Enhancing the Sustainability Performance of Agri-Food Supply Chains by Implementing Industry 4.0

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Abstract. In order to enhance the sustainability in the supply chain, its members should define and pursue common objectives in the three dimensions of the sustainability (economic, environmental and social). The Agri-Food Supply Chain (AFSC) is a network of different members such as farmers (producers), processors and distributors (wholesales, retailers…), etc.. In order to achieve the performance objectives of the AFSC, Industry 4.0 technologies can be implemented. The aim of this paper is to present a classification of these technologies according to two criteria: objective to be achieved (environmental or social) specified in the main issues to be covered in each objective and member of the AFSC supply chain where it is implemented. In this work, we focus on technologies that deal with environmental and social sustainability because economic sustainability will depend on the specific characteristics of the business (a supply chain using a specific Industry 4.0 technology may be profitable while others do not).

Keywords: Sustainability · Performance · Agri-food supply chains · Industry 4.0

1 Introduction

As [1] point out, Industry 4.0 has become an "integration factor" for various new technologies towards a new generation of more efficient, agile, and sustainable industrial systems where collaboration issues are at the heart of most challenges of this movement. Collaborative networks community is a field for the analysis and development of Industry 4.0 knowledge [1, 2]. The term "Industry 4.0" comprises several technologies as Internet of Things (IoT), Big Data, Artificial Intelligence, Virtual Reality, 3D Printing, Cyber Security, etc. [3].

On the other hand, Sustainable supply chain management is defined by [4] as *'the management of material, information and capital flows as well as cooperation among companies along the supply chain while taking goals from all three dimensions of sustainable development, i.e., economic, environmental and social into account which are derived from customer and stakeholder requirements'*. Thus, the supply chain members should define and pursue common objectives in the three dimensions of the

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sustainability. The sustainability performance of the supply chain will be monitored by the achievement of all these objectives.

The Agri-Food Supply Chain (AFSC), as any other supply chain, is a network of different actors working together in different processes and activities in order to bring products and services to the market, with the purpose of satisfying customers' demands [5]. Different actors can be considered depending of the AFSC type. The most complex AFSC would include farmers (producers), processors and different tiers of distributors (wholesales, retailers…). Simpler AFSC would substitute the processors by different types of traders. These actors perform different activities, such as growing, harvesting, storaging, processing, washing, sorting, grading, packaging, labeling and distributing, etc. However, AFSCs hold some relevant characteristics that characterize them [6]: limited shelf-life, high levels of uncertainty and increasing awareness in environmental and social aspects.

In order to achieve the performance objectives of the AFSC, Industry 4.0 technologies can be implemented. The aim of this paper is to present a classification of these technologies according to two criteria: objective to be achieved (environmental or social) specified in the main issues to be covered in each objective and member of the AFSC supply chain where it is implemented.

The paper is structured as follows. Section 2 presents the background. Section 3 presents the main issues of environmental sustainability in AFSC and Industry 4.0 main technologies to enhance its performance. Section 4 presents the main issues of social sustainability in AFSC and Industry 4.0 main technologies to enhance its performance. Finally, in the last section, conclusions are exposed.

2 Background

Industry 4.0 is a field of growing interest at both practitioner and academic levels but is still in its initial stage of development and implementation. Previous literature reviews propose different classification frameworks. [7] expose a literature review on Industry 4.0 technologies for manufacturing processes to identify theoretical and methodological approaches. Some recent literature reviews link Industry 4.0 and sustainability concepts. [8] present a review of works that assess the relation between Industry 4.0 and specific objectives of the three dimensions of sustainability (economic, environmental or social). [9] analyze the environmental impact and challenges of Industry 4.0 from four different scenarios: deployment, operation and technologies, integration and compliance with the sustainable development goals, and long-run scenario. [10] develop a review of works to show the impact of Industry 4.0 technologies on environmental sustainability but limited to waste collection issue. Other related works are [11–13]. In these works, it is observed that there is a lack of studies focusing on providing a framework addressing the intersection of the following components in AFSC: AFSC members, environmental and social sustainability issues, and Industry 4.0-based technologies. Therefore, the aim of our work is to focus on how these technologies can enhance AFSC environmental and social issues, respectively, depending on the AFSC main actors (farmers, processors and distributors). Due to space limitations, social issues will be more extensively deployed than the environmental ones.

3 Industry 4.0-Based Technologies for Environmental Sustainability

Environmental sustainability performance is approached in various ways in the literature. Some authors distinguish between input and output oriented indicators. Others classify them into different categories such as procurement, internal operation and product development. Using the works [14–17], we consider as the most relevant environmental sustainability issues: soil management, crop protection, water management, animal welfare, energy efficiency, waste control and pollution control.

Table 1 shows how Industry 4.0-related technologies can enhance soil and waste management issues. Table 1 is an adaptation from [18].

