the best combination of efficiency and sustainable performance. A challenge that occurs during the shaping of frameworks by using simulation and optimization models is managing the uncertainty of the factors that affect the agri-food supply chain systems which are mostly related to food production conditions and food demand range.

In the case of the agri-food supply chains, there have been attempts for horizontal cooperation systems, such as the collaborative green transportation system, where farmers from different firms share the warehouses and the transportation equipment, achieving to reduce the cost and gas emissions [31]. There are also frameworks proposing that the supplier selection process and criteria affect the sustainable performance of the agri-food supply chains. More specifically it is shown that a slightly exceeded amount of product ordered could double the food waste, affecting negatively the overall sustainable performance [30]. Considering that the agri-food supply chains aim to achieve a high-performance sustainable outcome and at the same time a competitive advantage the organization of a robust coordinated system is promoted as a necessary action plan [32]. In order to achieve the coordination between the parts of the agri-food supply chains, stakeholders tend to sign contracts between them, eliminating the middlemen and enhancing their communication [17].

The coordination in agri-food supply chains appears to be complex in some cases though, affecting the sustainable performance of the agri-food supply chains [33].

Decision-making is highly important while aiming to optimize the agri-food supply chain systems' sustainable performance. The consideration of sustainability in the decision making processes was less developed until recently as the reduction of material and energy use started to interest the agri-food industry [10]. The use of decision support tools is necessary, as they support long-term strategic planning of the agri-food supply chain systems. The Collaboration Planning Tool (CPT) is a proposed technology system that aims to enhance the classic ERP planning systems [22]. Using CPT, information about the product flow and resources available from all the stages of the agri-food supply chain can be collected and used in order to propose strategic planning alternatives. All this information can be used in order to optimize the agri-food supply chain networks, by evaluating the relations and collaboration between the stakeholders.

All the proposed frameworks and technologies presented are mostly based on information-sharing technologies. There has been recent research on the technologies used in order to support information sharing through the agri-food supply chains. Internet of Things (IoT) traceability systems that use sensor technologies are proposed as a way to monitor the products' condition through all the stages of the agri-food supply chain, giving the customers more information about product safety and quality [34]. Real-time information sharing systems have also been designed in order to achieve better visibility through the agri-food supply chain networks [35]. Big data technology, combined with blockchain technology can also provide stakeholders with more information about the origin and condition of the product by assuring data protection at all times [36].

The agri-food supply chains are considered as a special case of supply chains. The agricultural products differ from others and possess various properties that have to be protected through all the stages of the agri-food supply chain. The safety and quality standards of food products are high as the consumers have started to be more demanding about the products they buy. Setting higher food safety and quality standards affects the way the food supply chains function from farm to fork. Starting from the primary production, agricultural production systems should be well established and technically organized in order to produce higher quality products. Most of the food products, especially in the case of crop production pass through the stage of selection and sorting. With quality and safety standards being strict, an important amount of products is considered inappropriate and is discarded. In this case, this consumer-focused set of standards leads to increased food losses, which negatively affects the sustainable performance of the agri-food supply chain in environmental, economic and social aspects. The case is the same during the next stages of the agri-food supply chains. During processing, distribution and retailing food losses are still high, depending on the standards set from each stakeholder. As food waste is a major issue that the agri-food supply chains come against, there are several solutions proposed, some of them have already started to be implemented. It is noticed that while establishing new procedures in order to achieve the production of safe and high-quality products, there is more focus on the consumer requirements, and

less on the sustainable targets of all stakeholders. The conduction of more organized research on the priorities set by all stakeholders considering all aspects of sustainable performance of the agri-food supply chains by setting panels of experts and the use the results in order to shape frameworks towards the alignment of interests of all parties could lead to the creation of optimized models, approached from a more sustainable point of view [10]. Moreover, proposing ways in order to reduce energy consumption during the procedures taking place could significantly enrich the existed and new models, enhancing the sustainable goals of the agri-food supply chains.

Cooperation and coordination between the stakeholders of the agri-food supply chains is also a matter of interest that affects their sustainable management. The communication and cooperation between stakeholders of both the same and different agri-food supply chains and the creation of sustainable agri-food supply networks is promoted as a way to improve the efficiency of current agri-food systems. In order for all stakeholders to work together and set common goals towards the assurance of the total efficiency of the agri-food supply chain knowledge sharing and information sharing models have started to be established. Especially in the case of agri-food supply chains, the implementation of Big Data technology alongside the integration of IoT platforms is necessary, as there is a lot of important information for food production systems in order to optimize the procedures and facilitate decision-making through all the stages. As food production systems become more complicated, the management of uncertainties is very important in order to make the right decisions and establish a long-term strategic planning. As a result, the acquisition of more data through Big Data Technologies can support decision-making. Blockchain technology can assure data transition through the agri-food supply chain, ensuring their integrity and protection and thus support current Big Data technologies achieving the acquisition of reliable data.

5 Conclusion

Sustainable performance in the agri-food supply chains has become a field of interest for all stakeholders. Environmental, economic and social aspects of agri-food supply chain management are usually researched separately. However, these three aspects are strongly interrelated with each other, defining the sustainability performance of agri-food supply chains. In order for an agri-food supply chain system to be characterized as efficient all aspects of sustainable performance should be in the center of their strategic planning and the agri-food supply chains should be optimized in a way that all stakeholders' goals and interests are considered. New technologies play an important role on the improvement and optimization of agri-food supply chain systems. The optimization of agri-food supply chain networks and the management of the uncertainties involved are linked to the prioritization of the critical success factors affecting sustainable performance. There are further areas of research regarding the prioritization of these factors by experts in order to understand more deeply the ways agri-food supply chain systems are adapted to each case. The ultimate goal

is to align interests, achieve the formulation of more sustainable agri-food supply chain systems and support agri-food supply chain management by the use of more advanced systems that enhance information sharing and ensure data integrity.

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