Leveraging on technology and sustainability to innovate the supply chain: a proposal of agri-food value chain model

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Abstract

Purpose – Nowadays, the agri-food industry is called to face several sustainability challenges that require the development of new sustainable models. The adoption of new technological assets from Industry 4.0 supports the companies during the implementation of sustainability practices. Several models design the operation management of the food supply chains (FSCs). Because none extant models resulted complete in technological and sustainability elements, this paper aims to propose an innovative and sustainable agri-food value chain model, contributing to extend understating of how supply chains can become more sustainable through the Industry 4.0 technologies.

Design/methodology/approach – Thanks to a well-structured and replicable systematic literature review and sequent content analysis, this work recognized and compared the extant FSC models, focusing on the interaction of five key elements: activities, flows, stakeholders, technologies and sustainability. The output of the comparison leading in the definition of the proposed model is discussed in a focus group of 10 experts and tested in a case study.

Findings – Fifteen extant models were recognized in literature and analysed to discover their features and to putt in light peculiarities and differences among them. This analysis provided useful insights to design and propose a new innovative and sustainable agri-food value chain model; an example for the olive oil business case is provided.

Originality/value – The adding value of the work is the proposed model which regards innovative elements such as recirculation flows, external stakeholders and Industry 4.0 technologies usage which allows enhancing the agri-FSCs operational efficiency and sustainability.

Keywords AFVC framework, Supply chain model, Food, Olive oil, Digitalization

Paper type Research paper

Introduction

The food supply chain (FSC) is a system of phases consisting of a sequence of economic activities through which materials flow downstream (Kayikci *et al.*, 2020). FSC requires coordination across several stakeholders across countries and continents, to ensure the product distribution to the end customer (Braziotis *et al.*, 2013).

The FSC differs from other industrial supply chains because it must deal with:

- the unique nature of the products, as they usually refer to goods with a short lifecycle;
- the high product differentiation;
- the product seasonality in harvesting and production operations;
- the variability of the quality and quantity of agricultural inputs;
- the specific requirements regarding transport, storage conditions, quality and recycling of materials;
- the need to comply with national/international legislation and regulations on safety, public health and environmental sustainability;
- the need for specialized attributes, such as traceability and trust (Garcia-Torres *et al.*, 2019);
- the need for high efficiency and productivity of the equipment; and
- the greater complexity of agricultural production operations within the FSC (Tsolakis *et al.*, 2014).

Although these features could introduce several differences along the supply chains of several food products, all FSCs have the same aim: to be agile and resilient by operating efficiently and in the best way to ensure the survival of production and logistics companies by satisfying customers' needs, which are

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constantly evolving (Zhao *et al.*, 2022). Achieving this goal is essential in the current historical period, characterized by a persistent pandemic condition that undermines the sustainability of business realities (Singh *et al.*, 2021). To generate the maximum value in a dynamic and uncertain macro-environment, the supply flows along the supply chains must be synchronized with the value flows driven by the market demand (Savino *et al.*, 2015). Therefore, considering the market needs as a driver, the FSC is consequently dependent on the rapid evolution of tastes, preferences, needs and habits of end-customers (Shashi *et al.*, 2021). When the value flows are considered within a FSC, it is recognized as an agri-food value chain (AFVC) (Cucagna and Goldsmith, 2018).

An AFVC includes all the activities necessary to bring food products to consumers, considering not only production, processing, storage, distribution and sales but also the consumption phase (Gómez *et al.*, 2011). The AFVC includes the participation, in the activities and process flows, internal (e.g. farmers, producers, retailers and consumers) and external stakeholders (e.g. non-profit organizations, governments, shareholders, doctors and research institutes). These actors represent a community that is involved in the planning, coordination and implementation of activities and flows of the AFVC (Kodish *et al.*, 2019).

Sustainability plays an even more pervasive and strategic role in agri-business because food is a common thread linking all 17 UN Sustainable Development Goals. However, the current agri-food industry is affected by several sustainability issues such as: up to one-third of food is wasted, 800 million people remain undernourished, 2 billion are deficient in micronutrients, while obesity is on the rise, planet warms, soils degrade, population and consumes growth, lack of transport infrastructure and poor supply chain management strategies (Krishnan *et al.*, 2021; Rust *et al.*, 2020). Therefore, improved sustainability across FSC represents an imperative for the current agri-food sector.

For example, the circularity of resources appears to be one of the solutions for safeguarding the environment (Dora *et al.*, 2021). In fact, thinking of the food sector with a circular and non-linear mindset allows for less waste of resources and more savings in economic terms.

Addressing sustainability challenges is the aim of the agenda of many governments and organisations across the world (Rogers and Srivastava, 2021).

In this context, a model based on the 3Ps (people, planet, profit) is shaped, allowing the identification of points of improvement for agents and areas at the various levels of the FSCs (Fisk, 2010). According to Savino *et al.* (2015), the integration of sustainability and green concepts into an existing supply chain model is very important to achieve not only environmental but also economic and social sustainability goals. Nowadays, driven by external pressures, such as those coming from regulatory, market and stakeholder requirements (Lu *et al.*, 2018), sustainability is not only implemented in the internal company activities but also integrated in the key business processes along the entire supply chain (Lu *et al.*, 2022). The integration of sustainability within supply chain management practices (such as purchasing guided by attention to environmental safeguards, sustainable warehousing and packaging) can, as demonstrated by empirical evidences, support organizations in the reduction of waste, the creation of a green image as a marketing strategy, the increase of labour satisfaction, the improvement of operational efficiency and the achievement of better financial performance (Lu *et al.*, 2022).

Since the advent of the fourth industrial revolution, the Industry 4.0 phenomenon has pervaded all industrial sectors, leading towards more digitalized processes and interconnected assets (Papadopoulos *et al.*, 2022). The usage of Industry 4.0 technologies is expected to facilitate company operations, specifically in planning and control activities (Hofmann and Rüsch, 2017) and in mitigating supply chain risks and any resulting disruptions (Brookbanks and Parry, 2022) and contribute to solving some of the sustainability challenges of agri-food industry (Dlodlo and Kalezhi, 2015; Dora *et al.*, 2022; Friedman and Ormiston, 2022; Lin *et al.*, 2018; Liopa-Tsakalidi *et al.*, 2013; Pérez Perales *et al.*, 2019; Phillips *et al.*, 2014). Focusing on the external environment of the company, Zhao *et al.* (2022) found that this kind of technology could have a positive impact on supply chain management with regard to the involvement and empowerment of stakeholders. The literature supplies some evidences about the consideration of technologies coming from the Industry 4.0 paradigm within supply chain activities with the aim of improving sustainability such as through the reduction of resource consumption and improvements in productivity (Stock and Seliger, 2016), leading overall business ecosystems to conceive the beginning of the fifth industrial revolution but without considering the relation among activities and their owners as a big frame of interconnections (Maddikunta *et al.*, 2022). Over time, several authors (Bruzzone *et al.*, 2009; Bukeviciute *et al.*, 2009; Kayikci *et al.*, 2020; Lu *et al.*, 2019; Majdalawieh *et al.*, 2021; Martínez-Guido *et al.*, 2018; Nagurney, 2021; Nagurney *et al.*, 2018; Singh *et al.*, 2021; Tsolakis *et al.*, 2014; Vats *et al.*, 2019; Vlajic *et al.*, 2018; van der Vorst *et al.*, 2005; Yakovleva, 2007; Zhao and Dou, 2011) have focused on the analysis of the FSC, proposing several models which aim to explain its operation through the interaction of several characteristics (see section Results of the Systematic Literature Review: the 15 FSC models). Analysing these models emerged that some of them are focused on the productive model of circular economy (Martínez-Guido *et al.*, 2018; Vats *et al.*, 2019; Tsolakis *et al.*, 2014; Vlajic *et al.*, 2018), others consider general sustainability issues (Kayikci *et al.*, 2020; Yakovleva, 2007) and others adopt technologies for different purposes (Kayikci *et al.*, 2020; Majdalawieh *et al.*, 2021; van der Vorst *et al.*, 2005; Vats *et al.*, 2019; Tsolakis *et al.*, 2014).

Among them, no model embraces both sustainability and technological issues while supplying a guide to improve AFVC performance in the current competitive and international scenario. However, the current sustainability challenges of the agri-food industry discussed above require that the entire sector takes a sustainable approach to the supply chain that can be achieved using technologies as a sustainability driver. Therefore, moved by this real problem and with the aim of overcoming the limits of the research field, the purpose statement of this study is to propose an innovative and sustainable AFVC model contributing to extend understating of how supply chains can become more sustainable through the Industry 4.0 technologies. According to this purpose, the following research questions were established:

RQ1. What elements make an AFVC capable of enhancing the management of sustainability issues?

RQ2. What relationships enable the different elements to act as a model?

To give an answer to these questions the present study proposes a new AFVC model which encompass several elements capable to address the current sustainability issues. Specifically, this study starts from an initial systematic literature review aimed at identifying the existing FSC models. The subsequent analysis and comparison of FSC models provides a guideline in the definition of the elements on which to base the new operational model of AFVC: activities, flows, stakeholders and technologies. The proposed model is discussed, considering all its components to clarify its novelty, and the theoretical and practical implications are debated. Limits and follow-ups close the study.

