

CYBER-PHYSICAL SOCIAL SPACE IN AGRICULTURE AND RISKS

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Abstract

Population growth, the subsequent need to meet food needs, and other challenges facing agriculture have led to an accelerated development of innovations driven by artificial intelligence and automation. Industry 4.0 considers cyber-physical systems as a driving factor in increasing agriculture's efficiency while considering environmental issues. This paper aims to present various aspects of the processes in cyber-physical social spaces for agriculture and identify the main advantages and risks associated with the transition to production primarily oriented towards human well-being. We utilize Eurostat public data for local small and medium-sized enterprises (SMEs) for the years 2021-2023 to highlight the initial level of digital transformation. Based on a survey of recent scientific work the study identifies eight categories of risk factors related to the adaptation to the new digital environment, e.g. data protection and labor market change. Furthermore, we specify the main challenges more prevalent for SMEs in agriculture. SMEs tend to show a low propensity to adopt digital technologies and therefore manifest low investment activity. Policy-makers should consider the conservatism issue, among other factors, when developing policies to accelerate digitalization in agriculture.

Key words: intelligent systems, cyber-physical-social spaces, smart crop production

INTRODUCTION

Digital technologies are becoming increasingly sophisticated and integrated and are causing significant changes in society and the economy, while also exercising their impact on agriculture. A number of new virtual platforms for smart agriculture are emerging, integrating heterogeneous technologies and different approaches to collect, store and process information for smart crop production in Bulgaria.

The creation of Cyber-Physical Systems – CPS is made possible and partly predetermined by the development of the Internet of Things (IoT) [34]. CPS are formed by combining computational and physical components, where “physical” are the elements of the system occupying physical space, and “cyber” are the computational and communication elements.

Cyber-physical systems and the spaces they construct reflect the relationship of the physical to the virtual world by integrating computational and physical processes and interacting with the environment in which they are situated [2]. Cyber-physical space integrates data collected in different physical,

and cybernetic systems. The new cyber-physical reality is fundamental to social change in all spheres of life and society [34].

The review of related literature shows that scientific researches still do not provide unambiguous evidence on the impact and adoption of new technologies by SMEs. [21] points out the existence of a “contextual and methodological gap” between cyber-physical systems and their role in Industry 4.0. A positive impact of CPS is indicated as better placement of industries, which will give them an advantage to meet future requirements.

The application of Industry 4.0 technologies highlights some important issues for society arising from the development of cyber-physical systems. The first relates to the security and protection of personal data, and the second concerns questions about how we can better align the use of new technologies with achieving social goals. The development of new technologies and cyber-physical systems highlighted the manifestation of a side, mainly indicated as unfavourable, social effect – a shift in the role of the human factor in the production process. We see a striving to overcome this effect in the Industry 5.0

concept, primarily embracing the idea of achieving a human-oriented system [6].

In this context, the purpose of the paper is to present various aspects of the processes in cyber-physical social spaces for agriculture, as well as to identify and summarize the main advantages and risks in the context of the growing requirements for transitioning to a production primarily oriented towards human well-being.

MATERIALS AND METHODS

A survey of recent research work was conducted on aspects and processes in cyber-physical social spaces for agriculture, providing readers with relevant papers and highlighting the main advantages and risks, with a focus on agricultural enterprises. To leverage the latest advancements in this scientific field, we first conducted a search in the Web of Science and Scopus databases. The search query was conducted using the key words of this paper and applying the basic operators “OR” and “AND” for a combination of the keyword. The final strings were the following: “cyber-physical-social space” AND “agriculture”; “digitalization” AND “industry 4.0 OR 5.0” AND “agriculture”. Next, to integrate policy implications on the digital transformation of agriculture and empirical surveys on the digital process, we also Google searched for official EU documents and available national agencies’ analysis reports. Different policy measures (national programs) of the Ministry of Innovation and Growth were also considered, such as Programs on fostering the digitalization process. Some documents and reports providing important insights are the research and analysis report of the Bulgarian Industrial Chamber for determining the needs for digital skills by economic sectors; the European Commission’s document on sustainable, human-centric and resilient European industry; EU Digital Decade Country Report 2023 for Bulgaria related to its performance in the transition process striving to achieve the overall targets of the EU until 2030.

