Applications of Digital Twins (DT) and Internet of Things (IoT) in the Supply Chain: The Case of Food Industry

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Abstract: - Nowadays, supply chains need to be more flexible and innovative due to the rapid development of technology, along with growing demands for high-quality products and more efficient services. The use of advanced automation technologies, such as the Internet of Things (IoT) and Digital Twins (DT), is the key to accomplishing these objectives. In particular, the food industry is gradually implementing these tools, and with it comes its prompt evolution. However, the extent and approach of this integration remain unclear. This research aims to elucidate the aforementioned issues through two main parts. First, a comprehensive review of the existing literature documented both the inadequacies of the global supply chain and the potential benefits of Digital Twins (DT) and the Internet of Things (IoT) in its operational processes. The second part of the study focused on assessing the level of automation in the Greek Food Industry using a questionnaire. The results were subjected to statistical analysis and compared with findings from similar studies on the European Food Industry. Ultimately, the study aimed to highlight the role of automation technologies in addressing the operational challenges of the supply chain and the optimization of the production processes in the Greek Food Industry.

Key-Words: - Supply Chain, Food and Drink Industry, Industry 4.0, Industry 5.0, Automation technologies, Internet of things, Digital Twins.

Received: March 27, 2025. Revised: July 11, 2025. Accepted: August 26, 2025. Published: September 30, 2025.

1 Introduction

The Fourth Industrial Revolution introduced automation into traditional industrial practices, optimizing production through technologies that enhance efficiency and reduce costs without compromising product quality. Meanwhile, humanity is moving towards the Fifth Industrial Revolution, in which robots support humans in the production processes, introducing a human-centered approach and an emphasis on sustainability.

Industry 5.0 aims to integrate production processes with environmental sustainability by aligning with the Sustainable Development Goals of the UN's Agenda 2030, with digitization being a prerequisite for its successful implementation. The "smart" factories developed as part of Industry 4.0 combine technologies such as predictive maintenance and digital twins, enabling real-time optimization of production processes and adaptation to dynamic conditions.

The need to reduce food waste and the growing demands for safe and quality products, indicate the importance for the implementation of new automation technologies in the food industry. Particularly, one in seven people worldwide is at risk of hunger and a significant portion of food is wasted annually in Europe. Also, food waste is linked to the depletion of natural resources, leading to considerable environmental implications.

Advanced technologies such as the Internet of Things (IoT) and Digital Twins (DT) can help reduce waste and optimize production processes. The IoT connects various parts of an industrial facility, providing real-time data on operations and environmental conditions, thereby enabling immediate adjustments in production. DT creates virtual replicas of physical systems, enabling the assessment of new products and processes while reducing financial risks. These technologies also contribute to reducing energy consumption and promoting the use of alternative energy sources, thereby supporting the development of the "smart" factory with a holistic approach to management and communication.

Following an extensive review of the existing literature, it was found that several studies address the applications of the IoT and DT across various sectors of the supply chain. However, no study to date has offered a comprehensive review and comparative analysis of the findings, nor has any research focused on automation in the Greek food industry. This gap highlighted the need for the present study.

The aim of this study is to highlight the contemporary operational challenges facing the supply chain and to examine the role of automation technologies in their prompt resolution. Additionally, the study seeks to investigate the level of automation within the Greek food industry and to evaluate the potential benefits of implementing these technologies for optimizing the production processes and the end-products, with sustainability serving as a guiding principle.

In summary, the research questions guiding this study are as follows:

1. What are the key challenges facing the global supply chain and the food industry?
2. How can automation technologies, specifically the Internet of Things (IoT) and Digital Twins (DT), contribute to addressing these challenges?
3. To what extent has the Greek food industry adopted automation technologies?

To address the above research questions, the study was structured into two parts. The first part reviewed the benefits and challenges arising from the implementation of the IoT and DT in the global supply chain and the European food industry, through a comprehensive analysis of existing literature and case studies. The second part examined the extent to which automation has been integrated into the Greek food industry through a questionnaire survey and compared the results to findings from relevant European studies. The study concludes by presenting its key findings and offering recommendations for future research.

2 Theoretical Background

The Industrial Revolution marks a pivotal era in human history, driving profound technological, social, and economic advancements. From the late 18th century to the present day, it has significantly transformed production processes and industrial operations, increasing efficiency and productivity. As the transition progresses from Industry 1.0 to Industry 5.0, the focus has shifted from purely mechanical innovations to advanced digital systems and human-centered approaches. This development highlights the ongoing evolution of industry in response to contemporary challenges.

2.1 Industrial Revolution: From Industry 1.0 to 5.0

Throughout history, four industrial revolutions have taken place, as outlined below: The First Revolution, known as the Mechanical Revolution (late 18th century), was marked by the widespread adoption of steam-powered machinery, particularly in the textile and metallurgy industries. This machinery increased productivity and optimized the industrial processes. The Second Revolution, referred to as the Electrical Revolution (late 19th to early 20th century), introduced the groundbreaking use of electricity. This invention was the beginning of mass production lines and enabled large-scale energy production and distribution. This brought about profound transformations in industrial operations and urban infrastructures. The Third Revolution, known as the Automation Revolution (mid-20th century), introduced automation and electronic computing into manufacturing practices. Production processes became more flexible and efficient, with computing and electronic systems emerging as key factors of industrial advancement, [1].

The global society is currently undergoing the Fourth Industrial Revolution, also known as the Digital Revolution, in which worldwide production networks are facing disruptive challenges driven by emerging technologies such as Big Data, the Internet of Things, artificial intelligence, and sensor technologies. This revolution is characterized by the profound integration and interaction between digital systems and the physical world.

The Fourth Industrial Revolution has had a positive impact on productivity and economic growth, contributing to cost reduction and the enhancement of global supply chains. However, Greek businesses continue to face significant challenges, including the need for strategic transformation and improvement of their workforce's digital skills. While many companies acknowledge the importance of information technologies, few have developed digital strategies. Furthermore, the country's prolonged economic crisis has constrained infrastructure development and investment. Additionally, the education system has not fully aligned with the demands of the employment sector, particularly in terms of digital skills, [2].

The shift towards a "smart" factory extends beyond the mere implementation of advanced technologies; it also requires structural flexibility, a skilled workforce, continuous learning, and adaptability. Since the COVID-19 pandemic, Europe continues to encounter challenges such as climate change and the need to develop resilient economic systems, while also striving to reduce its dependency on raw material imports. Digitization and the transition to Industry 4.0 have proven insufficient to fully address these objectives, leading to the emergence of Industry 5.0 as a more human-centered and sustainable approach.

Industry 5.0 promotes three core values: the human-centered approach, sustainability, and resilience. It is based upon the synergy between humans and technology, aligning processes with human needs and integrating technological precision with human creativity. Additionally, it highlights the principles of the circular economy to mitigate environmental implications and foster the development of resilient businesses capable of managing crises. This approach aims to promote sustainable development while addressing the social and economic challenges of the modern-day context, [3].

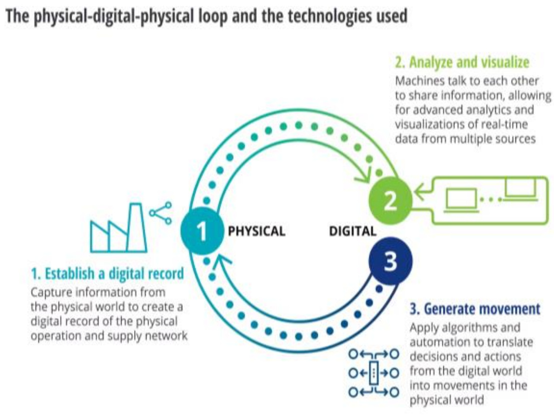


Fig. 1: Connection between the physical and digital world (physical-to-digital-to-physical loop, PDP Loop)
Source: [4]

Industry 5.0 essentially represents the next evolutionary step in the progression of the Fourth Industrial Revolution, marking a transition from Cyber-Physical Systems and technologies to Cyber-Physical-Social Systems that incorporate human values, as illustrated in Figure 1, [4]. Specifically, artificial intelligence and DT technologies provide flexibility in the design of new production processes and new products by enabling the digital representation of reality, as well as the real-time collection and analysis of large volumes of data. This, in turn, enhances the development of customer-specific solutions and accelerates new product development, ensuring alignment with the dynamic demands of the market.