Research methodology

The research methodology that guided this study is composed of four main phases (Figure 1):

1 *Systematic literature review of FSC models*. A systematic literature review was carried out, according to the PRISMA flowchart (Page *et al.*, 2021) (Figure 1), with the aim of defining the boundaries of knowledge of the field of analysis (Bak *et al.*, 2022). A search scheme composed of representative keywords combined through Boolean operators (Ely and Scott, 2007) was defined to identify the sample for analysis:

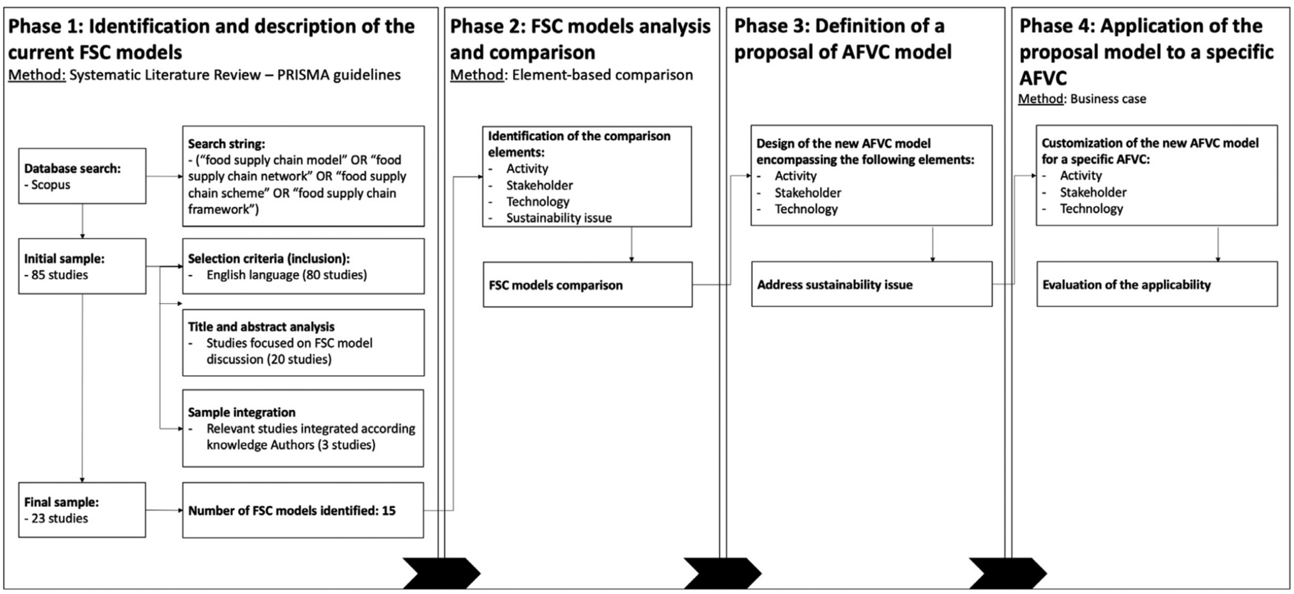
("food supply chain model" OR "food supply chain network" OR "food supply chain scheme" OR "food supply chain framework").

The choice of this research scheme was guided by the authors' desire to obtain a broad selection process, focused to identify the studies in which a FSC model is proposed without directing the research towards any characterization of the model such as sustainable production models (e.g. circular economy, lean-green, agro-forestry and low-miles).

The search scheme was used for searching Scopus (www.scopus.com) in October 2021. This scientific database, managed by Elsevier Publishing, is considered to be one of the most extensive databases (Mishra *et al.*, 2016) because it is more comprehensive than others, such as Web of Science, which provides only ISI indexed journals (Yong-Hak, 2019). An initial sample of 85 studies was identified. Considering as an inclusion criterion only studies in the English language (80 studies) and realizing the assessment of title and abstract, 20 studies focused on FSC models were identified. This sample was extended by three papers known to the authors (Bukeviciute *et al.*, 2009; Tsolakis *et al.*, 2014; Yakovleva, 2007) which were considered relevant for the present study but not retrieved in the initial sample. From the analysis of the full text of this final sample, 15 FSC models emerged.

2 *Analysis and comparison of FSC models*. The 15 FSC models were analysed following an element-based comparison through the following elements: activities, flows, stakeholders, technologies and sustainability issues. Specifically, activities, flows and stakeholders emerged from the analysis of models as the most frequently used elements in FSC models, and for this reason they were inductively considered in the comparison. Technologies and sustainability were introduced by the authors and according to Bruzzone *et al.* (2009), Kayikci *et al.* (2020), Majdalawieh *et al.* (2021), Tsolakis *et al.* (2014), Vats *et al.* (2019) and Yakovleva (2007), to address the purpose statement of the study.

Figure 1 Research methodology



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3 *Definition of a proposal of an AFVC model.* A new version of the AFVC model was designed encompassing activities, flows, stakeholders and technologies to achieve sustainability. Once the model was designed, it was validated in a focus group (Morgan, 1996) composed by 10 experts coming from academia and food businesses (two researchers of FVC field, two managers of food producer company, two managers of food processor company, two managers of food transport company and two managers of food selling companies). This first level of validation was focused to: (i) verify the systematization of the contents in the model. Specifically, stakeholders, activities, flows and technologies were discussed by the experts of the focus group and several suggestions emerged leading us in the improvement of the proposed AFVC model; (ii) discuss the potential sustainable benefits coming from the model adoption. Specifically, starting from the benefits identified for the several FVC models we asked the experts for a comparison on the potential sustainable benefits coming from the AFVC model adoption.
4 *Application of the proposed model to a specific AFVC.* The proposed AFVC model was applied to olive oil AFVC to explicate its customization features and maximize the comprehensibility of the same, according the case study method. Several interviews were conducted with the managerial and operative employees of the several companies operating along the studied supply chain for two purposes: analyse the business processes and technological assets to conduct the case study, and the utility of the proposed model in increasing the awareness about the several elements composing the supply chain, the Industry 4.0 technologies and the benefits in sustainability practices, envisaged in Phase 3 by the focus group experts, coming from the adoption of the proposed AFVC model.

The experimentation in the case study allowed us to assess the ability of the considered technologies to positively impact sustainability dimensions, confirming (or not) the evidences from literature background. Therefore, this phase, even if exploratory as it is composed by a single case study, allowed us to understand the utility of the model to: (i) increase the awareness of AFVC actors about the phases, activities, flows and stakeholders that compose the network in which they operate, and (ii) increase the awareness about the Industry 4.0 technologies in reference to the activity in which they can be used and the benefits in sustainable practices they bring.

The results coming from literature review and FSC models analysis and comparison (Phases 1 and 2) allowed us to identify all elements useful to design the proposed AFVC model: activities, flows, stakeholders and technologies (Phase 3). The application of the proposed model in a specific case study (Phase 4) represents first and exploratory activities useful to validate and test the utility of the proposed model.

Results of the systematic literature review: the 15 FSC models

Table 1 collects the 15 analysed models, highlighting, for each study, the name of the model proposed in the study; the scope for which the model was studied, designed or developed; the application context, which refers to the specific product or FSC considered by the model; the benefits that the model is capable of bringing and the bibliographic references.

From the analysis performed, several different scopes of the study, design and/or development of FSC models can be pointed out: measuring sustainability performance (regarding food loss, recycling and reuses process, food waste, circular economy and cost savings), improving FSC functions, detecting and enhancing the interaction of FSC stakeholders and related activities, highlighting the technological support in facilitating activities along the FSC (with special mention of logistic ones), tracking and ensuring food product quality and safety and ensuring consumer trust through transparency. It is interesting to note the presence of FSC models based on the principles of the productive model of circular economy. Moreover, in some cases, the technologies were accelerators in the achievement of the FSC models' scope. Regarding the analysis of the application context, it emerged that fruit and vegetable products were the most frequently studied. Finally, it is interesting to note that among the several benefits the most addressed by the retrieved FSC models are:

- improving the measurement capability of FSC sustainability performance, especially the environmental one, through framework- or technological-based solutions;
- supporting the decision-making process among the stakeholders according operational or managerial issues; and
- supporting the government in significant at large-scale initiatives for environmental sustainability.

Analysis and comparison of the FSC models

This section presents a comparison among the retrieved FSC models by highlighting the commonalities and differences between them. This comparison considers activities, flows between them, supporting technologies and stakeholders involved, and the sustainability dimensions that the model is capable of addressing, identified starting from the benefits shown in Table 1. Table 2 summarizes the comparison of FSC models. It is structured in three levels through which an increasing level of detail is added regarding the five elements analysed. The description of each element is provided in the Appendix.

A proposal of a new agri-food value chain model

Our proposal of an AFVC model has its roots in the results of the analysis conducted on FSC models and on the comparison between them. The proposed AFVC model, shown in Figure 2, graphs the integration of four fundamental elements (*activities, flows, stakeholders* and *technologies*) capable of enhancing AFVC management to solve *sustainability issues*. To facilitate the readiness of the model, in Figure 2, the authors of this paper chose to identify:

- activities with rectangular boxes;
- flows with straight (linear flow) or dotted (circular flow) lines;
- stakeholders with rounded rectangular boxes; and
- technologies with single circular icons.