To outline the level of digitalization of SMEs in Bulgaria we use public data from the

Eurostat for local SMEs and large companies for 2021-2023, and data from Bulgarian national statistical institute –for industrial enterprises available for the period 2014-2022. The methodological approach adopted in the next part of the paper is as follows: we first discuss the cyber-physical social space advantages, focusing on such data processing space in agriculture; next, we highlight the enterprises’ initial digitalization level in Bulgaria as a basis for future policy implications; in the third subsection we identify and summarize main potential risks and challenges related to digital transformation for agricultural enterprises, and finally an overall frame for overcoming the challenges is outlined.

RESULTS AND DISCUSSIONS

Cyber-physical social space advantages in agriculture

Today, agricultural practices are supported by digital technologies and new approaches, such as remote sensing, cloud computing, Internet of Things (IoT), etc., leading to the concept of "smart agriculture" [17]. This concept can be viewed as an ecosystem that integrates physical, biological, ecological, chemical, economic, and social sciences to develop practices that do not have a harmful effect on the environment.

Sensor network technology enables the generation of large amounts of data from multiple locations, collected by various sensors that sense physical phenomena. At a later stage, the collected data can be combined through intelligent cybernetic processes and processed and analyzed through intelligent applications to provide better services for agriculture.

Efforts to help monitor and manage agricultural processes are linked to the development of smart agricultural infrastructures based on CPS and IoT [19]. Models of such systems can be found in specialized literature. In [14], an agricultural CPS integrating three worlds: physical, mental and artificial is presented. We can consider the physical world in agriculture comprised of the production resources and outcomes, including

plants, livestock and others, that are aligned with cyberspace by various IoT techniques. The relevant professional competence and experience is referred to the mental world. And finally, the artificial world supports different models and solutions to impact the physical world. Kiani et al. (2018) describe an architecture for monitoring soil moisture and temperature in small farms using wireless sensor networks and IoT technologies [18]. Another architecture and prototype application for precision agriculture using a wireless sensor network is proposed by [16].

Kamilaris et al. (2017) provide an overview of current research and projects in the field of big data analytics for problem-solving in agriculture [13]. The aim is to plan cropping, harvesting, irrigation and fertilization more efficiently by using actively collected information.

Logistics is an important application area for CPS in agriculture, on which high expectations are placed in the digital transformation process of SMEs. Literature shows systematic research related to the use of technology by SMEs to increase competitiveness and supply chain flexibility. In supply chain management, cyber-physical systems occupy a crucial role to improve tracking, automation and efficiency in Industry 4.0. CPS is expected to further "revolutionize manufacturing, logistics, healthcare, and other sectors" [29] and fully integrate Industry 5.0. concept and technologies. [32] outlined the technologies used by SMEs to smoothly adjust to the supply chain disruptions in Industry 5.0 and see their role in "achieving enterprise agility, operational transparency and sustainable business practices"

Cyber-physical social space in agriculture integrates approaches and tools that offer storage and access capabilities to data and services.

The main advantages of such a data processing space can be summarized as:

- Maintains means for collecting and efficiently storing data. Data collection covers the entire process. This data can come from various sources, such as: data from reports, from activities in forums, from scientific

seminars and discussions, bibliographic data, etc. [23].

- Provides knowledge management tools with intelligent search and reading capabilities, data integrity and correctness controls, automated information retrieval, and more. Stored information is available at different access levels and from different applications for retrieval, display and decision making, and data access control.

- Means to transform and visualize information so that it can be easily perceived and tackled by the user and various applications. The main requirements for the collected information are: to be stored in a secure and persistent way and to be presented to users and applications in a convenient form [10].

- Creates opportunities to integrate disparate technologies and tools. Integrating components based on common architectural methods and approaches for the entire space ensures context dependency and autonomous behavior of components. The space is open to new components and the possibilities for conducting and managing different processes become very large.

- The use of artificial intelligence tools and techniques enables prediction of outcomes and partial automation of the monitoring and impact process [31].

Level of digitalization in Bulgaria

The data for Bulgaria show a low level and slow pace of digitalization. According to the annual Digital Intensity Index (DII) for 2023, businesses in Bulgaria are ranked 27th in the adoption of digital technologies - total businesses [7]. A bit above 2/3 (70.6%) of businesses fall into the very low Digital intensity level category. The low score is due to the performance of SMEs with 71.6%. Barely 7.4% of the large businesses in Bulgaria have very high digital intensity, significantly lagging behind of the average of EU large businesses - 26.3%.

The slow pace of digital transformation is reflected in the high share of SMEs that have adopted digital technologies at a basic level - 47% by 2023, compared to the EU average of 69% (Figure 1).

