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Logistics 4.0 toward circular economy in the agri-food sector

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ABSTRACT

Technological development, automation, digitalization, networking, new forms of communication, etc. initiated a new industrial revolution, also known as Industry 4.0. It represents a new form of organization and control of the value chain in the product life cycle. It is a concept that is intensively changing production processes, but its effects are also visible in other areas of human activity, primarily trade, health, agriculture, logistics, etc. By applying the solutions and technologies of Industry 4.0 in the field of logistics, the concept of Logistics 4.0 was developed with the aim of achieving greater efficiency of logistics systems and processes. On the other hand Circular Economy is a model of production and consumption, which involves sharing, leasing, reusing, repairing, refurbishing and recycling existing materials and products as long as possible, whose efficiency greatly depends on the logistics activities and processes. Having previous in mind, the subject of this paper is to rank the main interest areas of circular economy in terms of applying the industry 4.0 technologies for performing the logistics activities within the agri-food sector. The aim is to determine the area which has the greatest potential for further development and should thus be in focus of the future planning of industry 4.0 based logistics activities in the agri-food CE context. Since the circular economy is a systemic approach to economic development designed to benefit businesses, society, and the environment, this is a multi-criteria decision making (MCDM) problem. For solving it a hybrid MCDM model combining the Analytical Hierarchy Proces (AHP) method for establishing the criteria weights, and the Comprehensive distance-Based RAnking (COBRA) method for the final ranking of the alternatives, is proposed. The results indicate that the most important CE interest areas are Reuse/Remanufacturing/Recycle, Supply Chain Management and Product Lifecycle Management.

1. Introduction

In the broadest sense, logistics encompasses all systems and processes that enable the movement of material and non-material flows [1]. Processes that include the movement of these flows can be grouped from the aspect of direction and identified with the terms of forward logistics (flows from the place of origin to the place of consumption) and reverse logistics (flows from the place of consumption to the place of disposal, destruction, reuse, remanufacturing, recycling, etc.). However, both are covered by the term closed loop supply chain (CLSP) [2], which is often identified with the circular economy (CE) concept [3].

The main goals of the CE are the optimization of resources, reduction of raw materials consumption, and waste recovery by recycling or giving a product or some of its parts a second life. Therefore, CE is seen as a new production and consumption model that ensures sustainable growth over time. Hawing in mind the increasing importance of sustainability, it is clear why CE is becoming an important research topic, and especially the optimization of logistics processes that enable its efficient functioning. A significant contribution to the optimization of these processes is made by modern technologies developed within the paradigms known as Industry 4.0 (I4.0). The application of these technologies and their mutual networking for the realization of logistics activities has led to the creation of the concept of Logistics 4.0.

I4.0 represents a revolution that has initiated significant changes in all areas of human activity, including the agri-food sector as one of the primary, if not the most important economic sectors. Since it is fundamental to face the challenge of food security in the coming years, the agri-food sector cannot allow itself to lose the opportunities offered by modern trends brought by the concepts of CE and Logistics 4.0. Accordingly, the aim of this paper is to consider the possibilities of applying I4.0 technologies for the implementation of logistics activities in the CE interest areas within the agri-food sector and to rank these

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Logistics 4.0 based CE interest areas in order to identify those which have the greatest potential for further development and should thus be in the focus of future planning and development of strategies. Since this is a multi-criteria decision-making (MCDM) problem, a novel hybrid model which combines Analytical Hierarchy Process (AHP) method for obtaining the criteria weights, and the Comprehensive distance-Based RAnking (COBRA) method for the final ranking of the alternatives (CE interest areas) is proposed for solving it.

The main contributions of the paper are the investigation of the application of I4.0 technologies for performing the logistics activities within the individual areas of the CE in the agri-food sector, the establishment of a framework for the evaluation and identification of the main interest areas, definition of a unique set of criteria for the evaluation of the CE interest areas, and the development of a novel hybrid MCDM model which combines AHP and COBRA methods.

The paper is organized as follows. The next section provides the background of the study which points out the main I4.0 technologies used in logistics as well as the main CE interest areas. Third section deals with the establishment of the Logistics 4.0 based CE interest areas in the agri-food sector. Fourth section provides the methodology for prioritizing the CE interest areas, while the following section provides the results obtained by applying the proposed methodology. Final section discusses the obtained results and provides main conclusions and future research directions.

2. Background of the study

Logistics 4.0 is defined as the application of the I4.0 technologies in the field of logistics [4]. I4.0 technologies that found the widest application in logistics so far are Internet of Things (IoT), Autonomous Vehicles (AV), Automated Guided Vehicles (AGV), Artificial Intelligence (AI), Dig Data and Data Mining (BD&DM), Blockchain (BC), Cloud Computing (CC), Augmented Reality (AR), Additive Manufacturing (AM), Progressive Robotics (PR) and Electronic/Mobile Markeplace (EMM) [4,5].

The CE is “a model of production and consumption, which involves sharing, leasing, reusing, repairing, refurbishing and recycling existing materials and products as long as possible, thus extending the life cycle of products” [6]. When it comes to CE, it is mostly related to reverse logistics (e.g. [7,8]). However, if one carefully analyzes the definition of CE and one of its main objectives, which is to plan the product life cycle to minimize or avoid any waste in the first place [9], then it is clear that CE encompasses the entire supply chain and that in addition to return logistics includes forward logistics, as well as all business activities and non-material flows that accompany them. Rosa et al. [10] identified supply chain management, circular business model, product lifecycle management, digital transformation, resource efficiency, smart services, reuse, remanufacturing and recycling as the main areas of interest of CE. CE is very much influenced by the new business paradigm brought by the development of I4.0 through the application of modern technologies in its main interest areas. Of course, this paradigm shift in is present in all business and economic sectors, including the agri-food sector, which will be further investigated in the following.

CE is often identified with the closed loop supply chain therefore it is obvious that one of the main CE areas of interest is the *Supply Chain Management* (SCM) [11]. SCM is the process of planning, implementing and controlling all activities in the supply chain in the most efficient way possible. The supply chain includes all transfers of physical goods and services needed to produce and valorize goods on the market, i.e. to reach the end consumer. In the agri-food sector SCM activities are becoming more and more challenging due to the need to shorten the implementation time of all supply chain activities, integrate the quality control, track and trace the agri-food products along the chain, control the temperature over long distances, deal with the product perishability issues and variability in quality of agri-food products, etc. [12]. These challenges can be addressed by applying innovative I4.0 technologies which have recently generated drastic changes in the design, operation and management of supply chains [13]. These changes are also visible in the agri-food sector, in which almost all known I4.0 technologies have been used in the field of SCM, namely, IoT (e.g. [14]), AV (e.g. [15]), AGV (e.g. [16]), AI (e.g. [17]), BD&DM (e.g. [18]), BC (e.g. [19]), CC (e. g. [20]), AR (e.g. [21]), AM (e.g. [22]), PR (e.g. [23]), EMM (e.g. [12]), etc.

CE cannot be achieved in independent companies or by vertical integration of individual activities. Companies need to connect with each other by creating networks between suppliers and consumers within which value chains are created. Accordingly, one of the basic prerequisites for the establishment of the CE is the adoption of a *Circular Business Model* (CBM) which involves defining the company’s business strategy to create, add and preserve value for all participants in the value chain while minimizing economic, environmental and social costs [24]. Due to the growing demands for achieving overall sustainability, CBM is becoming the frequent subject of discussions and analyzes in the academic, business and policy frameworks. Miranda et al. [25] point out that one of the basic preconditions for the implementation of CBM is the development and adoption of sustainably oriented innovations. They see technology as an indispensable element of the agri-food system and a driver of innovations in CE. On the other hand, Poponi et al. [26] point out that the development of new technologies and their application in the agri-food sector contributes to increasing the competitiveness, productivity and efficiency of companies. Accordingly, the I4.0 technologies are seen as an imperative in the future development of CBM in the agri-food sector. Previous research has analyzed the application of certain I4.0 technologies in the development of CBM, such as: IoT (e.g. [27]), BC (e.g. [28]), BD&DM (e.g. [29]) and AM (e.g. [30]). However, there are no researches dealing exclusively with the application of these and other I4.0 technologies for the development of CBM in the agree-food sector.

The CE’s area of interest that further encourages a circular mindset and supports the aforementioned CBMs and the execution of their commercial strategies is *Product Lifecycle Management* (PLM) [31]. PLM is a business strategy that integrates various tools and technologies that simplify the flow of information through three basic phases of the product life cycle: Beginning-of-life (BOL) which includes design and production, Middle-of-life (MOL) which includes distribution, use and providing support in terms of repair and maintenance, and End-of-life (EOL) which involves the withdrawal of products with the aim of disassembling, remanufacturing, reusing, recycling or disposing [32]. The wider application of I4.0 technologies could take the PLM on a whole new level. As for the agri-food sector, only IoT has found wider application for PLM so far (e.g. [33]). However, there are examples of the application of some other I4.0 technologies for PLM, such as: AI (e.g. [34]), BD&DM (e.g. [35]), BC (e.g. [36]), CC (e.g. [37]), AR (e.g. [38]), AM (e.g. [39]), which could find their potential application in the agri-food sector as well.

Another important area of CE is *Digital Transformation* (DT) which can be defined as an organizational strategy that involves the application of digital technologies in order to improve business performance [40]. It is generally defined by four basic dimensions, technology application, value creation changes, structural changes, and the financial aspect [41]. As one of the main goals of I4.0 is the digitization of physical objects and their integration into the digital environment [42], I4.0 technologies are the main drivers of digital transformation. In the agri-food sector, DT is seen as one of the main drivers of the next agricultural revolution, which could reduce the negative effects of the previous "green revolution" that has been recorded in the past couple of decades [43]. I4.0 technologies that were specifically analyzed in the context of DT in the agri-food sector are IoT and BD&DM (e.g. [43]), BC (e.g. [44]), CC and PR (e.g. [45]), AI (e.g. [46]), AM (e.g. [47]) and DM (e.g. [48]). In addition, there are examples of using I4.0 technologies for achieving DT in some other sectors, such as AV (e.g. [49]) and AR (e.g. [50]).