2.2 Automation - Advanced Technologies

Automation and advanced technologies have been pivotal in transforming industrial processes over several decades. Early automation technologies, which were developed during the Third Industrial Revolution, established the foundation for modern advancements, improving production efficiency and precision. As the era of Industry 4.0 unfolded, new technologies like Cyber-Physical Systems (CPS), the Internet of Things (IoT), and Digital Twins (DT) revolutionized industries by enhancing connectivity, flexibility, and real-time monitoring. These innovations offered unprecedented opportunities for the advancement of intelligent manufacturing systems; yet they also introduced challenges related to cybersecurity and environmental sustainability. Hence, the industries and all the interested parties of the supply chain need to understand the evolution and impact of automation technologies, in order to be effective and not a potential obstacle in their processes.

2.2.1 Early Automation Technologies

The technologies of the Third Industrial Revolution paved the way for the development of todays' advanced automation systems. In particular, between 1960 and 1990, pivotal technologies such as Programmable Logic Controllers (PLCs) and Computer Numerical Control (CNC) Systems enabled greater precision and flexibility in production processes. PLCs replaced conventional relay-based control panels by offering digital storage and programmable functions, while CNC machines introduced the automated manufacturing of components with high accuracy and consistency. Furthermore, industrial robots were used to perform hazardous and repetitive tasks, improving safety and efficiency.

Moreover, Computer-Aided Design (CAD) and Computer-Aided Manufacturing (CAM) systems enhanced digital design and production capabilities, while Industrial Control Systems (ICS), such as SCADA, enabled real-time control and monitoring of physical processes. Also, the above technologies facilitated data collection, which are important for the management of industrial operations across sectors such as energy and manufacturing. Overall, these technologies laid the foundation for the subsequent evolution of automated production and control systems, [5].

2.2.2 Technologies of Industry 4.0

The transition to Industry 4.0 marks the beginning of a new era where connectivity technologies, artificial intelligence, and Cyber-Physical Systems (CPS) converge to develop "smart" factories that are adaptable and automated. Specifically, CPS use digital and physical systems for real time monitoring and optimization of the production. These processes lead to significant improvements in industries such as manufacturing, energy, and logistics. The efficiency of CPS, is based on six key functions, known as the 6Cs. These include connection, cloud-based data processing, content analysis, adaptation, community and the use of "cyber-models". Furthermore, collaborative robots (cobots) and horizontal-vertical systems improve production’s adaptability and transparency, aligning the industry with consumer demands for safe and quality products, [6].

2.2.2.1 Internet of Things (IoT)

The Internet of Things (IoT) introduces a technological transformation that connects machinery and systems. This intercommunication enables real-time remote monitoring and control of production processes. The IoT consists of three key components: the "smart" devices that collect data, the communication networks that connect them, and the computational systems that process the data through cloud computing. The four types of communication in IoT include device-to-device communication, device-to-cloud, device-to-gateway, and gateway-to-cloud, [7]. Specifically for industry, the Industrial Internet of Things (IIoT) is applied in large industrial facilities, offering innovative solutions in agriculture, healthcare, and robotics. Additionally, the Internet of Services (IoS) uses the Internet to provide value in sectors such as logistics services and electronic banking, [8].

2.2.2.2 Digital Twins

Digital twins are virtual replicas of physical objects, processes, or systems created by collecting data from sensors and interconnected devices. They enhance productivity and workflow, enabling manufacturers to simulate processes and evaluate modifications to minimize downtime and improve production capacity. Digital twins are defined by physical entities and data, the modeling of physical processes, interaction with the physical environment, and continuous real-time updates and synchronization. Also, there are three subcategories of digital twins: the Digital Model, the Digital Shadow, and the fully integrated Digital Twin that differ in the level of level of data integration between the physical and the digital counterpart. It is evident that creating a DT requires meticulous process design, the application of standardized techniques, and the utilization of consistent data models to ensure system flexibility and efficiency, optimize information management, and minimize the volume of data needed to support applications, [9].

2.2.2.3 Other Industry 4.0 Technologies

1. Cloud Computing: Enables the remote storage, management, and data processing through internet-based infrastructures, providing flexibility, scalability, and access to computational resources, regardless of time and location.
2. Artificial Intelligence (AI) and Machine Learning (ML): Analyze data and extract knowledge, allowing systems to learn from experience and progressively improve their performance, thereby enhancing automation and operational efficiency.
3. Big Data Analytics: Big data analytics enables the efficient processing and analysis of large volumes of data to support strategic decision-making and to uncover patterns that are not apparent through traditional analytical approaches.
4. Additive Manufacturing: Commonly known as 3D printing, creates objects by adding material layer by layer, allowing the cost- and time-efficient production of complex and customized components.
5. Interface of Things / Extended Reality: Extended reality integrates augmented and virtual reality technologies to merge the physical and digital environments, enhancing user interaction, simulation, and immersive training.
6. Robots, Cobots, and Drones: Robots, collaborative robots (cobots), and drones incorporate autonomous technologies to perform repetitive or hazardous tasks. Cobots are specifically designed to work alongside humans to increase safety and efficiency in industrial settings.
7. Blockchain: Blockchain is a distributed database technology that ensures transparency, integrity, and security in transactions by recording data in an

immutable way without the need for a central authority.

2.2.3 Challenges and Weaknesses of Industry 4.0 Technologies: The Significance of Cyber Security

Although Industry 4.0 technologies offer significant advantages, they also encounter numerous challenges. Key limitations include high capital investment for infrastructure, the shortage of specialized human resources, and the complexity of integrating new systems into traditional industrial environments. In terms of security, increased connectivity raises vulnerability to cyberattacks, while personal and corporate information is exposed to new risks of breaches and unauthorized access. From an ethical perspective, concerns have been raised regarding the replacement of human labor by automated systems, which intensify fear of job displacement and exacerbate social inequality. In the context of sustainability, technological advancement requires significant energy consumption and resource use, emphasizing the need for environmentally friendly solutions and the development of circular production models.

With regard to cyberattacks, the ENISA Threat Landscape 2024 report indicates that DDoS and Ransomware continue to dominate the cyber threat landscape, with 19,754 vulnerabilities recorded, of which 9.3% were classified as critical and 21.8% as high-risk. Business Email Compromise (BEC) attacks have surged, while Malware-as-a-Service (MaaS) remains a growing concern. Furthermore, open-source software attacks, such as the XZ Utils supply chain breach, are on the rise, and DDoS-for-Hire services allow even inexperienced users to launch large-scale attacks, [10].

To address these risks, cybersecurity measures must prioritize the core principles of information security: confidentiality, to ensure the protection of sensitive data; integrity, to maintain accurate data; and availability, to support real-time monitoring and fault detection. In this context, a robust cybersecurity strategy is essential for the secure deployment and advancement of emerging technologies in today's digital landscape.

2.3 Supply Chain

During the 1990s, product delivery processes from warehouses to end customers were often inefficient and time-consuming, typically requiring between 15 and 30 days. The traditional procedures relied on manual operations and were prone to issues such as lost orders or stockouts, resulting in extended service times. Over time, these inefficiencies -along with the evolution of distribution channels- were addressed through technological innovations that enabled real-time tracking of shipments and improved delivery accuracy. This enhanced connectivity among collaborating organizations contributed to the emergence of supply chain management as a strategic discipline, which emphasizes the importance of zero errors, commonly referred to as six-sigma performance, [11].

