LUISS

Department
of Business and Management
Course of Management of Circular Economy

Blockchain Application to the CE: the recycling of agri-food waste
EMPIRICAL RESEARCH

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Academic Year 2021/2022

1. INTRODUCTION 3

2. LITERATURE REVIEW AND THEORETICAL FRAMEWORK 5

2.1. RQ1 What are the key enablers or barriers that can impact the success of a circular economy project on the food waste supply chain using blockchain technology? 6

2.2. RQ2 What is the role of blockchain technology in enhancing the efficiency of the food waste recycling process within a Circular Economy perspective? 13

2.3. RQ3 How can Geographic Information Systems (GIS) be integrated with blockchain technology in a food waste recycling project? 15

3. RESEARCH METHODOLOGY 18

4. CASE STUDY 19

4.1. Key enablers or barriers that can impact the success of a circular economy project (Re-Waste) on the food waste supply chain using blockchain technology? 23

4.2. The role of Blockchain technology in improving the efficiency of a food waste recycling process (Re-Waste) from a CE perspective 26

4.3. How can Geographic Information Systems (GIS) be integrated with BCT a the food waste recycling project (Re-Waste) 30

5. DISCUSSION 33

6. CONCLUSION 37

7. REFERENCES 38

ABSTRACT

This study analyzes the potential applications of Blockchain Technology (BCT) to the entire agri-food supply chain, from food production to food waste recycling in agriculture, in line with the Circular Economy (CE) model. The aim is to evaluate the possible and future adoption of blockchain technologies in terms of the benefits they could bring to this sector and how they can be combined with the Track Chain 4.0 project (by the Centro di Ricerche e Studi dei Laghi CRSL) and the Re-Waste project (by Tuscia University), and the improvements they would create for supporting food waste recovery and the CE.

The design, conceptualization, and development of a blockchain-based tracking system in a smart food context will be explored. The system under examination will provide authentication and digital preservation of food-related data, leading to improved traceability and food safety.

The potential advantages and challenges of implementing this system in food waste recycling will be evaluated. The Guidelines for Collecting and Reporting Data on Research and Experimental Development of the "Frascati Manual 2015" were utilized to assess the rationale behind the innovation achieved through the project, which is crucial for obtaining tax benefits provided by European and Italian legislation.

Disposition

The research paper is structured into six chapters: introduction (Ch.1), literature review and theoretical framework (Ch.2), methodology (Ch.3), case study (Re-Waste Project) (Ch.4), results (Ch.5) and conclusion and suggestions for future research (Ch.6).

Keywords: Re-Waste project, Track Chain 4.0 project, food waste recycling, blockchain, circular economy, Geographic Information System (G.I.S.), Geo-Blockchain.

1. INTRODUCTION

The consumption of resources available on our planet has reached completely unsustainable levels and can be effectively represented through "Earth overshoot Day". Earth Overshoot Day is computed by dividing the planet's biocapacity (the sum of ecological resources Earth can generate in a given year) by humanity's Ecological Footprint (humanity's demand for resources in the same year), and multiplying by 365, the number of days in a year.

One of the factors contributing to this unsustainable consumption of resources is food waste. In 2022, the global volume of food waste was estimated to reach over 1.6 billion tons, with almost one-third of all food produced being wasted (FAO, 2022). Food waste generates greenhouse gasses (3.3 billion tonnes of CO2 equivalent released into the atmosphere annually) and contributes to global warming. The direct economic consequences of food wastage (excluding fish and seafood) amount to about $750 billion annually. (FAO, 2022).

There are various reasons for food waste along the food supply chain, including spills, damage during handling or transportation, and deterioration during distribution. The later in the supply chain that a product is lost or wasted, the greater the environmental cost, as the impacts of processing, transport, and cooking are added to the initial production impact.

Consumers have become increasingly aware of ethical and environmental concerns in recent years. The European Circular Economy Action Plan recognizes the circular economy (CE) as a key component of a larger transition towards climate neutrality and long-term economic stability. Companies that adopt a CE approach can reap several environmental benefits, including waste recovery and reuse, resource efficiency, circular inputs, and reduced carbon dioxide emissions. (Maranesi & De Giovanni, 2020). Therefore the CE has been proposed as a way to address the negative consequences of traditional economic activities and promote sustainability, but there are challenges to its implementation.

Böckel et al. (2021) believe that Blockchain Technology (BCT) could help overcome these barriers and enable the CE to reach its full potential. There is a growing body of research and application of BCT to the CE worldwide. The research paper will present case studies from Italy, specifically the Track chain 4.0 model (developed by the Centro di Ricerche e Studi dei Laghi CRSL) and the Re-waste project (under development by the University of Tuscia). Track Chain 4.0 is a model that applies BCT and develops digitized software and processes for companies and start-ups operating in the agri-food industry with a tailor-made approach. Re Waste is a CE project using innovative technologies and systems to recycle food waste.

BCT has the potential to bring transparency and certainty to the waste management sector in Italy, which has been prone to issues with interpretation and management. Blockchain technology can effectively reduce food waste along the supply chain through improved efficiency in food storage and distribution by directly addressing the waste cycle. Additionally, BCT has potential applications in waste cycle tracking, a particularly complex process in Italy as demonstrated by the failure of the Italian waste traceability control system (SISTRI), which was introduced in 2009 by the Ministry of the Environment, the Protection of Natural Resources, and the Sea[1].

The idea behind this research is to link the Track-Chain 4.0 model, which aims to enhance the efficiency in the food supply chain of companies through innovation, with the innovative Re-Waste project, which seeks to recycle food waste sustainably and from a Circular Economy perspective.

The Track-Chain 4.0 research project stems from the innovative approach taken by the food industry to create a new and innovative model for analyzing the evolution and application of ICT methods and technologies in Smart Food. The project focuses on:

- conceptualizing and creatively developing the digital storage of confidential company data in the blockchain (tracking of the distribution chain, exclusive recipes, etc.) to ensure data validity, integrity and accessibility over time;
- innovating the operational and systemic assets of participating companies, with a particular emphasis on management, administration, quality, and production.

[1] SISTRI was an information system implemented in Italy to monitor and regulate the movement of waste with a focus on preventing illegal transport of hazardous waste. In 2010, it was introduced to replace the paper-based traceability control system in order to improve transparency, timely monitoring, and simplify waste management administration. The system included all parties involved in the production, recovery, and disposal of waste and encompassed all modes of transport (sea, rail, road). SISTRI utilized electronic systems and technology, such as USB keys and black boxes, to facilitate information exchange and deter illegal shipments The data collected was managed by the environmental police division of the Carabinieri and shared with the Ministry of the Environment and the European Commission. However, the system faced numerous problems from the beginning, including a controversial 400 million euro tender awarded to Selex (Finmeccanica group), which resulted in 25 arrests and an investigation by the DDA in Naples.

The goal is to create a new, effective, and systematic process at the industrial, training, productive, and organizational levels. The interdisciplinary design model considers the latest protocols and ICT systems in blockchain, the need to establish new relationships between project participants, and a corporate training and development process. All elements developed within the project are transferable to other businesses or projects.

The research will address the following questions through a comprehensive literature review, relevant case studies (the Track-Chain 4.0 project), and a theoretical framework for the implementation of blockchain and GIS technology in the Re-Waste project:

- RQ1 What are the key enablers or barriers that can impact the success of a circular economy project on the food waste supply chain using blockchain technology?
- RQ2 What is the role of blockchain technology in enhancing the efficiency of the food waste recycling process within a Circular Economy perspective?
- RQ3 How can Geographic Information Systems (GIS) be integrated with blockchain technology in a food waste recycling project?

The objective is to identify the most effective solutions and construct a theoretical framework for implementing blockchain technology in food waste recycling within a Circular Economy context (Re-Waste Project).

2. LITERATURE REVIEW AND THEORETICAL FRAMEWORK

The Circular Economy (CE) and Blockchain Technology (BCT) have been widely acknowledged as crucial elements for sustainable development and waste reduction, with the potential to transform the traditional linear economic model and promote closed-loop systems and resource efficiency. Despite growing interest in these areas, there is a significant research gap in the intersection of CE, blockchain, and food waste, particularly in the post-consumption phase of the agri-food supply chain (Ada et al., 2021; Agnusdei & Coluccia, 2022; Baralla et al., 2023).

