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CRITICAL FACTORS FOR INDUSTRY 4.0. AND ITS IMPACT ON THE CIRCULAR ECONOMY PERFORMANCE IN THE AGRI-FOOD

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1. INTRODUCTION

With the recent geopolitical and health crises, it is as urgent as ever for the world's economies to be more sustainable and environment friendly (Rajput & Singh, 2019a), while advancing technologically. In response, policymakers worldwide aim to reduce greenhouse gas emissions, and global warming, address the shortage of resources, and manage waste disposal and recycling (Fuso Nerini et al., 2019) (Dantas et al., 2021a) but also to more efficiently implement clean technologies and sustainable practices (Ambekar et al., 2019). International bodies are also advocating for revised legislation that supports sustainability as a prerequisite for awarding contracts as prescribed in the United Nations (UN) Agenda (Dantas et al., 2021a); Agostini & Filippini, 2019; Rashed & Shah, 2021). The interlinkage between the green and digital transition in the European Union (also known as the “twin transition”) is part of the strategic commitment of the continent to “zero emission” until 2050.

The dynamic development of the digital economy results in the constant emergence of new concepts that revolutionize modern business. After the transformative effects of water and steam power in the nineteenth century, and electricity in the Twentieth century, it was the beginning of the computer era after the 1970s that changed the modern economy and caused quantum leaps in productivity. Today, industrial value creation, sensor technology, interconnectivity, and data analysis allow mass customization and computerization of manufacturing, leading to the emergence of the so-called Fourth Industrial Revolution or Industry 4.0. (Piccarozzi et al., 2018). This revolution began in 2011 with the German government’s High Tech 2020 Strategy, and it was the first substantial shift in the economy that was foreseen. The main objective of this national strategic initiative was to drive digital manufacturing forward by increasing digitization and the interconnection of products, value chains, and business models (Gajšek & Sternad, 2020).

Characterized by completely automated and intelligent production, Industry 4.0. is setting high goals through the front-end technologies: Smart Manufacturing, Smart Products, Smart Supply Chain, and Smart Working, while using four base elements: Internet of Things, Cloud Services, Big Data, and Analytics (Frank et al., 2019). Highlighting the application of Industry 4.0, several governments proposed other advanced initiatives around the world, such as - la Nouvelle France Industrielle, the Made in China 2025 initiative, and the Smart Manufacturing Leadership Coalition, in the United States of America. (Bongomin et al., 2020)

In fact, “Industry 4.0.” is a very broad domain that includes: product development, production processes, efficiency and strategy, data management, relationship with consumers, and competitiveness, amongst others. Only a few authors focus on the management perspective of Industry 4.0. in the enterprise (Jan Johansson, 2017); Strange & Zucchella, 2017). A single article (Piccarozzi et al., 2018) offers a revision of principal issues in the management studies related to Industry 4.0. (production methods, business models, strategy, human resources, SMEs, supply chains, sustainability, information systems, and social innovation). However, the management literature still lacks a systematic formulation of management strategy and the critical factors to be implemented by the governance in the industrial organization. Also, advanced and digital manufacturing technologies can unlock the circularity of resources with supply chains, despite the fact that the connection between a circular economy and Industry 4.0. has not been well explored so far (Lopes de Sousa Jabbour et al., 2019).

This article takes a new approach to systematizing the implications of the adoption of Industry 4.0 to the circular economy performance of companies. The objective is to contribute to filling the gaps in the management literature and to identify critical success factors to be endorsed by the management team in industrial organizations to quickly adapt, increase performance, and competitiveness with Industry 4.0. while improving the sustainability indicators of the business. A particular focus is on the agri-food industry, considering its 4.0 industry infancy.

Therefore, our main research questions are:

1) How are Industry 4.0 and circular economy interrelated in the academic management literature?
2) What are the critical success factors for digitalizing industrial organizations that contribute to a circular economy?
3) Do they differ in the agri-food sector?

This article contributes to the literature by discussing how the Industry 4.0. concept relates to the CE strategies in the organizations. The work is unique as it addresses a significant gap in the knowledge of two comparatively recent concepts in the academic literature – Industry 4.0. and circular economy. We provide insights from their interconnection, with a focus on a specific sector that could serve as a base for the development of sustainable operations management decisions in the agri-food sector. The academic literature is first screened for the I4.0 technologies and CE practices applied, and further analyzed to understand the stronger links in between.