The above introduces the "revolution" of the Supply Chain (SC). The term supply chain refers to the flow of materials, information, and services starting from raw material suppliers, through production processes and warehouses, and ultimately reaching end customers. Supply chains are networks of interconnected and interdependent organizations that collaborate to control, manage, and improve the flow of goods and information across all stages. These networks may include suppliers, intermediaries (such as wholesalers), warehouses, service providers (such as Third Party Logistics, or 3PL), distribution centers, and customers, [12].

2.3.1 The Value of Supply Chain and the Role of Logistics

Logistics represent a key subset of the supply chain, focusing on the movement and geographic positioning of inventory, as well as the management of orders, transportation, warehousing, and materials. This process adds value by synchronizing and integrating the various elements of the supply chain, thereby ensuring optimal utilization of inventory and infrastructure. Overall, effective logistics management requires the implementation of coordinated activities by Supply Chain Information Systems (SCIS), which enable real-time inventory tracking and the efficient allocation of resources.

The value in the supply chain is expressed in three forms: economic value, which emphasizes cost-efficiency and high quality; market value, which refers to the availability of high-demand products at the right time and place; and relevance value, which adjusts products to meet the needs of each customer. Achieving these values requires collaboration of all interested parties and effective resource management to achieve a competitive advantage and enhance overall business efficiency, [11].

The entire set of actions required to deliver a product or service is described by Porter's value chain. According to Porter, as shown in Figure 2, in order to assess whether a business holds a true competitive advantage -meaning it maximizes value and performance in each operation- it should analyze its value chain and the individual activities that comprise it.

Porter divided these activities into two categories: primary and support. The primary activities are vital to the value of the chain and include the following, [13]:

1. Inbound Logistics: Storage and inventory management.
2. Operations: Activities involved in processing raw materials into end products.
3. Outbound Logistics: Activities for distributing end products to consumers.
4. Sales and Marketing: Strategies that aim to increase product and brand recognition among the target consumer group.
5. Service: Practices such as managing customer complaints and providing technical support to improve the overall customer experience.

The support activities improve the efficiency of the aforementioned primary activities and include the following, [13]:

1. Procurement: The process of sourcing raw materials needed to keep production running.
2. Technological Development: Practices and technologies that aim to increase productivity and quality.
3. Human Resources (HR): Strategies to help the workforce keep up with the latest consumer demands and to support the continuous development of their skills.
4. Infrastructure: The company's internal structure and the policies that ensure efficient intercommunication among its departments.

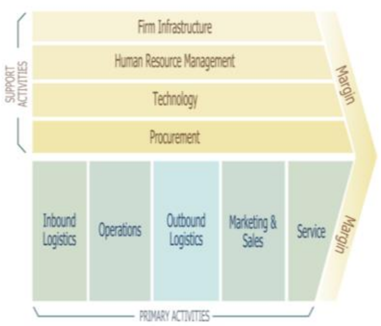


Fig. 2: Porter's value chain
Source: [14]

2.3.2 Challenges of the Modern Supply Chain

Major worldwide disruptions like the COVID-19 pandemic and the energy crisis triggered by the war in Ukraine, have significantly affected the operations of the global supply chain. In particular, challenges such as delays, product shortages, and rising costs have highlighted the need for greater flexibility, resilience, and strategic adaptation.

As a result, the global trade in 2024 is being shaped by factors such as geopolitical tensions, environmental concerns, and rapid technological advancements, which also introduce new challenges, such as cyberattacks, shortages of raw materials and increased energy costs, [15].

Additionally, phenomena such as droughts affecting key maritime routes and ongoing geopolitical instability are causing global trade routes to be rearranged and shipping costs to rise. Companies are adapting through better inventory management, strategic sourcing practices, and the creation of internal distribution networks. However, significant challenges remain, such as the lack of process transparency and insufficient resilience, that hinder the efficient operation of supply chains. According to the 2023 "Annual Industry Report" by MHI (Material Handling Industry) in collaboration with Deloitte, as shown in Figure 3, the main issues facing supply chains include lack of skilled workforce and sudden disruptions in supply chain operations, followed by inventory shortages and challenges in meeting growing consumer demands, [16].

Fig. 3: The results of the Annual Industry Report by MHI (Material Handling Industry) in collaboration with Deloitte in 2023
Source: [16]

Addressing the challenges facing global supply chains in 2024 requires innovation, flexibility, and strategic foresight. Investments in resilient infrastructures, sustainable practices, and collaborative partnerships are essential for enhancing efficiency, while risk management supported by data analytics and ongoing upskilling enables adaptation to a dynamic environment. The Supply Chain Risk Management (SCRM) strategy supports organizations predict and mitigate potential risks, thereby ensuring operational continuity amid events and uncertainties, [17].

Technological advancements, such as blockchain, big data analytics, and real-time tracking applications, enhance visibility and risk management in supply chains. At the same time, the implementation of automation technologies, such as autonomous vehicles and route optimization software, has improved logistics efficiency. Nevertheless, integrating these emerging technologies with legacy systems remains a considerable challenge, as their effective deployment requires flexibility and system interoperability.

3 Food Industry

The food and beverage industry constitutes one of the main pillars of the European economy, making a significant contribution to production and employment. In 2020, as illustrated in Figure 4, it generated a turnover of €1.112 trillion and an added value of €229 billion in the EU, with the most profitable sectors being beverages and meat products. In Greece, this industry reports a turnover of €16 billion, with approximately 131,000 professionals employed across 15,907 companies. However, population growth and climate change place increasing pressure on food production and sustainability, raising concerns about the economic affordability of a healthy diet, [18].

The food industry is responsible for 26% of global greenhouse gas emissions and faces environmental and social challenges, including land degradation and the depletion of natural resources. Overall, the food crisis, climate-related disasters, and geopolitical conflicts are highlighting the need for sustainable production processes. In response, the United Nations Sustainable Development Goals (SDGs) call on the food industry to support global food safety by adopting practices that enhance a circular economy and the responsible management of resources, [19].

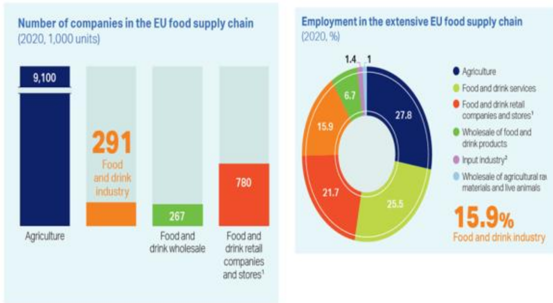


Fig. 4: Statistical data of the food industry in Europe
Source: [18]

To address these challenges, the food industry should adopt a more sustainable approach to its production processes, such as the use of green technologies and resource recycling. In addition, traceability and transparency are the main requirements to mitigate public health risks caused by foodborne illnesses and for meeting the growing consumer demand for safer food products. As a result, integrating advanced technologies into production processes is essential for not only enhancing efficiency but also for promoting resource conservation and improving the overall sustainability of food supply chains. A notable example of advanced technology is the use digital twins, which allow real-time simulation and optimization of production processes.

However, digitalization in the food and beverage sector faces several challenges, such as financial limitations, inadequate digital skills among the workforce, and lack of basic infrastructure. A key first step in overcoming these barriers could be collaboration with research institutions, along with providing training in the use of automation technologies.

3.1 The Food Industry's Lag in Automation Compared to Other Sectors of Supply Chain

In today's rapidly evolving industrial landscape, the integration of advanced technologies like the Internet of Things (IoT) and Digital Twins (DT) is optimizing logistics processes and supply chain management. These technologies provide real-time collection of data, enhance operational efficiency, and support decision-making processes. Industries across various sectors are increasingly adopting these technologies to stay competitive and meet growing demands.