Table 1 FSC models: systematic literature review synthesis

FSC model name	Scope	Context	Benefits	Reference
Schematic diagram of a supply chain from the perspective of the processor	Stimulating interactions among the main FSC actors and some external stakeholders (e.g. NGOs – non-governmental organiszations, governments). The related activities were redesigned with the aim of reducing non-value-adding activities (e.g. inventory storage). Leveraging on information and communication technologies (ICT) decision support systems, the model enriched with new stakeholder like technological providers	Fresh agricultural products (such as fresh vegetables, flowers and fruit)	Supporting decision-making on supply chain (re)design thanks to technological tools implementation	van der Vorst *et al.* (2005)
N.A.	Measuring sustainability performance of FSC identifying some best practices that met the three sustainability dimensions	Potatoes and chickens	Improving the measurement capability of food supply chain sustainability performance through framework-based solution	Yakovleva (2007)
Fresh FSC model	Facing the FSC uncertainties through lean and flexible logistic design which support the entire product lifecycle. Minimizing handling operations by using cross-docking approach. Increasing product lifecycle just keeping track about quality and safety of perishable foods	Fresh (such as meat, fish, fruits and vegetables) and dairy products	Supporting logistics network re-engineering as well as operation management	Bruzzone *et al.* (2009)
Schematic representation of the FSC	Stimulating competition and practices through horizontal and vertical integration of FSC improving its functioning and its effects on food prices in UE and the relations among different food industry	N.A	Deriving policy recommendations basing on an in-depth market monitoring	Bukeviciute *et al.* (2009)
FSCN of apple and its products	Optimizing and reducing production and transportation costs along the four stages of apple FSC through a metaheuristic algorithm approach	Apple and its derivatives	Improving the handle of facility location and production capacity selection, thanks to an optimization model	Zhao and Dou (2011)
AFSC conceptual system	Including several external AFSC stakeholders (e.g. industrial partners, research institutes, logistics service providers, importers and exporters) in addition to the traditional ones. Adopting commitment towards sustainable practices like recycling and energy recovery. Assuring the product quality assessment and maximizing profit by a robust and dynamic model that foster ICT in all AFSC phases	Fresh, perishable and seasonable products	Clarifying natural hierarchy of the decision-making process for the design and planning of AFSCs, also from environmental sustainability perspective	Tsolakis *et al.* (2014)
FSCN superstructure	Providing a super-structured and resilient FSC model by emphasizing several viewpoints (food commodities, water and energy). Minimizing food losses in supply services in case of interrupting operations during the COVID-19 pandemic	Animal products	Measuring the natural disasters economic and environmental impact on the food network, through a mathematic optimization model	Martínez-Guido *et al.* (2018)
The fresh produce supply chain network topology with quality deterioration	Constructing a FSC network game theory model which captures competition among food firms, along with the quality associated with their fresh products as they move along the entire FSC	Fresh products (e.g. meat products, dairy products, fruits or vegetables)	Ensuring the capture competition among food businesses	Nagurney *et al.* (2018)

(*continued*)

Table 1

FSC model name	Scope	Context	Benefits	Reference
Circular supply chains	Steering supply chains towards more sustainable business practices and allowing an economic return by the application of circular economy issues (like recycling and resource reuse) to fresh food products	Fresh products	Increasing the food business awareness about the economic benefit deriving from environmental sustainable practices	Vlajic *et al.* (2018)
The Farm-Distributor-Retailer FSCN model	Analysing the relationship between traceability and network structure to propose a comprehensive measure that recommends strategies to be applied to spinach distribution, but in general to any commodity	Spinach, but generalized to any commodity	Assessing, proactively, network traceability and recommend strategies for its improvement	Lu *et al.* (2019)
Traditional supply chain network and the modern one	Shortening the Indian supply chain through the direct selling from farmer/ processor to the customers. Identifying food losses and wastage that occur at the production, processing and consumption stages. Improving FSC activities thanks to technologic applications (like radio frequency identification [RFID])	Perishable products like fruits and vegetables	Helping the food waste and losses monitoring and reduction along the supply chain. Supporting the government in significant at large scale initiatives for environmental sustainability	Vats *et al.* (2019)
Blockchain in the dairy sector; blockchain-driven cold FSC	Monitoring the parameters of production environmental conditions about dairy and cold products by Internet of Things (IoT) sensors and guaranteeing food information truthfulness through blockchain to ensure safe handling throughout the entire FSC. Thanks to a sustainable approach based on ICT, this system ensures overtime, the high-quality supply of agricultural product.	Dairy products and frozen foods	Resolving major challenges, such as traceability, trust and accountability in the food industry, through technological solutions implementation	Kayikci *et al.* (2020)
Blockchain-based framework for fresh and frozen FSC	Identifying and eliminating food adulteration and contamination enhancing quality and safety through blockchain and IoT technologies that respectively monitored the storage parameters of poultry products during transportation and regulated transactions among several network entities. Improving transaction transparency gave a positive impact on consumer trust and the overall brand value	Fresh and frozen food	Ensuring the integrity of supply chain transactions by eliminating a central authority, thanks to technological tools	Majdalawieh *et al.* (2021)
The perishable food supply chain network (FSCN) topology	Streamlining the model proposed by Nagurney *et al.* (2018) in terms of nodes and flows without changing its structure to face some FSC uncertainties triggered by the pandemic condition. Speeding up the distribution of perishable products by introducing a direct link between the manufacturing companies and the customers	Perishable food products (such as a meat or dairy product, fresh fruit or vegetable, etc.)	Quantifying the impacts of labor availability disruptions on food business performance	Nagurney (2021)
FSCN of public distribution system	Highlighting the difficulties during the COVID-19 pandemic in the Indian scenario and so evaluating alternative routes for wheat delivery	Food grain	Supporting in the development of a resilient and responsive food supply chain, assisting it in providing decision-making for rerouting the vehicles thanks to a simulation model	Singh *et al.* (2021)

Source: Authors' own creation

Table 2 Five elements of comparison among FSC models

	Activities																
	Production/supply of raw materials			*Processing*				*Control*		*Decision*		*Distribution*				*Marketing*	
References	Agricultural cultivation	Breeding	Supply of non-food raw materials	Food processing	Packaging	Reuse	Disposal	Quality and safety control	Testing	Decision-making	Marketing research	*Warehousing*	Food distribution	Non-food distribution	Transport/shipping	Retailing	Wholesaling
Yakovleva (2007)	X			X									X		X	X	X
Bukeviciute *et al.* (2009)	X	X	X	X							X			X	X	X	
Van der Vorst *et al.* (2005)					X					X					X		
Vats *et al.* (2019)																	
Bruzzone *et al.* (2009)		X			X			X					X			X	X
Nagurney *et al.* (2018)	X			X								X			X	X	
Nagurney (2021)	X			X								X			X	X	
Majdalawieh *et al.* (2021)		X		X	X			X	X			X	X		X	X	
Tsolakis *et al.* (2014)	X			X	X			X		X		X	X		X	X	X
Martínez-Guido *et al.* (2021)	X	X		X													
Vlajic *et al.* (2018)						X	X			X	X						
Kayikci *et al.* (2020)	X				X								X	X	X	X	X
Lu *et al.* (2019)													X				
Zhao and Dou (2011)	X			X									X				
Singh *et al.* (2021)	X														X	X	X

Source: Authors' own creation

(*continued*)