The article is organized as follows: after this Introduction, Section 2 reveals the methods used for the analysis. Section 3 presents the results and content analysis of the findings: key concepts of CE and smart manufacturing, their interconnection, and implementation in the agri-food industry. Finally, Section 4 brings the conclusion and offers an agenda for further research.

2. METHOD

Consistently with the study aims, the research design consists of two parts: the methodology followed for assessing the critical success factors for Industry 4.0. trough Systemic literature review method (SLR) with PRISMA, and qualitative data analysis to assess how those factors differ in the agri-food sector.

The analysis of the academic papers was carried out following a Systematic Literature Review method (SLR) widely accepted, providing an in-depth understanding of the academic point of view and the status of the current research. The authors followed the SLR guidelines laid down by (Tranfield et al., 2003) and the Preferred Reporting Items for Systematic Review and Meta-analysis (PRISMA) framework and 65 articles were found eligible after thorough reading and inclusion in the analysis (Ghobakhloo et al., 2021; Sony et al., 2021).

The stages of the analysis are described in detail in Table 1.

Table 1. Research methodology for SLR

Research phases	Phase description- Characteristics	Phase description- Objective
Record Identification	Include all published articles with a relationship with Industry 4.0.	Collect articles that relate to the research topic
Screening	The strategy was established considering the descriptive analysis	Include published articles, also- managerial aspects, critical success factors, and period frame
Eligibility	Maximize the opportunities to verify arguments constructed as well as relationships between categories	Analyze similarities and differences between Industry 4.0. and Agri-food 4.0. implementation in SMEs and relationships to sustainability
Included	This phase was carried out with the compilation of all the selected material in an organized manner.	Formulate the answers to the two initially defined research questions

The work is one of the first studies that provides an extensive analysis*[1] and review of 65 publications that appeared from 01/01/2012 to 01/06/2022. The methodology used in the development of this research is based on qualitative analysis content. The research was conducted from March 2022 to June 2022. The keywords included in the research process are "Industry 4.0", management", "success factors", "SME digitalization", "sustainability", "smart manufacturing", and "challenges". The databases include Google Scholar and Scopus.

[1] (*this version provides preliminary results, as we are in the final stage of evaluation of the selected articles using the NVIVO software)

