13rd International Conference on Industrial Engineering and Operations Management
XXIII Congreso de Ingeniería de Organización
Gijón, Spain, July 11-12, 2019

Industry 4.0 for the Development of More Efficient Decision Support Tools for the Management of Environmental Sustainability in the Agri-Food Supply Chain

Pérez D[1], Verdecho M.J[2], Alarcón F[3]

Abstract The agri-food supply chain (ASC) has received a great attention in the last decade due to sustainable issues, not only economical but also environmental and social. This implies that the traditional management methods must be reviewed and changed. Therefore new decision models must arise in which environmental and social aspects will have to be addressed in greater or lesser extent to complement the traditional economical-driven decision models. In this paper a characterization of the main actors and decisions taken throughout a generic ASC as well as the main environmental issues that could affect those decisions are first reviewed. Then, it is aimed to know how each one of these aspects could be enhanced with the incorporation of Industry 4.0 - related technologies to develop more efficient decision support tools for the management of sustainability in ASC.

Keywords: Industry 4.0, Environmental sustainability, Decision models, Agri-food supply chain,

1 Introduction

Environmental and social sustainability issues in Agri-food Supply Chains (ASC), are becoming very relevant mainly due to two factors. Firstly, the increasing number of public legislation rules and technical specifications to be met and, secondly,

[1] David Pérez Perales (✉e-mail: dapepe@omp.upv.es)
[2] Maria José Verdecho Díez (e-mail: mverdecho@omp.upv.es)
[3] Faustino Alarcón Valero (e-mail: faualva@omp.upv.es)
[1,2,3]Research Centre on Production Management and Engineering (CIGIP), Universitat Politècnica de València, Camino de Vera, s/n, 46022, Valencia, Spain

the growing awareness throughout the different ASC members (producers, processors, distributors, retailers…) mainly as a consequence of final clients concern about purchasing sustainable products and services (Pérez et al. 2019).

This fact makes that the traditional economic-driven management methods are no longer efficient and must be accommodated to these new sustainable conditions. In order to meet this new scenario, SC decision models/methods that account for environmental and social issues must be developed.

On the other hand, new technologies have emerged in the last years as a consequence of the "Industry 4.0" revolution (Bozá et al. 2019). However, just a few works have addressed in which extent Industry 4.0 - related technologies have positively contributed to this new sustainable scenario in ASC management (ASCM).

Due to space constraints, in this paper we just focus on environmental issues, and how these technologies have brought important and relevant impacts to environmental sustainability in the practical arena allowing the development of more sustainable decision support tools for ASCM.

The paper is structured as follows: In Chapter 2 a generic ASC is characterized, pointing out the main actors and decisions as well as its main peculiarities. Chapter 3 focuses on the concept of sustainability, and in which extent SC decision models account for this concept, focusing on environmental aspects. It is in chapter 4 where the most important technologies addressed by Industry 4.0 are first analyzed and then how they can lead to more sustainable decision support tools for ASCM. Finally, in Chapter 5 some conclusions are drawn.

2 Characterizing the Agri-food Supply Chain

The term agri-food supply chain (ASC) has been associated to describe the activities from production to distribution that bring agricultural or horticultural products from the farm to the folk (Prima et al., 2016).

From a process point of view, Verdouw et al. (2010) identify the basic transformations in a generic fruit supply chain: growing and harvesting; processing; washing, sorting and grading; packaging and labeling: storage and distribution; retailing. All this processes are carried out throughout the ASC by the different actors/stages (producers/farmers, processors and distributors) from upstream to downstream.

Some relevant peculiarities of ASC are the following (Pérez et al, 2018):

1. Limited products shelf-life and the importance that consumers give to aspects such as quality and health.
2. High levels of uncertainty mainly due to weather unexpected variations and products demand and price variability.
3. Increasing awareness in environmental and social issues.

After this characterization of the main processes/decisions taken by the different actors throughout a generic ASC, as well as the main peculiarities that differenciate it from others SC´s, the next section focuses on the third one, that is, the increasing awareness about "sustainability". In addition to that, a brief review about how Decision models address sustainable issues for ASCM is conducted.