This study aims to fill this research gap by providing a comprehensive overview of the literature on CE, blockchain, and food waste and identifying the key enablers and effective methodologies for the implementation of BCT in the post-consumption phase of the agri-food supply chain. The post-consumption phase is a critical area of focus, encompassing the entire lifecycle of food products, from consumption to disposal and recycling. This phase is particularly relevant in the context of the 2030 Agenda for Sustainable Development, which prioritizes sustainable production and consumption, specifically targeting a reduction in waste generation through prevention, reduction, recycling, and reuse. Implementing CE principles in the post-consumption phase of the agri-food supply chain can provide solutions for resource utilization, waste management and emission reduction across the supply chain. It is relevant in the 2030 Agenda for Sustainable Development context, which prioritizes sustainable production and consumption, aiming to reduce waste generation through prevention, reduction, recycling, and reuse. Implementing CE principles in the post-consumption phase of the agri-food supply chain can provide solutions for resource utilization, waste management, and emission reduction across the supply chain. However, implementing CE principles in the agri-food industry faces several challenges, such as stringent legal regulations, significant technology investment, a corporate culture within companies, and a lack of understanding of CE.

CE refers to an economy designed to be restorative and centred on reusing materials from end-of-life products, promoting economic growth through resource conservation (EMF, 2013). The concept of a CE, in which resources are used in a perpetual loop, has been discussed in economic and policy circles since the 1970s and further developed through the Cradle-to-Cradle design principles in the 1990s (PwC, 2019; Pearce & Turner, 1989; McDonough and Braungart, 2013). The United Nations Sustainable Development Goals also prioritize sustainable production and consumption, targeting a reduction in waste generation through prevention, reduction, recycling, and reuse (United Nations, 2020). The CE has the potential to achieve this by reducing waste, conserving resources, and shifting business models (Geissdoerfer et al., 2017; Kirchherr et al., 2017; Korhonen et al., 2018).

2.1. RQ1 What are the key enablers or barriers that can impact the success of a circular economy project on the food waste supply chain using blockchain technology?

The first requirement for project development is its financial sustainability, which is particularly critical for R&D projects. A food waste recycling project that aims to align with a circular and sustainable economy perspective must overcome numerous barriers and take advantage of the economic and tax incentives provided for innovative R&D projects.

The European Union continues to prioritize sustainability and actively promote the circular economy (CE), which seeks to balance economic activities with environmental well-being through the principles of "reducing, reusing, and recycling". This transition aligns with the 2030 Agenda and was defined in the Green Deal at the end of 2019. Blockchain identification as a key enabler for the CE is a new field in research and practice (Bockel, Nuzum & Weissbrod, 2021). BCT has been identified as a key tool in overcoming challenges to implementing a CE (Kouhizadeh et al., 2019a,b). According to Böhmecke-Schwafert et al. (2022), blockchain can provide technical infrastructure for CE processes, optimize these processes, enable transactions without a trusted intermediary, and improve security. BCT has the potential to support the CE across several industries, including plastics, construction, food, critical raw materials, and biomass (European Commission, 2015), by creating digital networks for transparent supply chain information and facilitating circular resource flows, waste reduction, and improved decision-making data (Kouhizadeh et al., 2019).

The primary goal of the CE is to find solutions for the challenges of resource utilization, waste management, and emission reduction across the supply chain by providing products, components, and materials that minimize waste and aim for zero waste (Ada et al., 2021). Food waste is a major issue in contemporary society, causing significant environmental impact and economic harm to firms. Food waste is one of the major issues in contemporary society. It leads to significant environmental impact in terms of inefficient use of natural resources as well as an economical cost, harming firms. However, food waste can also be seen as a solution to other problems, such as public health and financial profit. It highlights the issue's complexity and links it to the three parts of sustainable development: economics, social issues, and environmental impact. (Mattsson, Williams & Berghel, 2018; Vishkaei & De Giovanni, 2022).

It is essential to understand the current state and remaining knowledge gaps concerning BCT application in the CE for food waste management (Bockel, Nuzum & Weissbrod, 2021). Implementing the CE requires addressing numerous challenges, such as stringent legal regulations, significant technology investment, and corporate culture within companies (Ada et al., 2021). The shift towards the CE requires re-evaluating traditional business models to identify more sustainable solutions and requires digital transformation progress, similar to e-commerce and Industry 4.0 (De Giovanni, 2022). To fully understand the benefits of BCT, firms need to analyze the strategic changes required, estimate the economic outcomes, and assess the implications for the entire supply chain network (Saberi et al., 2018; De Giovanni, 2022). In operations and supply chain management, BCT can increase transparency, verify the authenticity of raw materials and goods, and ensure traceability and risk mitigation (De Giovanni, 2022).

Ada et al. (2021) conducted a comprehensive review of 136 articles from WOS and Scopus databases to investigate the barriers to implementing CE in the food supply chain and to emphasize the role of digital technologies in overcoming these challenges. Through a content analysis of the research articles, they identified seven main categories of barriers and thirty sub-barrier categories (Tab.1).

Barriers	Description	Sub-Barriers
Cultural	Relates To Societal Beliefs, Values, And Norms That Can Influence The Acceptance And Implementation Of CE	(B1) Lacking consumer awareness and interest (B2) Hesitant company culture (B3) Inadequate knowledge about CE (B4) Currently operating in a linear system
Business and business finance	Economic Investment And Financial Support Are Critical For Developing Technological Infrastructure	(B5) Weak economic incentives (B6) Major investment costs (B7) High cost of receiving recycling product; (B8) Mismatch between return and profit (B9) Increased research cost (B10) Limited business model applications
Regulatory and governmental	Government Support Is Required To Effectively Manage CE Dimensions, And Government Regulations, Incentives, And Environmental Standards Are Important To Deal With CE Barriers	(B11) Lack of conductive legal systems (B12) Policy challenges (B13) Taxation and incentives (B14) Existing loose environmental regulations (B15) Different focuses between central and local governments (B16) Lack of proper waste infrastructure (B17) Lack of standard system for CE performance
Technological	Relates To The Technological Infrastructure Required For CE Transition	(B18) Technical limitations of recycling (B19) Need for data integration (B20) Lack of eco-efficiency of the technological processes
Managerial	Include A Lack Of Collaboration And Missing Information, And Training Is Important To Improve Skills And Knowledge In The Supply Chain And Overcome Difficulties In Defining And Implementing CE	(B21) Poor leadership and management (B22) Missing information exchange (B23) Lack of collaboration (B24) Higher priority of other issues (B25) Ineffective labor
Supply-chain management	Issues With Enhancing The Network Of Activities, Complexity, And Increasing Information, And Collaboration In The Supply Chain Is Necessary To Deal With The Lack Of Eco-Literacy Among Supply Chain Partners	(B26) Lack of eco-literacy among supply-chain partners (B27) Need for a high-level supply chain integration (B28) Unavailable effective framework adaptation
Knowledge and skills	Relate To The Understanding Of Ce And The Skills Necessary To Implement It	(B29) Difficulty in defining CE (B30) Difficulties in implementation of CE

Table 1 - Main potential barriers and sub-barriers to the implementation of CE (CE) in the food supply chain (From Ada et al. 2021).

Preethi and Radhakrishnan (2019) identified several significant challenges in the waste management cycle, including a lack of technology for tracking waste flow, accountability, and awareness and enforcement. Similarly, Laouar et al. (2019) identified seven major problems in waste management (Table 2).

N	Problem	description
1	Final destination of waste	Waste is often transferred to illegal sites to avoid landfill tax or illegal export, where the informal sector dominates the waste collection, recycling or sale to private entities, making enforcement of the laws extremely difficult and losing the economic value of waste.
2	Loss of economic value of waste	The economic value of waste is shown in the process of recycling. On the contrary, a large proportion of them are disposed of by illegal means such as burning, burying and throwing in rivers and oceans, resulting in environmental and health problems and a lack of economic value of waste
3	Cheating and manipulation	When disposing of waste, payment is made per kilogram. In this case, local authorities can not verify the number of kilograms because they do not have a bridge of weight. In similar scenarios, some waste streams that generate a lot of money have been forged because of incorrect and unverifiable information sharing through the balance bridge.
4	Loss and wrong of information	During the stage of filling waste management records, these papers are sometimes lost as they fly during transportation or are filled out in the wrong characters upon departure. This is due to the fact that there is one copy of these records at one central point
5	Lack of knowledge about technology	Lack of knowledge of the latest technologies and their limited applications leads to cummins in waste management
6	Lack of control	Regular government inspections at the waste plant take a lot of effort and time, and often the data is not fully monitored due to a lack of resources
7	Lack of awareness and strict laws	Non-tracking of previous procedures and non-preservation make the application of the laws and accountability very difficult

Table 2 - The top 7 problems in the waste chain from Laouar et al. (2019)

By utilizing advanced technologies and circular economy (CE) principles, significant progress can be made in streamlining food supply chains, increasing transparency, and promoting sustainability. Industry 4.0 tools (as shown in Table 3) offer powerful solutions for overcoming obstacles and addressing key challenges in the food industry. These technologies can help improve efficiency, resilience, and overall performance, reducing food waste.