There is a growing consensus in the literature that the transition to CE offers a number of opportunities for systems to achieve a higher degree of *Resource Efficiency* (RE) [51]. According to the most widely accepted definition, RE means "*the use of limited natural resources in a sustainable way while minimizing environmental impact*" [52]. In this paper, the understanding of RE is raised to an even higher level, so in addition to natural, it takes into account other resources, such as time, people, money, equipment, vehicles, computer hardware and software, etc. In recent years, it has been noticed in the literature that the agri-food sector has become one of the most demanding and critical sectors in Europe in terms of consumption of resources, primarily natural such as fossil fuels, minerals, groundwater, land, etc. [53], but also others. This has led to greater interest of researchers in circularity in the agri-food sector and the ways in which it supports the development of innovations that promote RE [54]. These innovations in recent years are reflected in the application of various I4.0 technologies. To achieve RE in the agri-food sector, only IoT technology has been investigated in the literature so far (e.g. [55]). In other sectors, there are examples of the application of some other I4.0 technologies, such as: AV (e.g. [56]), AI (e.g. [57]), CC (e.g. [58]), BD&DM and BC (e.g. [59]), AM (e.g. [60]) and PR (e.g. [61]). Other I.40 technologies have not yet been investigated in the context of RE.

Smart Services (SS) are a powerful tool for achieving CE goals through dematerialization, extending product life and improving digitization efficiency [62]. SS is defined as "*a digital service that emerges as a product of collected and processed data based on networked, smart technical systems and platforms*" [63]. SS require cross-functional cooperation between different areas, e.g. different sectors in the company or different companies in the network, and provide services in one sector based on information collected in other sectors. This connection and mutual cooperation of the sector is largely enabled by the application of I4.0 technologies. For the creation of SS in the agri-food sector, the application of the following I4.0 technologies has been investigated in the literature so far: IoT (e.g. [64]), AV (e.g. [65]), AI (e.g. [66]), BD&DM (e.g. [67]), BC (e.g. [68]), CC (e.g. [69]) and EMM (e.g. [70]). For application in other sectors, AGV (e.g. [71]) and AR (e.g. [72]) technologies were investigated. So far, there are no examples of the application of other I4.0 technologies in the field of SS.

Regardless of the reason for return, all products should tried to be reused, if that is not possible their parts should be reused or they should be remanufactured, and if none of this is possible then the products should be recycled. Reuse (RU) is the process of using a product again for the purpose for which it was originally intended or for some other purpose [73]. Remanufacturing (RM) is "the rebuilding of a product to specifications of the original manufactured product using a combination of reused, repaired and new parts" [74]. Recycling (RC) is the process of obtaining the raw material from waste materials after certain degree of processing [75]. Reuse, remanufacturing and recycling are the main interest areas of CE with which they are often identified. However, there is one important difference between these processes and CE. They all begins in the final stages of the product's life cycle, when it becomes waste or being withdrawn from the market, while the CE begins in the earliest stages of the life cycle and aims to prevent waste from ever occurring [76]. Technological innovations brought by I4.0 have a significant impact on the field of reuse, remanufacturing and recycling in all industries. So far, the application of the following I4.0 technologies to support these processes in various fields has been investigated in the literature: IoT (e.g. [77]), AI (e.g. [78]), BD&DM (e.g. [79]), BC (e.g. [80]), CC (e.g. [81]) AR (e.g. [82]), AM (e.g. [83]) and PR (e.g. [84]). However, no I4.0 technology has been explicitly explored so far for performing reuse, remanufacturing or recycling processes in the agri-food sector.

It is clear that there are researches dealing with the application of certain I4.0 technologies for performing logistics activities (e.g. [4,5]) or developing different areas of CE (e.g. [10]). However, there are no papers in the existing literature that deal exclusively with the wider application of I4.0 technologies for the development of individual areas of CE in the agri-food sector, and this is the research gap that this paper tries to cover.

3. Logistics 4.0 based circular economy in the agri-food sector

Areas of CE in which industry 4.0 technologies are used for the realization of logistics activities in the agri-food sector are seen as the alternatives in this paper. The aim is to identify those areas of CE that contribute most to the sustainability of the CE system in the agri-food sector and to which the greatest attention should be paid in the future plans and actions. Most important CE interest areas in the agri-food sector are described in the following.

3.1. Supply chain management

Since SCM is one of the broadest interest areas of CE, it provides most opportunities for the application of various I4.0 technologies for performing the activities of forward, reverse and business logistics. IoT is used in almost all phases of the agri-food supply chain and all logistics subsystems. It can be used for managing and processing orders and exchanging information between different participants in the chain, for managing transport operations, vehicle locating and routing, fleet management, for managing warehousing operations (transshipment, order-picking, loading/unloading), optimizing inventory levels, for optimization of automatic packaging and labeling, development of smart packaging that have the ability to monitor various parameters of goods, etc. Considering the relationship between transport time, transport costs and product perishability, the possibilities of applying AV in agri-food SCM are more than wide. One of the most influential would be the application of autonomous delivery vehicles as a replacement for retail facilities. This would lead to a change in business and distribution models which would be based on autonomous delivery of ordered goods directly to consumers. AGV technology is widely used in various parts of the agri-food supply chain, primarily for the implementation of internal transport and transshipment processes in various nodes of the logistics network (production facilities, terminals, ports, logistics centers, etc.). AI-based systems in agri-food SCM contribute to maintaining the quality of agri-food products through testing and monitoring of food at each stage of the supply chain, enable sorting of products against a number of criteria in a short time, provide and improve hygiene standards by accelerating the sanitation of vehicles and equipment, enable the preparation of food and beverages according to the specific requirements of users, etc. The application of BD&DM technology facilitates SCM in the agri-food sector by supporting the management of various segments of the supply chain, such as order processing, transport, storage, inventories, packaging, available resources planning, last mile optimization, customer loyalty management, supply chain risk management, valorization of returns, etc. BC technology enables the creation of transparent, reliable, unchangeable and verifiable records that are the basis for the development of the agri-food traceability system. CC technology provides the flexibility needed to cope with the unpredictable variations in supply quality and quantity that characterize agri-food supply chains. CC enables more efficient application of various systems that are integral parts of SCM, such as Warehouse Management System (WMS), Inventory Management System (IMS), Transport Management System (TMS), Intelligent Transport System (ITS), Package Management System (PMS), etc. AR technology can be used to improve the efficiency of agri-food product processing, product advertising, quality assessment, etc. AM technology supports personalized mechanisms for nutritional control and development of food products in accordance with the specific requirements of users. These requirements in terms of product characteristics are accompanied by requirements for the delivery of these goods. In that way, the traditional supply chains are being reconfigured and the so-called customized supply chains are being established. PR technology is used in agri-food supply chains in the stages of providing raw materials (for sowing crops, harvesting, etc.), in the production phase to perform various operations of processing, production, packaging, etc., as well as in the distribution stages to perform various storage operations (loading, unloading, sorting, etc.). EMM technology makes it easier for participants in the agri-food supply chains to procure, trade and cooperate with partners, diversify business opportunities, improve profitability and access the new markets that were previously inaccessible due to the geographical barriers.

3.2. *Circular business model*

In the agri-food sector, I4.0 technologies can be applied for the realization of numerous activities and processes in the field of business logistics. IoT can be applied to establish a flow control system based on Kanban management method to visualize the locations, times and quantities of goods and materials collection/delivery, which is especially important for the agri-food products that have a limited expiration date. IoT can also be used to collect large amounts of data, whose adequate structuring and analysis using BD&DM technologies can improve the overall circularity of the system. In addition, BD&DM can be used to establish strategic and tactical decision support systems, to plan agri-food logistics network by identifying locations for delivery and collection of agri-food products and ways to connect them, manage customer loyalty, as well as to assess innovative business models. AI can be applied to simulate the CE system with the aim of auditing cooperative agri-food networks, assessing the impact of changing business models, as well as to forecast the potential for redistribution of production. BC technology can enable better business cooperation between network participants by ensuring the security and confidentiality of data and information exchange, which is especially important for the logistics of a sector whose flows are accompanied by a large number of documents, such as the agri-food sector. Agri-food is one of the sectors with the greatest potential for the application of EMMs, especially in recent years in the circumstances of the COVID-19 pandemic. This technology enables the creation of new business models and logistics markets through the expansion of supply and improvement of services.

3.3. *Product lifecycle management*

In the agri-food sector, various I4.0 technologies can support performance of forward and reverse logistics operations encompassed by the PLM as one of the interest areas of the CE. IoT can be applied for establishing a platform for animal/food product information sharing, track of raw materials and finished products, their surveillance during consumption in the consumers' households and undertaking the proactive corrective actions before the corruption of the products, e.g. food spoilage due to the inadequate storage, expiration, etc. AI in combination with other I4.0 technology can be applied to support various logistics-related operations in the agri-food sector. With the support of BD&DM technology for market analysis, identification of target users and their requirements, AI can be applied to agri-food product design, rapid concept development based on existing products, improving the quality of innovation and efficiency of product design, providing accurate, high quality and personalized services of sales, product deliveries, product returns and other related services, etc. In combination with AR technology, AI can be used for personalized and collaborative product design, especially packaging that can have a crucial impact on the agri-food product attractiveness, product testing, product inspection, visualization and planning of warehousing operations, etc. In addition to the above, AI can be applied independently to improve the efficiency of the raw material procurement process, selection of suppliers, planning production schedules, improving automation, reliability and safety of production, etc. In addition to the above, BD&DM can be used to accurately predict supplier performance, irregular vehicle and equipment maintenance processes, energy consumption, etc. BC technology can be applied for PLM in the agri-food sector to manage customer relationships, product data, product quality, to track product origin, prevent product counterfeiting, etc. CC facilitates the development of a single PLM system that integrates various individual systems to control internal operations, as well as the creation of a cloud production system. AM strengthens PLM competencies by providing opportunities to improve the performance of agri-food products, such as shorter time from idea to market, fast creation of trial products, reduced product development costs, improved product quality, better material control, faster production, etc.