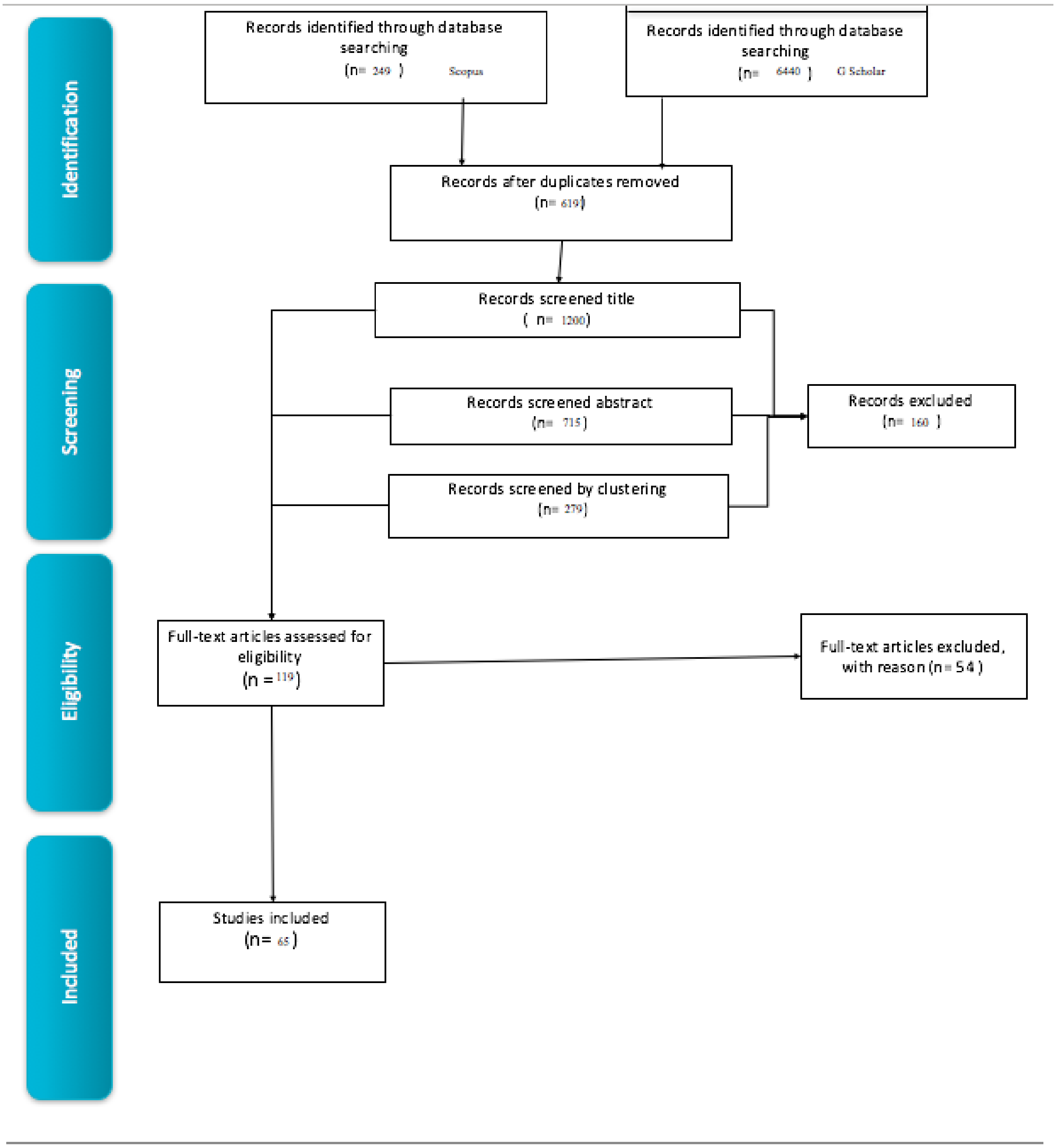

Figure 1. PRISMA method for Industry 4.0. success factors

3. RESULTS

The bibliographic analysis of academic journals and the content analysis are now presented.

3.1 Industry 4.0 and its critical success factors

Industry 4.0's vision of decentralized, autonomous networks of smart products and automated equipment collaborating for a fully predictive industry manufacturing (Piccarozzi et al., 2018). Several technological advancements are implemented in industries – information and communication technology to digitalize information and integrate systems, cyber-physical infrastructure like sensors, robots, or additive manufacturing in the design and product creation, network communications, and ICT- based support for human workers like augmented reality, intelligent tools, etc. (Davies, 2015) to realize the firms' strategies to achieve better performance, and demand-led, production flow while increasing the management control (Cirillo et al., 2021). However, the academic literature is still under-researched if there is a unique path a company could follow, and what are the critical factors to define a new organizational model for industrial organizations in the Industry 4.0. era.

Some authors suggest that modern management in the digital enterprise is realized through the adaptation of new information systems. The Management information systems (MIS) use new data processing solutions to define strategy, and build highly integrative enterprise-wide systems including CRM, ERP, or others to control processes (Davenpport,1998) and create new business models (Johnson, 2018). However, even though the implementation of MIS promises greater organizational efficiencies and strategic effectiveness (with an impact on growth related to increased flexibility; productivity; cybersecurity; quality of products and services) due to data analysis, companies often fail to expand their product or market potential or reduce their costs by using the decision support systems (Dalmarco et al., 2017).

Meanwhile, digital technologies can create tension between old values and new ones (Martínez-Caro et al., 2020); between traditional management theories and decision-making techniques and modern ones. The process needs strong leadership, a well-defined strategy, and inclusive team commitment. Focusing only on MIS will not solve the puzzle. However, business structures will evolve efficiently based on the new data processing solutions (Gölzer & Fritzsche, 2017) and unleash their full potential only if they successfully define the organizational culture that best suits their digital strategy (Martínez-Caro et al., 2020, Papazov & Mihaylova, 2015).

Additionally, new business models are evolving centering on substantial changes in product life-cycle and consumer relations. Disruptive technologies and digital enterprise innovation are changing the technological landscape, entrepreneurial practices, and most importantly consumer behaviors (Scholz et al., 2020) while creating business models focused on the fast-changing individual consumer preferences and value creation. A cross-lined product life-cycles becomes a central element of the value networks, which combines different factors – equipment, human organization, process, and product. The traditional project and process management are reorganized with the new agile methods (an iterative and adaptive approach, relying on short customer-oriented feedback loops, self-organization in interdisciplinary teams, and formal as well as informal communication). Companies increasingly support their project portfolio management processes with the information systems software, while improving quality and adapting fast to the Scrum method (Scholz et al., 2020).