3 Decision models for Sustainable Agri-Food Supply Chain Management

The agri-food supply chain (ASC) has received a great attention in the last decade due to sustainable issues, not only economical but also environmental and social. This is reflected in the way in which decision models are formulated since traditional economical-driven ones have incorporated environmental and social aspects to a greater or lesser extent.

Achieving sustainable ASCM is not an easy task. All the actors must prioritize their financial benefits but at the same time considering the increasing demand on environmental or social aspects. This is mainly due to two circumstances: companies are subject to many public legislation constraints and final clients are becoming more concerned about purchasing sustainable products and services, therefore forcing upstream the ASC to meet certain levels (Verdecho et al. 2018)

In this third section a brief review about the extent in which decision models (either conceptual or operations research-based) address sustainable issues in ASCM is conducted. Due to space constraints, this review just has focused on the environmental issues that, in some cases, complement the economical ones.

It must first be remarked that most of the decision models only consider the trade-off between economic and environmental aspects, neglecting social ones. These studies only focus on environmental (known as green ASC by some authors) and economic aspects attempting to turn environmental impact into economic value in their models. Just a few articles, addressing conceptual models, focus on social aspects.

Another aspect to note is that although there are a few decision models considering the three aspects of sustainability (Bourlakis et al. 2014) and although they point out an enormous number of indicators, the interactions among them are very difficult to quantify and are often ignored (Gerbens et al. 2003).

The most addressed environmental sustainability issues (Gerbens et al. 2003; Bourlakis et al. 2014; Prima et al. 2016; Beier et al.2017; Verdecho et al. 2018, Pérez et al. 2019) have been: crop protection, soil management, water management, animal welfare, energy efficiency, pollution control and waste control.

4 Contribution of Industry 4.0 technologies for the development of more sustainable decision support tools for ASCM

"Industry 4.0" is a relative new paradigm (coined by "Industrie 4.0 Working Group and the "Plattform Industrie 4.0" in 2011) that comprises a set of technologies and related features that allow, among other things, autonomous decision-making, interoperability, agility, flexibility, efficiency and cost reductions (Erol et al. 2016).

Industry 4.0 has therefore led to a new form of managing the Supply Chain, also known as "Supply Chain Management 4.0" (SCM 4.0). But SCM 4.0 comprises in turn a broad spectrum of concepts, being one of them of increasing relevance in the last decade, the sustainability concept.

In the previous section, some Decision models for Sustainable ASCM were analyzed with the aim to know which specific environmental issues were the most addressed.

The point is how these Industry 4.0 technologies are contributing to improve, in a greater or lesser extent, the management of this sustainable issues, so that more efficient Decision support tools can be developed for sustainable ASCM.

For a more comprenhensible view of this contribution, a classification scheme of Industry 4.0 - technologies, based on some of this paper´s authors (Boza, et al. 2019) is followed **(Table 1).**

Table 1 Industry 4.0 – based technologies: a classification scheme

INDUSTRY 4.0 – BASED TECHNOLOGIES	
Cluster	**Definition**
Internet of Things (IoT)	IoT may be defined as everyday objects which can be equipped with identifying, sensing, networking and processing capabilities that will allow them to communicate with one another and with other devices and services over the Internet to achieve some useful objective **Specific Technologies:** RFID, GPS chips, sensors, smartcards, actuators…
Cyber-Physical Systems (CPS)	CPS are defined as transformative technologies for managing interconnected systems between its physical assets and computational capabilities. By integrating CPS with production, logistics and services in the current industrial practices, today's factories will be transformed into Industry 4.0 factories with significant economic potential. The combination of these technologies will also facilitate the link back from the virtual to the physical world. **Specific Technologies:** M2M, machine vision, 3D-printing, Additive manufacturing…
Smart Data	Future plants will produce a large amount of data that will need to be saved, processed and analyzed. This data management will be possible due to increasing storage capacities, lower computation and data-storing costs and advanced methods and tools to handle big data processing and analyzing. **Specific Technologies:** Cloud computing, big data, wireless networks…