Ada et al. (2021) highlighted the importance of the innovative use of Industry 4.0 tools in a circular built environment for implementing a CE approach in streamlining food supply chains, increasing transparency, and promoting sustainability. These tools, such as IoT and blockchain, can overcome technical and regulatory challenges and improve efficiency, resilience, and overall performance in both food and food-waste supply chains.

Tang et al. (2022) emphasized the impact of Industry 4.0 on implementing CE practices and using BCT to enhance company performance in India. Their research findings indicate that the application of BCT significantly improves CE practices in areas such as green manufacturing, green design, recycling, and remanufacturing.

Furthermore, the authors argue that Industry 4.0 holds great potential to significantly enhance business operations, financial performance, and environmental performance. They suggest that businesses can achieve long-term objectives by incorporating Industry 4.0 into their manufacturing processes.

CE DIMENSIONS	**INDUSTRY 4.0 TECHNOLOGIES**
Reuse	CPS, BDA, AI, 3DP, RFID, Barcodes,Nanotechnologies, Blockchain
Recycle	IoT, CPS, BDA, CC, AI,3DP, RFID, Barcodes,
Blockchain	Reduce IoT, 3DP
Remanufacturing	IoT, BDA, CC, AI, 3DP, RFID, Barcodes, Robotics
Repair	IoT, CPS, BDA, 3DP
Recover	CC
Refurbish	CPS, AI
Repurpose	Machine Learning
Rethink	AGV, Machine Learning
Redesign	Iot, AGV, Machine Learning

Table 3 - Proposed digital technologies to deal with barriers related to CE dimensions. (From Ada et al. 2021).

Blockchain Technology (BCT) has the potential to bring transparency to complex global food supply chains and guide current food production towards greater sustainability and efficiency. BCT can decrease food waste, enhance working conditions in the food supply chain, and encourage sustainable consumption habits. The technology can lead to better planning, and support circular flows in production.

The European Union recognizes the potential of BCT to drive circularity, reduce material use, and foster an entrepreneurial culture (European Commission, 2020). Furthermore, BCT can help mitigate food waste by preventing recalls and addressing issues such as resource waste and biodiversity loss (Kouhizadeh, Zhu, & Sarkis, 2020). In the future, food systems based on geoBCT will aim for circularity, better food waste management, and closed nutrient cycles, and minimize food waste through careful transportation and storage, while maintaining the cold chain in distribution (Jurgilevich et al., 2016).

Wünsche & Fernqvist (2022) conducted interviews with eight leading BCT providers to evaluate the current state of BCT and to map out its advantages, disadvantages, incentives, motives, and expectations for implementation in global food systems (Fig. 1). The interviews revealed that the main benefits of BCT for the CE are better planning that improves recycling, motivation through crypto tokens, and traceability of records that help identify supply chain flaws and prevent food contamination and spoilage. All interviewees considered BCT to be beneficial, but they also highlighted the difficulties due to the high implementation costs and the lack of incentives for businesses throughout the food chain, from farms to the food and retail industry. Wünsche & Fernqvist (2022) conclude that in order to convince all actors along the supply chain of the benefits of BCT, despite the initially high costs of implementation, more government or societal pressure at the global level may be necessary.

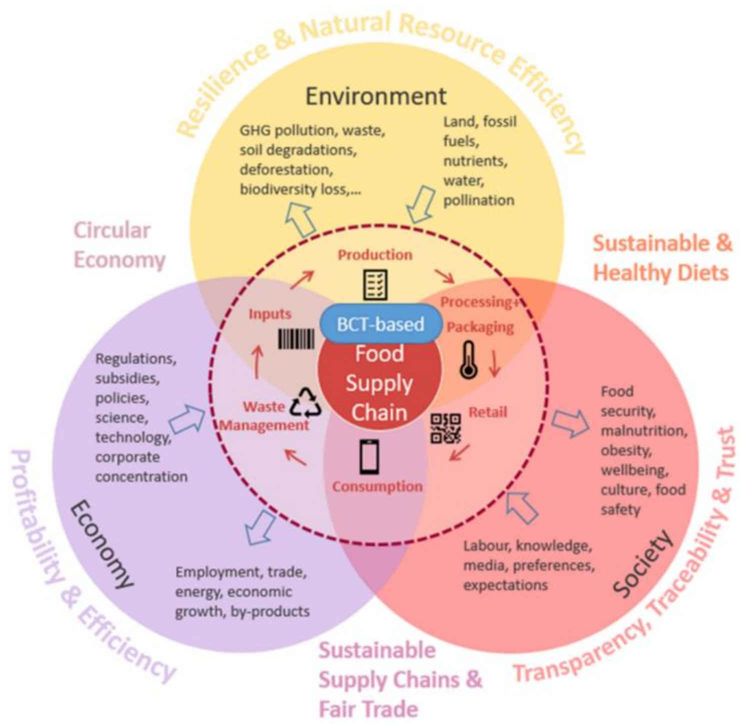

Figura 1 - Sustainable Food System Framework and potential influences from BTC. A conceptualisation of Wünsche & Fernqvist (2022) based on the Food System Framework proposed by the Institute of Food Science and Technology (IFST).

These aspects are relevant for countries such as Italy, which face specific barriers. A recent report on the diffusion of BCT in Small and Medium-Sized enterprises in Italy (SME) by the Blockchain Expert Policy Advisory Board (BEPAB) of the OECD Organization for Economic Cooperation and Development (Bianchini & Kwon, 2020) shows that Italian blockchain companies reported that "complying with regulations and the complexity of administrative procedures" were the most significant barriers for the majority of firms (57%) and were seen as "somewhat an obstacle" by another 20%, particularly concerning smart contracts, hash codes, and digital signatures. "Obtaining financing" was the second crucial obstacle, being a major or minor obstacle for about 40%. The difficulties of explaining the new technology to clients and finding talent were considered to be less critical barriers.

A survey of the Smart Agrifood Observatory of the Politecnico di Milano (Politecnico di Milano, 2020) found a growing interest in blockchain-based applications in the field of food tracking and certification and that a relevant share of companies is focusing on agri-food. In Italy, many companies have made some Industry 4.0 investments to take advantage of financial and fiscal opportunities rather than to utilize new technology effectively.

Therefore, it is clear that at this stage in Italy, the projects based on BCT with the greatest chance of success must be characterized by a high degree of innovation to be eligible for the relative tax benefits provided by Italian and European legislation.

2.2. RQ2 What is the role of blockchain technology in enhancing the efficiency of the food waste recycling process within a Circular Economy perspective?

A comprehensive examination of the existing literature has been performed to comprehend the new perspectives that technologies such as the Blockchain and Circular Economy (BCT) have opened for companies in the food waste recycling sector. Research conducted in January 2023 using the keywords "Blockchain and Circular Economy" found 175 papers on the Web of Science (WOS) and 187 on Scopus. Approximately thirty review articles were created from these documents between 2020 and 2023, which shows a significant number of publications on the topic and demonstrates the links between these emerging research streams. These findings provide new insights into the potential benefits of implementing a circular economy using blockchain technology.

However, only a few studies have explored the challenges firms face in adopting business models at the intersection of Circular Economy (CE) and digitalization. In particular, Rejeb et al. (2023) conducted a systematic literature review of articles published before July 2022 to examine the role of blockchain technology in the transition towards the circular economy. They identified fourteen main themes and related gaps at the intersection of BC and CE. This study revealed that research on BC and CE is dispersed across various academic disciplines and confirmed the findings of Chauhan Parida & Dhir's (2022), which highlighted that research in this sector is fragmented across interdisciplinary fields, with publications scattered across a multitude of journals, methodologies, and themes.