3.4. *Digital transformation*

Most of the technologies related to Industry 4.0 have a significant impact on the DT in the agri-food sector through the implementation of various business logistics activities. IoT enables digitalization of relations between participants in logistics chains through the establishment of systems for collecting, exchanging and managing information on various chain processes quickly and accurately in order to overcome problems arising from the great diversity of agri-food products and specific requirements for the logistics processes they generate. These systems have the ability to collect, monitor and analyze data in real time, thus creating databases that can be used in decision-making processes. CC technology enables wider and more efficient application of various systems, such as Enterprise Resource Planning (ERP), Electronic Data Interchange (EDI), telematics, etc., in the cloud. These systems enable the collection of large amounts of data, various performance measurements and feedbacks. With the support of BD&DM technology, these systems support responsible business management, which, among other things, enables the valorization of agri-food products, obtaining of timely warnings, anticipating the adverse situations, planning the actions to eliminate the consequences, etc. AI enables digitalization of the processes of monitoring the status of goods and means of transport, and with the support of AR technology facilitates the implementation of logistics activities, primarily those related to transport, e.g. navigation and movement of vehicles in difficult conditions, improving the ability of drivers, improving traffic safety, and thus goods, etc. EMMs are closely related to DT because they are the main drivers of digitalization of the market, which enables the realization of very fast electronic transactions, which is of particular importance in agri-food supply chains. As these electronic transactions are subject to abuse, the required level of security is provided by the BC technology, which enables the creation of digital contracts, digital bill of lading, etc. Unlike previous technologies that predominantly contribute to the digitalization of the company's relationship with the environment, the following technologies digitize the company's internal processes. AM as a new production technology leads to the digitalization of food design and production processes thus enabling product characteristics to be adapted to individual requirements of consumers in relation to their health and physical activity. PR technology contributes to the digitalization of the process of storage/warehousing, sorting, internal transport and other activities which support the production process.

3.5. *Resource efficiency*

Logistics operations provide additional margins for achieving RE in the context of CE which by definition already implies resource saving and does not leave much room for further improvements. These improvements in the agri-food sector can be achieved by applying various I4.0 technologies. IoT can be used to develop a system that improves productivity based on the collection of data on the engagement of resources, both natural and other, in real time and making adequate decisions based on them. The system enables monitoring and identification of processes that are less efficient and suggests actions for their optimization. AVs, which often include electric drive, which automatically select and follow optimal routes and do not require the involvement of drivers, contribute to the reduction of natural resources, primarily fuel, but also other resources, primarily monetary, time and human. AI technology, supported by BD&DM technologies for data collection and analysis, can be used to identify potential places for resource rationalization, as well as resource savings through better planning of logistics operations, primarily transport and inventory, but also ordering and warehousing. Optimal planning of logistics operations reduces the consumption of energy and other resources (people, money, time) through better allocation and capacity planning. BC technology provides savings in time and human resources through checking, controlling and ensuring the accuracy and reliability of information and data on transport documents, inventories status, customer requirements, providers and other participants in the chain. CC technology through sharing enables savings in the purchase and use of hardware and software resources used in all phases of the logistics chain, as well as the people needed to install and maintain them. Through the visualization of production and logistics operations, primarily transport, storage and transshipment, AR technology enables better preparation, planning and optimization of processes in the agri-food sector. Due to better organization and training of workers, natural resources can be saved, primarily energy and raw materials, but also other resources, such as time, money and people. AM enables the reduction of energy consumption, primarily fuel, due to the reduction of transport activities due to the use of raw materials that can be found closer to the place of production. Additionally supported by PR technology, AM also enables the reduction of manpower that has been replaced by machines, as well as costs and time of performing production and logistics processes, primarily transshipment and warehousing, but also AGV supported internal transport processes. EMM enables the allocation of resources, primarily monetary, time and human, which would initially be used for the implementation of traditional trade operations, to other activities, primarily logistics (transport, storage and distribution).

3.6. Smart services

In the agri-food sector, most I4.0 technologies are applied to the development of smart services in all phases of the supply chain, i.e. in the forward, reverse and business logistics sectors. IoT can be used in the part of the supply chain in charge of procurement of raw materials to provide crop performance assessment services. IoT enables the development of a system for monitoring and analysis of crop data in real time, which creates the conditions for finding crops that achieve the best yield in local cultivation conditions. IoT can also be used to develop systems that identify shortages or expiration of certain agri-food products, and automatically initiate procurement and distribution or reverse logistics processes. Combined with CC and BC technologies, IoT enables the development of advanced product tracking services. CC provides services for collecting, storing, sharing, managing and analyzing data on agri-food products anywhere, anytime and from any computer, with the only condition of being able to connect to the internet and access to a web browser. CC in combination with EMM technology can be used to develop a smart online shopping platform that can provide essential information to both buyers and sellers that can ultimately lead to higher sales and higher profitability, improved marketing and pricing strategies, etc. Furthermore, EMM in combination with AR technology can be used to improve the experience of online retail shopping by providing potential customers not only to review the product to the smallest detail, but also to suggest modifications that can be implemented using AM technology (e.g. product or packaging customization, installation of various sensors, etc.). AV can be used for smart agriculture, for the processing like sowing, fertilizing and harvesting agricultural products, i.e. for the processes of providing raw materials in the supply chain. They can also be used in the phases of agri-food supply chains in charge of distributing and delivering products to the end users, as well as collecting and returning them in reverse logistics processes. AGV vehicles can replace the work of people in harsh environments that prevail in the nodes of agri-food supply chain networks that arise as a result of requirements for certain temperature regimes. In combination with PR and AI technologies, they can be used for automatic collection, sorting and packing of eggs, milking and feeding cows, automatic cleaning, reloading, transshipment, etc. In addition, AI technology can facilitate decision-making based on data and forecasts. Also, AI in combination with BC technology can be used to develop smart contract systems in which BC allows a combination of payment, financing and visibility systems and AI technology allows face recognition as a way to eliminate fraud in agri-food supply chains. In addition, BC technology enables reliable product traceability, which is especially important in the agri-food sector. BD&DM technology can be applied for forecasting, benchmarking and creating risk management models, e.g. poor crop yield due to adverse weather conditions, etc.

3.7. Reuse/remanufacturing/recycling

Reuse, remanufacturing and recycling are the main processes that drive the return logistics activities. Reuse in the agri-food sector mostly refers to the redistribution of products in order to reduce the volume of surplus products generated. Remanufacturing also referred to as the refurbishment or reconditioning, in the agri-food sector implies the return of the damaged or faulty packaged products, misshaped products, wrong weighted products, broken products, etc., with the aim of eliminating these shortcomings and re-producing the same products in accordance with the expected and designed characteristics. Recycling in the agri-food sector refers to the use of raw materials obtained from processing the returned or waste products to produce other products, such as animal food, biomasses for fertilization, energy sources (biofuels), etc. Almost all I4.0 technologies used in this interest area of CE are used in order to form a single waste and returnable management system whose ultimate goal is to collect waste and returnable materials, transport them to the appropriate processing centers (recycling, redistribution or remanufacturing centers) and redistribute them or process them so that they can be used again as raw materials to produce the same product (remanufacturing) or new product (recycling). Accordingly, the system consists of four basic modules: collection, transport, redistribution, and processing. In the collection and redistribution modules, IoT technology can be used to communicate objects such as waste collection bins, vehicles and retail shops, which ensure efficient and fast waste collection, distribution, better utilization of vehicles, better route planning, etc. In this module, as well as in the transport module, there is a wide scope for application of the AV technology. With the support of BD&DM technologies, which collect, store and process large amounts of data, and AI technology, which allows automatic decision making, these vehicles reach their full potential and can completely independently perform processes of collection, distribution and transport. AGV technology can be used in the processing module to perform the internal transport process. Other technologies such as IoT, BD&DM, AI and PR are used in this module to implement the processes of sampling, classification, sorting, monitoring, as well as for data statistical analysis. AM technology through promoting in-situ recycling affects all three modules since it enables local sourcing, which simplifies collection processes, reduces transport distances and thus makes it cheaper, and combines processing with production activities. BC technology allows tracking of materials with unique codes or digital badges from the moment of collection to the moment of processing. With CC technology, the entire waste and return management system can function fully in the cloud, reducing the required hardware and software resources.

4. Methodology

To solve the MCDM problem in this paper, a novel hybrid model is defined that combines AHP and COBRA methods. The AHP method was used to obtain criteria weights, while the COBRA method was used to rank the alternatives.

The AHP method, developed by Saaty [85], is based on the establishment of a hierarchical model with the main goal at the top, criteria and sub-criteria at the lower level of the hierarchy and alternatives at the bottom. This method enables the solution of complicated problems through the analysis of simultaneous interactions of numerous factors in a complex, unstructured environment [86]. The main advantages of the method are its flexibility and simplicity in finding solutions, it allows subjective and objective consideration of both qualitative and quantitative information, allows decomposition of problems into hierarchical levels, which enables analysis of problems with varying degrees of detail, measures the consistency of evaluation made by the decision makers, etc. [86]. The AHP method is very popular and has found wide application in various fields, including logistics (e.g. [87]), I4.0 (e.g. [88]) and CE (e.g. [89]). Due to the mentioned advantages, and above all due to the possibility of hierarchical structuring of the problem, this method was chosen to determine the weights of criteria and sub-criteria in this paper.