Although the food industry has demonstrated notable progress in automation, it still lags behind other sectors in the implementation of IoT and DT technologies. The following sections examine the impact of IoT and DT on modern supply chains, highlighting their applications and the value they add to industries, particularly in contrast to their limited adoption within the food industry.

3.1.1 Applications of IoT and Their Role in Food Industry

DHL, one of the world's leading courier and logistics company, has become a market leader by offering a broad range of transportation and logistics services all over the world. As part of its innovation and sustainability strategy, the company has invested in advanced technologies like the IoT to enhance its supply chain operations. As a result, DHL improved its efficiency by providing real-time data and enhanced tracking of goods in transit. Through partnerships with companies like Agheera and the deployment of IoT sensors, DHL can monitor the condition of shipments, optimize logistics processes, reduce costs, and offer more personalized services to its customers, [20].

Furthermore, IoT technology offer valuable applications and benefits for stakeholders across logistics and supply chain management. These include real-time tracking of product location and condition, smarter route optimization, and more accurate forecasting of customer demands. Leading companies such as Amazon, Maersk, and Volvo have already integrated IoT into their operations, achieving efficiency and cost reduction. In the food sector, IoT enables the effective management of perishable goods and quality control, while in the automotive industry, it facilitates the management of transportation processes and enhances safety. The adoption of IoT through the interest parties of the supply chain provides competitive advantages, enhancing both financial performance and environmental sustainability, [21].

Regarding to food and beverage industry, it is increasingly expected to adopt digital technologies, such as artificial intelligence, IoT, big data analytics, and DT. The integration of these technologies aligns with the concept of the smart industry, which is characterized by a high level of automation, remote operation control, real-time data acquisition, and the digital representation of products or processes with the ability for intervention and optimization.

Real-time design, monitoring, and control strategies in the food supply chain are essential for ensuring the efficient and effective flow of products from producers to consumers. The collaborative engagement of all stakeholders in real time contributes to minimizing waste, enhancing product quality, ensuring compliance with food regulations, and supporting informed decision-making to respond to market demands, [22].

IoT technology has significant applications across various sectors of the food and beverage industry, supporting efficient process management from production to consumer (farm to fork). By enabling real-time data analysis and simulation, IoT facilitates remote monitoring, predictive maintenance of equipment, and effective responses to supply chain disruptions. Its real-time capabilities improve communication with suppliers and customers, enhance traceability, and provide full process transparency, ultimately resulting in product quality and safety. Additionally, continuous monitoring of production processes and environmental conditions promotes energy efficiency and reduce waste.

Examples of IoT applications in the food industry include smart agriculture and livestock management, smart greenhouses and automated production facilities, quality control by detecting harmful substances for the public health, and smart food labeling that provides consumers with transparent information about a product's origin and the sustainability of its production process. Specifically, IoT enhances inventory management, food traceability, and the conservation of resources such as water and energy. It also contributes to improved food waste management and facilitates rapid responses to product recalls through technologies such as RFID systems. Despite challenges related to cost and infrastructure requirements, IoT presents substantial opportunities for improving efficiency, preserving resources, and minimizing waste across the food industry, [23].

3.1.2 Applications of DT and Their Role in Food Industry

Lean manufacturing, developed within the framework of the Toyota Production System, aims to minimize waste and maximize productivity. With the emergence of the Fourth Industrial Revolution, lean principles have gained even greater significance through the integration with advanced technologies, such as DT. This combination enables the simulation of production processes and the improvement of operational efficiency. Moreover, it allows for performance forecasting and proactive adaptation to market changes and customer needs. Companies like General Electric and Boeing utilize

DT to optimize maintenance and productivity. Also, in the aerospace sector, their application has increased the efficiency and safety of production systems, [24].

Digital twins are increasingly applied across various sectors, including supply chains and agriculture, to enable real-time monitoring, data analysis, and informed decision-making. In Just-in-Time (JIT) production and cold chain logistics, DT support the prediction and prevention of shortages, as well as, the optimization of equipment maintenance. In the primary production sector, which includes agriculture and livestock farming, sensors and data analytics are used to improve the efficiency and sustainability of the production processes. Digital Twins platforms like Siemens MindSphere, GE Predix, and Microsoft Azure offer advanced tools for monitoring and analyzing industrial systems in order to improve facility operations and maintenance in real-time, [25].

In the food industry, DT technology has a key role in industrial digitization, offering enhanced flexibility and operational efficiency. Within the food supply chain, digital twins enable real-time simulation and monitoring of production processes, resulting in accurate decision-making and facilitating communication among all stakeholders.

A notable application of DT is in an ice cream production facility, where an Activity-Based Simulation (ABS) model is used to minimize data redundancy and extract key information more efficiently. As a result, the improved production processes, along with the proper handling and maintenance of infrastructure enhanced the overall operational and financial performance, [22].

Hence, the implementation of DT in the food industry allows for accurate simulation and in-depth analysis of production processes, offering valuable insights into equipment capabilities and operational performance. By using data collected from sensors along with advanced analytics, DT can detect issues and identify the root causes of malfunctions, predict outcomes related to product quality and safety, and help reduce maintenance costs and unforeseen operational downtime. Furthermore, when combined with advanced technologies like artificial intelligence, DT can enhance the efficiency and adaptability of processes, thus adding greater value to food production and ensuring higher standards of safety.

4 Research and Design

In the present study, a questionnaire was selected for primary data collection, as it can be easily, quickly, and cost-effectively distributed to many participants via various online platforms. Moreover, it requires minimal time to complete, allowing respondents to participate at their convenience. Importantly, the anonymity and independence of responses help minimize potential researcher bias and enhance the objectivity of the collected data.

The questionnaire was designed in two stages. In the first stage, the conceptualization and operationalization of key concepts were undertaken to define the dependent and independent (structural) variables, along with their corresponding components (items). In the second stage, decisions were made regarding the type of questions and responses, as well as the overall structure and purpose of the questionnaire. Specifically, the identification of the key concepts and their interrelationships was based upon similar studies previously conducted in Europe.

One of the primary studies was the Digital Economy and Society Index (DESI) report, published in 2022 by the European Commission**.** This report monitors the annual digital progress of EU member states, outlining their profiles, initiatives, needs, and how these are addressed. The DESI study is aligned with the goals set by the European programme "Path to the Digital Decade", which prioritizes four main pillars: the enhancement of digital skills across the population, the development of secure and sustainable digital infrastructures, the digital transformation of businesses, and the digitalization of public services, [26].

A second online study was the "Are Europe's food SMEs ready for AI-based technologies?", published in 2021 by the European Institute of Innovation and Technology (EIT Food). EIT Food collaborates with enterprises and academic institutions to foster innovation in the agri-food sector and strengthen food safety systems through advanced technologies. The study focused on SMEs (10-250 employees) in Spain, France, Italy, Germany, and Poland. It gathered insights into how these businesses collect, store, and analyse operational data; an essential process for the adoption of artificial intelligence technologies, by the principles of Industry 4.0, [27]**.**

The third study, published in 2019 by the European Commission, examined the extent to which artificial intelligence technologies have been implemented by companies across Europe. It involved a large-scale telephone survey covering all EU member states as well as Norway, Iceland, and the United Kingdom. Data were collected from 9,640 companies, and the study measured five performance indicators: awareness of AI technologies, adoption, sourcing of AI solutions, and internal and external barriers to implementation. These findings provided a comprehensive overview of the current state of AI integration and the challenges that European enterprises face in adopting such technologies, [28].