Xie et al. (2022) conducted a comprehensive content-based review of the literature on the application of blockchain technology in the recycling chain. They showed that BCT could bring significant benefits to this sector, but technical, organizational, and environmental limitations still need to be addressed, which may impact adoption behaviour and further scalability. Baralla et al. (2023) analyzed the state of the art of the entire waste supply-chain within the circular economy model, from waste generation to recycling and reuse. They analyzed sixty-six papers but found that only sixteen provided technical details about the proposed blockchain platform, concluding that technical research into the applications of blockchain technology in waste management is still in its early stages.

Yontar (2023) evaluated the role of blockchain technology in sustainable supply chain management for the agri-food sector within the circular economy framework. The study used PESTEL analysis to identify twelve critical success factors for agri-food supply chain management and then employed Analytic Network Process and Multi-Attribute Ideal-Real Comparative Analysis methods to prioritize these factors. The study concluded that blockchain technology's political and technological aspects are critical for success, aligning to reduce waste and increase resource use and food security in the circular economy.

Among original research papers, Liu et al. (2020) proposed a theoretical industrial blockchain-based framework for product lifecycle management (industrial waste). Laouar et al. (2019) demonstrated a blockchain-based approach to waste tracking, enabling waste data reporting in a single system and designing a smart contract-based system to regulate the flow of solid waste. Liu et a. (2021) displayed a unified and transparent double-chain system comprising a public blockchain CreditChain and a consortium blockchain M-InfoChain capable of promoting a demand shift towards more recyclable plastics, as it provides a unified and unambiguous system of reference. Shmeltz et al. (2019) presented a feasible approach to reduce the problem of illegal waste dumping by using the benefits of blockchain technology. With the implementation of the proposed solution, the benefit for citizens would be a transparent waste reuse and transport system. Scott et al. (2021) proposed a hybrid blockchain solution called Polkadot parachain[2] for complete solid household waste tracking from generation to recycling and reuse.

Some studies only apply BCT to electronic waste (Sahoo & Halder 2020; Gupta & Bedi 2018; Dua et al. 2020; Dasaklis et al. 2020). Wang et al. (2019) analysed the application of BCT to the full waste tracking of power batteries from waste generation to recycling and reuse. Ahmad et al. (2021b) described the application of the BCT of medical supplies and equipment for COVID-19 by tracing these special wastes from production to disposal. Another series of studies deal with the application of BCT to waste in general (Lamichhane et al. 2017; Pelonero et al. 2020; Utomo et al. 2020; França et al. 2020) but only for the phases of waste consumption and collection of the waste supply chain. Other papers talk very generically about a blockchain-based system to monitor waste, discussing the advantages, disadvantages, and costs of using a public, private, or hybrid blockchain (Latif et al., 2019; Gopalakrishnan et al., 2021). However, there are no studies found that have applied BCT to food waste from a circular economy perspective.

[2] A blockchain technology that allows for the development of a network of blockchains, each called a parachain that can be customized to the business needs of a given Application)

In recent years, several commercial blockchain waste management projects have been launched as start-ups or pilot projects, including Swachhcoin[3], Recereu[4] , RecycleGo[5], Partitalia[6], Plastic bank[7], End of Waste [8], and Topolytics[9], but their results have not been published in scientific literature, and technical information is unavailable. BCT has been introduced in the food supply chain in recent years, but there are no established applications in the food waste sector. The literature analysis shows that research on this sector is fragmented across interdisciplinary fields, with publications scattered across many journals, methodologies and themes. Few studies examine the challenges firms face in adopting business models. According to a literature analysis (Scupus, January 2023) (Fig.2), less than 10% of publications on this subject area are in economics, econometrics, finance, business, management, and accounting. This lack of knowledge creates a challenge for companies as it requires integration with technical-scientific skills, which are not always available in SMEs.

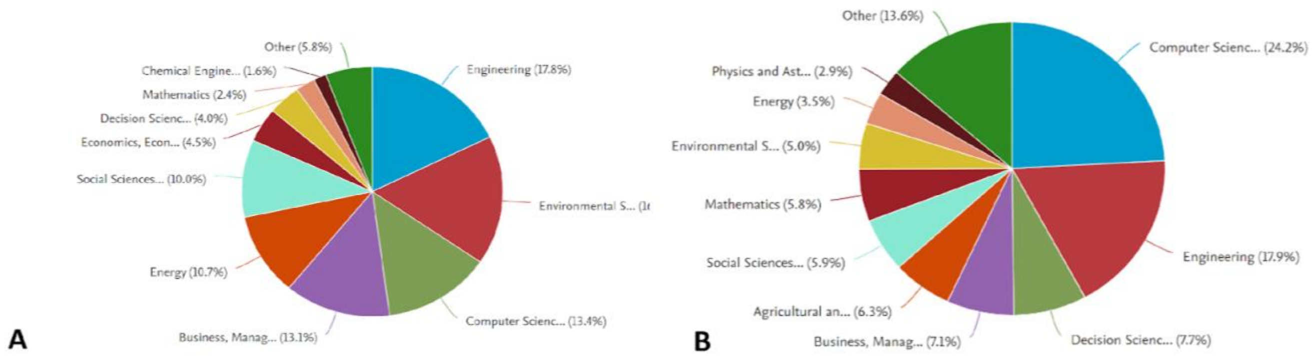

Figura 2 - Documents by subject area research string (Scopus, January 2023): A) "Blockchain AND Circular Economy" (187 papers); B) "Blockchain AND food" (1036 papers)

2.3. RQ3 How can Geographic Information Systems (GIS) be integrated with blockchain technology in a food waste recycling project?

Geospatial Blockchain or GeoBlockchain, as defined by Papantoniou (2020), refers to the combination of blockchain and Geographic Information Systems (GIS) in order to "identify spatial trends of blockchain transactions". GeoBlockchain solutions use a crypto-spatial

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[3] Swachhcoin Whitepaper. http://swachhcoin.com/

[4] Recereum. https://recereum.com/

[5] RecycleGo. https://recyclego.com/

[6] Partitalia. https://www.partitalia.com/

[7] Katz, D.: Plastic bank: launching social plastic® revolution. Field Actions Science Reports. The journal of field actions (Special Issue 19), 96{99 (2019)

[8] End of Waste (EOW). https://endofwaste.com/

[9] https://topolytics.com/

coordinate system to provide an immutable spatial context that is not present in traditional blockchains, allowing GIS technologies to track geographical and spatial behaviours within the blockchain (Papantoniou and Hilton, 2021). The primary goal of GeoBlockchain is not to share geospatial information as data but rather to verify the geographic origin or source of blockchain transactions (Papantoniou, 2020).

Research on the implementation of GIS technology with blockchain is limited. A search conducted in January 2023 using the keywords "Blockchain AND Geographic Information Systems" produced 47 results on Scopus and 28 papers on WOS. Expanding the search to include "Blockchain AND GPS" produced 104 papers on Scopus and 58 on WOS, with many of these being conference papers and reviews but only a few original articles. None of the articles specifically deal with food waste, although some explore the applications of GPS-GIS and blockchain technologies in the agri-food industry and may be relevant to the topics being considered.

In particular, Wu et al. (2022) analyzed the whole- tea supply chain from planting to sales and presented a BCT system framework based on IoT technologies, (RFID) sensors, geographic information system (GIS) and global positioning system (GPS) that can automate the collection of information about the critical aspects of traceability. Xie et al. (2022) proposed an integrated, machine-to-machine traceability data generation system that automatically collects field operation information. This system includes an IoT-based integrated hardware system, GPS, RFID sensors, a smart farm cloud (SFC) platform, and a mobile application, which accomplishes the collection, upload, and storage of operation information. The system was used in the Biological Soil Disinfestation (BSD) organic apple orchard in Qixia, Shandong, China.

Baralla et al. (2018; 2021) presented a system aimed at increasing the potential tourism of an Italian region, Sardinia, by promoting local products and the uniqueness of tradition and culture. The system utilizes blockchain technology and the Ethereum platform to create a traceable and transparent agri-food distribution chain through smart contracts. The system solves the problem of traceability by using decentralized and reliable blockchain technology to safeguard local food products and create digital identity cards. The system also utilizes IoT devices, such as temperature and humidity sensors and GPS, to monitor food preservation and check goods delivery. This system is particularly suitable for cold chain management and may encourage the purchase of typical products by increasing the local economy.