The COBRA method developed by Krstić et al. [5], is based on ranking the alternatives according to the comprehensive measure of distance obtained as a combination of multiple distance measurements, namely Euclidian and Taxicab, from the multiple solutions, namely positive ideal, negative ideal and average solution. Finding a compromise solution, the ability to consider criteria that have different measures, the need for minimal intervention of decision makers, stability and ease of use are the main advantages of this method and the main reason why it was chosen in this paper to rank the alternatives. The COBRA method is one of the youngest MCDM methods and has only been used so far in the literature for ranking the applicability of the Industry 4.0 technologies in reverse logistics [5].

Application steps of the proposed hybrid MCDM model are described below.

Step 1: Define the problem structure. First, it is necessary to define the elements of the structure, i.e. the objective, alternatives (variants) and the criteria for their prioritization.
Step 2: Define the evaluation scale. The pair-wise comparisons and the evaluations of the alternatives in this paper are done by using the standardized nine-point scale (Saaty scale) (Table 1) [85].
Step 3: Obtain the criteria weights by applying the AHP metod.
Step 3.1: Form a matrix for pair wise comparison of the elements:

$$P = \begin{bmatrix} p_{11} & p_{12} & \cdots & p_{1o} \\ p_{21} & p_{22} & \cdots & p_{2o} \\ \vdots & \vdots & \ddots & \vdots \\ p_{o1} & p_{o2} & \cdots & p_{oo} \end{bmatrix}, \; p_{ij} = 1, \; p_{ji} = 1 \Big/ p_{ij}, \; p_{ij} \neq 0 \tag{1}$$

elements of which are p_{ij} *(i,j = 1,2,...,o)* and denote the importance of element *i* in relation to element *j,* and *o* is the total number of elements.

Step 3.2: Obtain the element weights based on the eigenvector. First, it is necessary to set up a matrix equation:

$$PW = \lambda_{\max} W \tag{2}$$

Table 1
Saaty scale for criteria evaluation.

Numerical value	Linguistic assessment
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2,4,6 i 8	Intermediate values

where *W* is the element weights matrix, and λ_{max} is the eigenvalue of the matrix *A*. Eq. (2) becomes equation:

$$(P - \lambda_{\max} I)W = 0 \tag{3}$$

where *I* is the identity matrix (matrix whose elements on the main diagonal have a value of 1).

λ_{max} is obtained by solving the equation:

$$\det(P - \lambda_{\max} I) = 0 \tag{4}$$

Based on the value λ_{max} and by transforming the matrix Eq. (3), the system of linear equations is obtained. By solving this system of equations, while respecting the condition $\sum_{i=1}^{o} w_i = 1$, the values of the element weights w_i are obtained.

Step 3.3: Determine the consistency of the evaluations. In order to control the results of the method it is necessary to calculate the Consistency Ratio (*CR*) for each matrix and the overall inconsistency of the hierarchical structure. *CR* is calculated as follows [85]:

$$CR = CI/RI, \tag{5}$$

where *CI* denotes the Consistency Index and can be calculated as:

$$CI = \frac{\lambda_{\max} - n}{n - 1} \tag{6}$$

RI denotes the Random Index values of which, for the matrix of different sizes, can be seen in the paper of Saaty [85]. *CR* is used for checking the consistency of pair wise comparisons and must be less than 0.10. Only then it can be said that the comparisons are acceptable.

Step 4: Rank the alternatives using the COBRA method [5].
Step 4.1: Establish the evaluations a_{ij} of the alternatives *j* (*j* = *1,...,m*) in relation to criteria *i* (*i* = *1,...,o*), thus forming the decision matrix *A*:

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1o} \\ a_{21} & a_{22} & \cdots & a_{2o} \\ \vdots & \vdots & \ddots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mo} \end{bmatrix}, \tag{7}$$

where *o* is the total number of criteria, and *m* is the total number of the alternatives taken into consideration.

Step 4.2: Form the normalized decision matrix Δ:

$$\Delta = [\alpha_{ij}]_{m \times o}, \tag{8}$$

where

$$\alpha_{ij} = \frac{a_{ij}}{\max_j a_{ij}}, \tag{9}$$

Step 4.3: Form the weighted normalized decision matrix Δ_w in the following way:

$$\Delta_w = [w_i \times \alpha_{ij}]_{m \times o}, \tag{10}$$

where w_i is the relative weight of criterion *i.*

Step 4.4: For each criterion function determine the positive ideal (*PIS_i*), negative ideal (*NIS_i*) and average solution (*AS_i*) in the following way:

$$\begin{array}{l} PIS_i = \max_j\left(w_i \times \alpha_{ij}\right), \forall\, i = 1, ..., o\, for\, i \in B \\ PIS_i = \min_j\left(w_i \times \alpha_{ij}\right), \forall\, i = 1, ..., o\, for\, i \in C \end{array}, \tag{11}$$

$$\begin{array}{l} NIS_i = \min_j\left(w_i \times \alpha_{ij}\right), \forall\, i = 1, ..., o\, for\, i \in B \\ NIS_i = \max_j\left(w_i \times \alpha_{ij}\right), \forall\, i = 1, ..., o\, for\, i \in C \end{array}, \tag{12}$$

$$AS_i = \frac{\sum_{j=1}^{m}\left(w_i \times \alpha_{ij}\right)}{o}, \ \forall i = 1, ..., o\, for\, i \in B, C, \tag{13}$$

where B is the set of benefit and C the set of cost criteria.

Step 4.5: For each alternative determine the distances from the positive ideal (*$d(PIS_i)$*) and negative ideal (*$d(NIS_i)$*) solutions, as well as the positive (*$d(AS_i^+)$*) and negative (*$d(AS_i^-)$*) distances from the average solution in the following way:

$$d(S_i) = dE(S_i) + \sigma \times dE(S_i) \times dT(S_i), \ \forall i = 1, ..., o \tag{14}$$

where S_i represents any solution (*PIS_i*, *NIS_i* or *AS_i*), σ is the correction coefficient obtained in the following way:

$$\sigma = \max_j dE(S_i)_j - \min_j dE(S_i)_j \tag{15}$$

$dE(S_i)_j$ and *$dT(S_i)_j$* denote the Euclidian and Taxicab distances, respectively, which are for the positive ideal solution obtained as follows:

$$dE(PIS_i)_j = \sqrt{\sum_{i=1}^{o}\left(PIS_i - w_i \times \alpha_{ij}\right)^2}, \ \forall j = 1, ..., m, \ \forall i = 1, ..., o \tag{16}$$

$$dT(PIS_i)_j = \sum_{i=1}^{o}\left|PIS_i - w_i \times \alpha_{ij}\right|, \ \forall j = 1, ..., m, \ \forall i = 1, ..., o \tag{17}$$

for the negative ideal solution obtained as follows:

$$dE(NIS_i)_j = \sqrt{\sum_{i=1}^{o}\left(NIS_i - w_i \times \alpha_{ij}\right)^2}, \ \forall j = 1, ..., m, \ \forall i = 1, ..., o \tag{18}$$

$$dT(NIS_i)_j = \sum_{i=1}^{o}\left|NIS_i - w_i \times \alpha_{ij}\right|, \ \forall j = 1, ..., m, \ \forall i = 1, ..., o \tag{19}$$

for the positive distance from the average solution obtained as follows:

$$dE(AS_i)_j^+ = \sqrt{\sum_{i=1}^{o}\tau^+\left(AS_i - w_i \times \alpha_{ij}\right)^2}, \ \forall j = 1, ..., m, \ \forall i = 1, ..., o \tag{20}$$

$$dT(AS_i)_j^+ = \sum_{i=1}^{o}\tau^+\left|NIS_i - w_i \times \alpha_{ij}\right|, \ \forall j = 1, ..., m, \ \forall i = 1, ..., o \tag{21}$$

where

$$\tau^+ = \begin{cases} 1\ if\, AS_i < w_i \times \alpha_{ij} \\ 0\ if\, AS_i > w_i \times \alpha_{ij} \end{cases} \tag{22}$$

and for the negative distance from the average solution obtained as follows:

$$dE(AS_i)_j^- = \sqrt{\sum_{i=1}^{o}\tau^-\left(AS_i - w_i \times \alpha_{ij}\right)^2}, \ \forall j = 1, ..., m, \ \forall i = 1, ..., o \tag{23}$$

$$dT(AS_i)_j^- = \sum_{i=1}^{o}\tau^-\left|NIS_i - w_i \times \alpha_{ij}\right|, \ \forall j = 1, ..., m, \ \forall i = 1, ..., o \tag{24}$$

where

$$\tau^- = \begin{cases} 1\ if\, AS_i > w_i \times \alpha_{ij} \\ 0\ if\, AS_i < w_i \times \alpha_{ij} \end{cases} \tag{25}$$

Step 4.6: Rank the alternatives according to the increasing values of the comprehensive distances (*dC_i*) obtained in the following way:

$$dC_j = \frac{d(PIS_i)_j - d(NIS_i)_j - d(AS_i)_j^+ + d(AS_i)_j^-}{4}, \ \forall j = 1, ..., m \tag{26}$$

5. Prioritizing CE interest areas in the agri-food sector

Prioritizing the CE interest areas is the MCDM problem which is solved by applying the established model. The first step of the model implies the definition of the problem structure (objective, alternatives, criteria and sub-criteria). The objective is clear, to identify the CE interest areas that contribute most to the sustainability of the CE system in the agri-food sector. Alternatives are thus the CE interest areas explained in Section 3. The only elements remaining for the establishment of the problem structure are the criteria and sub-criteria for the evaluation of the CE interest areas.

Since CE is a systemic approach to economic development designed to benefit businesses, society, and the environment, three main criteria are defined, namely *Economic* (Ec.), *Social* (So.) and *Environmental* (En.). All this criteria are composed of sub-criteria.