Table 1. Industry 4.0-based technologies for environmental sustainability of soil and waste management (adapted from [18])

Soil Management			
REF	Farmers		
[19-21]	(1) **Aerial drones** to map weeds, yield and soil variation; (2) **Performance maps** that allow to know the performance of the soil in a certain area thanks to **georeferenced images** of the soil; (3) **Robots** capable of microdot application of fertilizer; (4) **Smart tractors GPS controlled** steering and optimized route planning to diminish soil erosion and saving fuel costs		
Waste Management			
REF	Farmers	Processors	Distributors
[22-24]	(1) **ICT** to the deployment of "production on demand" business models; (2) **Precision agriculture leveraging technologies** for decisions related to planting and harvesting time	(1) **Intelligent equipment** enables quality detections in the process, reducing the number of failures and material consumption; (2) **Cloud computing** platform to share data with suppliers to synchronize orders and shipments and reducing stock	(1) **Artificial intelligence** applied to consumers trends to reduce waste; (2) **Automatic control** of temperature to reduce product spoilage; (3) **Point of sale applications** that collect and transmit information at the point of sale in real time by reading their respective barcodes

4 Industry 4.0-Based Technologies for Social Sustainability

Social sustainability performance is also approached in various ways in the literature. Although social standards such as ISO 260000 and Social Accountability SA8000 are well-known among companies, there is a wide spectrum about the different issues that must be taken into consideration to manage and measure this social performance, mainly due to their intangible nature. Using the works ([6, 25–27]) we use as the most relevant social sustainability issues: employment, work conditions, safety, health, nutrition, traceability and community engagement. Table 2 shows how Industry 4.0-related technologies can enhance each one of the previous issues, affecting the overall social sustainability performance of a generic AFSC. It has to be noted that the literature regarding social sustainability technologies so far is not so extent as the literature dealing with environmental technologies.

Table 2. Industry 4.0-based technologies for social sustainability

REF	Farmers	Processors	Distributors
Employment			
[28, 29]	(1) Cooperatively used **farm-monitoring technology** of agriculture might influence employment opportunities and job profiles of farmers and farming related professionals	(1) **Digital technologies** to automate some tasks where labor is difficult to hire	(1) **ICTs** for better employee education, integration and inclusion, work enrichment, and better work-life balance
Work conditions			
[30]	(1) **ICT tools** to lower administrative workload, enhance regulatory laws, allow "hands-free" reporting automation and make work/life balance for farmers easier; (2) **"Farmer-friendly" technologies** designed taking into account the final client	(1) **Intelligent assistance systems** can simplify some tasks providing some previously unknown information (f.e. **augmented reality glasses**); (2) **Intelligent assistance systems**, such as **Learn instruments**, can make work more ergonomic simplifying it	(1) **ICT application** in non-automated transportation activities can provide digital information that can help to make more ergonomic and safer labour conditions by optimizing loading-related tasks
Safety			
[31–33]	(1) **Smart Devices** implemented in tractors that send alerts when they detect immediate overturning risks; (2). **Drones** used in the fields, enabling farmers to control growth in a comfortable and safety manner	(1) **Intelligent Manufacturing equipment** in processes controlled by **ICT** to reduce pollutants and noise	(1) **Intelligent tachograph** that allows the driver to book parking, cancel telematics tolls in advance and helps reduce unnecessary stops by traffic agencies; (2) **GPS** that allows trucks drivers remote access to data (speed, distance…) on work time, avoiding delays and helping to meet the delivery time

(*continued*)

Table 2. (*continued*)

REF	Farmers	Processors	Distributors
Health			
[34, 35]	(1) **ICT** tools to make farmers more aware about consumer eating habits, and how their sold products are perceived and performed in the market-place; (2) The use of the **IoT** to maintain healthier crops and optimize the use of fertilizers and pesticides	(1) **Automated machines** to perform dangerous, dirty and demanding tasks previously manually managed	(1) **Intelligent packaging** that has sensors in each package for sending real-time data on the status of the products via cellular network or wifi to a platform for processing and analysis; (2) **Intelligent processing tools** for making consumer habits more understandable and having a better feedback from them
Nutrition			
[36, 37]	(1) Application of **genetic modified crops** to improve food production and nutrients	(1) Use of **High Intensity Ultra-Sound technology** to induce some changes in the nutritional profile of some beverages	(1) **Food testing devices and freshness sensors** to supervise and prevent products to loss their nutrients
Traceability			
[38–40]	(1) **Geographic information systems (GIS), global positioning systems (GPS) and remote sensing (RS)** integration to allow site-specific agriculture and obtain agriculture products-related data on the farm	(1) **Life-cycle improvement technology** and food processing technology	(1) **Logistics tracking software;** (2) **ICT tools** providing consumers with more complete, transparent and reliable information **on** food composition, origin and health-related issues (f.e. intolerances)
Community engagement			
[41, 42]	(1) **Blockchain technologies** to check sustainable performance indicators such as the resources origin or child labour conditions; (2) **Online networks** to facilitate direct delivery between farmers and market place points (f.e Food-hub.org and LocalHarvest.org programs)		(1) **ICT-based business models** to encourage engagement among regional supply chains (e.g. online shopping)

5 Conclusions

Sustainability in the supply chain is a topic of high interest in business and academic literature. Sustainability is composed of three dimensions: economic, environmental and social sustainability. Supply chains pursuing sustainability must define common objectives (in these three dimensions) to be reached by the different members.

The accomplishment of these objectives in AFSCs can be supported by the introduction of Industry 4.0 technologies. Specifically, different Industry 4.0 technologies can be used to support specific issues within sustainability dimensions. In this work, on the one hand, we have selected as environmental issues: soil management, crop protection, water management, animal welfare, energy efficiency, waste control and pollution control. On the other hand, we have defined as social issues: employment, work conditions, safety, health, nutrition, traceability and community engagement. It has to be noted that in this work, we focus on technologies that deal with environmental and social sustainability because economic sustainability will depend on the specific characteristics of the business. Once the environmental and social issues have been defined, the different Industry 4.0 technologies have been associated to each issue and to the different members (farmers, processors and distributors) of the supply chain.

In the literature, there are less Industry 4.0-related technologies explicitly reported for dealing with social sustainability issues than in the environmental case, probably due to the different nature. There is still a need to develop further both environmental and, especially, social technologies that improve the sustainability performance of AFSCs in order to improve efficiency and competitiveness.

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