The introduction of intelligent management and automated manufacturing based on big data, cyber-physical and dynamic production network systems is raising new challenges related to data integrity, data privacy, and data protection (Rajput & Singh, 2019a). Cyber-attacks could also include destroying equipment, altering product designs, or modifying manufacturing processes (Vitliemov et al., 2020), which is of extremely high cost for the factory (Elhabashy et al., 2019). In the industrial organization, cyber threats are usually prevented with the use of blockchain technologies by protecting the data from unintended manipulation or data injection by insiders (Song & Moon, 2020)

As previously mentioned, the academic literature review lacks a robust theoretical comparison between traditional and digital management in the industrial organization (Jan Johansson, 2017) (Strange & Zucchella, 2017). Most authors study some management aspects of the industrial organization in the Industry 4.0 era - Almada-Lobo (2015) focuses on decentralization and control, Prause et al. (2017), Shinkevich et al. (2020) et al. suggest new business models for manufacturing of complex mass customization products in small series with the help of networks and smart logistics, Žemaitis & Prause (2014), Antonova & Stoycheva (2018) add open innovation or lean tools, etc. Other research also indicates that training is the most important factor for success, that managers have a prominent role in the success and/or failure of an Industry 4.0 project, and that SMEs should be supported by external experts.

3.2 Smart manufacturing and the role of circular economy

Several technological advancements characterizing Industry 4.0. are implemented in a specific group of industrial enterprises - the so-called Smart Factories – information and communication technologies to digitalize information and to integrate systems, cyber-physical infrastructure like sensors, robots, or additive manufacturing in the design and product creation, network communications and ICT- based support for human workers like augmented reality, intelligent tools, etc. to realize the firms' strategies to achieve better performance, and demand-led, production flow while increasing the management control (Cirillo et al., 2021).

On the one hand, Industry 4.0. and especially smart factories have this unique opportunity to revolutionize traditional manufacturing while aiming to reduce the environmental footprint – waste, energy consumption, and overproduction. On the other hand, smart production systems require massive data centers to process and support their network needs, which utilize a significant amount of energy resources(Waibel et al., 2017). However. assessing the environmental impact of smart manufacturing is yet under-researched. Meanwhile, even to be proved sustainable, smart manufacturing is still challenging for the management teams. There are various obstacles related to the organizational change and the needed investments, data ownership and security, legal and standard issues, employment and skills development, etc.

The smart manufacturing concept as implemented in Europe takes advantage of the recent technological leap in Artificial Intelligence (AI), Cloud Computing (CC), and the Internet of Things (IoT) contributing to achieving reliable and sustainable processes (Koh et al., 2019; Tariq, 2021) In 2019, Deloitte realized an online survey (that combined with secondary data and economic projections) in Europe and two more continents – North America and Asia, with more than 600 executives from factories in a different stage of transformation towards smart manufacturing, and proved a significant correlation between smart manufacturing and labor productivity and growth. However, sustainability assets weren't precisely examined. Most of the environmental assessment work related to manufacturing in the academic literature focuses on the product rather than the process level. Cwiklicki & Wojnarowska (2020) raise a concern that the connections between I-4.0 technologies (comprising smart manufacturing) and sustainability implementation are not well understood, creating a quandary in understanding these linkages.

In addition, the sustainability term is presented differently in the existing academic research. Some authors relate Industry 4.0. and smart factories to the environmental footprint. (Stock & Seliger, 2016) defines macro-opportunities for sustainability (business models and value creation networks) and micro-opportunities focused more on equipment, human, organization, process, and product. General Jonas Žemaitis and Prause (2014), suggest product traceability and transparency during the entire life-cycle of the product (from cradle to grave). Others explore sustainable manufacturing based on the 6R (i.e., reduce, redesign, reuse, and recycle) (Jayal et al., 2010), or various green issues - enabling the development of green products, green manufacturing processes, and green supply chain management (Lopes de Sousa Jabbour et al., 2018a)

Lopes de Sousa Jabbour (2018) identifies eleven factors that should be carefully managed when introducing Industry 4.0 in environmentally-sustainable manufacturing (i.e., management leadership, readiness for organizational change, top management commitment, strategic alignment, training, and capacity building, empowerment, teamwork, organizational culture, communication, project management, national culture, and regional differences). Piccarozzi et al., 2018 offer a revision of principal issues in the management studies related to Industry 4.0. (production method, business model, strategy, human resources, SMEs, supply chain, sustainability, information systems, and social innovation). Since academic research deals with the complex integration of Industry 4.0. and environmentally-sustainable manufacturing – are still rare, and the management side of sustainability in the industrial organization needs to be further studied.