Economic criterion includes the following sub-criteria. *Implementation costs* (Ec.1) – Costs of adapting technology to a specific purpose, purchasing equipment, software development, training of workers, development of necessary regulations, etc., which will enable the application of I4.0 technologies for the implementation of logistics processes within the CE area of interest. *Operational costs* (Ec.2) – Reduction of operating costs of logistics activities (ordering, packaging, distribution, collection, storage, transport, inventories, transshipment, etc.) as a result of the application of I4.0 technologies within the CE area of interest. *Material value preservation* (Ec.3) – The degree of preservation of the value of goods or materials that is enabled by the application of I4.0 technologies in logistics processes within the area of interest of CE.

Social criterion includes the following sub-criteria. *Health* (So.1) – Degree of reduction of negative effects of the logistics activities, primarily transport, on the health of people as a result of the I4.0 technologies application within the CE interest area. *Safety* (So.2) – Degree of people safety improvement, primarily pedestrians and drivers, but also workers in the logistics and processing facilities, throughout the logistics network as a result of the I4.0 technologies application within the CE interest area. *Labor market* (So.3) – Degree of positive influence of the CE interest area on the labor market, i.e. job creation and simplification of work activities as a result of I4.0 technologies application within the CE interest area.

Environmental criterion includes the following sub-criteria. *Waste reduction* (En.1) – The contribution of the CE interest area to waste reduction as a result of the application of I4.0 technology for the implementation of logistics activities within this area. *Emissions reduction* (En.2) - Contribution of the CE area of interest to the reduction of emissions of gasses, particles and noise as a result of the application of I4.0 technology for the implementation of logistics activities within this area. *Energy resource preservation* (En.3) - Degree of preservation of renewable and non-renewable energy sources as a result of the application of I4.0 technologies for the implementation of logistics activities within this area.

The following steps of the proposed model imply the establishment of the criteria and sub-criteria weights using the AHP method and the ranking of the alternatives using the COBRA method. The evaluations necessary for the application of these methods are obtained through the series of roundtables and interviews with the experts with many years of experience belonging to various groups, such as members of the academia, representatives of logistics service providers, and logistics service users (manufacturing and trading companies). The evaluations are synthesized in the way that majority evaluations of some criteria or alternative were adopted as the representative evaluation of the entire expert pool. The pair wise comparisons of the criteria and sub-criteria obtained in this way were used to establish the pair wise matrices, by applying the Eq. (1). By applying the Eqs. (2)–(4) the criteria and sub-criteria weights are obtained. Pair wise matrices and the obtained weights are presented in Table 2. By applying the Eqs. (5) and (6) the consistencies of the evaluations are checked and all values were less than 0.1, which means that all comparisons are acceptable.

The final sub-criteria weights are obtained by multiplying the weights of sub-criteria with the weights of the corresponding criteria. The obtained sub-criteria weights are $w(\mathrm{Ec.1}) = 0.160$, $w(\mathrm{Ec.2}) = 0.088$, $w(\mathrm{Ec.3}) = 0.292$, $w(\mathrm{So.1}) = 0.160$, $w(\mathrm{So.2}) = 0.088$, $w(\mathrm{So.3}) = 0.048$, $w(\mathrm{En.1}) = 0.082$, $w(\mathrm{En.2}) = 0.041$, $w(\mathrm{En.3}) = 0.041$.

Evaluations of the CE interest areas in relation to the established sets of sub-criteria, established by the expert pool, were then used to rank the alternatives using the COBRA method. Decision matrix is obtained according to the Eq. (7) (Table 3).

Decision matrix is then normalized using the Eqs. (8) and (9), and weighted using the Eq. (10). For each criterion function positive ideal (PIS_i), negative ideal (NIS_i) and average solution (AS_i) are obtained using the Eqs. (11), (12) and (13), respectively. By applying the Eqs. (14) - (25) the distances from the positive ideal ($d(PIS_i)$) and negative ideal ($d(NIS_i)$) solutions, as well as the positive ($d(AS_i^+)$) and negative ($d(AS_i^-)$) distances from the average solution are obtained for each alternative. By applying the Eq. (26) comprehensive distances (dC_i) are obtained and by arranging them in the increasing order the final ranking of CE interest areas is established. Values based on which the ranking is established, as well as the ranking itself are presented in Table 4.

In order to check the stability of the obtained solution, a sensitivity analysis is performed. The results presented in the Table 4 are taken as the basic scenario (Sc.0). In addition to this one, four more scenarios have been defined. In the first one (Sc.1) all criteria weights have been equalized. In the remaining scenarios (Sc.2, Sc.3 and Sc.4) the three most important criterions have been neglected, respectively. The obtained results of the sensitivity analysis are presented in Table 5 and Fig. 1. RU/RM/RC was ranked as the best in most of the scenarios (in 3 out of 5), while the SCM is ranked as either the second best (in 3 out of 5 scenarios) or even the best one (in 2 scenarios). It can be concluded from the results that the most important CE interest area is RU/RM/RC, followed by the SCM and PLM.

6. Discussion

Results indicated that the RU/RM/RC, SCM and PLM are the interest areas that contribute most to the sustainability of the CE system in the agri-food sector and to which the greatest attention should be paid in the future plans and actions. RU/RM/RC is expectedly the most important area since it is a driver of the reverse logistics operations and thus one of the core areas of the CE. Thus, in most economic sectors this area has been fully developed with very little margin left to make further dramatic improvements. However, this area has been somewhat limited in the agri-food sector due to the specific characteristics of the product which limits their reusability, recyclability and remanufacturability [90]. and its use. This is one of the main reasons why this area is considered most important in the context of circularity of the agri-food sector. SCM is the area covering the greatest extent of the logistics activities among the CE interest areas [91]. Since it opens wide space for optimization of logistics activities in order to achieve sustainability of the CE system in all sectors, including the agri-food sector [92], SCM is also expectedly highly rated. PLM is also seen as a key concept for ensuring a transition towards more sustainable production and consumption patterns [93]. Since the agri-food production systems and consumption patterns are among the leading drivers of impacts on the sustainability [94], the PLM should be one of the main focus areas in the plans and strategies for achieving the sustainability of the CE in the agri-food sector.

The theoretical implications of the conducted research are reflected in the creation of a framework for the evaluation and ranking of CE areas, the definition of an original set of criteria for this evaluation, as well as the identification of CE areas in which the application of Industry 4.0 technologies would improve the efficiency of the implementation of logistics activities in the agri-food sector to the greatest extent. Researchers could use the mentioned framework as well as the defined set of criteria to rank CE areas in sectors other than agri-food, which makes them universally applicable. Identifying the most significant areas of CE in the context of the application of Industry 4.0 technologies for the realization of logistics activities in the agri-food sector should direct the focus of researchers towards the identification of new technologies and the possibilities of their application in these areas. The practical (managerial) implications of the conducted research are reflected in the provision of support to decision makers who belong to different stakeholders (research and development, manufacturing, sales, and consumers) and policymakers at different levels (local, national, and regional authorities) when making decisions about the creation of strategies and plans. The results of this research define the focus of future actions that should be undertaken to improve the circularity of the agri-food sector. For RU/RC/RM, these actions would entail launching initiatives and providing incentives (e.g. through subsidies, tax reliefs, etc.) for the development and application of Industry 4.0 technological solutions which would increase the recyclability, reusability, and remanufacturability of the agri-food products and encouraged the use of such products by consumers. In the case of SCM and PLM, these actions would imply a redefinition of business models by the management of manufacturing, trading, and logistics service provider companies to focus on circularity as one of the main conditions for gaining a competitive advantage in the market.

A new hybrid MCDM model, which combines AHP and COBRA methods, was developed in this paper, Although these methods are not new, they are combined for the first time in this paper to overcome the shortcomings and use the advantages of the individual methods. The AHP method belongs to the group of pair vise comparison methods, which means that it requires a comparison of all pairs of elements (alternatives or criteria) in relation to all elements from a higher hierarchical level [95]. In the case of the problem from this paper, it would

Table 2

Pair wise comparison of criteria/sub-criteria and obtained weights.

	Criteria			Sub-criteria											
	Ec.	So.	En.		Ec.1	Ec.2	Ec.3		So.1	So.2	So.3		En.1	En.2	En.3
Ec.	/	1.00	2.00	Ec.1	/	2.00	0.50	So.1	/	1.00	2.00	En.1	/	2.00	2.00
So.	1.00	/	1.00	Ec.2	0.50	/	0.33	So.2	1.00	/	1.00	En.2	0.50	/	1.00
En.	0.50	1.00	/	Ec.3	2.00	3.00	/	So.3	0.50	1.00	/	En.3	0.50	1.00	/
w	0.54	0.30	0.16		0.30	0.16	0.54		0.54	0.30	0.16		0.50	0.25	0.25

Table 3
Evaluations of the CE interest areas in relation to sub-criteria.

	Ec.1	Ec.2	Ec.3	So.1	So.2	So.3	En.1	En.2	En.3
SCM	5	9	7	9	9	8	8	9	8
CBM	9	8	6	5	4	5	6	4	7
PLM	8	4	8	6	3	4	7	3	6
DT	6	3	4	3	7	7	4	6	4
RE	4	6	3	7	2	3	2	2	9
SS	3	5	5	4	6	9	3	7	5
RU/RM/RC	7	7	9	8	8	6	9	8	3

Table 4
Final ranking of the CE interest areas.

	d(PIS)	d(NIS)	$d(AS^{+})$	$d(AS^{-})$	dC	Rank
SCM	−0.244	0.508	0.234	−0.209	−0.048	2
CBM	−0.044	0.123	0.029	−0.168	−0.015	4
PLM	−0.218	0.392	0.160	−0.103	−0.034	3
DT	0.441	−0.491	−0.278	0.247	0.056	6
RE	0.596	−0.518	−0.225	0.411	0.069	7
SS	0.355	−0.460	−0.258	0.148	0.047	5
RU/RM/RC	−0.887	0.447	0.338	−0.326	−0.079	1

imply significantly more evaluation, and therefore the consumption of limited resources (time, human, computational, etc.) in the phase of data collection and processing. On the other hand, the COBRA method, which belongs to the group of distance-based methods, is not adequate for obtaining criteria weights. The aforementioned reasons were the main motivation for integrating these two methods into a single model. The limitation of the defined model stems from the limitations of the COBRA method, namely its complexity in obtaining results based on already collected data [5].