4.1 Questionnaire Design

The purpose of this questionnaire is to investigate the level of automation in all the operational activities of Greek food industries, including both large and small to medium-sized enterprises. These activities include raw material and end-product inventory management, production processes, distribution of end-products, and communication among all stakeholders in the food supply chain (a holistic approach). Accordingly, the dependent variable (dimension) of the questionnaire is the level of automation in business operations.

Subsequently, through a review of the aforementioned studies, the factors (sub-dimensions) that determine the digital transformation of businesses and serve as the independent (structural) variables in this study were identified as follows (conceptualization process):

1. Human Capital
2. Integration of Digital Technology
3. Digital Public Services

According to the DESI index report, these factors have the same impact on the dependent variable and are specifically connected through a cause-and-effect relationship. Moreover, they function synergistically in driving the digital transformation of businesses, [26].

However, it should be noted that this conceptualization is not necessarily unique. Different definitions of elements may lead to diverse approaches. Therefore, the concepts are confined to this specific group of characteristics defined in the present study, [29].

Finally, during the process of operationalizing the above structural variables, their components (items/indicators) were identified. These components consist of characteristics, statements, or questions that define each structural variable and form its measurement scale. The components are content-complete, and their values -derived from respondents' answers- are mutually exclusive, as each response category represents a distinct meaning and cannot be equated with another category, [29]. Table 1 presents an overview of the variables and concepts incorporated in this questionnaire.

Table 1. Total set of questionnaire variables

Dependent variable (dimension)	Independent / Structural variables (sub – dimensions)	Items / Indicators	Description of the items/ indicators
Automation percentage of business operations	Human Capital	Basic digital skills	Skills related to the use of the internet, basic data entry programs (e.g. Excel) and ERP software.
		Knowledge of information and communication technologies (ICT)	Skills related to programming, machine learning, cloud computing, application management and big data analysis.
	Integration of digital technology	Advanced automation technologies	Predictive maintenance, forecasting internal and external risks through artificial intelligence applications, real-time decision-making through machine learning and algorithms, use of digital twins for predicting potential issues or creating innovative products, use of the Internet of Things (IoT) for communication between all departments within an industry, as well as stakeholders in the supply chain (traceability).
		Digitalized data sets	Software (operating systems, databases), data storage programs / use of cloud computing.
		Automated equipment and production lines	Computing equipment (IT resources), robotic systems on the production line for general and specialized tasks (generic and specialized robots, collaborative robots / cobots), sensors.
	Digital public services	Government support for businesses and employees	State-run programs for adopting advanced technologies, training stakeholders in the food supply chain on digital skills (applications, adoption methods, consultancy agencies, demonstrations - seminars), enhancing regulations and laws about personal data, online infrastructures for elimination of bureaucracy.

Source: created by the authors

4.2 Structure

This study addresses an issue for which there are few references in the European context, and no prior research has been conducted in Greece. Therefore, it constitutes an exploratory quantitative study on the level of automation in Greek food industries.

Specifically, quantitative data were collected through a structured questionnaire consisting of closed-ended questions. The questions were presented in a specific order, progressing from general to more specific topics, in order to enhance face validity, which encourages respondents' engagement with the questionnaire.

The measurement scale of answers is a five-point Likert scale, which enables respondents to position themselves at a neutral/midpoint or clearly express a tendency toward one end of the scale.

Finally, the questionnaire is divided into three main sections (Table 1), comprising a total of thirteen (13) questions. A separate section at the end includes nine (9) additional demographic questions. Finally, the estimated time to complete the questionnaire is approximately 15 minutes.

4.3 Reliability and Validity

Questionnaires must demonstrate both reliability and validity. Reliability refers to the degree of consistency among the variables, including the stability of responses over time, and the extent to which results are free from measurement errors. Several types of reliability exist, but for Likert-type scales, internal consistency reliability is most commonly assessed.

The reliability test was conducted by calculating the Cronbach's alpha coefficient using the SPSS software. This coefficient reflects the average inter-item correlation among the questions of the questionnaire. Values greater than 0.70 are considered acceptable and indicate that the questionnaire is consistent and reliable, [29]. The results of the reliability test for the present questionnaire are presented in Figure 5, where the coefficient is equal to 0.869.

Regarding validity, the literature often presents ambiguity regarding its definition and various types. Among these, construct validity is most frequently emphasized. It refers to the extent to which the operationalization of the concepts within the questionnaire accurately represents the concept being studied.

Case Processing Summary

		N	%
Cases	Valid	36	69,2
	Excluded[a]	16	30,8
	Total	52	100,0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics

Cronbach's Alpha	N of Items
,869	70

Fig. 5: Results of the reliability test of the questionnaire using Cronbach's alpha coefficient (Cases: the number of valid responses, Total: the total number of responses, N of items: the total number of question items)
Source: created by the authors

4.4 Conducting the Research and Analyzing Results

The present study was conducted through the Google Forms application. This method offers ease of use, rapid response time, and broad geographical coverage. The questionnaire was distributed to four hundred (400) corporate email addresses of Greek food production companies, as well as to two (2) online groups of food and beverage industry stakeholders, comprising a total of 18,619 individual members (convenience sampling). The target population (elements) consists of employees working in food-related enterprises, spanning the entire food supply chain, from primary production (agriculture) to the wholesale distribution of final products across the country.

Data collection was conducted in two phases. The first began on May 8, 2024, and yielded forty-five (45) responses by June 4, 2024. Due to the low response rate, the questionnaire was redistributed to the same email addresses on June 5, 2024. Following this second distribution, the total number of responses reached fifty-two (52) by June 24, 2024, at which point the data processing and analysis phase commenced. Data analysis was carried out using SPSS software v29 (29.0.2.0) for Windows (x64), employing descriptive statistics (e.g., frequency tables) and hypothesis testing techniques, as shown in Table 2. These methods supported the interpretation of findings, allowed for comparison with existing literature, and contributed to a deeper understanding of practical applications, while also identifying potential directions for future research.

Table 2. The types of hypothesis and significance tests used in the present study

Type of Hypothesis Test – Significance	Test of Normality	Description
Variables with two values (e.g., gender)	Variables follow a normal distribution	Independent samples t-test: – if $p > 0.05$, there is no statistically significant difference – if $p < 0.05$, there is a statistically significant difference (confidence interval: 95%)
	Variables do not follow a normal distribution	Non-parametric independent samples: Mann-Whitney U (2 samples)
Variables with more than two values (e.g., age)	Variables follow a normal distribution	One-way ANOVA (k samples)
	Variables do not follow a normal distribution	Non-parametric independent samples: Kruskal-Wallis 1-way ANOVA (k samples)

Source: created by the authors

In particular, the normality test of a distribution is divided into the Kolmogorov-Smirnov test for N

> 50 and the Shapiro-Wilk test for $N \leq 50$, where N represents the degrees of freedom (df). Moreover, the significance level (p-value) is an indicator of the distance between sample means. When $p < 0.05$, the distance between the means falls within the 5% of extreme values, indicating a statistically significant difference between them. A significance level of $p = 0.05$ means there is a 5% probability of rejecting the null hypothesis when it is true (a 5% risk of Type I Error). All tests conducted in the present study were based on the p-value. Also, non-parametric tests refer to the homogeneity rather than the equality of the sample means. Finally, the One-Way ANOVA (Analysis of Variance) test is used to compare the means of three or more independent samples to determine whether there are statistically significant differences concerning a quantitative variable.

5 Results

The total number of responses was fifty-two (52), corresponding to 13% of the total emails sent, excluding responses from the two online groups. Therefore, the actual response rate is likely lower, although it cannot be accurately determined. For this reason, the main limitation of this study is the low number of responses compared to the sample size, which introduces an estimation error.