Cheng & Ma (2021) conducted a study on the construction of a digital food ID and intelligent monitoring system based on blockchain traceability technology. The study had two novelty aspects: the blockchain integration and enhancement and the digital ID system design. The decentralization of the blockchain and the mechanism of mutual verification of the block owners were used to prove transactions effectively, and the latest models were used to improve efficiency. The study also discussed the implementation of the monitoring system, which considered the data release issue when multiple consumers request multiple data sources simultaneously. The system was implemented with coding theories, and the method was simulated to verify the models.

Rejeb et al. (2022) reviewed the literature surrounding digitalization in the food supply chain (FSC) technological advances such as blockchain, artificial intelligence, big data, social media, and geographic information systems and highlighted how these technologies represent a building block of the digital transformation that supports the resilience of the FSC and increases its efficiency. Wallace & Manning (2022) presented recent advances in developing transparent data systems to demonstrate food provenance, including Blockchain, and using GIS and stable isotope analysis to provide provenance, mapping and identification methods.

Ali & Aboelmaged (2022) discussed the role of GIS technology in the Australian food and beverage supply chain integration of Supply Chain 4.0, which they defined as the restructuring of supply chain design, planning, production, and distribution using fully automated Industry 4.0 technologies. D'Amico et al. (2022) conducted a systematic review of the literature on strategies and practices for developing a multidimensional platform for analyzing and integrating decision-making in the smart and sustainable bioeconomy. They found that technologies such as sensors, real-time monitoring stations, GPS tracking systems, IoT, smart grids, precision mechanics, and automation have the potential to improve the circularity of various dimensions, including waste, water and wastewater, energy, land, biodiversity, economy, health, safety, education, and agriculture. The study emphasized that effective and efficient implementation of the smart and sustainable bioeconomy requires ongoing planning, monitoring, and analysis of social, economic, technological, and environmental dimensions. Additionally, it can improve participation, accountability, and understanding among citizens, local authorities, and companies, although it also poses various social, economic, and environmental challenges currently being studied by the scientific and managerial community.

Davies and Garrett (2018) suggested integrating technology, including GPS and blockchain, to build sustainable urban food ecosystems (UFEs) and optimize the use of resources and people to enhance the relationship between food, water, energy, and nutrition.

Chen et al. (2021) attempted to address the issue of counterfeit tobacco products and tracking by proposing a blockchain-based traceable and verifiable logistics system for tobacco products using GPS and RFID technologies.

Wang et al. (2020) conducted a systematic analysis of blockchain technology integration with GIS and discussed the potential opportunities. A new architecture of blockchain GIS was proposed, and its potential applications were described in detail. Zhao et al. (2022) reviewed the literature on the application of blockchain technology to geospatial data, including geospatial technologies such as GIS and remote sensing. The authors noted that data privacy, integrity, and security are crucial to sharing and storing geospatial data, which are significant barriers to promoting and developing open GIS. Many articles deal with the applications of these technologies in construction and architecture. The remaining articles on other possible applications of GIS and GPS technology integrated with the BCT cover extensive areas that range from cadastral records; to smart cities, medical fields and traceability of medical waste during the pandemic COVID 19; blockchain-based spatial crowdsourcing systems for spatial information collection, computer science, engineering, mathematics etc.

Regarding the research question (RQ3), most of the analyzed articles approached the topic in general terms and were in the field of mathematics, computer science, and engineering. Only a small percentage (3%) was in the subject area of Business and Management (Scopus, January 2023), but with articles that were not relevant to the study. The few articles of real interest (i.e. Xie et al., 2022 or Baralla et al., 2018, 2021) provide extremely technical contributions. Literature review shows that BCT can be successfully integrated with GPS GIS technology, the Internet of Things, RFID sensors, and automation (AI) and can potentially improve circularity and food waste recycling programs. However, the actual applications of these technologies are still relatively few, and there are no reference studies or experiences to evaluate the effects of their implementation in the food-waste chain.

3. RESEARCH METHODOLOGY

This work aims to be one of the first to assess the possible benefits of applying blockchain technology in the food-waste sector from a circular and sustainable economy perspective. The three proposed research questions (RQs) summarize the main barriers to introducing this technology in this area and highlight the role and opportunities it could represent.

The research methodology involves three successive steps. First, the research questions will be analyzed using literature studies. The databases used for the literature review include WOS, Scopus, Science Direct-Elsevier, IEEE Xplore, JSTOR, and Research Gate. Reports from the Food and Agriculture Organization of the United Nations (FAO), the OECD Organization for Economic Cooperation and Development, the Italian Ministry of Economy and Finance (MEF), ISPRA, the Digital Innovation Observatories of the School of Management at Politecnico di Milano, and consulting firms such as McKinsey, Deloitte, and Ernst & Young were used for specific aspects. Finally, standards produced by institutes such as ISO, UNI, CEN-ELEC, CEN, and ETSI were also consulted.

The second step consists of analyzing the possible applications of the GIS and blockchain technology to a theoretical case study: the Re-Waste project. The third and final step involves a discussion of how the combination of technological and business innovations proposed in the Re-Waste project can overcome the main barriers previously identified by responding to the three research questions.

4. CASE STUDY

As shown by the detailed, updated, and comprehensive analysis by Baralla et al. (2023), the use of blockchain technology in the waste management sector has been studied with a focus on state of the art in literature and ongoing industrial projects. However, the authors found that no projects currently apply blockchain technology (BCT) in the food waste cycle. The Re-Waste project was developed using a theoretical approach, as no case studies could be used as specific references in the food waste sector.

In the following, the innovative Re-Waste project is briefly presented. Then, the application of BCT in two case studies that utilize the Track Chain 4.0 model is discussed. These case studies highlight the fundamental role of innovation assessment (Frascati Manual and Oslo guideline) in obtaining tax benefits expected for R&D projects. Finally, an innovative application of BCT to the Re-Waste project is presented, in which the structure and organization of the Track Chain 4.0 Model have been implemented and developed through the application of new technologies (Geoblockchain, IoT, RFID, IDSS, AI).

Projects like Re-Waste are essential in the closure “end-to-end “of the food-waste supply chain from a circular economy perspective. In discussing the Track Chain, 4.0 model and the development of a BCT project, including the Re-Waste project, RQ 1 and RQ2 will be analysed with a specific focus on RQ3 in this latest project.

The research project aims to analyze and develop a blockchain traceability system for managing raw and secondary raw material processes and procurement systems in the various stages of waste treatment in the agri-food sector. This research will complement the Re-Waste project, promoted by the University of Tuscia and directed by Professor Andrea Colantoni.

Re-Waste proposes a circular economy approach to enhance organic waste in Lazio, turning it into a resource for agriculture. The significant waste in the agri-food chain includes waste from collective restaurant distribution and consumption phases and vegetable waste from vegetable products that are considered particular waste. Re-Waste aims to create low-impact products from food waste to be used as fertilizers, soil improvers, and biostimulants in agriculture, improving plants' natural defences and enhancing growth and productivity.

The project will contribute to managing waste from canteens and in the region's agriculture by using the patented Smart Cara CS10 and specific mushrooms as wood decay agents to extract molecules of interest from waste and optimize existing ones. The proposed system aligns with the circular economy and the European 2020 objective of self-disposal of organic waste by producers (“zero waste”).

The research project will also increase the added value of food waste by promoting the deployment of digital and blockchain-based infrastructure for improving agricultural data sharing and scaling up a sustainable agricultural recycling program. This deployment will enhance the added value of food waste and its ability to provide local, economic, social, and environmental benefits, promoting more transparent relationships between actors in the supply chains. Using BCT guarantees transparency throughout the supply chain and communicates the products' real quality to customers (Ruzza, Morandini & Chielli, 2022).

According to the Food and Agriculture Organization of the United Nations (F.A.O.), about one-third of all food produced worldwide is lost or wasted in the transition between producer and consumer. In Europe, approximately 87.6 million tons of food are lost yearly (FAO, 2022).

In the European Union (E.U.), an estimated 20% of the food produced is lost or wasted. (FAO, 2022). The E.U. has intervened on more than one occasion to address this issue. The E.U. issued the “waste directive”, which invited Member States and their citizens to reduce food waste between primary production and distribution, reduce food waste in households, encourage food donations, and monitor and evaluate the implementation of food waste prevention measures. The E.U. has also given further impetus to the fight against food loss and waste with the European Green New Deal presentation

European Green New Deal[10] which includes a new action plan for the CE. This plan provides a system for reusing discarded agri-food products.