The theoretical implications are reflected in providing a basis for researchers to develop new hybrid MCDM models of that would include the whole or individual parts of the model developed in this paper. The practical (managerial) implications are reflected in the possibilities of applying the defined model by practitioners to solve problems from this or some other field. The defined model is universally applicable and with certain adjustments, it could be used to solve problems in any field.

7. Conclusion

The goal of this paper was to identify the CE interest areas which are most affected by the application of the I4.0 technologies for performing the logistics activities within the agri-food sector. After establishing the alternatives, they were evaluated in relation to the defined set of criteria and ranked. For obtaining the criteria weights the AHP method is used, while the COBRA method is used for obtaining the final rank of the alternatives.

Table 5
Sensitivity analysis.

	Sc.0		Sc.1		Sc.2		Sc.3		Sc.4	
	dC	Rank	dC	Rank	dC	Rank	dC	Rank	dC	Rank
SCM	−0.048	2	−0.060	1	−0.038	1	−0.060	2	−0.034	2
CBM	−0.015	4	−0.005	3	−0.017	3	0.005	4	−0.022	4
PLM	−0.034	3	0.012	4	−0.003	4	−0.026	3	−0.036	3
DT	0.056	6	0.027	6	0.029	6	0.059	6	0.043	6
RE	0.069	7	0.043	7	0.027	5	0.063	7	0.081	7
SS	0.047	5	0.015	5	0.038	7	0.033	5	0.039	5
RU/RM/RC	−0.079	1	−0.035	2	−0.036	2	−0.078	1	−0.073	1

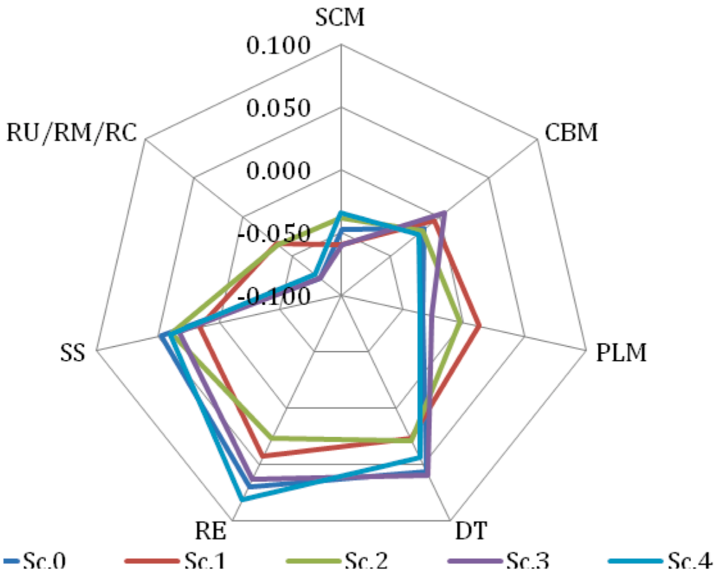

Fig. 1. Sensitivity analysis.

One of the main contributions of this paper is the investigation of the wider application of I4.0 technologies for performing the logistics activities within the individual areas of the CE in the agri-food sector. Another one is the establishment of a framework for the evaluation and identification of the main interest areas which will be in focus of future plans, actions and development strategies aiming at achieving the sustainable CE in the agri-food sector. Significant contribution is also the definition of a unique set of criteria for the evaluation of the CE interest areas. Last, but certainly not least contribution is the development of a novel hybrid MCDM model which combines AHP and COBRA methods. Future researches could investigate the applicability of the I4.0 based logistics activities in the main CE interest areas for some other sector. Since CE is a concept that influences multiple stakeholders, future researches could also investigate main CE interest areas priority in relation to the individual aims and goals of the various stakeholders, as well as the compromise priorities in relation to all of their goals combined.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] S. Zečević, Conceptual definition of logistics, logistics chains, optimality criteria, logistics centers, city logistics, logistics providers (in Serbian), invited lecture, in: Proceedings of the Symposium: Logistics – A Factor of Success, Belgrade, 2006.

[2] N.R. Kumar, R.S. Kumar, Closed loop supply chain management and reverse logistics-A literature review, Int. J. Eng. Res. 6 (4) (2013) 455–468.

[3] M. Farooque, A. Zhang, M. Thürer, T. Qu, D. Huisingh, Circular supply chain management: a definition and structured literature review, J. Clean. Prod. 228 (2019) 882–900, https://doi.org/10.1016/j.jclepro.2019.04.303.

[4] M. Krstić, S. Tadić, S. Zečević, Technological solutions in Logistics 4.0, Ekon. Preduz. 69 (6–7) (2021) 385–401, https://doi.org/10.5937/EKOPRE2106385K.

[5] M. Krstić, G. Agnusdei, P.P. Miglietta, S. Tadić, V. Roso, Evaluating the applicability of the industry 4.0 technologies in reverse logistics using a new MCDM method: cOmprehensive distance Based RAnking (COBRA), Sustainability 14 (2022) 5632, https://doi.org/10.3390/su14095632.

[6] EP – European Parliament, Circular economy: definition, importance and benefits, https://www.europarl.europa.eu/news/en/headlines/economy/20151201STO05603/circular-economy-definition-importance-and-benefits; 2021 [accessed 12 April 2022].

[7] V. Julianelli, R.G.G. Caiado, L.F. Scavarda, SPDMF. Cruz, Interplay between reverse logistics and circular economy: critical success factors-based taxonomy and framework, Resour. Conserv. Recycl. 158 (2020), 104784, https://doi.org/10.1016/j.resconrec.2020.104784.

[8] M. Bernon, B. Tjahjono, E.F. Ripanti, Aligning retail reverse logistics practice with circular economy values: an exploratory framework, Prod. Plan. Control 29 (6) (2018) 483–497, https://doi.org/10.1080/09537287.2018.1449266.

[9] EMF - Ellen MacArthur Foundation, Recycling and the circular economy: what's the difference?, https://ellenmacarthurfoundation.org/articles/recycling-and-the-circular-economy-whats-the-difference; 2012 [accessed 12 April 2022].

[10] P. Rosa, C. Sassanelli, A. Urbinati, D. Chiaroni, S. Terzi, Assessing relations between circular economy and industry 4.0: a systematic literature review, Int. J. Prod. Res. 58 (6) (2020) 1662–1687, https://doi.org/10.1080/00207543.2019.1680896.

[11] A. Mahmoum Gonbadi, A. Genovese, A Sgalambro, Closed-loop supply chain design for the transition towards a circular economy: a systematic literature review of methods, applications and current gaps, J. Clean. Prod. 323 (2021), 129101, https://doi.org/10.1016/j.jclepro.2021.129101.

[12] Scope for industry 4.0 in agri-food supply chain C. Soosay, R. Kannusamy, W. Kersten, T. Blecker, C. Ringle, The road to a digitalized supply chain management: smart and digital solutions for supply chain management, in: Proceedings of the Hamburg International Conference of Logistics (HICL), Berlin, 2018, pp. 37–56. epubli GmbH.

[13] E. Hofmann, H. Sternberg, H. Chen, A. Pflaum, G. Prockl, Supply chain management and industry 4.0: conducting research in the digital age, Int. J. Phys. Distrib. Logist. Manag. 49 (10) (2019) 945–955, https://doi.org/10.1108/IJPDLM-11-2019-399.

[14] S. Yadav, S. Luthra, D. Garg, Internet of things (IoT) based coordination system in agri-food supply chain: development of an efficient framework using DEMATEL-ISM, Oper. Manag. Res. (2020) 1–27, https://doi.org/10.1007/s12063-020-00164-x, 2020.

[15] B.R. Heard, M. Taiebat, M. Xu, S.A. Miller, Sustainability implications of connected and autonomous vehicles for the food supply chain, Resour. Conserv. Recycl. 128 (2018) 22–24, https://doi.org/10.1016/j.resconrec.2017.09.021.

[16] S. Hmidach, Y. El Kihel, D. Amegouz, B. El Kihel, Y. Regad, Optimizing warehouse logistics flows by integrating new technologies: case study of an agri-food industry, in: Proceedings of the IEEE 2nd International Conference on Electronics, Control, Optimization and Computer Science (ICECOCS), 2020, pp. 1–5. IEEE.

[17] A. Di Vaio, F. Boccia, L. Landriani, R. Palladino, Artificial intelligence in the agri-food system: rethinking sustainable business models in the COVID-19 scenario, Sustainability 12 (12) (2020) 4851, https://doi.org/10.3390/su12124851.

[18] J.P. Belaud, N. Prioux, C. Vialle, C. Sablayrolles, Big data for agri-food 4.0: application to sustainability management for by-products supply chain, Comput. Ind. 111 (2019) 41–50, https://doi.org/10.1016/j.compind.2019.06.006.

[19] M.P. Caro, M.S. Ali, M. Vecchio, R. Giaffreda, Blockchain-based traceability in agri-food supply chain management: a practical implementation, in: Proceedings of the IoT Vertical and Topical Summit on Agriculture-Tuscany (IOT Tuscany), 2018, pp. 1–4. IEEE.