Nonetheless, all responses were valid and complete, with no missing data observed. Furthermore, following the data analysis, it was identified that including a question in the general information section regarding the number of years the business has been in operation would have added value. Such information could have enabled the comparison of automation levels between newly established and long-standing enterprises.

5.1 Respondents' General Demographic Information

Based on the responses in the demographic section, as shown in Table 3, it was found that the percentages of women (53.8%) and men (46.2%) employed in the Greek food and beverage industries do not differ significantly. According to Eurostat's report in 2020, 59% of individuals employed in the food supply sector across the European Union were men, indicating that the gender distribution observed in the present study aligns with EU-level patterns in the food industry, [30]. Additionally, the age groups ranged mainly from 25 to 44 years old, with an average of over ten (10) years of work experience and a tertiary level of education. Particularly, in Table 3, the percentages are presented in descending order within each category, and the frequency refers to the number of individuals who selected the corresponding response.

Table 3. Respondents' answers regarding general demographic information

Question	Answer	Frequency	Percent (%)
Gender	Female	28	53.8
	Male	24	46.2
Age (years)	25 – 34	18	34.6
	35 – 44	12	23.2
	45 – 54	10	19.2
	55+	10	19.2
	18 – 24	2	3.8
Education	Tertiary education	28	53.8
	Postgraduate / Doctoral degree	21	40.4
	Primary / Secondary education	3	5.8
Work Experience (years)	More than 10	32	61.5
	0 – 4	12	23.1
	5 – 9	8	15.4

Source: created by the authors

Furthermore, it was observed that most participants are employed in the departments of administration and quality control, while it is noteworthy that no respondents selected the research and development (R&D) department for new product development. Moreover, the majority of the Greek food and beverage industries are concentrated in Attica (the capital of Greece) and belong to medium-sized businesses, employing between 50 and 249 employees. Overall, the predominant sectors of activity in the Greek food and beverage industries are the production of animal-based foods (dairy industry, meat industry), distillation, and wholesale trade. Finally, regarding employees' educational level, postgraduate/doctoral degrees are most commonly reported among employees of plant-based food production companies, beverage companies, and wholesale businesses. In contrast, primary/secondary education was reported exclusively by employees in animal-based food production companies.

Based on the above results, it can be inferred that the primary sector in the country employs a relatively small portion of the workforce. Moreover, departments such as Information Technology (IT), Logistics, and Research and Development (R&D) appear to be underrepresented. Thus, it is worth considering whether the current level of stuffing is sufficient to adequately respond to the evolving demands of the market. Strengthening organizational capacity through the recruitment and deployment of appropriately skilled personnel may be essential through appropriate staffing to ensuring operational effectiveness and long-term competitiveness. Emerging demands include the development of sustainable and health-conscious products, enhanced traceability, real-time product monitoring, and increased process automation. In contrast, the largest percentage of employees appear to be employed in administrative roles.

5.2 The Factor of Human Capital

This part analyses and compares the results of the first main section of the questionnaire, which focuses on both the basic digital and Information and Communication Technology (ICT) skills of individuals employed in the food and beverage industry.

5.2.1 Basic Digital Skills of Human Capital

Regarding basic digital skills, it was found that most employees primarily use two (2) specific applications: Email (92.3%) and Microsoft Office tools (88.5%). Furthermore, 59.6% of the sample reported using enterprise resource planning (ERP) software, while statistical software for data analysis (such as SPSS) was the least commonly used among respondents. Subsequently, a comparison of these results with participants' characteristics, using a non-parametric t-test for gender and a non-parametric ANOVA for age, education level, and department of employment, revealed no statistically significant difference in application usage across these groups. Specifically, the p-values range from 0.057 to 0.844 (> 0.05), with a 95% confidence interval (CI). However, it is noteworthy that the use of statistical software for data analysis was more prevalent among individuals aged 55 and above, as well as among employees of Sales/Marketing departments. In contrast, usage of such tools remained low across all education levels. Despite the above findings, 76.9% of respondents claim that developing their basic digital skills is very important for their work.

5.2.2 ICT Skills of Human Capital

On the other hand, ICT skills refer to the ability to use and manage technological tools and resources related to the processing, storage, and transmission of information. These include, among others, cloud computing, big data management, and machine learning.

According to the respondents' answers, as shown in Table 4, a relatively good level of knowledge in cloud computing is observed across the entire sample, with 34.6% of respondents reporting familiarity with the concept. In contrast, for the remaining applications listed in this question: Big Data Analytics, Machine Learning, Artificial Intelligence, Programming Languages (e.g., Python), and Cybersecurity, the most frequent response is "I don't know" with an average rate of approximately 40%. Among these, programming languages show the highest percentage of unfamiliarity, with 63.5% of the respondents indicating a lack of knowledge.

Table 4. Assessment of the respondents' knowledge level concerning the following ICT skills

Digital Skills (ICT skills)	Most Frequent Response
Cloud Computing	Good (34.6%)
Programming Languages (e.g., Python)	I don't know (63.5%)
Machine Learning	I don't know (44.2%)
Cybersecurity	I don't know (38.5%)
Big Data Analytics	I don't know (30.8%)
Artificial Intelligence	I don't know (30.8%)

Source: created by the authors

Subsequently, a comparison of these results with participants' characteristics using a non-parametric t-test for gender and a non-parametric ANOVA for age, education level, and department of employment, reveals no statistically significant differences in the use of the aforementioned applications (p-values range from 0.151 to 0.880, all > 0.05, with a 95% confidence interval). However, knowledge of cloud computing is found to be more widespread among individuals aged 25 to 54 and those working in administrative departments. Additionally, along with machine learning, it is more prevalent among respondents holding postgraduate or doctoral degrees. Finally, employees in accounting departments appear to possess slightly more knowledge of cybersecurity topics compared to employees in other departments.

The only exception is employees in IT and logistics departments, who, on average, demonstrate moderate to good knowledge of these applications. Notably, respondents appear to be evenly divided between those who perceive the development of ICT skills as less important for their work and those who consider it to be of greater importance.

The final question in this section explores the barriers that participants may face in developing digital and ICT skills. The findings indicate that the most significant obstacle is the lack of time due to personal obligations or work overload (57.7%), particularly among the 18-24 age group. Equally important for individuals aged 18-34 is the absence of incentives or recognition from the workplace (42.3%). Furthermore, the majority of respondents do not perceive technological uncertainty as a major barrier, with the only exception being the 55+ age group, which identified it as a highly significant concern. Finally, no statistically significant differences were found between the responses of male and female participants ($p > 0.05$; CI: 95%).

5.3 The Factor of Integration of Digital Technology

The purpose of the second section of the questionnaire is to review the level of automation of operations and processes in the Greek food and beverage industry. Specifically, it examines the implementation of advanced automation technologies, the existence of appropriate infrastructures, and the internal barriers businesses face in their application.

Notably, the results presented in the following Table 5 show the usage percentages of advanced automation technologies in the food industries where the respondents are employed. These technologies were selected based on the previously mentioned studies regarding automation in the European industrial sector and the principles set by Industry 4.0.