Advanced Processing Analytics	A typical enterprise generates very large and diverse data sets coming from its distributed business locations. These massive amounts of detailed data can be combined and analyzed by predictive analytics, data mining, simulation or statistics. Doing this process in real-time creates a business advantage for the company by giving insight into the real-world dynamics of their business **Specific Technologies:** Artificial intelligence, predictive analytics, simulation models, machine learning, automated robots…
Humans Machines interaction	It refers to the interaction and communication between human users and a machine, a dynamic technical system, via a human-machine interface. It studies the ways in which humans make, or do not make, use of computational artifacts, systems and infrastructures. **Specific Technologies:** Smart mobile devices, embedded computation, augmented reality, smart glasses, touch interfaces…

As aforementioned, only the environmental aspects of sustainability will be analyzed, that is, in which extent Industry 4.0 – based technologies may affect to the development of more sustainable decision models (from an environmental point of view) for ASC management.

Many works, as the one of Beier et al. (2017) affirm that just a little research is devoted to investigating the impact of digitalized industry on relevant industry sustainability aspects. However, Lopes Sousa Jabbour et al. (2018) affirm that a few emerging works are providing insight into the integration of Industry 4.0 technologies and environmentally-sustainable manufacturing. In the same line, Müller et al. (2018) propose a research model in which empirical results show a positive and highly significant relationship between environmental benefits and Industry 4.0 implementation.

Table 2 shows the contribution of some Industry 4.0 - based technologies to enhance the most addressed ASC environmental issues in decision models (section 3). Additionally, the ASC actors (producers-prod; processors-proc and distributors-dist) being the most benefited of the implementation of these technologies are also shown. Just seven references are quoted here due to space restrictions, each one related to one of the previous selected issues, respectively (Bo and Wang, 2011; Satyanarayana, 2013; Roopaei et al. 2017; Bagavathiappan et al. 2009; Dahl 2015; Fagerholt et al. 2010; Wolfert et al. 2017).

Table 2 Industry 4.0 for environmental sustainability in ASCM

	INDUSTRY 4.0 FOR ENVIRONMENTAL SUSTAINABILITY IN ASCM
Crop Protection	<u>**PROD**</u>: 1) **Digital probes** (with GPRS technology) of solar radiation, temperature and humidity, gases and wind conditions; 2) **Sensors** in the "silobag" that control seeds and via GSM signals are sent to farmers; 3) **Genome editing**: A technique that enables scientists to hack into genomes, make precise incisions, and insert desired traits into plants; 4) **Cloud computing** that allows the farmer to create prediction models in real time and non-linear relationships between ecological groups of pests; 5) **Drones** flying over the farms and detecting diseases in the leaves; they then send images and warning messages to farmers.