In the Farm to Fork strategy,[11]the European Union is committed to reducing food waste per capita at retail and consumer levels by 50% by 2030 and providing tools for reusing agri-food waste from a circular economic perspective (European Union, 2020). In particular, "The circular bio-based economy is still a largely untapped potential for farmers and their cooperatives. For example, advanced bio-refineries that produce bio-fertilisers, protein feed, bioenergy, and bio-chemicals offer opportunities to transition to a climate-neutral European economy and create new jobs in primary production" (European Union, 2020).

Italy intends to strengthen the strategic role of the agricultural, food and forestry sectors within the complex national economic system, as well as in the European and international context, particularly in areas where these activities are concentrated. These endeavours can leverage the opportunities presented by the ecological transition, digitalization, the CE, and reducing food waste through agroecology. Sustainability and inclusiveness can be drivers of competitiveness at the sectoral and regional levels, and agri-food waste can be transformed into a resource, helping to achieve the objectives outlined in the European Green New Deal.

According to the latest ISPRA report (ISPRA, 2020) for Italy, 67.7% of the organic fraction originates from restaurants and canteens, where a project for tracking and recovery of food waste could be implemented. The waste sorting can be further divided as follows:

- Restaurants and canteens contribute 67.7%
- Waste for domestic composting accounts for 3.7%
- Waste from garden and park maintenance accounts for 27.8%
- Waste from major markets accounts for 0.8%

Re-waste enables the creation of a secure and sustainable approach to controlling crop diseases. This is achieved through a model that recycles wet organic waste and transforms it into a resource. The primary innovation of this project is the ability to reduce the volume and weight of agri-food waste on-site (in companies producing waste) by up to 90%, thus reducing pollution and the high costs associated with waste management. The processed waste can then be used for sustainable agricultural production by providing low-cost plant protection products.

[10] https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/delivering-european-green-deal_en
[11] https://food.ec.europa.eu/horizontal-topics/farm-fork-strategy_en

Food waste contains valuable biomolecules such as phytochemicals, bioactive phenolic compounds, oligosaccharides, and minerals that can alter critical physiological processes in crops (Ceccarelli et al., 2022). This research project aims to exploit these waste by-products to develop a sustainable strategy for crop growth, development, and resilience to abiotic stresses and to replace chemical fertilizers. Agronomic trials were conducted on two model species for agriculture (wheat and tomato) by using agro-food waste, i.e. orange peel and crustacean shells, that were compacted and dehydrated, the solid residue (S.R.) obtained at the end of the compaction cycle was directly added to the growth substrate (fig. 3).

The goal of this study was to investigate the potential of using food waste as a source of bioactive products and as a soil improver in a circular economy and sustainable agriculture. The Smart Cara CS10 device was used to reduce the volume and weight of food waste by up to 90% and remove the liquid fraction. The resulting solid residues (S.R.) were then used as a high-quality organo-mineral fertilizer, soil improver and compost. The addition of low doses of S.R. was found to positively influence various morpho-physiological parameters of model crops, such as Arabidopsis thaliana and Triticum spp., suggesting that they may be effective in regulating plant physiology. Additionally, S.R. was found to improve soil's hydrogeological and breathable characteristics and have soil remediation effects by positively impacting plant-microbiome relationships and optimizing interactions with beneficial microorganisms. Furthermore, tests were conducted to assess the effect of S.R. on growth and productivity in a protected environment, in compliance with the specific environmental requirements of each crop. The S.R. obtained at the end of the compaction cycle was used to obtain bioactive oligosaccharides, such as chitooligosaccharides and oligogalacturonides, which have the potential to serve as alternatives to traditional agrochemicals. These oligosaccharides were found to stimulate the innate immune system of plants and effectively counteract phytopathogens (Savatin, 2022).

In conclusion, this research project highlights the potential of using food waste as a sustainable source of bioactive products and soil improver in a circular economy and sustainable agriculture. The study demonstrates that the Smart Cara CS10 device can effectively reduce the volume and weight of food waste while producing high-quality organo-mineral fertilizer and soil improver. The results suggest that the solid residues obtained have the potential to improve soil characteristics, stimulate the innate immune system of plants, and meet production needs on a company scale with increased yields, improved nutrient efficiency, biocontrol, crop protection, and increased tolerance to abiotic stress (Savatin, 2022; Ceccarelli et al., 2022).

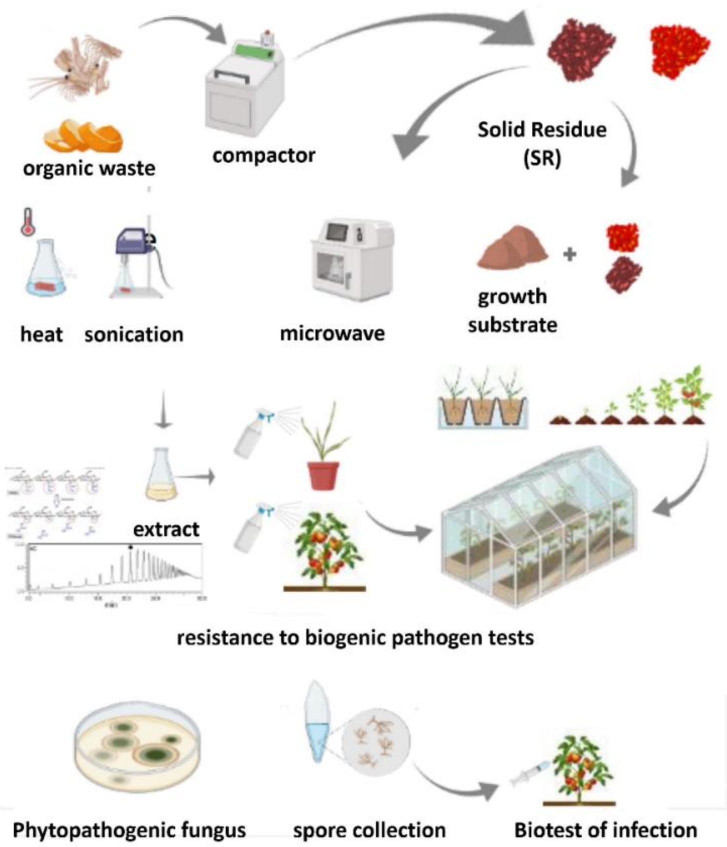

Figura 3 - The main stages of the Re-Waste Project

4.1. Key enablers or barriers that can impact the success of a circular economy project (Re-Waste) on the food waste supply chain using blockchain technology?

The project re-waste to find concrete application in the potentially interested farms/companies must overcome many barriers and take advantage of all the incentives partially identified in the literature review. A critical element of the RE-Waste process is the certification and tracking of the organic products obtained thanks to recycling organic waste. But for this process stage, many BTC applications can already be taken as benchmarks. So to effectively structure the theoretical framework of the Re-Waste Project and address the research question, the Track Chain 4.0 model was identified, which has been successfully applied in similar/blockchain projects in Italy. This model has been developed by the Centro di Ricerche e Studi dei Laghi (CRSL)[12] digital hub, which supports companies in training activities involving advanced technologies like blockchain, IoT, big data, and artificial intelligence. In

[12] Founded in 2017, CRSL – Centro Ricerche e Studi dei Laghi, is a relatively young but highly dynamic reality that has received prestigious accreditations: It is a spin-off of the Carolina Albasio High School of Castellanza, and is one of the founders of the POLO UNIVERSITARIO METIS Foundation. CRSL is registered in the National Research Registry file of MIUR and is certified by Unioncamere as a 4.0 Technology Transfer Center (CTT). As 4.0 CTT, CRSL has developed a series of new technologies to be transferred as part of the subsidies on innovative assets; this is an extension of the activities of CRSL, which aims to implement some services related to the issues of its 8 Departments, in terms of innovation, process quality, safety, environment and energyhttps://www.crslaghi.net/en/

particular, CRSL digital hub supports companies in projects involving the latest technologies, such as big data applications, cloud tools, machine learning systems and artificial intelligence, Blockchain and Internet of Things (IoT) solutions.