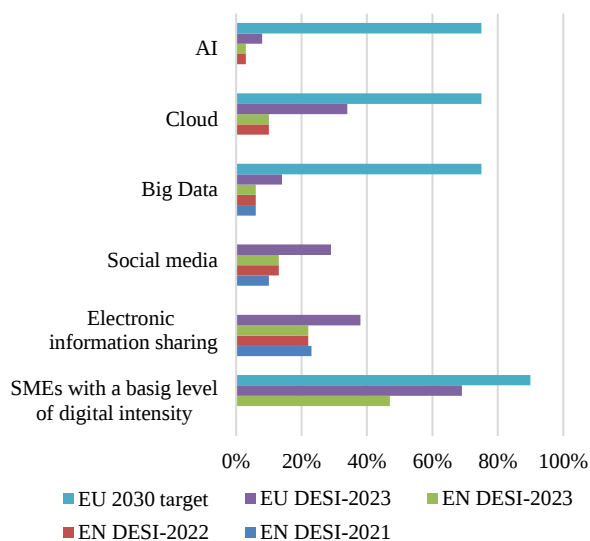


Fig. 1. Level of business digitalization in Bulgaria
Source: [7].

The use of cloud services and artificial intelligence, as well as big data analytics for business operations, is still at a basic, baseline level. Over the three-year period, the indicators for Bulgaria remain low, with the exception of social media usage, which increases marginally from 10% in 2021 to 13% in 2022 and 2023.

Empirical studies on the level of digitalization and the readiness of SMEs in Bulgaria to adopt new technologies in the context of Industry 4.0, although insufficient in number, also show a slow transformation process and a cautious attitude of enterprises. [1] pointed out that of 80 livestock enterprises only 12% of them offer the possibility of online ordering; only one out of five enterprises uses hosting with database services; to a small extent medium-sized and especially large enterprises take advantage of the benefits of digital technologies. The authors point out that large enterprises express a willingness to invest in digitalization in the medium term; SMEs report a need to implement digital solutions for remote communication with customers and contractors.

In the food sector, large dairy processing enterprises with an existing digitalization programme and strategy are highly digitised, while only 3 out of 9 enterprises processing other food products (KID08-10.8) have implemented and use cyber-physical systems [4].

Even innovation-intensive sectors such as Industry (NACE B-E) are characterized by slow adoption of innovations and new products (Figure 2).

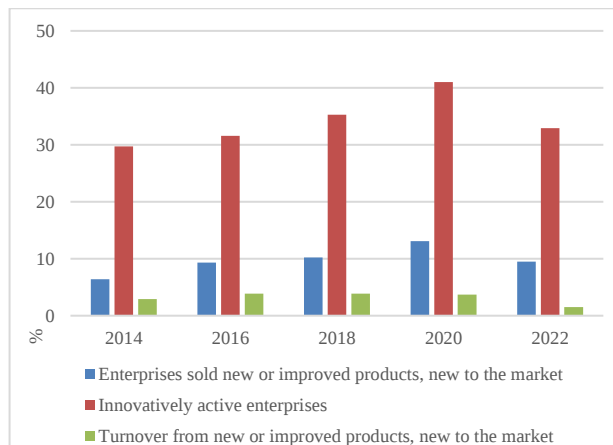


Fig. 2. Innovation activity in industry
Source: Own calculations based on the data from National Statistical Institute, 2024 [22].

It is notable that the share of innovation active enterprises decreases after 2020.

The slow process of introducing innovations and implementing Industry 4.0 technologies in Bulgaria is in line with research in other countries. Research covering Finland, Spain, Ireland, Croatia, Romania, Austria, and Argentina reveal that digital transformation has begun its journey, but many companies have started to transform their production or their linkages with consumers, but "the majority are still in the early stages of this transition," having "strong reliance on traditional tools and a limited adoption of integrated applications" [33]. Achieving measurable results within the scope of Industry 4.0 and 5.0 concepts is not yet possible as the level of digitalization in enterprises is still low to "foster sustainability in their SCs [supply chains] and require urgent identification of key I5.0 enablers" [11].