Table 2

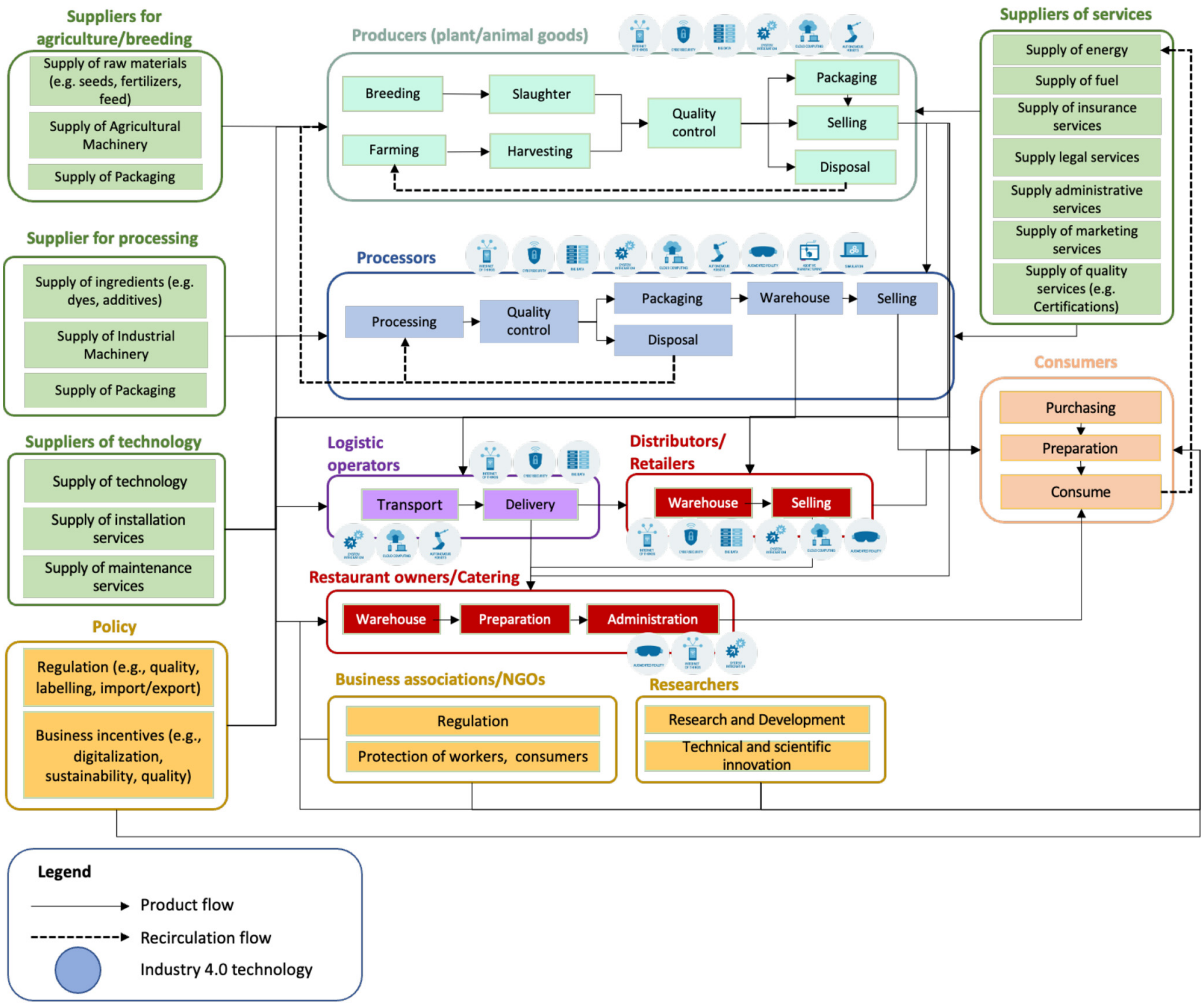
	Activities		Flows						Stakeholders									
	Marketing			*Linear*				*Circular*	*Producers/ suppliers of raw materials*		*Processing companies*					*Distributors*		
References	Food catering	*Public and regulatory policy*	Product flows	Information flows	Financial flows	Process flows	Energy flows	Energy and natural resource flows	Farmers	Breeders	Processors	Packers	Warehouse workers	Food safety inspector	ICT analyst	Logistic companies	Transporters	Brokers
Yakovleva (2007)	X	X	X	X	X	X	X	X	X		X							
Bukeviciute *et al.* (2009)	X	X							X	X	X							
Van der Vorst *et al.* (2005)		X							X		X				X			
Vats *et al.* (2019)									X		X						X	
Bruzzone *et al.* (2009)			X						X	X						X	X	
Nagurney *et al.* (2018)			X						X		X							
Nagurney (2021)			X						X		X							
Majdalawieh *et al.* (2021)				X					X	X	X	X	X	X			X	
Tsolakis *et al.* (2014)			X	X	X	X		X	X							X	X	X
Martínez-Guido *et al.* (2021)			X				X		X		X					X		
Vlajic *et al.* (2018)			X					X	X		X						X	
Kayikci *et al.* (2020)			X	X					X		X	X	X			X	X	
Lu *et al.* (2019)			X						X		X							X
Zhao and Dou (2011)									X		X						X	
Singh *et al.* (2021)									X		X							

(*Continued*)

Table 2

	Stakeholders								Technologies						Sustainability		
	Traders				*External stakeholder*				*General*		*Specific*				*Sustainability Dimensions*		
References	Wholesalers	Retailers	Caterers	*Consumers*	NGO	Governmental and administrative authorities	Shareholders	Research institutes	ICT	Management software	RFID	IoT sensors	Blockchain	Technologies supporting blockchain	Economic	Social	Environmental
Yakovleva (2007)	X	X		X											X	X	X
Bukeviciute *et al.* (2009)	X	X		X												X	X
Van der Vorst *et al.* (2005)	X	X			X	X	X		X								
Vats *et al.* (2019)		X		X							X						X
Bruzzone *et al.* (2009)				X						X							
Nagurney *et al.* (2018)																	
Nagurney (2021)																	
Majdalawieh *et al.* (2021)	X	X		X							X	X	X				
Tsolakis *et al.* (2014)				X		X		X	X								X
Martínez-Guido *et al.* (2021)		X													X		X
Vlajic *et al.* (2018)		X													X		X
Kayikci *et al.* (2020)	X	X	X	X					X		X	X	X	X			X
Lu *et al.* (2019)		X															
Zhao and Dou (2011)				X													
Singh *et al.* (2021)	X	X															

Figure 2 The proposed AFVC model



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Thanks to the colour usage, it is possible to distinguish the different stakeholder categories and all the activities that can be performed by them. For example, light blue is used for "producers", blue for "processors" and green for "suppliers".

Below is a detailed discussion of the activities, flows, stakeholders and technologies in the proposed model. These elements represent the answer to *RQ1*. Specifically, the flows represented in Figure 2 are better described below, and Table 3 is provided to clarify the starting and ending points for each flow, to increase the readability of Figure 2. The envisaged flows (product and recirculation flows) also answer *RQ2*.

Activities

The AFVC activities are strictly linked with the category of stakeholder that performs them. For the common and most recognized actors of the FSC, such as "producers", "processors", "logistics operators", "distributors/retailers", "restaurant owners/catering" and "consumers", the activities follow a business process logic and are thus graphed through sequential flows. Therefore, for each of these stakeholders, the model shows a box with activities and logical flows. Referring to the actors not previously encompassed in the extant models (e.g. "suppliers of services", "suppliers for agriculture/breeding", "suppliers for processing", "suppliers of technology", "policy makers", "business association/NGO" and "researchers"), the model proposes a list of all possible activities that each stakeholder category can perform and represents them following a business macro-process logic.

Flows

Between activities and/or stakeholders, two types of flows are represented in the model: (i) linear flows, represented by a continuous black line, indicating the exchange of raw materials, natural resources, services and/or information; and (ii) circular flows, represented with a black dotted line, which identify recycling and reuse flows of waste from production and processing in the agricultural and food industry and from

Table 3 Matrix of flows among stakeholders

Stakeholders AFVC starting point of flow		Stakeholders AFVC final point of flow												
		Producers	Processors	Logistics operators	Distributors/ Retailers	Restaurant owners/ Catering	Supplier for agriculture/ breeding	Supplier for processing	Supplier of technology	Supplier of services	Policy	Business associations/ NGOs	Researcher	Consumers
Stakeholders AFVC starting point of flow	Producers	RF	LF	LF	LF	LF								LF
	Processors	LF		LF	LF									LF
	Logistics operators				LF	LF								
	Distributors/ Retailers					LF								LF
	Restaurant owners/ Catering													LF
	Suppliers for agriculture/ breeding	LF												
	Suppliers for processing			LF										
	Suppliers of technology				LF									
	Suppliers of services	LF	LF											
	Policy		LF	LF										LF
	Business associations/ NGOs					LF								LF
	Researchers					LF								LF
	Consumers									RF				

Notes: LF = linear flow; RF = recirculation flow
Source: Authors' own creation

consumers in the energy production phase. To add clarity to the flows presented in the model, the dual-entry matrix in Table 3 synthetizes the interactions among stakeholders and the starting or final point of the flow, both for linear and recirculation flows: for example, "processors" interact with "producers", "logistics operators", "distributors/retailers" and "consumers" and the flow starts at the "processors" point within the AFVC and could end at one of the previously mentioned stakeholders AFVC points. It is necessary to underline that for the processes described in the model, some linear flows connect an activity to a stakeholder category without addressing to a particular activity (as happens for the "selling" activity of the "producers" or "processors" processes, which are linked directly to "consumers"); while, in other cases, the flows of a product connect two stakeholders (as happens for "supplier for agriculture and breeding" and "producers of plants/animal goods"). Finally, the circular flows always connect a specific activity to another activity within the same process (as happens in the case of "disposal"-"farming" or "disposal"-"processing", which are related, respectively, to "producers" and "processors") or to another stakeholder (as happens for the flow that connects the "disposal" activity in "processors" to "producers" or the flow that connects the "consume" activity in "consumers" to the "supply of energy" activity in "suppliers of services"). The presence of these flows among the other elements of the model ensures its capability to act as a model and not as a set of isolated elements.

Stakeholders

The proposed model considers the following AFVC stakeholders:

- producers, represented in light blue colour, which include both farmers and breeders;
- processors, represented in blue colour, which include food and semi-finished and finished product companies and other actors such as packers, warehouse workers, food safety inspectors and information and communication technologies (ICT) analysts;
- logistics operators, represented in purple colour, which comprise logistics companies and therefore the transporters and the intermediaries/brokers that take care of imports and exports;
- distributors/retailers and restaurant owners and catering, represented in red colour, which include, respectively, the categories of wholesale and retail sellers as well as the macro category of restaurateurs, catering, and canteen operators;
- consumers, represented in pink colour;
- suppliers for agriculture/breeding, represented in green colour, in particular supplying raw materials (such as seeds, fertilizers and feed), agricultural machinery and packaging;
- suppliers for processing, represented in green colour, namely, those supplying industrial ingredients (such as dyes and additives), industrial machinery and packaging;
- suppliers of services, represented in green colour, such as insurance, legal, administrative and marketing services and fuel and energy providers;
- suppliers of technology, represented in green colour, which include technology providers as well as installation and maintenance service providers;
- policymakers, represented in orange colour, including national governments and associated ministries and regulatory and administrative authorities (regional, district and urban);
- business associations/NGOs, represented in orange colour, including international organizations (e.g. the Food and Agriculture Organization); and
- researchers, represented in orange colour, including research and development entities and academia.