In the analysis of the two cases where the Track Chain 4.0 model was applied - Cannoleria Siciliana and Pastificio Pasta - the firms that operated in a linear system faced various barriers in implementing Blockchain Technology (BCT) in their production processes. The primary challenge was the difficulties associated with the investments required to acquire new technologies. The Track Chain 4.0 model helped these companies access the tax benefits of Industry 4.0, which were proposed in the early stages of the projects. These R&D projects, to be eligible for the tax relief provided by current Italian legislation, had to comply with the requirements outlined in the Frascati Manual (OECD, 2015), specifically, Chapter 1, points 1.32 and 1.33, and Chapter 2, points 2.7 and 2.8, as well as the Oslo Manual (OECD/Eurostat, 2018) guidance on measuring innovation. R&D is defined as systematic and creative work aimed at increasing the stock of knowledge and developing new applications of existing knowledge (point 1.32). For an activity to be considered R&D, it must meet the following criteria according to points 1.33 and 2.7 of the Frascati Manual:

- Novel
- Creative
- Uncertain
- Systematic
- Transferable and/or Reproducible"

All five criteria must be met, at least in principle, every time an R&D activity is undertaken, whether on a continuous or occasional basis (point 2.8). Therefore, through the analysis of the two projects in which the Track Chain 4.0 model was applied, the necessary activities to meet the R&D criteria and obtain the respective tax benefits were identified and summarized in Table 4. In addition, for each of the companies involved, a form of "objectively verifiable indicators" (OVI) consistent with the indications of the Frascati manual and the guidelines of the Oslo Handbook was created and compiled to assess the technical and scientific aspects of the project.

The following main barriers and limitations were found in the two companies involved in the Track Chain 4.0 project before its implementation:

- Lack of adequate ICT tools
- Staff with inadequate ICT knowledge
- Absence or inadequate knowledge of blockchain technology (BCT)

- Limited traditional business model applications
- Limited traditional leadership and management
- Poor penetration capacity in new markets

Regarding the first three barriers identified, the Track Chain 4.0 project provided the technical knowledge and adequate training to the staff who must manage the new IT /BCT tools and processes.

Human Resources (HR) is a vital hub in Industry 4.0 innovation. It is fully included in Track-Chain 4.0, not just from a productive point of view but also from the sense of belonging to the working reality in which they participate. Investing in workers' knowledge, internal and external means improving company knowledge, encouraging innovation processes and increasing performance. It also allows a greater alignment between human and artificial resources and thus enhances the knowledge and ability of the former to utilize the latter's potential.

R&D criteria	activity
novel	An analysis was made of the evolution of the external environment and of the needs of companies and the market. Based on this analysis, the company's operating model has been redesigned through the development and application of innovative ICT technology (Ethereum blockchain). The aim was to improve the efficiency of the company, the effectiveness of marketing actions and product traceability.
creative	The application of the model As Is - To Be (Business Process Modeling) for the Company has allowed to define the critical factors of the processes (As-Is) and then to develop or apply concretely and creatively the available technology to overcome these critical issues to Increase efficiency and create new ICT tools for businesses This has allowed the transformation of the operating model of the company (To Be).
uncertain	For each project, an accurate analysis has been carried out of the uncertainty factors that still remain present, and that represents one of the characteristics of innovative projects. In addition to the onerous/economic aspect of the investment made, it is uncertain ex-ante the actual impact that the project maintains on the entire design of the same "Innovation disengagement" remains one of the highest uncertainty parameters, as successful innovation requires major changes in workforce management and training, as well as a great effort in internal communication and change management. The factors of uncertainty (despite the efforts made to minimize them) remain, especially in cases such as those under consideration where the introduction of innovative ICT tools requires building renewed relational systems between the activities and the staff involved in the new processes.
systematic	The transformation processes in companies introduced with the application of the track chain 4.0 model are permanent and innovative and involve systematically implementing all the organizational and productive models of the previous system.
transferable and/or reproducible	The model, the knowledge and the functionalities developed within the track chain 4.0 project are easily transferable to other contexts or new business projects as the result of the research is potentially reproducible as a model of response to similar needs of the sector. Its application demonstrates this to two companies (Pastificio Pasta and Cannoleria Siciliana) with different types of products and organizational models of departure.

Table 4 - the five main R&D projects criteria established by the Frascati Manual

To overcome the other main barriers, the project Track-Chain 4.0 has transformed the business organization through a helpful tool that is shared and open to further links in Information and

Communication Technologies (ICT) and has developed new models and BCT methodologies for data security, validation with a positive implementation of the supply chain in the food sector.

The main barrier to overcome, however, is the cultural one. Many Italian SMEs, especially in the agri-food chain of products of excellence, have rooted traditional management models. Blockchain technology is still in development, and the cases where its application has led to tangible benefits to production processes are still too limited in the Italian SMEs to incentivize entrepreneurs to integrate them into their companies.

To make the ITC and BCT innovations permanent after the experimental phase, it is, therefore, necessary that the top management perceives the efficiency of production processes and that consumers' understanding of the traceability of products results in an effective increase in sales. However, in the field of farms, digital innovation and precision agriculture are operating a remarkable transformation that can also be a driving force for the introduction of blockchain technology.

The market of organic products is constantly growing; therefore, the possibility of having certified and traceable organic agri-food throughout all supply-chain can significantly expand the business possibilities of the farms/firms.

4.2. The role of Blockchain technology in improving the efficiency of a food waste recycling process (Re-Waste) from a CE perspective

This project aims to improve food waste recycling by focusing on small-scale actors. Blockchain Technology (BCT) can allow farms to collect food waste treated with Re-Waste technology and trace the obtained organic products. The Track Chain 4.0 model can be applied to enable farms/companies interested in Re-Waste technology to receive tax advantages and organize or reorganize their production processes to implement the BCT. However, there is currently a lack of research studies or specific initiatives that detail the application of BCT to the food waste cycle from a Circular Economy (EC) perspective. Thus, this study aims to develop a theoretical framework to guide future implementation phases.

From that premise, we will discuss how the BCT can be applied to the Re-Waste project. To effectively implement the theoretical framework presented in this study, it is crucial to accurately identify and contextualize the challenges and key facilitators involved in integrating blockchain technology for monitoring the circular lifecycle of food waste. It is well known that the blockchain-based infrastructure will increase value chain transparency and improve agricultural data sharing, supporting business process improvement and mechanization (Ge et al., 2017; Burke, 2019; Zhao et al., 2019; McEntire & Kennedy, 2019). There are fewer and more isolated cases where BCT has been applied with the success of the waste cycle (Baralla et al., 2023), but, as far as we know, none is known in Italy.

The focus in the waste-supply chain is on developing a modular architecture that enables fast system configuration. The distributed ledger layer acts as a decentralized data management system, enabling the storage and retrieval of data and ensuring its legal validation. According to Laouar et al. (2023), a model (Fig 4) was developed with the main components and actors of a blockchain-based food-waste management system. The contribution of blockchain usage will be discussed for each phase.