Soil Management	**PROD**: 1) **Robots** capable of microdot application of fertilizer; 2) **Smart tractors GPS controlled** steering and optimized route planning to diminish soil erosion and saving fuel costs; 3) **Aerial drones** to map weeds, yield and soil variation; 4) **Sensors and GPS** incorporated to the agricultural machinery to achieve samples of soil characteristics and elaborate maps that help the farmer to know which crop variety would have a better yield and to establish plans for the application of fertilizers according to the insufficiencies that the analyzed area presents.
Water Management	**PROD:** 1) **Intelligent ultrasound sensors** as a mechanism for the detection and measurement of parameters related to the flow of liquid in crops. This system has a direct and automatic connection with the "Cloud" generating a **Big Data** in real time and online 2) **WSN networks** for the implementation of Intelligent Irrigation Systems, which can detect temperature, light, humidity and pH measurements through the sensors. 3) **Wireless microelectro-mechanical sensors** (MEMS) placed on the leaves of the plant, which transmit data in real time to a server for further analysis and interpretation.
Animal welfare	**PROD**: 1) **Sensors** attached to livestock allowing monitoring of animal health and wellbeing; 2) **RFID** systems for tracking animals throughout the lifecycle and tracing individuals following a disease outbreak ; 3) **Bioacoustics devices** (microphones or hydrophones) in enclosures or via collars so that health and/or welfare status can be monitored continuously via sound; 4) **Microwave Doppler radar or laser distance** sensors for monitoring respiratory activity; 5) **Infra-red thermography** (IRT) devices measure radiated heat from particular body parts, without the need for restraint or handling.
Energy efficiency	**PROD:** 1) **Sensors** to capture data about energy consumption and then transmit it to a **smart-phone app.** **PROC:** 1) **Automated Systems** that allow equipment to run faster or slower depending on the demand saving energy; 2) **Automated Systems** to recycle unavoidable food waste through anaerobic digestion (AD) capturing the biogas produced and using it to generate heat and electricity **DIST**: 1) **Smart Data** captured by sensors to have an on-line monitoring of the fleet energy consumption.
Pollution Control	**PROD:** 1) **Advanced bio-f** broad spectrum of products based on naturally occurring micro-organisms for pre- and postharvest application. The solutions reduce chemical pollution to land and water, help address biodiversity decline and mitigate risks to human health and wellbeing from conventional agri chemicals. **PROC:** 1) **Renewable energy-based technology** to generate electricity and reduce carbon emissions. **DIST**: 1) **Intelligent algorithms** to minimize the shipments distance and therefore save fuel emissions; 2) **Electric trucks** to distribute to reduce the CO2 emissions.
Waste management	**PROD:** 1) **Precision agriculture leveraging technologies** for decisions related to planting and harvesting time; 2) **Smart labelling/packaging** solutions; 3) **ICT** to the development and operation of radically new farm business models, such as "production on demand" **PROC:** 1) **Cloud computing** platform to share data with suppliers to sincronize orders and shipments and reducing stock; 2) **Intelligent equipment** allows in-process quality detections that lead to smaller failure rates and thus less rejects and material consumption; **DIST**: 1) **Internet** for the automatic collection of real time data on the consumption patterns of the final customer; 2) **POS (point of sale) applications** that collect and transmit sales information at the point of sale in real time by reading their respective barcodes; 3) **Automatic control of temperature** to reduce product spoilage; 4) **Artificial intelligence** applied to consumers trends to reduce waste.

Some insights that can be pointed out are the following:

1. Input oriented issues (crop protection, soil and water management, animal welfare and energy efficiency) mostly concern to producers/farmers while output oriented (pollution and waste control) concern to the whole ASC.

2. Some of the Industry 4.0 - based technologies allow the producers/farmers the so-called "precision agriculture". This has an immediate effect in the economic benefit since less resources/inputs for obtaining the same outputs are used (for example crop yield), while meeting the environmental objectives/constraints. No trade-off is done in this case between economical and environmental sustainability.
3. Some of the Industry 4.0 - based technologies can help, specially to producers/farmers, to reduce the uncertainty in the behaviour of external variables. For example the reduction of the demand uncertainty allows producers/farmers to take more accurate decisions about growing, harvesting and storing/transporting. This results in not only economical benefits (more efficient production, better post-harvest deterioration control, higher product quality, longer permanence in the market…), but also environmental, because waste is reduced drastically.

5 Conclusions

In this paper a generic ASC is characterized with the aim to focus on environmental sustainability issues and how the different decision models approach them.

The main contribution is to analyze in which extent the most considered environmental issues could be enhanced with the incorporation of Industry 4.0 - related technologies to develop more efficient decision support tools for the management of sustainability in ASC.

6 Acknowledgements

Authors of this publication acknowledge the contribution of the Project GV/2017/065 "Development of a decision support tool for the management and improvement of sustainability in supply chains" funded by the Regional Government of Valencia

7 References

Bagavathiappan, S., Saravanan, T., Philip, J., Jayakumar, T., Raj, B., Karunanithi, R., & Jagadeesan, K., 2009. Infrared thermal imaging for detection of peripheral vascular disorders. Journal of medical physics, 34(1), pp. 43–47. doi:10.4103/0971-6203.48720

Beier, G., Niehoff, S., Ziems, T. & Xue, B., 2017. Sustainability aspects of a digitalized industry - A comparative study from China and Germany. Int. J. Precis. Eng. Manuf.-Green Technology, 4, pp. 227–234.