To cope with the low level of digitalization, as of 2023, Bulgaria has undertaken some measures to strengthen its digitalization policy and foster the transformation process. Here we could mention a programme funding for technological modernization and financing for 'Solutions in the field of information and communication technologies and cyber security in small and medium-sized enterprises'. Another initiative of the Ministry

of Innovation and Growth is to promote the Industry 4.0 standards and the implementation of cybersecurity processes in SMEs. Low levels of digitalization show the significant need to implement additional measures to achieve the Digital Decade targets - respectively 90% for basic level of digital intensity for SMEs and 75% for adopting cloud computing services, big data and artificial intelligence.

Smart agriculture, potential risks and challenges

The enormous potential of artificial intelligence, the integration of the physical and virtual world, creates conditions for increased revenue and improved quality of life, the creation of smart cities, smart homes, smart environment and agriculture, energy independence, significant progress in many fields and industries.

Unfortunately, we must also consider the **negative impacts** of this change, such as: job losses; cybercrime; algorithmic errors and incomprehensibility; the need for new concepts of responsibility, accountability and governance; and a number of others.

Adaptation to the new digital environment is complicated by the evolving process of automating unskilled and low-skilled jobs, through robots and software algorithms. Technologies that speed up and expand information processing can also dramatically shorten jobs.

Social networks open doors and minimize barriers to connection and communication, but give rise to new forms of social anxiety. Digitalization facilitates a number of processes, but also stimulates new types of fraud [24].

The study of risk, or, as it is commonly called, **risk management** is the subject of various sciences, in the constructions of many theories, in the vast variety of methods, models, algorithms, programs, devices and systems of engineering, technology and man.

A risk is an event or a group of related random events causing harm to an object possessing the given risk [28]. An object is defined as a material object or property interest or some property of an object, and an injury (damage) is an impairment or loss of a property of the object.

Risk as an event or as a set of events has a set of discrete and/or continuous realizations, each

of which has its own probability and amount of damage. Risk can also be thought of as the danger of something uncertain, the negation of certainty. Uncertainties are the doubts that a person has about being able to predict which of all possible outcomes will come to pass. Uncertainty is the personal sense of risk.

Risk management is a coordinated set of activities to guide and direct an organization with respect to risk (ISO/IEC Guide 73). A **management system** is a framework of policies, procedures, guidelines, and associated resources to achieve an organization's objectives [25]. The main risk factors identified so far that potentially affect the application areas of modern information technologies are analyzed in [27].

Eight categories of risk factors have been formulated:

1. **Privacy and data protection** - a factor that includes risks of privacy abuse, surveillance, monitoring, online harassment, stalking, collection, protection of personal data, security threat, increased vulnerability, cyber-risk, potential for breach of trust. Lack of regulations may lead to unwanted scrutiny.
2. **Job/labour market change** - a factor that includes risks of job loss, reduced resilience after job loss, more contract/task based work (compared to typically more stable long term employment), global and regional supply chain and logistics.
3. **Risks of attention disorders** - include mental distraction causing accidents, trauma from negative experiences, increased dependence and escape from reality, attention deficit, addiction, etc.
4. **Manipulation** - risks caused by dissemination of inaccurate information, lack of transparency where users are not aware of information algorithms, higher complexity and loss of control, dishonest algorithms, misunderstanding. Creating realistic fake news is becoming easier, putting people at risk of losing money, being accused of things they did not do, or being misled. This can lead to a polarization of society as well as assist in manipulating events.
5. **Fragmentation** - increased polarization, inequality, legally regulated governance structures, presence and tolerance of restricted and access-restrictive environments, regions or

countries. In a number of cases, automated systems can lead to the reinforcement and perpetuation of social divisions in cases of granting of credit, consideration of job applications, in medical treatment, and legal matters.

6. Liability and accountability - a risk factor that is based on informal, formal, regulated or unregulated ownership of algorithms and their applications, liability and fiduciary rights. An important challenge is determining whose liability for damages, who will cover damages - the owner, the producer or the application developer.

7. Ecology, ecosystem and ethics - factors that have an all-round impact and provoke risks related to the increase in waste volumes, additional burden on the environment, the impact of 3D printing technologies on the economy and ecology of agriculture, manipulating factors for health, product quality, violations in production control, etc.

8. Change in revenue/expenditure structure and asset ownership - factors affecting the whole economic and social system and redistributive mechanisms associated with the risk of non-competitive and non-market superiority in terms of intellectual property as a source of value in production, less investment capital in the system, reduction in infringement revenues and insurance reimbursement, lobbying against automation, etc.