Technologies

Given the role that technology currently plays in the agri-food industry and the benefits in terms of operational efficiency and sustainability that the digitalization process can bring, the technological element was introduced within the proposed AFVC model.

The international scientific scenario collects several contributions about the use of I4.0 technologies for sustainable purposes in agri-food sector, adopting both methodological and experimental lens. Farmers can perform environmental sustainability, for example, for soil and waste management, thanks to the usage of:

- aerial drones, to map weeds, yield and soil variation;
- georeferenced maps to know the performance of the soil in a certain area;
- robots for automated irrigation/fertilization; and
- smart tractors based on Global Positioning System technologies capable of steering, planning optimized routes, diminishing the soil erosion and saving fuel costs (Pérez Perales *et al.*, 2019; Phillips *et al.*, 2014).

Processors can perform environmental sustainability, for example, for waste management, thanks to the usage of:

- intelligent equipment capable of enabling quality detection in the operations, reducing the number of failures and material consumption; and
- cloud computing platform capable of sharing data with suppliers to synchronize orders and shipments and reducing stocks (Liopa-Tsakalidi *et al.*, 2013).

Distributors can perform environmental sustainability, for example, for waste management, thanks to the usage of:

- automatic control of temperature based on sensors technologies to reduce product spoilage; and
- point-of-sale applications that collect and transmit, in real time, information about the product by reading the tag technologies (Pérez Perales *et al.*, 2019).

Some evidences are also provided for social and economic sustainability goals. For example, farmers, using cooperatively farm-monitoring technology, can influence the employment opportunities and job profiles and save cost of technological implementation (Pérez Perales *et al.*, 2019). Processors can improve traceability improving the risk sharing along the supply chain (economic sustainability) and enhancing the consumer safety (social sustainability) towards the implementation of traceability technologies based on Internet of Things (IoT) and blockchain (Lin *et al.*, 2018). Distributors can stimulate community engagement thanks to business model based on ICT, encouraging the involvement of stakeholders among regional supply chain (e.g. online shopping) (Dlodlo and Kalezhi, 2015).

Specifically, in this work, the authors refer to the technological families of Industry 4.0, as it is considered the main phenomenon that guides the digitalization process of all industries, defined through nine pillars (Erboz, 2017) which are described in the Appendix.

The model proposed in Figure 2 shows, for each of the traditional actors of the AFVC, the technologies currently used, as evidence of the digitalization process. Table 4 summarizes how the nine pillars of Industry 4.0-based technologies can impact and support each of these stakeholders in performing its own activities, providing also an example of how each technology can support the stakeholder.

As shown in Table 4, the list of technologies and the assignment to the different stakeholder is not to be understood as complete and exhaustive but represents a starting point deriving from the current international scenario which can be integrated and updated over time in accordance with developments in the agri-food digitization process currently in place.

Addressing sustainability issues

The proposed AFVC model was conceived to graphically formalize the activities, flows, stakeholders and technologies involved within an AFVC with the purpose of enhancing management of the overall chain to improve its social, economic and environmental sustainability. To assess the capability of the model to support business in sustainable practices, the experts composing the focus group (see Phase 3

Table 4 Nine pillars of Industry 4.0 supporting stakeholders

Nine pillars of Industry 4.0		Traditional actors of AFSC						
		Producers	Processors	Logistics operators	Distributors/ Retailers	Restaurant owners & catering		
Nine pillars of Industry 4.0	Internet of Things (IoT)	X	X	X	X	X	*Sensors for climate and production/processing/storage/ distribution/traceability parameters and food quality monitoring, along AFSC*	*Example of Industry 4.0 technology utilization for stakeholder support*
	Cybersecurity	X	X	X	X		*Security infrastructure for data and server protection, to not compromise sensible information, production/processing/storage/ distribution/traceability parameters*	
	Augmented reality (AR)		X		X	X	*Virtualization technologies for redesign procedures and improve user experience*	
	Big data	X	X	X	X		*Big data able to feed analytics useful for decision support systems and machine learning*	
	Autonomous robots	X	X	X			*Robots and drones for improvement and optimization of production/processing/storage activities*	
	Additive manufacturing		X				*Advanced technologies, such as 3D printer, for replicate raw material or complex product, also leveraging on sustainable materials*	
	Simulation		X				*Simulation tools, such as digital twin, for forecasting model definition*	
	System integration	X	X	X	X	X	*Integrated systems, such as cyber physical system, for more connectivity among infrastructure and technological assets, along AFSC*	
	Cloud computing	X	X	X	X		*Virtual storage systems for a big amount of data, for ensuring the remote access to key information*	

Source: Authors' own creation

of Research Methodology) recognised several potential sustainable benefits that a company can obtain from the adoption of the proposed AFVC model.

Following the key points defined by the 3Ps model for addressing sustainability issues along the AFVC (Fisk, 2010), the proposed AFVC model could be useful to obtain the following sustainable benefits:

1 Social sustainability (people)
   - leveraging the involvement of stakeholders which deal with quality-oriented services (e.g. certification entities) and the protection of workers (e.g. business associations), the proposed model could increase, respectively, consumer health protection and the protection of workers in terms of safety, health, housing and sanitation;
   - considering the overall AFVC as a network of stakeholders, the proposed model could enable the agri-food sector to achieve a real and integrated cooperation to move the adoption of the same standards and technology and the building of a supplier code of conduct regarding consumer and society;
   - including the academic and research world within the interactions among AFVC activities, the model could help to develop new knowledge and skills, reducing the distance between researchers and the real problems of the analysis context, improving the quality and usefulness of the research; and
   - involving policymakers, the model could foster the relationship between the food system and policy initiatives, with the aim of improving public–private partnerships for carrying out social projects and encouraging the establishment of regulations and incentives that will be useful to support the several operators along the supply chain.

2 Economic sustainability (profit):
   - being based on specific activities focused on "quality control" within different processes, the proposed model could ensure that high quality standards will be provided in the production of consumer-friendly products and/or services, enabling a premium price;
   - introducing technologies to support product and service management, the proposed model could ensure a reduction of costs in risk management, a better value distribution among the several AFVC stakeholders and an increase in the protection of small and micro enterprises, such as farming companies;
   - foreseeing the introduction of technologies within the key processes of AFVC (of producers, processors, logistics operators, distributors/retailers and restaurant owners/catering), the proposed model could increase the operational efficiency of the individual company but also the entire supply chain, with consequent cost reductions; and
   - seeing the AFVC as a network of stakeholders, the proposed model could be capable of providing society with products or services to stimulate a sharing economy.

3 Environmental sustainability (planet):
   - considering circular flows among activities, the proposed model could make it possible to consider how to reconcile efficient production and environmental responsibility, stimulating virtuous dynamics of the circular economy through, for instance, food waste reduction, reuse and recycling;
   - foreseeing the technology usage in the processes, such as sensors operating according to IoT logic, the proposed model could allow agri-food companies in environmental condition monitoring to reduce soil pollution and degradation and to conduct pest control;
   - foreseeing the technology usage in the processes, such as sustainable smart grids for sustainable energy sources, the proposed model could allow the production of renewable energy to be increased, moving towards a model of self-production of energy;
   - leveraging the usage of technology, such as sensors, big data and analytics, along the key activities of the AFVC, the proposed model could allow calculation of the water, carbon and energy footprints (per item and per AFVC); and
   - foreseeing stakeholder integration, the proposed model could allow the coordination of environmental protection efforts along the entire supply chain.