Table 5. Percentage of application of advanced automation technologies in the food industries where the respondents are employed

Predictive maintenance, energy resource management and decision-making using machine learning algorithms.	Percentage of responses
It is not used	57,70%
I don't know	25,00%
It is currently used	13,50%
There is a plan to be used in the next six (6) years	3,80%

Optimization of processes or equipment through artificial intelligence.	Percentage of responses
It is not used	67,30%
It is currently used	11,50%
There is a plan to be used in the next six (6) years	11,50%
I don't know	9,60%

Use of digital twins for the virtual representation of a production process or an innovative product.	Percentage of responses
It is not used	65,40%
I don't know	25,00%
There is a plan to be used in the next six (6) years	5,80%
It is currently used	3,80%

Use of the Internet of Things (IoT) for communication between all departments within an industry and across the supply chain.	Percentage of responses
It is not used	50,00%
I don't know	19,20%
It is currently used	17,30%
There is a plan to be used in the next six (6) years	13,50%

Automation equipment and machinery, such as robots (or cobots) and sensors (e.g. RFID).	Percentage of responses
It is not used	46,20%
It is currently used	26,90%
There is a plan to be used in the next six (6) years	15,40%
I don't know	11,50%

Source: created by the authors

As shown in Table 5, the response “It is not used” predominates on average, with artificial intelligence and digital twins receiving the highest percentages. In contrast, robots and sensors (26.9%) hold the largest share of “It is currently used” technologies in the industrial environment, while the IoT is the technology most frequently identified as “There is a plan to be used in the next six (6) years”. This six-year timeframe aligns with the EU’s Path to the Digital Decade program, which aims to achieve a digital Europe by 2030.

The research results indicate no statistically significant differences in the application of technologies across different company sectors, except for those involved in the production of plant-based foods, which use robots, sensors, and IoT to a greater extent. Most companies in the sample are well-equipped with software, hardware, and networks, with the majority having either developed or acquired ready-made solutions. Medium-sized companies (50-249 employees) show the highest rates of software adoption, while the most pronounced shortage of specialized human resources is observed in Crete. Among sectors, food additive manufacturing shows the greatest need for qualified staff.

To provide a clearer understanding of the level of automation within the enterprises employing the respondents, two statistical analyses were conducted using SPSS: Principal Component Analysis (PCA) and K-Means Clustering. Specifically, PCA analysis was used to reduce the dimensionality of the dataset by consolidating statistically significant variables into a predefined number of components. These components were then grouped into clusters using the K-Means algorithm, [28].

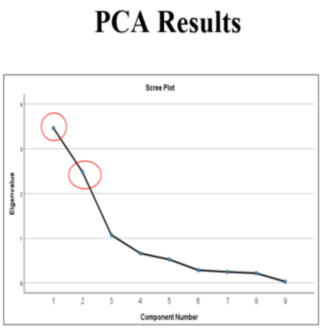
As shown in Figure 6, the results of the PCA analysis are presented in the table titled KMO and Bartlett's Test. The Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy assesses whether PCA is an appropriate technique for summarizing the initial dataset’s variables. A KMO value above 0.60 is considered acceptable for factor analysis; therefore, the value of 0.671 in the present study confirms the adequacy of the sample. In the same table, Bartlett's Test of Sphericity examines whether the correlation matrix significantly differs from an identity matrix, indicating the presence of relationships among variables. A significance value (Sig.) less than 0.05 confirms that the correlations are sufficient for PCA to be meaningful. In this case, the resulting Sig. = 0.001 < 0.05, supports the suitability of applying PCA.

Subsequently, the Scree Plot diagram is presented, where the horizontal axis represents the principal components (component numbers), and the vertical axis displays the eigenvalues, which indicate the proportion of total variance explained by each component. Higher eigenvalues suggest that the respective component accounts for a greater share of the overall variance in the data. However, the most important element of the Scree Plot is the so-called "elbow." This is when the eigenvalues decline gradually and indicate the number of principal components that should be considered. Components before the "elbow" are considered significant, while those following it are typically regarded as less important or as statistical noise.

Therefore, in this study, two (2) components were identified as significant, thematically corresponding to the initial nine variables (i.e., the current adoption status of advanced automation technologies and IT resources). The difference is that the principal components represent the structural variables after being empirically confirmed through respondents' answers, whereas the questionnaire items were initially grouped only by their thematic similarity. This alignment confirms that the scales used in the questionnaire are characterized by structural validity.

Furthermore, as illustrated in Figure 6, the table Rotation Sums of Squared Loadings presents the two significant eigenvalues in the Total column (3.089, 2.885). The corresponding percentages of the initial variance explained by each component are shown in the next column: 34.318% for the first component and 31.833% for the second. Combined, these two components account for 66.151% of the total variance, as shown in the final column, indicating a substantial proportion of the dataset's original variability explained by the extracted components.

PCA Results



KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy		0,671
Bartlett's Test of Sphericity	Approx. Chi-Square	307,128
	df	36
	Sig.	<,001

ROTATION SUMS OF SQUARED LOADINGS		
Total	% of Variance	Cumulative %
3,089	34,318	34,318
2,865	31,833	66,151

Fig. 6: Results of PCA Analysis using SPSS Software
Source: created by the authors

Finally, as shown in Figure 7, the scatter plot illustrates the relationships between the data after dimensionality reduction. Specifically, it displays the distribution of the data points along the axes of the principal components identified in the analysis, where each point represents an observation from the original data set. In this case, as expected, two distinct clusters emerge, corresponding to the two main components shown in the plot. Notably, no outliers (i.e., data points far from the main body of the observations) are detected.

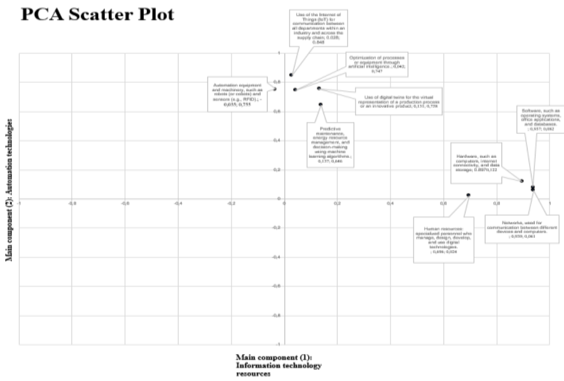


Fig. 7: Results of PCA Analysis using SPSS Software
Source: created by the authors

Table 6. Internal barriers to the implementation of advanced technologies in businesses, listed in order of decreasing significance

Internal Obstacle	Percentage of Choice
Lack of skills among the existing workforce.	Important (46.2%)
Difficulty recruiting qualified personnel for use, development, and maintenance of the applications.	Important (40.4%)
Cost of implementation and adaptation.	Important (38.5%)
Complex algorithms and difficulty understanding them.	Important (36.5%)
Insufficient information regarding the capabilities and benefits of the application.	Important (36.5%)
Lack of funding, resources, and infrastructure for digital transformation support.	Important (34.6%)
Unsuitable or incompatible hardware/equipment.	Important (25.0%)
Lack of storage space for large data volumes.	Less significant (19.2%)
Lack of trust towards the producers of electronic data and systems.	Not important (40.4%)

Source: created by the authors

In conclusion, the PCA analysis confirmed the structural validity of the questionnaire sections, with the results regarding the principal components aligning with expectations and no outliers detected. However, the K-Means clustering analysis revealed significant variation within the groups. This suggests that, although the overall level of automation in the country's businesses remains relatively low, there is a significant heterogeneity, at least in terms of the characteristics examined in this study (industry sector, location, and company size). Therefore, while the method offered a clearer representation of the sample's automation profile, its effectiveness could be enhanced with a larger sample size.

The final questions of this section of the questionnaire addressed two key issues: the internal barriers that businesses face in adopting automation technologies, and which ICT skills are considered most important by the respondents. As illustrated in Table 6, the main internal barriers to the adoption of advanced technologies include the insufficient digital and ICT skills among the existing workforce and the difficulty in recruiting specialized personnel. These challenges were more commonly reported by waste management companies, distilleries, and plant-based food producers. Small enterprises (<50 employees) reported greater barriers, primarily due to the high implementation costs, limited government subsidies, and the complexity of automation algorithms. In contrast, for medium and large industries (50+ employees), the main barrier was the inadequate digital and ICT skill level of the workforce. Finally, respondents identified skills in big data analytics as more important than skills in robotics or machine learning, although the differences in the distribution of responses were relatively minor.