It is known that the risk can manifest itself not only as an expected adverse event with a negative impact but also as an unspecified effect. For this reason, we can consider significant the decisions related to the identification, assessment, and monitoring of risk outcomes, focusing on the methods of multi-criteria decision analysis, including fuzzy logic models and other algorithms and applications. To manage and mitigate risks in the monitored environment in a cyber-physical social space, it is appropriate to consider the following five-phase framework [26, 27]:

The first phase is to define and register all sources of potential risk

The second phase concerns analysis and quantitative and qualitative evaluation of both risk and its attributes

The third phase, once we have identified the risk frame, is to choose appropriate instruments for impact, for example, which standards or models and algorithms we will use;

The fourth phase is to apply the selected instruments to the given environment or object;

The fifth phase is related to risk monitoring and follow-up risk valuations in terms of review and, when necessary, returning to previous phases.

The risk management standard of the Federation of European Risk Management Associations (FERMA) presents a common understanding of risk management as a process. In the USA, the National Institute of Standards and Technology of the US Department of Commerce (NIST) produces standards in the area of risk management for specific purposes. For example, NIST SP 800-37 presents a framework for managing information systems and organizations.

The general and specific steps recommended in these standards are illustrated in Figure 3.

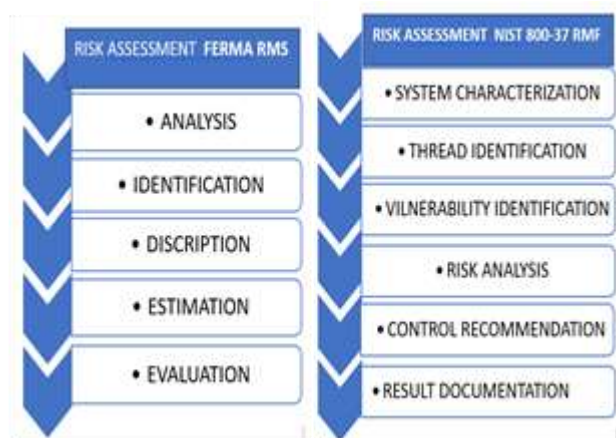


Fig. 3. Steps in FERMA and NIST standards
Source: Own contribution.

Together with the significant increase in risk factors, the growing complexity and interdependence of new technologies— such as artificial intelligence, blockchain technology, the Internet of Things, and 3D printing — pose a number of additional problems for businesses. These are related to building a holistic approach and a long-term vision for implementing smart technologies and absorbing their benefits. As practice has shown in recent years, the development and availability of Industry 4.0 technologies are not

sufficient drivers for their adoption and deployment. Technological capabilities are a key enabler, but their adoption is influenced by other factors, that are equally significant, such as staff skills and funding opportunities [3]. Accelerating the transformation process faces some major challenges in terms of adoption and understanding of Industry 4.0 technologies; overcoming sustainable corporate practices; financing investment not only in new technologies but also in building competencies and skills associated with them, including staff; propensity to fundamentally change the business and connectivity with customers and suppliers; understanding the smart technology-human interaction, etc.

[20] summarize 28 challenges to overcome in implementing Industry 5.0, which can be grouped in terms of reluctance on the part of workers and managers to change the established culture of the company; operational complexity and high cost of new technologies; increased data security concerns due to greater connectivity; prohibitive investment costs for food companies.

We can summarize some challenges that appear with greater severity for SMEs in agriculture:

(i) *Polarization in adoption of new technologies from Industry 4.0 by large and SMEs* - The early stage of the digital transformation process in agriculture shows a state of adoption of new technologies and building CPS mainly in large enterprises through the implementation of good manufacturing practices and partial application (where available) of mostly new technologies and little connectivity by SMEs. In the latter, where digital transformation is ongoing, we observe single, sporadic investments in digital solutions and a lack of implementation of comprehensive solutions, such as cyber-physical systems. The low level of digitisation and the implementation of partial solutions further hampers interoperability between different enterprise systems and makes it difficult to share and integrate data.

(ii) *Limited financial resources* - Limited financial resources and low investment activity in the sector (including due to low profitability) may be a slowing factor in the digitalization of

the agricultural sector. Demand for finance is often hampered by restrictive credit policies towards the sector. Agriculture has traditionally been ranked by lending institutions as a higher overall risk sector in the allocation of credit capital. Targeted policies to improve access to credit capital will help accelerate the adoption of new technologies;

(iii) *Slow payback period* - we can assume that the potential benefits of the investments made in digitalization will take a considerable time to materialise. Especially for SMEs in agriculture, the cost of investment can significantly exceed future cash flows over a long period of time. The slow return on investment in digitalization may further reduce the propensity to digitally transform, respectively adopt new technologies and CPS.