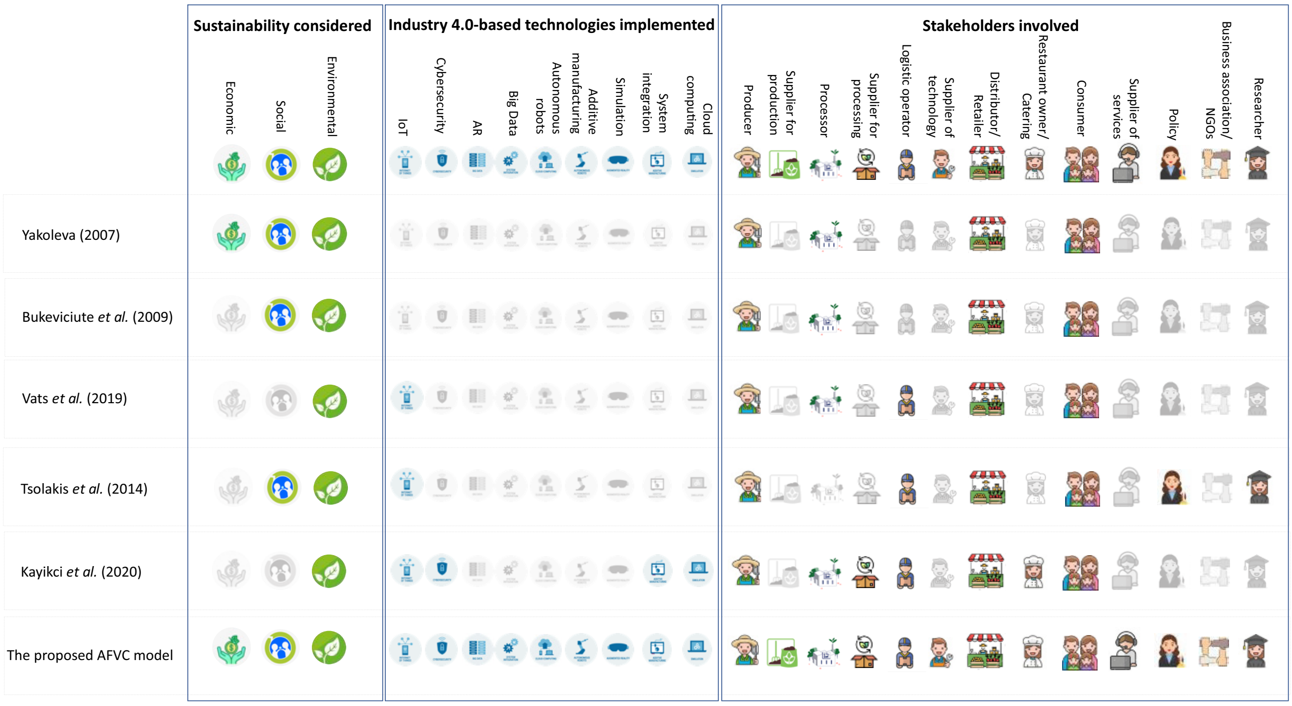
Figures 3 summarizes a comparison between the FSC models discovered in the literature (basing on the evidences shown in Tables 1 and 2) and the proposed AFVC model from the sustainability viewpoint. Specifically, for each model, the dimensions of sustainability implemented, the technologies that allow this and the stakeholders who benefit from the technological adoption are shown.

Application of the proposal to a specific AFVC: the business case of olive oil value chain

The selected case study is the olive oil AFVC. Italy is the second biggest olive producer in the world (ISTAT, 2021) and the leading olive oil consumer (International Olive Oil Council, 2021). The olive sector accounts for 2.4% of the national Italian agri-food industry turnover (ISMEA, 2020) and olive oil is one of the products representatives of "Made in Italy" food around the world. Moreover, actually, this sector faces various challenges that jeopardise its competitive position with respect to the other main producers, such as Spain, Tunisia, Greece and Portugal (Lombardo *et al.*, 2021). It is affected by many criticalities which could be solved with the aim of implementing a sustainable supply chain, such as its water and carbon footprint, socio-cultural sustainability and the negative impact generated by the *Xylella fastidiosa* infection, which is causing a dramatic drop in olive production (Lombardo *et al.*, 2021). All these reasons lead us to consider the olive oil sector eligible for the case study.

The analysis of olive oil AFVC starts with the farming activities that enable olive production. In July 2022, thanks to interviews and focus groups conducted with managerial and operative employees, the authors analysed the business processes and technological assets of an Apulian company

Figure 3 Comparison between extant models, with declared sustainable perspective and the proposed one

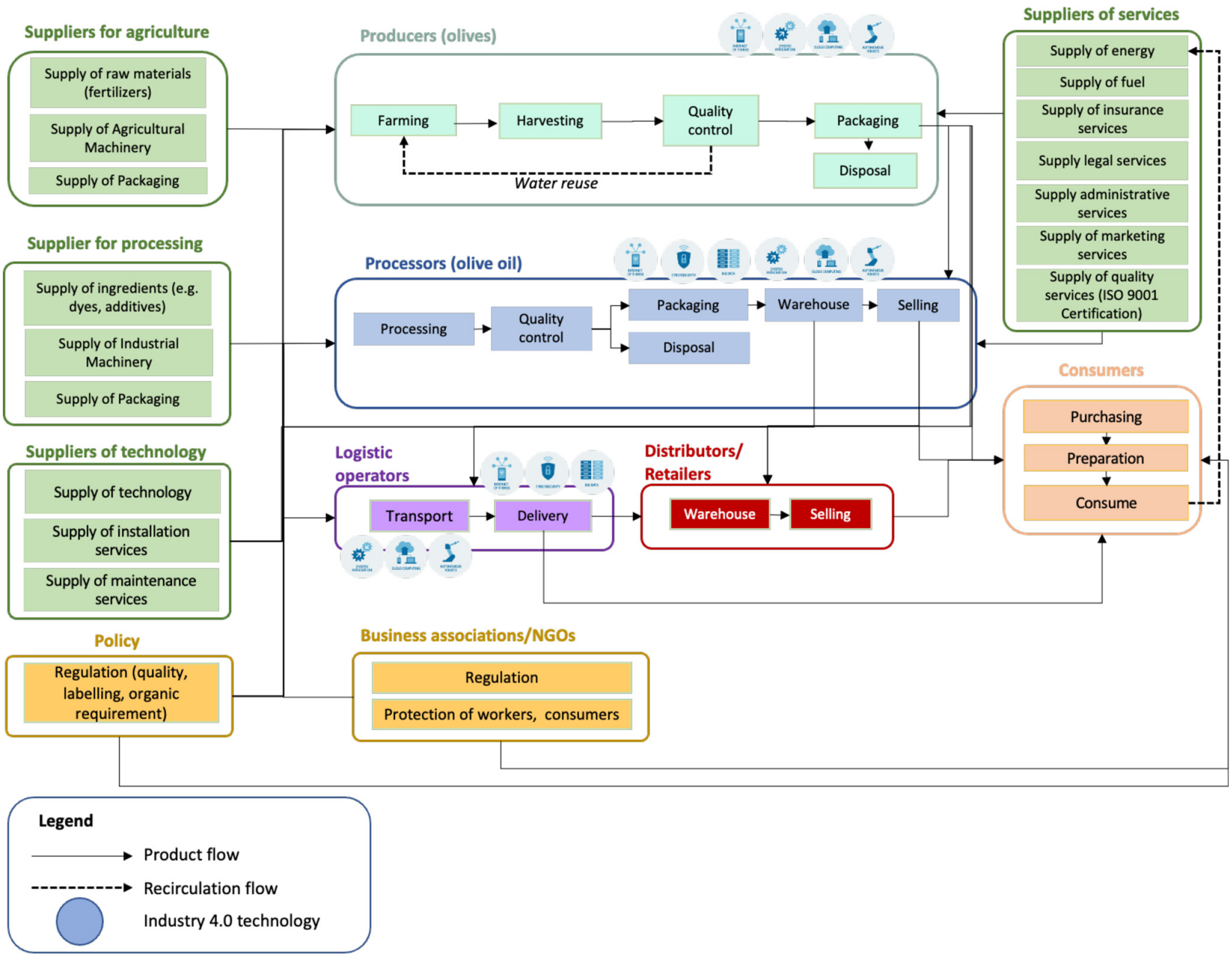


Source: Authors' own creation

which deals with organic olive oil production and retailing with an ecological footprint and ISO9001 quality certification. Therefore, in the national context described above, Apulia is one of the most representative regions, with companies excelling in the production of olive oil (Graziana Galeone, 2019). The selected production company has five hectares of land cultivated with Leccine olive species. The field is georeferenced and equipped with sensors located on the plants to monitor the air condition (e.g. temperature, humidity, tVOC and eCO_2). After the harvesting phase (hand-picked with the help of a self-propelled mechanical shaker), olives are submitted to quality control, where they are washed and observed by farmers to detect any unsuitable ones (which are disposed of). After this phase, the water is purified through filtering technologies and UV lamps, and it is reused for the irrigation activity of the next cultivation phase. The filter ensures that the sand particles with a specific gravity much higher than that of water were removed. The UV lamps generate ultraviolet radiation capable of ensuring the reduction of the bacterial load without the use of polluting chemicals. Olives represent the raw material for the processing phase, thanks to which the company obtains the final product. The processing phase is performed in a non-proprietary mill, remotely monitored thanks to sensors applied within the machinery. Specifically, this sensor is capable of monitoring temperature and its variation during the oil extraction from olive, certifying the cold extraction technique and therefore guaranteeing the quality of the oil produced. After the production, the extracted olive oil is put into aluminium cans, ready to be sold through a low-miles modality (oil mill store point and in two branded stores). Figure 4 presents the tailored AFVC model for the olive oil value chain. It differs from the general one presented in Figure 2 given the absence of some activities (e.g. the ones linked to the breeding process and sale of the raw material), stakeholders (e.g. restaurant owners/catering; researchers), flows (e.g. circular ones from disposal by processors to producer activities and linear ones for the absent activities or stakeholders boxes) and technologies (e.g. for producer activities: cybersecurity, big data; for processor activities: augmented reality, additive manufacturing, simulation).

Finally, to assess the utility of the proposed model, we conduct several interviews with the managerial and operative employees involved in the case study activities investigating about: the awareness about the several elements composing the supply chain, the Industry 4.0 technologies and the benefits that the proposed model could bring in sustainable practices. From these interviews emerged that the proposed model allowed the companies involved to increase the awareness of AFVC with reference to phases, activities, flows and stakeholders that compose the network in which them operate thanks to the possibility to see the figure representative of the AFVC. Moreover, it also increased the companies' awareness about the Industry 4.0 technologies in reference to the activity in which they can be used and the benefits in sustainable practices they brings. To better clarify the use of technologies in the several activities and the benefits in sustainable practices that they bring, Table 5 introduces a further level of detail.