5.4 The Factor of Government Support

The third and final section of the questionnaire explores the external barriers to the adoption of automation technologies by industries, specifically those stemming from governmental factors and market trends. As shown in Table 7, among the most frequently cited external challenges was the need for stricter regulations concerning data security and privacy. For large enterprises, as well as distilleries and waste management companies, the main issues include the lack of government funding and insufficient development of digital infrastructures. Additionally, although to a lesser extent, other important barriers include limited awareness of advanced technologies and the absence of incentives for ICT skills development from the work environment and the government.

Another noteworthy observation is the relatively close distribution of responses across the listed external obstacles, indicating that industries perceive various external factors as significantly hindering automation efforts. Although the need for stricter data regulations ranked highest (55.8%), several other barriers followed closely, such as regulatory uncertainty regarding AI (50%) and insufficient digital infrastructure (50%). This convergence of importance ratings suggests that the challenge is not isolated to a single policy or infrastructural domain, but rather reflects a broader systematic inadequacy. Therefore, a comprehensive approach that addresses regulatory clarity, digital infrastructure investment, and the development of ICT skills together may be more effective in enabling digital transformation in the Greek food industry.

Table 7. External barriers to the implementation of advanced technologies by businesses, ranked in descending order of significance

External Obstacle	Percentage of Choice
The need to set new stricter regulations regarding data security and confidentiality.	Important (55.8%)
Regulatory rules regarding the use of previous applications, such as artificial intelligence.	Important (50%)
Unsatisfactory development of digital infrastructure, such as fast and reliable internet connections, digital platforms, and applications for business support.	Important (50%)
Lack of information and testing of applications related to automation technologies.	Important (46.2%)
Lack of government funds to support the digital transformation of enterprises.	Important (44.2%)
Lack of incentives and subsidies for the ICT skills development from the work environment and the government.	Important (40.4%)

Source: created by the authors

6 Conclusions

The findings of this study highlight the significant challenges faced by small and medium-sized enterprises (SMEs) in the Greek food and beverage industry concerning the adoption and utilization of digital technologies. Although the majority of respondents acknowledge the importance of digital skills, the use of basic technological tools, such as office applications and enterprise resource planning (ERP) software, remains limited. In addition, the implementation of advanced technologies, such as artificial intelligence and digital twins, is still in its infancy, along with the adoption of robots and the Internet of Things (IoT) technologies.

One of the main internal barriers that industries face in adopting advance technologies is the shortage of specialized personnel, combined with a lack of digital and ICT skills among the existing workforce. In terms of external factors, the most significant challenges include inadequate legislation around data security and privacy, limited access to funding, and underdeveloped digital infrastructure. These results underscore the need for targeted policy measures and educational seminars, along with more open access to technological resources, in order to close the existing gaps and accelerate the digital transformation of the sector.

Findings from similar studies across both the food industry and the broader industrial sector in Europe reveal significant challenges that the European Union (EU) faces during the process of digital transformation, [31]. Achieving the ambitious EU's goals will require coordinated efforts on multiple aspects, including the development of effective policies, investing strategically in education and training, promoting innovation, and developing robust digital infrastructures.

Particular emphasis should be placed on enhancing the digital skills of the workforce, providing incentives and supporting innovation, as these are essential for successfully advancing the objectives of digital transformation. In addition, empowering SMEs and promoting advanced technologies, such as artificial intelligence (AI) and big data analytics, are key factors to ensuring the EU remains competitive on the global stage.

It is notable that although technologies like artificial intelligence (AI), big data, robotics, and the Internet of Things (IoT) are widely recognized as essential for maintaining market competitiveness, their adoption in the food industry remains limited.

In summary, existing studies agree that in order to overcome the above challenges and accelerate digital transformation at the national and EU levels, it is necessary to improve the digital skills of the workforce, encourage innovation, and implement coordinated policy measures.

Finally, despite the emphasis placed on business digitization and the numerous relevant studies, data availability at the EU level remains limited. There is still a clear need for future research on the adoption of advanced technologies by businesses across the European Union. Therefore, expanding research efforts would contribute to the effectiveness of the EU's digitalization strategy and better support businesses in adapting to emerging technological demands.

7 Future Research

The rapid evolution of digital technologies presents numerous opportunities and challenges that warrant extensive academic inquiry. Future research should prioritize understanding how small and medium-sized enterprises (SMEs) can accelerate the adoption of advanced technologies such as artificial intelligence, big data, the IoT, and DT. In Europe, where shortages of specialized personnel and infrastructure are prevalent, investigating successful implementation models from other regions or industries could offer valuable insights. Moreover, developing appropriate funding mechanisms and incentive schemes remains critical to facilitate technological integration in resource-constrained organizations, [32].

A key area of future research involves enhancing the digital skills of the workforce. While existing literature emphasizes the importance of education and training, there is a pressing need to develop harmonized courses tailored to the needs of diverse sectors, particularly SMEs and large enterprises, in order to upskill digital competencies of the workforce, [32]. Such initiatives are essential to bridge the digital skills gap and foster a culture of continuous learning amid technological advancements.

Cybersecurity and data management constitute another vital domain for future exploration. Given that approximately 75% of EU citizens consider cybersecurity crucial for adopting digital technologies, research should focus on establishing best practices for safeguarding business data and personal information. Investigations into how companies can incorporate compliance with EU data protection regulations, such as GDPR, while maintaining public trust are particularly pertinent. This entails examining technical, organizational, and policy measures that enhance resilience against cyber threats. As IoT systems become increasingly pervasive across sectors like healthcare, manufacturing, and smart cities, understanding layered security vulnerabilities and designing Blockchain-based protective architectures are crucial areas of ongoing research, [33].

The integration of Blockchain technology with IoT systems exemplifies a promising avenue for advancing secure, transparent, and scalable applications. Blockchain's decentralized and corruption-resistant features can address fundamental IoT vulnerabilities, such as authentication weaknesses and data manipulation risks. Developing Blockchain-enabled gateway nodes and decentralized data storage systems can greatly improve operational efficiency and reduce costs related to device maintenance and data management. To support the broader implementation of Blockchain - IoT solutions, future research should focus on addressing integration challenges and establishing standardized frameworks. Despite existing compatibility issues, this convergence also supports the development of next-generation internet models, like Web 3.0, which support new applications in areas like smart infrastructure, entertainment, and data-driven ecosystems, [34].

In the financial industry, future studies should examine how Blockchain can enhance transaction confidentiality, support secure data sharing, and strengthen fraud prevention. In particular, smart contracts have the potential to support environmental, social and governance (ESG) goals by aligning business operations with sustainability objectives. For industry stakeholders, empirical research on Blockchain's impact on financial performance and organizational resilience could provide valuable strategic insights, [35]. Additionally, Blockchain's role in supply chain management, especially in agriculture and manufacturing, requires further exploration. By addressing challenges related to traceability, food safety, and stakeholder trust, Blockchain-based solutions can optimize transparency and efficiency.

Finally, the convergence of FinTech with emerging technologies like AI, robotics, and communication systems is reshaping business and operational models. Future studies should examine the ways in which these innovations could be combined to support organizational agility, improve transparency, and promote sustainable development goals. In addition, in order to develop effective digital transformation strategies across the supply chain sectors, it will be crucial to study the broader implications of these technological shifts, such as their impact on governance, regulatory compliance, and stakeholder engagement, [35].

Declaration of Generative AI and AI-assisted Technologies in the Writing Process

The authors wrote, reviewed and edited the content as needed and verifies that none utilised artificial intelligence (AI) tools were used. The authors take full responsibility for the content of the publication.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

The authors equally contributed in the present research, at all stages from the formulation of the problem to the final findings and solution.

Sources of Funding for Research Presented in a Scientific Article or Scientific Article Itself

No funding was received for conducting this study.

Conflict of Interest

The authors have no conflicts of interest to declare that are relevant to the content of this article.