Bo, Y., & Wang, H., 2011. The Application of Cloud Computing and The Internet of Things in Agriculture and Forestry. International Joint Conference on Service Sciences, pp. 168–172. https://doi.org/10.1109/IJCSS.2011.40

Bourlakis, M., Maglaras, G., Aktas, E., Gallear, D. & Fotopoulos, C., 2014. Firm size and sustainable performance in food supply chains: Insights from Greek SMEs. International Journal of Production Economics, 152, pp. 112-130.

Boza, A., Alarcón, F., Perez, D., & Gómez, P., 2019. Industry 4.0 from the Supply Chain Perspective: Case Study in the Food Sector. In L. Ferreira, N. Lopes, J. Silva, G. Putnik, M. Cruz-Cunha, & P. Ávila (Eds.), Technological Developments in Industry 4.0 for Business Applications, pp. 331-351

Dahl R., 2015. A Second Life For Scraps: Making Biogas From Food Waste. Environmental health perspectives, 123(7), A180–A183. doi:10.1289/ehp.123-A180

Erol, S., Schumacher, A. & Sihn, W., 2016. Strategic guidance towards Industry 4.0 – a three-stage process model. In International Conference on Competitive Manufacturing, COMA'16.

Fagerholt, K., Laporte, G., & Norstad, I., 2010. Reducing fuel emissions by optimizing speed on shipping routes. Journal of the Operational Research Society 61(3), pp. 523-529. DOI: 10.1057/jors.2009.77

Gerbens, P.W., Moll, H.C. & Schoot, A.J.M., 2003. Design and development of a measuring method for environmental sustainability in food production systems. Ecological Economics, 46 (2), pp. 231–248

Lopes Sousa Jabbour, A.B., Jabbour, C.J.C., Foropon, C.; & Godinho Filho, M., 2018. When titans meet - Can industry 4.0 revolutionise the environmentally-sustainable manufacturing wave? The role of critical success factors. Technol. Forecast. Soc. Chang, 132, pp. 18–25.

Müller, J.M., Kiel, D. & Voigt, K.I., 2018. What Drives the Implementation of Industry 4.0. The Role of Opportunities and Challenges in the Context of Sustainability. Sustainability, 10, 247.

Pérez D., Alarcón, F. & Bozá, A., 2018. Industry 4.0: A Classification Scheme. In: Viles E., Ormazábal M., Lleó A. (eds) Closing the Gap Between Practice and Research in Industrial Engineering. Lecture Notes in Management and Industrial Engineering. Springer, Cham, pp. 343-350

Pérez, D., Alarcón, F., Drummond C. & Ortiz A., 2019. Towards a Sustainable Agri-food Supply Chain Model. The Case of LEAF. In: Ortiz Á., Andrés Romano C., Poler R., García-Sabater JP. (eds) Engineering Digital Transformation. Lecture Notes in Management and Industrial Engineering. Springer, Cham, pp. 333-341

Prima, W.A., Xing, K. & Amer, Y., 2016. Collaboration and sustainable agri-food supply chain: a literature review. MATEC, 5802004 . DOI: 10.1051/ matecconf/20165802004

Roopaei, M., Rad, P., Choo, K. R., & Choo, R., 2017. Cloud of Things in Smart Agriculture : Intelligent Irrigation Monitoring by Thermal Imaging. IEEE Xplore Digital Library, 4(1), pp. 10–15.

Satyanarayana, G. V., 2013. Wireless Sensor Based Remote Monitoring System for Agriculture Using ZigBee and GPS. Cac2s, pp. 110–114.

Verdecho, M.J., Pérez, D. & Alarcón F., 2018. Proposal of a Customer-Oriented Sustainable Balanced Scorecard for Agri-food Supply Chains. 12th International Conference on Industrial Engineering and Industrial Management. XXII Congreso de Ingeniería de Organización. Girona, Spain, July 12-13, 2018

Verdouw, C.N., Beulens, A.J.M., Trienekens, J.H. & Wolfert, J. (2010) 'Process modelling in demand-driven supply chains: A reference model for the fruit industry', Computers and Electronics in Agriculture, 73(2), pp. 174–187

Wolfert, S., Ge, L., Verdouw, C., & Bogaardt, M.,2017. Big Data in Smart Farming – A review. Agricultural Systems, 153, pp. 69–80. https://doi.org/10.1016/j.agsy.2017.01.023