Figure 4 AFVC model tailored for olive oil chain



Source: Authors' own creation

Comparing these benefits with the once recognised by the focus group for the adoption proposed AFVC model discussed in the previous section, the experimentation of the model in the case study confirms the capability of the proposed model to:

- assure the consumers health with quality-oriented product (e.g. avoiding formation of moulds and yeasts during the oil extraction phase or using purified water during the olive cropping phase) – social sustainability, people;
- address high quality standard in the production of product (e.g. certification of cold extraction technique) – economic sustainability, profit;
- distribute risk management among the AFVC stakeholders (e.g. distribute risk management among producer and miller) – economic sustainability, profit;
- foster the adoption of circular flows among activities reintroducing waste in the production process (e.g. water) – environmental sustainability, planet; and
- leverage on technologies to monitor environmental condition reducing production impacts (e.g. eCO_2) – environmental sustainability, planet.

Discussion and implications

Extant studies have proposed several FSC models, tailored according to different perspectives and objectives, as described in depth in the second section. To the best of the authors' knowledge and based on the results from the second phase of the present study methodology (Table 2), no one model considered and simultaneously critically analysed all the core elements needed to characterize the FSCs in the current worldwide scenario: activities, flows, stakeholders, technologies and sustainability issues. The innovativeness of the proposed model consists in the integration of all these different elements and in the representation of the interactions among them, in terms of human interfaces, concurrent activities and tangible or intangible flows. The integration of value flows bring us to consider the proposed model as an AFVC model (Cucagna and Goldsmith, 2018), overcoming the traditional vision of FSC model.

To better explain the potential of the proposed model, follow an example in which some value flows were discussed. A fundamental element of a FSC is the "farming" activity

Table 5 Benefits in sustainable practices coming from technologies adoption

Stakeholder	Technology family	Technical description of technology	Benefits in sustainable practices
Producer	Sensor to monitor air condition	Grove SGP30 Monitored parameters: temperature, humidity, tVOC and eCO_2	The parameters monitored by this sensor give to the producer insights about the quality of the air in the field. For example, eCO_2 parameter defines the approximate value of equivalent CO_2, giving an indication of the impact that the activities carried out in the field generated on global warming. This supports the farmer in the adoption of environmentally sustainable practices focused to reduce the CO_2 emission in the field such as the use of mechanical or electrical tools for the pruning of trees rather than fuel-powered tools
Producer	Water purification technologies	Centrifugal send filter 8218 A-3 UV RACK	These technologies allow purifying the water used in the olive cleaning eliminating the sand and the bacterial load from the water, without the use of polluting chemicals. This represents a sustainable production practice from two viewpoints: (i) reduce the environmental impact because no chemicals are used to clean water, and (ii) adopt a circular economy model reintroducing the water in the production process
Miller	System to monitor oil extraction conditions	DALT	This system allows monitoring temperature and its variation during the oil production. Temperature control is important to avoid the formation of moulds and yeasts in the product. This represents a sustainable production practice because it: (i) certifies the cold extraction technique to the producer and consumers, (ii) guarantees the quality of the oil produced, (iii) assures the safety of the final consumer and (iv) distributes risk management by assigning the part of its competence to the miller

Source: Authors' own creation

performed by the "producer" stakeholder, in some cases thanks to the support of technological tools, which is potentially influenced by FSC external activities performed by the "supplier for agriculture/breeding" stakeholder. Moreover, although the "farming" activity is located at the beginning of the chain, it could be impacted by an activity located at the end of the "producer" stakeholder sequence of activities: the "disposal". The interaction among these two elements works through an exchange of waste materials, creating a "circular flow". This example describes the potential of the proposed model: providing an integrated and systematized picture, it can support companies in the management of the AFVC offering the possibility to address the complexity of the FSC (Kodish *et al.*, 2019) and to improve the sustainable practices. Although the relevance of the integration of sustainable principles in the supply chain models is evident within the scientific panorama (Lu *et al.*, 2022; Savino *et al.*, 2015), our analysis reveals that few extant FSC models encompassed the sustainability perspective, and among them, even fewer leveraged technology for sustainability purposes. Leveraging the technological assets arising from the Industry 4.0 paradigm to fulfil the sustainability requirements, the proposed model opens the route to the fifth industrial revolution for the AFVC (Maddikunta *et al.*, 2022; Sharma *et al.*, 2022), for instance, through the provision of technology-based greener solutions (Demir *et al.*, 2019).

As described in Table 4, technologies of Industry 4.0 can impact and provide support to the several stakeholders of the supply chain. The IoT is mainly adopted to support operations and related stakeholders (such as, as mentioned in Table 4, producers, processors, logistic operator, distributor/retailers, restaurant owner and catering) to effectively realize real-time monitoring and control of the crop environment (e.g. temperature, humidity, light, shock or location), distribution processes and also food traceability (Kayikci *et al.*, 2020). Therefore, the adoption of IoT technology along the AFVC in the proposed model can enable agri-food companies and stakeholders to perform direct management of food quality and safety and to better manage the environmental impact of production as demonstrated by the experimentation in the case study.

The proposed model has the ambition of consider the technological support according an integrated perspective. For example, the adoption of RFID can bring benefits to AFVC in terms of inventory management and placement of goods in warehouses (Vats *et al.*, 2019). However, the RFID solution is still lacking and needs to be integrated with other technologies, such as cybersecurity and blockchain, to ensure transparency, integrity, traceability, credibility and protection of the rights of the end-consumer. Blockchain technology is highly applied to the food industry to regulate and control transactions between entities in the network and keep all parties within the network well informed about the activities carried out by each actor (Kayikci *et al.*, 2020) enhancing trusted relationship (Brookbanks and Parry, 2022). However, its application in an integrated manner, for example, to certify the ownership of the data coming from IoT-based traceability systems, it is still theoretical. Moreover, designing the AFVC as an interconnected operational scenario can require the adoption of ICTs in decision support processes, increasing production flexibility and reducing lead times by eliminating human intervention and introducing product standardization where possible. Therefore, implementing ICT systems in the agricultural sector at various stages of the FSC is now indispensable to ensure sustainable and stable agricultural development and to ensure a high quality of the agricultural product supply in the long run (Kayikci *et al.*, 2020).

The proposed AFVC model allows the implementation of three sustainability dimensions, therefore following the 3Ps model, some sustainable benefits coming from the adoption of the proposed AFVC model were envisaged through the discussion of the experts in the focus group (e.g. involvement of stakeholders to improve working conditions or consumers health; technology implementation to enhance the sharing economy and create a network among stakeholders at any AFVC level; and introduction of circular flows among activities to stimulate virtuous responsibility dynamics towards the environment). Some of them are also confirmed by the results of the case study. As a result, the proposed AFVC model is capable to support the agri-food business to simultaneously address the three dimensions of sustainability (environmental, social and economic) favouring the implementation of a complete sustainable development path.

For example, adopting the proposed model companies can conceive their business ecosystem as a big frame of interconnection (Maddikunta *et al.*, 2022) and address the sustainable development path from several perspectives:

- the network of stakeholders, especially in cases where the commitment to the adoption of such practices is driven by governmental organizations, NGOs and competitors (Tsolakis *et al.*, 2020); and
- the production model according to circular economy principles, because food losses and waste could be at all FSC stages, including the consumption stage (Vats *et al.*, 2019).

Theoretical and practical implications

Several theoretical and practical implications emerged from this study.

Researchers and academics can find in the present study not only a synthesis of the extant body of knowledge about FSC models but also an example of the methodological procedure for critically analysing supply chain models in every industrial field. Researchers, academics and practitioners may find our results useful to better understand the FSC research field by consulting the systematized framework of the extant knowledge and exploring the multiplicity of concepts that surround it. To the best of the authors' knowledge, this study is the first to provide a holistic AFVC model capable of encompassing a wide range of classic elements in supply chain models (e.g. activities, flows and stakeholders) including also innovative elements such as technologies and the benefits which they bring in sustainable practices. This opens a new research route focused on advancing operation management strategies in the agri-food industry considering these key elements starting from the supply chain design.

From the perspective of practical implications, this study aims to encourage managers of agri-food companies to redesign their operation management strategies considering how technologies could help, along the entire supply chain, to enhance the sustainability of the company. Specifically, agri-food companies can find in this study a way to easily conceptualize their core supply chain elements, identifying the Industry 4.0 technologies and understanding in which activities they can be applied to, which stakeholders it would be useful to involve and, which benefits in sustainable practices they brings.

The application of the proposed AFVC model provides an example about the possibility to use some of the Industry 4.0 technologies proposed (i.e. sensors) and can represent a stimulus for companies which want to invest in these technologies or in others.

The high-level perspective of the model permits its application within several different agri-food contexts. The customization feature of the proposed model allows agri-businesses to tailor it on their own needs and expertise, following the example of application supplied in this study. However, considering that the benefits of this kind of model are exploitable only if the model is adopted by all stakeholders, trade associations and governments can find in this study a reflection point that will be useful to guide, respectively, future business guidelines and regulations.

It is necessary to underlie that these practical implications are valuable for the analysed case and supposedly generalizable to the agricultural products and the entire agri-food industry.