[20] C.N. Verdouw, R.M. Robbemond, T. Verwaart, J. Wolfert, A.J. Beulens, A reference architecture for IoT-based logistic information systems in agri-food supply chains, Enterp. Inf. Syst. 12 (7) (2018) 755–779, https://doi.org/10.1080/17517575.2015.1072643.

[21] A. Rejeb, K. Rejeb, J.G. Keogh, Enablers of augmented reality in the food supply chain: a systematic literature review, J. Foodserv. Bus. Res. 24 (4) (2021) 415–444, https://doi.org/10.1080/15378020.2020.1859973.

[22] L. Bravi, F. Murmura, Additive manufacturing in the food sector: a literature review, Macromol. Symp. 395 (1) (2021), 2000199, https://doi.org/10.1002/masy.202000199.

[23] R.S. Mor, D. Kumar, A. Singh, K. Neethu, Robotics and automation for agri-food 4.0: innovation and challenges. Agri-Food 4.0, Emerald Publishing Limited, 2020, pp. 189–199, https://doi.org/10.1108/S1877-636120220000027013.

[24] BOI - Board of innovation. Circular economy business models explained, https://www.boardofinnovation.com/circular-economy-business-models-explained/; 2022 [accessed 17 March 2022).

[25] B.V. Miranda, G.F.A. Monteiro, V.P. Rodrigues, Circular agri-food systems: a governance perspective for the analysis of sustainable agri-food value chains, Technol. Forecast. Soc. Change 170 (2021), 120878, https://doi.org/10.1016/j.techfore.2021.120878.

[26] S. Poponi, G. Arcese, F. Pacchera, O. Martucci, Evaluating the transition to the circular economy in the agri-food sector: selection of indicators, Resour. Conserv. Recycl. 176 (2022), 105916, https://doi.org/10.1016/j.resconrec.2021.105916.

[27] I.A. Askoxylakis, Framework for pairing circular economy and the internet of things, in: Proceedings of the IEEE International Conference on Communications, 2018, pp. 1–6. IEEE.

[28] G. Alexandris, V. Katos, S. Alexaki, G. Hatzivasilis, Blockchains as enablers for auditing cooperative circular economy networks, in: Proceedings of the CAMAD 23rd IEEE International Workshop on Computer Aided Modeling and Design of Communication Links and Networks, 2018, pp. 1–7. IEEE.

[29] A. Soroka, L. Ying, H. Liangxiu, S.H. Muhammad, Big data driven customer insights for SMEs in redistributed manufacturing, Procedia CIRP 63 (2017) 692–697, https://doi.org/10.1016/j.procir.2017.03.319.

[30] J. Millard, M.N. Sorivelle, S. Deljanin, E. Unterfrauner, C. Voigt, Is the maker movement contributing to sustainability? Sustainability 10 (7) (2018) 2212, https://doi.org/10.3390/su10072212.

[31] M.P. Pessôa, J.J. Becker, Smart design engineering: a literature review of the impact of the 4th industrial revolution on product design and development, Res. Eng. Des. 31 (2) (2020) 175–195, https://doi.org/10.1007/s00163-020-00330-z.

[32] S. Terzi, A. Bouras, D. Dutta, M. Garetti, D. Kiritsis, Product lifecycle management–from its history to its new role, Int. J. Prod. Lifecycle Manag. 4 (4) (2010) 360–389.

[33] P. Brizzi, D. Conzon, F. Pramudianto, M. Paralic, M. Jacobsen, C. Pastrone, R. Tomasi, M.A. Spirito, The ebbits platform: leveraging on the internet of things to support meat traceability, in: Proceedings of the EFITA WCCA-CIGR Conference on Sustainable Agriculture through ICT Innovation, 2013, pp. 1–8.

[34] L. Wang, Z. Liu, A. Liu, F. Tao, Artificial intelligence in product lifecycle management, Int. J. Adv. Manuf. Technol. 114 (3) (2021) 771–796, https://doi.org/10.1007/s00170-021-06882-1.

[35] J. Li, F. Tao, Y. Cheng, L. Zhao, Big data in product lifecycle management, Int. J. Adv. Manuf. Technol. 81 (1) (2015) 667–684, https://doi.org/10.1007/s00170-015-7151-x.

[36] X.L. Liu, W.M. Wang, H. Guo, A.V. Barenji, Z. Li, G.Q. Huang, Industrial blockchain based framework for product lifecycle management in industry 4.0, Robot Comput. Integr. Manuf. 63 (2020), 101897, https://doi.org/10.1016/j.rcim.2019.101897.

[37] C. Holligan, V. Hargaden, N. Papakostas, Product lifecycle management and digital manufacturing technologies in the era of cloud computing, in: Proceedings of the International Conference on Engineering, Technology and Innovation (ICE/ITMC), 2017, pp. 909–918. IEEE.

[38] R. Quesada-Díaz, A. Syberfeldt, Product disassembly and inspection supported by augmented reality and product lifecycle management integration. Advances in Manufacturing Technology XXXIII, IOS Press, 2019, pp. 553–558.

[39] A. Romero, D.R. Vieira, How additive manufacturing improves product lifecycle management and supply chain management in the aviation sector?, in: Proceedings of the IFIP International Conference on Product Lifecycle Management, Cham, 2015, pp. 74–85. Springer.

[40] M. Wade, A Conceptual Framework for Digital Business Transformation, IMD, Lausanne, Switzerland, 2015.

[41] C. Matt, T. Hess, A. Benlian, Digital transformation strategies, Bus. Inf. Syst. Eng. 57 (5) (2015) 339–343, https://doi.org/10.1007/s12599-015-0401-5.

[42] M.X. Lee, Y.C. Lee, C.J. Chou, Essential implications of the digital transformation in industry 4.0, J. Sci. Ind. Res. 76 (8) (2017) 465–467.

[43] K. Kosior, Digital transformation in the agri-food sector–opportunities and challenges, Roczniki 20 (2) (2018) 98–104, https://doi.org/10.22004/ag.econ.293647 (Annals).

[44] G.A. Motta, B. Tekinerdogan, I.N. Athanasiadis, Blockchain applications in the agri-food domain: the first wave, Front. Blockchain 3 (6) (2020) 1–13, https://doi.org/10.3389/fbloc.2020.00006.

[45] I. Ali, K. Govindan, Extenuating operational risks through digital transformation of agri-food supply chains, Prod. Plan. Control (2021) 1–13, https://doi.org/10.1080/09537287.2021.1988177.

[46] J. Monteiro, J. Barata, Artificial intelligence in extended agri-food supply chain: a short review based on bibliometric analysis, Procedia Comput. Sci. 192 (2021) 3020–3029, https://doi.org/10.1016/j.procs.2021.09.074.

[47] M. Savastano, C. Amendola, F D'Ascenzo, How digital transformation is reshaping the manufacturing industry value chain: the new digital manufacturing ecosystem applied to a case study from the food industry. Network, Smart and Open, Springer, Cham, 2018, pp. 127–142.

[48] V. Dadi, S.R. Nikhil, R.S. Mor, T. Agarwal, S. Arora, Agri-food 4.0 and innovations: revamping the supply chain operations, Prod. Eng. Arch. 27 (2) (2021) 75–89, https://doi.org/10.30657/pea.2021.27.10.

[49] A. Manfreda, K. Ljubi, A. Groznik, Autonomous vehicles in the smart city era: an empirical study of adoption factors important for millennials, Int. J. Inf. Manag. 58 (2021), 102050, https://doi.org/10.1016/j.ijinfomgt.2019.102050.

[50] A. Bianchini, M. Pellegrini, J. Rossi, C. Saccani, A new productive model of circular economy enhanced by digital transformation in the Fourth Industrial Revolution-An integrated framework and real case studies, in: Proceedings of the 23rd Summer School Francesco Turco, Palermo, Italy, 2018, pp. 12–14. AIDI Associazione Italiana dei Docenti di Impianti Industriali.

[51] P. Núñez-Cacho, V. Molina-Moreno, F.A. Corpas-Iglesias, Cortés-García FJ, Family businesses transitioning to a circular economy model: the case of "Mercadona, Sustainability 10 (2) (2018) 538, https://doi.org/10.3390/su10020538.

[52] EC – European Comission. Resource efficiency – a business imperative, https://ec.europa.eu/environment/resource_efficiency/documents/factsheet_en.pdf; 2011 [accessed 30 March 2022].

[53] A. Muscio, R. Sisto, Are agri-food systems really switching to a circular economy model? Implications for European research and innovation policy, Sustainability 12 (14) (2020) 5554, https://doi.org/10.3390/su12145554.

[54] FAO - Food and Agriculture Organization of the United Nations. Pollutants from agriculture a serious threat to world's water, http://www.fao.org/news/story/en/item/1141534/icode/; 2018 [accessed 30 March 2022].

[55] S. Jagtap, G. Garcia-Garcia, S. Rahimifard, Optimisation of the resource efficiency of food manufacturing via the internet of things, Comput. Ind. 127 (2021), 103397, https://doi.org/10.1016/j.compind.2021.103397.

[56] K. Samal, H. Kumawat, P. Saha, M. Wolf, S. Mukhopadhyay, Task-driven rgb-lidar fusion for object tracking in resource-efficient autonomous system, IEEE Trans. Intell. Veh. 7 (1) (2021) 102–112, https://doi.org/10.1109/TIV.2021.3087664.

[57] L. Waltersmann, S. Kiemel, J. Stuhlsatz, A. Sauer, R. Miehe, Artificial intelligence applications for increasing resource efficiency in manufacturing companies – a comprehensive review, Sustainability 13 (12) (2021) 6689, https://doi.org/10.3390/su13126689.

[58] Y. Jararweh, L. Tawalbeh, F. Ababneh, F. Dosari, Resource efficient mobile computing using cloudlet infrastructure, in: Proceedings of the IEEE 9th International Conference on Mobile Ad-hoc and Sensor Networks, 2013, pp. 373–377. IEEE.