Very limited studies tried to integrate the three sustainability aspects (or the triple bottom line (TBL) assessment criteria introduced by Elkington in the mid-1900s) in their evaluation of smart manufacturing (Saad et al., 2019). Indeed, today the manufacturing industry is transforming from a linear to a circular economy. The emergence of digital transformation has helped industries explore and adopt cutting-edge technology and its applications to remodel their business operations, products, and services (Jafari-Sadeghi et al., 2021) to a strategy that incorporates all of the three pillars of sustainability Saad (et al., 2019), balancing the dimensions of economic growth, social inclusion, and environmental protection (Gupta & Vegelin, 2016). This can optimize the sustainable solutions to reduce the emission and resource from the industrial systems (Tseng et al., 2018). Industry 4.0 and circular economy (CE) have motivated business organizations to move toward the supply chain and offer a new outlook on production and consumption (Lopes de Sousa Jabbour et al., 2018b)

According to the "European Environment Agency (EEA, 2016, 9), the CE is "the concept that can, in principle, be applied to all kinds of natural resources, including biotic and abiotic materials, water, and land. Eco-design, repair, reuse, refurbishment, remanufacture, product sharing, waste prevention, and waste recycling are all important in a CE". Practices of CE will result in retrofitting industries, thereby enabling them to be more efficient in reusing, remanufacturing, and reducing the waste of resources. MacArthur (2015b) asserts that CE is based on three fundamental principles, namely "preserve and enhance natural capital," "optimize resource yields" and "foster systems effectiveness."(Sariatli, 2017) The adoption of these principles can be at diverse levels, e.g., micro: which relates to products and firms' views; meso: corresponding to a network of companies and macro: which signifies the actions undertaken by cities, regions, and nations (Acerbi & Taisch, 2020); (Ghisellini et al., 2016)).
The adoption and integration of Industry 4.0. technologies and CE facilitate the achievement of SDGs (Hidayatno et al., 2019;Saucedo-Martínez et al., 2017; Dantas et al., 2021b; Rajput & Singh, 2019b). The importance of integrating CE practices and digital technologies has been recognized by the academic community (Govindan & Hasanagic, 2018; Dantas et al., 2021). For example, a study by de Sousa Jabbour et al. (2018) integrated Industry 4.0. and CE principles using proposing six action areas that enable organizations to move towards the, namely (1) support regenerating capacity of ecosystem through reclaiming, retaining, and restoring the health of ecosystems; (2) extend the life of products through creating a design for durability and upgradability; (3) removal of waste in the production and supply chain processes; (4) extract bio-chemicals from organic waste; (5) dematerialize directly or indirectly and (6) implement I-4.0 technologies.

To summarize, the most significant components of Industry 4.0. are cyber-physical systems, the internet of things, cloud manufacturing, and additive manufacturing. However, Industry 4.0. is still a very broad concept, sometimes difficult to be implemented in organizations and it is done mostly through the so-called “smart factories”. The role of the management team is crucial, but it would be much easier if they dispose of it with a clear strategy or business model to respect while in transition to digital manufacturing. Following the theory review, the authors of this study extract 11 critical success factors from the management literature: strong leadership, well-defined management strategy and team commitment, organizational culture ready for changes and adaptation, the establishment of management information systems, agile project management, high level of cyber security, cross-lined product life-cycle and focus on consumer relations, respect of sustainability and regional specifics, and suggest that, according to research, they have the most significant impact on implementing Industry 4.0. in organizations. However, special focus is attributed to the environmental impact of production and more precisely to a circular economy in smart manufacturing, which covers all three aspects of sustainability and contributes to the achievement of the SDGs and the “twin transition” of the European Union.

3.2 Sustainably implementing Industry 4.0. in the agri-food sector

The agri-food industry represents a large percentage of total manufacturing added value, provides high employment, and takes a significant share of the gross domestic product (GDP) of most countries (FAO, 2017). Meanwhile, the sector is also facing challenges related to the growing demand for food, food safety, and insecurity, disrupted supply chains environmental externalities and sustainability, competitiveness, and technological adoption of SMEs (Stillitano et al., 2021), some of the challenges related to the recent geopolitical, health and economic shocks.