For these reasons, this study opens several research routes interesting both researchers and companies:

- evaluating, through numerous case studies, the performance of the proposed model through its application in more than one AFVC to consider the generalizability of the proposed model;
- assessing, through surveys, interviews or focus groups, the role of each stakeholder involved within the proposed model and the stakeholders' propensity to join and validate it to confirm the presence and linkages among macroprocesses associated with them;
- focusing on each specific macroprocess, one after another, to recognize the possibility of considering or not, one or more Industry 4.0 technologies and the relative benefits;
- stressing the analysis of the circular flows to evaluate the possibility of suggesting more strategic actions in line with the circular economy logic and perceiving the sustainability principles; and
- analysing the strategic actions made or planned by government and policymakers to stimulate sustainable practices within supply chain management and developing tools capable of evaluating and measuring its impact on the regional or national territory.

Closing remarks and limits

The study has collected and analysed the background literature about FSC models, comparing them according to five core elements: activities, flows, stakeholders, technologies and sustainability issues. No one model, to the best of the authors' knowledge, has simultaneously considered all these elements, leaving a space for a new proposal capable of encompassing the five core elements and the related relations (Figure 2). The proposed AFVC model is innovative over the previous models as it considers more FSC features and perspectives and focuses on the implementation of sustainability practices through the technologies' adoption. Several limitations affect this study. The proposed AFVC model was designed starting from the results of the analysis of 15 FSC models retrieved according to the systematic literature review procedure described in the Methodology section. The choice of other search parameters and databases could have led to a different starting sample of studies in which other models could be identified. However, this problem was partially contained by following a well-defined and validated literature review protocol (PRISMA) which led to the identification of high-quality works capable to enhance the quality of the final output of this study. The lack of validation of the proposed model in more than one business case study and the qualitative assessment of the related benefits represent a limit. Therefore, the proposed case study involves only a part of the stakeholders present in our model and not give information about the interaction between relevant actors, such as policymakers, technology providers or consumers. Moreover, only a part of the technologies mapped by our model have been validated by the proposed case study. According to the multiple case study method, a reinforced validation strategy provides the validation of the proposed AFVC model in several business contexts (different by product, activity and stakeholders in the value chain) and assessing the capabilities of other technologies in the improvement of sustainability practices, which represent the main follow-up of this study that the authors intend to explore.

Moreover, no market analysis was performed to evaluate the economic effort derived from the real implementation and integration of the I4.0-based technologies within the AFVC. Investigating these limits represents some of the possible follow-ups of the study.

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Appendix. Description of the elements of comparison of the FSC models

Follow the description of the several elements considered in the comparison of the 15 FSC models retrieved in the literature review.

Activities: (i) *Production/supply of raw materials* was related to what is needed for production activities, such as procurement of seeds or fertilizer and biofuels; (ii) *processing* referred to semi-finished or finished products and included several activities such as refining (sugar), grinding (cereals), cleaning, cutting or drying (fruit and vegetables), slaughter (in the case of livestock) and reuse and disposal (referring to waste production) because of the great heterogeneity of the agri-food industry (Bukeviciute *et al.*, 2009); (iv) *control* of quality and safety standards and testing packaging conditions through inspection according to different physical treatments to extend the food shelf life; (v) *decisions* included both marketing researches about products leading to the development of new products (Bukeviciute *et al.*, 2009) and researches oriented towards reverse logistics and how product value recovery feeds into circular flows (Vlajic *et al.*, 2018), enhancing decisions about the redefinition of FSC processes to remove non-value-adding activities or to promote product recovery; (vi) *warehousing*, which is a common activity in the FSC; (vii) *distribution* of food and non-food products within national and international markets; (viii) *marketing* encompassed activities which allow final consumers to be reached; (ix) *public and regulatory policy* was considered as an external and cross-cutting activity that includes the legislative, governmental and macroeconomic contexts (Yakovleva, 2007).

Flows: (i) *Linear flows* characterized the product, information and financial processes and primary energy flows; and (ii) *circular flows* referred to the reuse or recycling of energy and natural resources.

Stakeholders: (i) *Producers/suppliers of raw materials* encompassed farmers or breeders, considered both as individuals and as groups or cooperatives (Sutopo *et al.*, 2013; Tsolakis *et al.*, 2014); (ii) *processing companies* referred to processors, packaging and warehousing operators as well as food safety inspectors, such as government bodies responsible for evaluating food adulteration or contamination and checking that safety and quality standards were being maintained (Majdalawieh *et al.*, 2021), and ICT analysts, who were responsible for ensuring information transparency by exchanging stored or work-in-process information and standardizing product coding through IT infrastructure (Van Der Vorst, 2005); (iii) *distributors* were logistic companies, brokers, importers and exporters (Tsolakis *et al.*, 2014) associated with the traders category; (iv) *traders* were involved in storage and associated with the distribution but also linked to food services (e.g. caterers) including all actors operating in food services, including canteen operators (Bukeviciute *et al.*, 2009); (v) *consumers* encompassed the final step of the FSC; (vi) *external stakeholders* surrounded the FSC, adding value to processes and activities, among them national governments and associated ministries, regional, district and urban regulatory and administrative authorities (Tsolakis *et al.*, 2020), but also academic and scientific research and development institutes able to stimulate innovation in the FSC (Tsolakis *et al.*, 2014).

Technologies: (i) *General* ones referred more to ICT systems; (ii) *specific* ones highlighted the presence of blockchain and related supporting technologies, such as Global Positioning Systems, General Packet Radio Services and 5G, IoT devices, auto-ID like RFID/Near-Field Communication technology and managerial software that has been needed in FSC operations due to their potential to benefit activities within FSC processes.

Sustainability: This element was evaluated according to its three dimensions to understand the relationship among FSC processes by providing a set of sustainable practices for each dimension: (i) *economic sustainability*: lifecycle approach, economic growth, agricultural costing and food miles (Yakovleva, 2007); (ii) *social sustainability*: productive employment, gender equality, access to education and health care (Yakovleva, 2007) and corporate social responsibility (Tsolakis *et al.*, 2020); and (iii) *environmental sustainability*: carbon and water footprint indices (Tsolakis *et al.*, 2020; Yakovleva, 2007), green farming and waste management (Kayikci *et al.*, 2020; Tsolakis *et al.*, 2014; Vats *et al.*, 2019).

The comparison carried out above was useful to identify the key features of the extant FSC models on which to base the definition of the new integrative AFVC model presented in the next section.

Description of the nine pillars of Industry 4.0

Follows the description of the nine pillars which compose the Industry 4.0 paradigm:

1. IoT. This refers to a machine–machine interaction without human intervention (Xu *et al.*, 2014). This concept can be extended in the industrial field by the label "Industrial Internet of Things", which enables the interconnection of physical objects through sensors, actuators or other digital devices for the collection and exchange of data (information). In this way, devices can communicate and interact with each other, decentralizing analysis and decision-making and allowing real-time responses (Noor Hasnan and Yusoff, 2018).
2. Cybersecurity. This is the technology capable of protecting shared information and cyber-physical systems (CPSs) to address the problem of cybersecurity threats by providing reliable communications, controlling access to systems (Noor Hasnan and Yusoff, 2018; Wells *et al.*, 2014).
3. Augmented reality. This is a human–machine interaction technology that superimposes virtual information generated by the computer onto a real-world physical environment, mixing them consistently (Noor Hasnan and Yusoff, 2018; Silvestri *et al.*, 2020). It can provide operators with real-time information for maintenance, logistics and other common operating procedures via wearable devices that exploit the aforementioned technology (Silvestri *et al.*, 2020).
4. Big data. This consists of four parts: data volume, data variety, new data generation and analysis speed, and data value (Witkowski, 2017). The literature discusses big data analytics since it is an analytical technology that collects the data provided by the dissemination of sensors and IoT applicable in various fields such as forecasting solutions, quality control, process control, fault classification and threat prevention (Ge *et al.*, 2017).
5. Autonomous robots. These can interact with each other or directly help operators (cobots) to perform their tasks intelligently, with a focus on safety, flexibility, versatility and cooperation (Kamarul Bahrin *et al.*, 2016; Silvestri *et al.*, 2020).
6. Additive manufacturing. This is technology that allows a virtual model (such as a 3D computer-aided design model) to be converted into a physical object made in a fully automated way, for example, by means of 3D printing, favouring the production of customized products in small batches (Noor Hasnan and Yusoff, 2018; Silvestri *et al.*, 2020).
7. Simulation. This is a digital tool that uses real-time data to virtually test, analyse and optimize the design of production systems or any actual change to evaluate their effectiveness in advance (Noor Hasnan and Yusoff, 2018). Simulation is involved in value networks and real-time data optimization of intelligent systems (Chong *et al.*, 2018).
8. System integration. This refers to a universal and standardized data network system that allows horizontal and vertical integration of the systems through the entire supply chain, achieving a total connection between all actors (companies, departments and functions) taking part in a highly dynamic system that makes the value chain automated (Peres *et al.*, 2018; Stock and Seliger, 2016).
9. Cloud computing. This is a technology that allows the sharing of data in real time between devices (CPSs) operating in the production system and connected intelligently with the help of cloud systems (Noor Hasnan and Yusoff, 2018). This technology exploits computer services such as servers, storage, databases, networks, software, analytics and other applications to share information across systems both across the entire production line and externally, improving the scalability and flexibility of intelligent manufacturing systems (Noor Hasnan and Yusoff, 2018; Silvestri *et al.*, 2020).

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