(iv) *Slow change in attitudes to adopt new technologies from Industry 4.0 and CPS* - although digital short supply chains have huge potential to improve food chain organization, we can assume that this challenge will be applied to greater effect in agriculture. We know that an important focus of supply management in agriculture is risk management through short supply chains. At the same time, it can be assumed that consumers in a conservative and low-tech sector, such as agriculture will show caution and little flexibility in their experience with digital food chains. In their study [5] reveal a somewhat negative perception of digitized short food supply chains. Overall, the study shows the low level of trust in digital technologies and the presence of concerns about negative impacts, including social impacts.

Overcoming challenges

The initial stage of digital transformation underlines the need for all actors to join forces in order to achieve a gradual transition and meet the long-term goals of sustainability and human well-being. The range of actors includes not only agribusinesses and consumers, but also technology companies, government institutions, NGOs, and scientific institutions [30]. Consumers, through their expectations, competencies and skills, are the driving factor for digital transformation of enterprises. On the other hand, a significant

role can also be assigned to other actors through knowledge and skills transfer (from technology companies) to enterprises and support and funding for innovation and security policies, regulation (from government institutions).

In terms of promoting and supporting digital transformation in agriculture, and especially for SMEs, government support has a significant role to play. Agriculture has traditionally been a state-supported economic sector due to the specificity of the activity and the higher risk involved, as well as the lower profitability and investment activity in it. The financing of innovation (Industry 4.0), the formation of skills and competences, modernization and automation of production are also currently the subject of a number of government policies and documents. In this sense, the transformative role of digital technologies and cyber-physical systems can only be fully manifested if relevant policies are in place to promote investment in digitalization, with policy-makers working in collaboration with all stakeholders along the chain. There is broad agreement in the literature on the necessary involvement of policy-makers in strategically adapting supply chain operations by integrating Industry 5.0 and developing scalable models to facilitate the adoption of digital technologies [32].

[15] emphasize the collaborative efforts needed to achieve sustainable development through innovation, policy makers should collaborate to support SMEs in using technology for sustainable business practices. The transformative role of technology manifests itself not only as technological innovation, but also as a fundamental change in the way businesses and consumers interact. [9] identifies some components shaping the business model of a company operating in a digital environment, among which the new role of customers occupies a central place - as participants in the product design process; partners working together in a cyber-physical network, forming agile delivery teams; partnering with the customer throughout the product lifecycle. Other authors highlight the importance of "understanding consumer perceptions, leveraging online platforms

effectively, and emphasizing brand values to drive consumer engagement and purchasing decisions" [12]. Some strategies can be identified support agri-food enterprises: greater investment in employee training and engagement and the creation of cross-functional teams; the use of industry experts; the introduction of new technologies to be implemented gradually after testing and evaluation; and the integration of sustainable practices that meet the demand for more responsible products [8].

CONCLUSIONS

The concept of smart agriculture has been marked with increasing attention in recent years not only by the research community but also by local authorities, due to the real possibility to provide innovative applications based on the integration of new and heterogeneous technologies. In order to achieve this with the help of information and communication technologies, it is necessary to look for appropriate solutions and technological platforms, with strict consideration of potential risks, their nature and management.

At the micro level, the data show that SMEs in agriculture are generally at the very beginning of the digitalization of processes and products. The slow adoption of new technologies is also influenced by additional factors, such as the need for SMEs to enhance their professional competencies for working in a digital environment and to adopt a more flexible attitude towards the new digital reality. Currently, we observe a limited understanding of Industry 4.0 technologies, which is reflected in a reluctance to invest in employee training. In this sense, CPS and Industry 4.0 technologies continue to pose a significant challenge for businesses, especially SMEs, in terms of integrating new concepts and technologies into existing business models and implementing new ones by building long-term strategies for their integration. In this sense, the deployment of digital transformation requires businesses, especially SMEs, to understand the synergies between human and machine work (Industry 5.0) and, as a result, introduce new

technologies and cyber-physical systems to adapt to a changing digital environment. As with other manufacturing sectors, the benefits of this synergy for agriculture go beyond the cost-optimizing effects of automating production and enable value addition - for example, better meeting corporate governance requirements, consumer expectations (through product customization) and consumer participation in the production process and supply chain (in collaboration).

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