The term “Agri-Food 4.0” is an analogy to "Industry 4.0", coming from the concept “Agriculture 4.0” (Figure 1). The agri-food industry has been evolving progressively according to the technological development in the manufacturing sector – with the periods “Agriculture 1.0” related to the mechanization of systems, “Agriculture 2.0” related to the utilization of electricity and intensive production, “Agriculture 3.0” marked by robotics and automation with specialized machinery operating in the field and carrying out complete cycles in tasks, and currently influenced by the technologies, techniques, methods, and strategies proposed by the ‘Industry 4.0. , such as autonomous farming (Miranda et al., 2019)

Nowadays, Agriculture 4.0 farm activities are connected to the cloud. Following the European Industry 4.0. strategy, the next step with Agriculture 5.0 includes digitally-integrated enterprises, which rely on their production processes using robotics and some forms of artificial intelligence. The trend is building on an array of digital technologies: Internet of Things, Big Data, Artificial Intelligence, Block-chain, and digital practices: cooperation, mobility, and open innovation. The goal is for agri-food factories to become smarter, more efficient, safer, and more environmentally sustainable, due to the combination and integration of production technologies and devices, information and communication systems, data, and services in the network.

They imply a transformation of the production infrastructures (connected farms, new production equipment, connected tractors, and machines) and enable both increased productivity and quality and environmental protection. But smart agri-food factories also generate modifications in the value chain and business models with more emphasis on knowledge gathering, analysis, and exchange. (Commission, 2017), agri-food production systems (subsystems and variables that can be controlled in a smart manner (Miranda et al., 2019), business models based on the new Farm Management Information Systems (FMIS) (to support production management and meet the increased demands to reduce production costs, comply with agricultural standards, and maintain high product quality and safety) (Fountas et al., 2015)

Smart agri-food companies also constantly adapt their product life-cycle to the fast-changing consumer preferences with higher value to environmentally - friendly manufacturing (Veza et al., 2015) One of the primary needs to be met is constant competitiveness on the market, but also an adequate response to the unexpected interruptions of supply-chain due to pandemic, the war in Ukraine or other external factors.

Despite challenges for some companies and sectors, Industry 4.0. in agri-food embraces "networked manufacturing", "self-organizing adaptive logistics"and "customer integrated engineering" (General Jonas Žemaitis & Prause, 2014), and contributes to better management performances and higher results in the industrial enterprise (Sommer, 2015; Wang et al., 2016), while realizing sustainable industrial value creation on all the three sustainability dimensions- economic, environmental and social. Sustainability in digitalized agri-food organizations as described by (Albiero et al., 2020) and (Moldavska & Welo, 2017) could be related to energy and resource efficiency, increased productivity, shortening of innovation, etc. Other authors- General Jonas Žemaitis & Prause (2014), suggest product traceability and transparency during the entire life-cycle of the product, and operational strategies (Gunasekaran et al., 2013)) to achieve sustainable targets. The popular CE-based approaches for resolving the issues faced by the food sector consist of technology-based solutions, social and behavioral changes, and policy recommendations. However, the extant scientific literature on agri-food 4.0. lucks of consistent focus on the CE concept. A few studies analyze the performance of the different geographies, supply chains, and waste management systems in terms of CE ((Padilla-Rivera et al., 2020; Zeller et al., 2020). Zeller et al. (2020) have compared the environmental impacts of redirecting material flows from linear to circular systems and recognized the environmental performance of each of these systems. In addition, although CE has the potential to help the agri-food sector transition to a just and sustainable prospect, but the challenges and limitations of applying CE in the food sector are still unclear (Calisto Friant et al., 2020); Zhang et al., 2022). Based on Friant et al. (2020), divide the timeline of circularity concepts into three stages: the preamble period (1945–1980) dealing with resource limits and waste (i.e., circularity 1.0), the excitement period (1980–2010) dealing with eco-efficiency and techno-fixes (i.e., circularity 2.0), and the validity challenge period (2010-present) dealing with integrated approaches to resources, consumption, and waste (i.e., circularity 3.0), where various inconsistencies and theoretical conceptual contests of the CE need to be resolved.