[59] C. Xu, K. Wang, P. Li, S. Guo, J. Luo, B. Ye, M. Guo, Making big data open in edges: a resource-efficient blockchain-based approach, IEEE Trans. Parallel Distrib. Syst. 30 (4) (2018) 870–882, https://doi.org/10.1109/TPDS.2018.2871449.

[60] M. Despeisse, S. Ford, The role of additive manufacturing in improving resource efficiency and sustainability, in: Proceedings of the IFIP International Conference on Advances in Production Management Systems, Cham, 2015, pp. 129–136. Springer.

[61] F. Stuhlenmiller, S. Weyand, J. Jungblut, L. Schebek, D. Clever, S. Rinderknecht, Impact of cycle time and payload of an industrial robot on resource efficiency, Robotics 10 (1) (2021) 33, https://doi.org/10.3390/robotics10010033.

[62] F.A. Halstenberg, K. Lindow, R. Stark, Leveraging circular economy through a methodology for smart service systems engineering, Sustainability 11 (13) (2019) 3517, https://doi.org/10.3390/su11133517.

[63] S. Carsten, J. Monika, N. Jörg, R. Benedikt, Smart services, Procedia Soc. Behav. Sci. 238 (2018) 192–198, https://doi.org/10.1016/j.sbspro.2018.03.023.

[64] D. Georgakopoulos, P.P. Jayaraman, Internet of things: from internet scale sensing to smart services, Computing 98 (10) (2016) 1041–1058, https://doi.org/10.1007/s00607-016-0510-0.

[65] M. Haji, L. Kerbache, M. Muhammad, T Al-Ansari, Roles of technology in improving perishable food supply chains, Logistics 4 (4) (2020) 33, https://doi.org/10.3390/logistics4040033.

[66] N.N. Ahamed, R. Vignesh, Smart agriculture and food industry with blockchain and artificial intelligence, J. Comput. Sci. 18 (1) (2022) 1–17, https://doi.org/10.3844/jcssp.2022.1.17.

[67] S. Wolfert, L. Ge, C. Verdouw, M.J. Bogaardt, Big data in smart farming–a review, Agric. Syst. 153 (2017) 69–80, https://doi.org/10.1016/j.agsy.2017.01.023.

[68] M. Tripoli, J. Schmidhuber, Emerging Opportunities for the Application of Blockchain in the Agri-food Industry, FAO and ICTSD, Rome and Geneva, 2018, pp. 1–40.

[69] Z. Yu, D. Jung, S. Park, Y. Hu, K. Huang, B.A. Rasco, S. Wang, J. Ronholm, X. Lu, J. Chen, Smart traceability for food safety, Crit. Rev. Food Sci. Nutr. 62 (4) (2020) 1–12, https://doi.org/10.1080/10408398.2020.1830262.

[70] K.A. Sedek, M.N. Osman, M.A. Omar, M.H.A. Wahab, S.Z.S. Idrus, Smart agro E-marketplace architectural model based on cloud data platform, J. Phys. Conf. Ser. 1874 (1) (2021), 012022, https://doi.org/10.1088/1742-6596/1874/1/012022.

[71] S. Lu, C. Xu, R.Y. Zhong, L. Wang, A passive RFID tag-based locating and navigating approach for automated guided vehicle, Comput. Ind. Eng. 125 (2018) 628–636, https://doi.org/10.1016/j.cie.2017.12.026.

[72] S.G. Dacko, Enabling smart retail settings via mobile augmented reality shopping apps, Technol. Forecast. Soc. Change 124 (2017) 243–256, https://doi.org/10.1016/j.techfore.2016.09.032.

[73] M. Kalverkamp, A. Pehlken, T. Wuest, Cascade use and the management of product lifecycles, Sustainability 9 (9) (2017) 1540, https://doi.org/10.3390/su9091540.

[74] M.R. Johnson, I.P. McCarthy, Product recovery decisions within the context of extended producer responsibility, J. Eng. Technol. Manag. 34 (2014) 9–28, https://doi.org/10.1016/j.jengtecman.2013.11.002.

[75] G. Villalba, M. Segarra, A.I. Fernandez, J.M. Chimenos, F. Espiell, A proposal for quantifying the recyclability of materials, Resour. Conserv. Recycl. 37 (1) (2002) 39–53, https://doi.org/10.1016/S0921-3449(02)00056-3.

[76] A.M. Ragossnig, D.R. Schneider, Circular economy, recycling and end-of-waste, Waste Manag. Res. 37 (2) (2019) 109–111, https://doi.org/10.1177/0734242x19826776.

[77] P. Ren, M. Nie, H. Ming, Optimization of sports good recycling management system based on internet of things, Wirel. Commun. Mob. Comput. 2021 (2021) 1–11, https://doi.org/10.1155/2021/6415136.

[78] P.K. Gupta, V. Shree, L. Hiremath, S. Rajendran, R. Kumar, U.K. Wiil, The use of modern technology in smart waste management and recycling: artificial intelligence and machine learning, editors. Recent Advances in Computational Intelligence, Springer, Cham, 2019, pp. 173–188.

[79] M. Straka, M. Taušová, A. Rosová, M. Cehlár, P. Kačmáry, M. Sisol, P. Ignácz, C. Farkas, Big data analytics of a waste recycling simulation logistics system, Pol. J. Environ. Stud. 29 (3) (2020) 2355–2364, https://doi.org/10.15244/pjoes/108684.

[80] S. Khadke, P. Gupta, S. Rachakunta, C. Mahata, S. Dawn, M. Sharma, D. Varma, A. Pradhan, A.M.S. Krishna, S. Ramakrishna, S. Chakrabortty, G. Saianand, P. Sonar, S. Biring, J.K. Dash, G.K. Dalapati, Efficient plastic recycling and remolding circular economy using the technology of trust–blockchain, Sustainability 13 (16) (2021) 9142, https://doi.org/10.3390/su13169142.

[81] S. Maharshi, Cloud based disassembly of electric vehicle battery, Procedia Manuf. 30 (2019) 136–142, https://doi.org/10.1016/j.promfg.2019.02.020.

[82] D. Mourtzis, J. Angelopoulos, N. Panopoulos, Recycling and retrofitting for industrial equipment based on augmented reality, Procedia CIRP 90 (2020) 606–610, https://doi.org/10.1016/j.procir.2020.02.134.

[83] F.A.C. Sanchez, H. Boudaoud, M. Camargo, J.M. Pearce, Plastic recycling in additive manufacturing: a systematic literature review and opportunities for the circular economy, J. Clean. Prod. 264 (2020), 121602, https://doi.org/10.1016/j.jclepro.2020.121602.

[84] L. Chin, J. Lipton, M.C. Yuen, R. Kramer-Bottiglio, D. Rus, Automated recycling separation enabled by soft robotic material classification, in: Proceedings of the 2nd IEEE International Conference on Soft Robotics (RoboSoft), IEEE, 2019, pp. 102–107.

[85] T.L. Saaty, The Analytic Hierarchy Process, McGraw-Hill International, New York, NY, 1980.

[86] S. Oguztimur, Why fuzzy analytic hierarchy process approach for transport problems?, in: Proceedings of the 51st Congress of the European Regional Science Association: "New Challenges for European Regions and Urban Areas in a Globalised World", Barcelona, Spain, 2011, 30 August - 3 September 2011.

[87] C.N. Wang, N.A.T. Nguyen, T.T. Dang, C.M. Lu, A compromised decision-making approach to third-party logistics selection in sustainable supply chain using fuzzy AHP and fuzzy VIKOR methods, Mathematics 9 (8) (2021) 886, https://doi.org/10.3390/math9080886.

[88] A. Çalık, A novel Pythagorean fuzzy AHP and fuzzy TOPSIS methodology for green supplier selection in the industry 4.0 era, Soft Comput. 25 (3) (2021) 2253–2265, https://doi.org/10.1007/s00500-020-05294-9.

[89] G.K. Badhotiya, S. Avikal, G. Soni, N. Sengar, Analyzing barriers for the adoption of circular economy in the manufacturing sector, Int. J. Prod. Perform. Manag. 71 (3) (2021) 912–931, https://doi.org/10.1108/IJPPM-01-2021-0021.

[90] A. Muscio, R. Sisto, Are agri-food systems really switching to a circular economy model? Implications for European research and innovation policy, Sustainability 12 (14) (2020) 5554, https://doi.org/10.3390/su12145554.

[91] J.A. Cerqueira-Streit, G.Y. Endo, P. Guarnieri, L. Batista, Sustainable supply chain management in the route for a circular economy: an integrative literature review, Logistics 5 (4) (2021) 81, https://doi.org/10.3390/logistics5040081.

[92] N. Kusumowardani, B. Tjahjono, J. Lazell, D. Bek, N. Theodorakopoulos, P. Andrikopoulos, C.R. Priadi, A circular capability framework to address food waste and losses in the agri-food supply chain: the antecedents, principles and outcomes of circular economy, J. Bus. Res. 142 (2022) 17–31, https://doi.org/10.1016/j.jbusres.2021.12.020.

[93] R. Subramoniam, E. Sundin, S. Subramoniam, D. Huisingh, Riding the digital product life cycle waves towards a circular economy, Sustainability 13 (16) (2021) 8960, https://doi.org/10.3390/su13168960.

[94] T. Stillitano, E. Spada, N. Iofrida, G. Falcone, A.I. De Luca, Sustainable agri-food processes and circular economy pathways in a life cycle perspective: state of the art of applicative research, Sustainability 13 (5) (2021) 2472, https://doi.org/10.3390/su13052472.

[95] F.J. Carmone Jr, A. Kara, S.H Zanakis, A Monte Carlo investigation of incomplete pairwise comparison matrices in AHP, Eur. J. Oper. Res. 102 (3) (1997) 538–553, https://doi.org/10.1016/S0377-2217(96)00250-0.