A few studies enumerate the factors for transitioning the agri-food sector into a CE and digitalized production (Borrello et al., 2017). Padilla-Rivera et al. (2021) proposed a holistic framework and used it as an evaluation criterion to identify the social indicators for the assessment of the performance of CE strategies. However, from the managerial point of view, the sustainability term that combines innovation, technological and social perspective of Industry 4.0. in the agri-food sector is social innovation (Piccarozzi et al., 2018; Al-Obadi et al., 2022). It relates to the process of developing and deploying effective solutions to challenging and often systemic social and environmental issues in support of social progress.

4. DISCUSSION

The principles of Industry 4.0. are the horizontal and vertical integration of production systems driven by real-time data interchange and flexible manufacturing to enable customized production. The most significant components of Industry 4.0 are cyber-physical systems, the internet of things, cloud manufacturing, and additive manufacturing.

However, there is a gap between these two terms. Industry 4.0 is strongly cited from 2014, while Agriculture 4.0 is only recently quoted. In this work, 11 critical success factors for Industry 4.0. have been suggested from systematic literature with the PRISMA method: strong leadership, well-defined management strategy and team commitment, organizational culture ready for changes and adaptation, the establishment of management information systems, agile project management, high level of cyber security, cross-lined product life-cycle and focus on consumer relations, respect of sustainability (and more precisely circular economy) and regional specifics. They all apply to the agri-food sector as well. However, the transformational aspirations in terms of productivity and sustainability in each sector need to be further determined, articulated, reflected on and will evolve with the acceptability (or not) of individual digital technologies (Fielke et al., 2022). This is part of the social innovation process. In the agri-food context, the concept of social innovation is complex and multi-dimensional and often referred to as the social mechanisms of innovations, the social responsibility of innovations, and the innovation of society (Bock, 2016). It also covers challenges such as data exchange and communication standards, and the ability of farmers to invest and modernize their practices of production, which differ in different regions and societies.

Therefore, social innovation, rather than circular economy, could be defined as a high influencing critical success factor for Industry 4.0. implementation in the agri-food sector.

CONCLUSION

The industrial organization needs to adapt fast to the new digital situation to stay in the local and global markets. Unexpected events like the recent pandemic only highlight the urgency of shifting strategies. Management teams must figure out how to strengthen competitiveness and keep up with the trends of increased flexibility and speed of production, mass customization and increased quality, and better performance. European Commission has been trying to guide and support companies, especially SMEs, in the transition into smart factories, starting from 2006. The European Policies have been realized through strategic technology roadmaps, Technology Platforms (Frank et al., 2019) Communications, Tasks Force on Advanced Manufacturing for clean production, and the Digital Single Market initiative comprising the Digital innovation Hubs, digital-friendly regulatory framework, building, and financing partnerships, etc.

However, enterprises are still struggling to implement smart manufacturing. Among the main challenges described in the academic literature are the standardization of systems, platforms, and protocols, changes in work organization, availability of skilled workers, and the adoption of appropriate legal structures (Bonilla et al. 2018). Furthermore, there are significant costs and risks for firms as regards digital security in intellectual property protection, personal data, and privacy; operability of systems; environmental protection, and health and safety. While many businesses recognize these challenges, far fewer, especially among SMEs, have the management teams sufficiently prepared.

A recent survey conducted by the consulting firm Deloitte (2018) in 19 countries reveals that only 14% of chief executive officers are confident that their organizations are fully prepared to incorporate the changes brought about by Industry 4.0. They describe the 'lack of a digital strategy alongside resource scarcity as the most prominent barrier in both developed and developing economies. Moreover, the substantial investments needed for SMEs to transform into smart factories reach around €140 billion annually in Europe. Regional disparities and the unrealized potential of smart specialization are also slowing down the digitalization of European manufacturing.

Few researchers have conducted scientific research on barriers to the adoption of Industry 4.0 technologies. Some authors use empirical research methods based on survey research or interviews, others have focused on building structural models (Karadayi-Usta, 2020) or compared differences in enterprises in developed and developing countries based on a Grey Decision-Making Trial and Evaluation Laboratory (DEMATEL)(Chetty et al., 2020).

Our study suggests that before implementing Industry 4.0. managers should first study the current business model and then devise strategies to align the existing one with Industry 4.0 initiatives. This step is a very imperative aspect of the implementation of Industry 4.0. The managers can further use each of the critical factors identified in this study, with special attention to sustainability, as a guiding framework to successfully implement Industry 4.0. in their organizations. Managers from the agri-food sector would additionally benefit from considering social innovations in their portfolio of strategies.

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