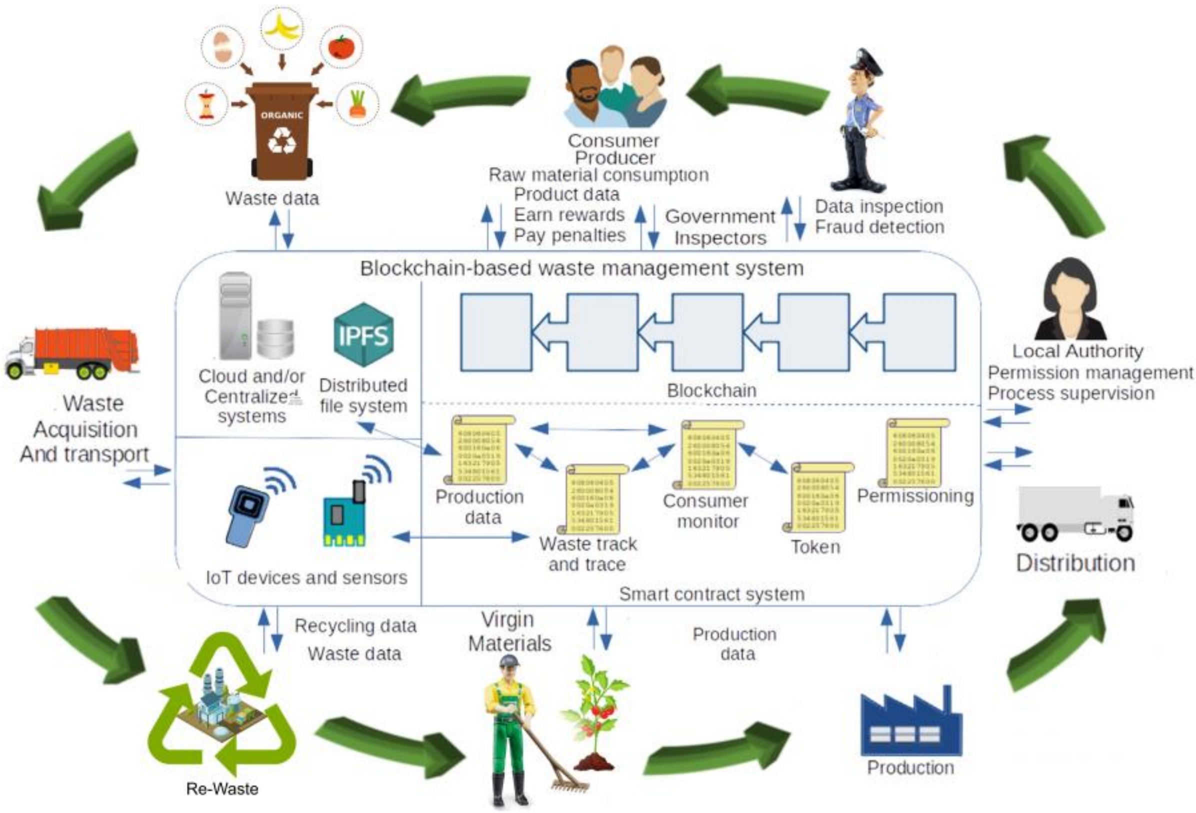

Figure 4 – Representation of the main components and actors of a blockchain-based management system (Re-waste project) in a CE model (after Baralla et al. 2023. modified and redesigned)

The Production Phase is crucial for waste prevention as it requires recording data on the composition and use of virgin materials through a smart contract on the blockchain. Authorized system members, such as government inspectors, can access this data through smart contracts that enforce access rules. The data can be used by the government to enforce extended producer responsibility through rewards or penalties. Producers can also access product life cycle information and make decisions accordingly.

In the Consumption Phase, consumers can access the composition and history of a product before purchasing it and then record the change of ownership through a blockchain transaction. Information about the product's status can be recorded anonymously or voluntarily, depending on the product type.

Local authorities and government inspectors can use this information to predict waste generation and implement citizen engagement policies, such as token-based incentives for product reuse.

The waste collection phase involves the consumer disposing of the consumed product in the appropriate receptacle or delivering it for disposal. Smart bins with RFID devices and IoT sensors can automatically record data on the type and quantity of waste produced by each consumer and transmit it through a transaction to a specific smart contract. Government inspectors can use this data to track waste and implement anti-fraud measures, and local authorities can use a smart contract-based reward system to encourage citizen engagement. Actors access data from the collection phase in subsequent phases to optimize disposal activities.

The Waste Acquisition and Transport Phase (begins the reverse supply chain). In this phase, waste collectors can automatically acquire and certify data on the weights and types of waste transported and the truck route through IoT scales and GPS devices. Smart contracts can verify this data without human intervention, and the waste collector can use blockchain data in route optimization software to optimize collection routes and times.

The Sorting and Treatment Phase. Food waste can be treated directly at production centers (with local installations such as SmartCara or Ecodyger) or at eco-centers. Poorly selected food waste material is processed at an eco-center. The eco-center can access data on the composition and amount of waste from previous phases to operate efficiently and securely and can record data on the amount and type of waste treated and the quantity and type of processed products (agricultural soil improvers or simple compost) through a specific smart contract. Governments can access this data to prevent waste mismanagement and implement Circular Economy (CE) policies.

The Recycling Phase. Food waste processed by the producer or at the eco-center can be delivered directly to the farms that recycle it. The farms or the recycling company can access data on the type of process from previous phases to optimize the recycling process and can record data on the amount and type of recycled material through a specific smart contract. Governments can access this data to verify the accuracy of recycling claims and implement CE policies.

A project like Re-Waste, if initially thought of as a standalone project, can only find its full application if inserted within the whole agri-food-waste chain in a Circular Economy model. Blockchain technology (BCT) is sufficiently evolved to allow its effective application both in the process of recycling food waste and in the subsequent production by farms and agri-food companies.

The Project Track Chain 4.0 utilized the Ethereum permissionless platform; however, several other options are also available. Ethereum can also function as a private platform with a configurable feature.

The OpenEthereum supports a Proof-of-Authority consensus engine[13], which can replace Proof-of-Work in private chain setups.

Considering that Ethereum, on September 15, 2022, has reduced its electrical energy requirement by at least 99.84% to 99.99% by changing its production method, it currently represents one of the most compatible platforms with the principles of sustainability underlying the CE. Ethereum also remains the most widespread platform, with many applications and software allowing the development of user-friendly interfaces for the stakeholders. Therefore, we can also consider using Ethereum to implement the Re-waste project.

The procedure for creating an interface with Ethereum will only be briefly outlined to provide a general idea of the process involved. It is important to note that advanced computer skills are required for this process. The first step is to install Metamask, which enables a distributed network architecture. Metamask is a browser extension that allows interaction with the Ethereum blockchain and the use of Ethereum-based smart contracts within a web browser. It serves as a digital wallet, storing Ethereum account information, enabling it to sign transactions and interact with decentralized applications (DApps) on the Ethereum network. Moreover, Metamask includes a built-in Ethereum browser that allows exploration of the Ethereum network and interaction with smart contracts and DApps without running a full Ethereum node. It also enables switching between different Ethereum networks (such as the main, test, and private networks) and managing multiple Ethereum accounts from within the web browser.

Ethereum supports smart contracts written in the Solidity object-oriented language for running decentralized applications (DApps). Solidity is a high-level language designed specifically for smart contract execution on the Ethereum Virtual Machine. To implement Solidity, one must write code in the programming language using an Integrated Development Environment (IDE) such as Remix. This IDE is designed specifically for working with Solidity and Ethereum, providing tools for writing, testing, and debugging Solidity code.

To develop the system's backend, it can use Solidity and the Remix IDE. The backend refers to the part of the system that runs on a server and handles the logic and processing for an application. It is responsible for storing and organizing data, communicating with external services, and performing other tasks. The frontend, on the other hand, is part of the system visible to the user and interacts with them, typically a web or mobile application.

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[13] https://openethereum.github.io/Proof-of-Authority-Chains

Then, two tools (Ganache and Truffle) can be used for developing and deploying smart contracts on the Ethereum platform. Ganache is an Ethereum blockchain environment that allows emulating the Ethereum blockchain rather than the live Ethereum network so that they can interact with smart contracts in their private blockchain. Truffle is a suite of tools for developing and deploying smart contracts on the Ethereum platform. It includes a set of libraries, command-line interfaces, and configuration files, making it easier to develop and deploy smart contracts using the Solidity programming language. Some of the key features of the Truffle framework include:

- Compiling and testing Solidity contracts: Truffle provides a set of tools for compiling Solidity code into bytecode that can be run on the Ethereum Virtual Machine, as well as tools for testing and debugging smart contracts.
- Managing contract dependencies: Truffle includes a package manager that allows you to manage the external dependencies of your smart contracts and include them in your project.
- Migrating contracts to the Ethereum network: Truffle provides a simple way to deploy your smart contracts to the Ethereum network and manage their deployment process.
- Interacting with smart contracts: Truffle includes a JavaScript library called Truffle Contract that makes it easy to interact with your deployed smart contracts from JavaScript code.
- Debugging contracts: Truffle includes a debugger that allows you to trace the execution of your smart contracts and identify any issues.

The Truffle framework is designed to streamline the process of developing and deploying smart contracts on the Ethereum platform, making it easier for developers to build decentralized applications (DApps).

The ReactJS JavaScript library can be used to build an application that loads all of its content and functionality on a single page, improving the user experience by creating a more responsive and seamless feel rather than requiring the user to navigate multiple pages.

4.3. How can Geographic Information Systems (GIS) be integrated with BCT a the food waste recycling project (Re-Waste)

Specialized open-source Application Programming Interfaces (APIs) such as Quantum GIS (QGIS), Geographic Resources Analysis Support System (GRASS GIS), and Google GIS can be utilized To visualize and manage cartographic data and open-source Geographic Information Systems (GIS) within a geoblockchain. Standardized methods, such as eXtensible Markup Language (XML) and Javascript Object Notation (JSON) to facilitate the exchange of information, can be used for transmitting data over the internet. These APIs and information transmission methods will enable the visualization and management of cartographic data and open-source GIS within the geoblockchain and simplify the exchange of information between different systems and platforms.

The web3.js library can be used to interact with GIS data stored on the Ethereum network and display it in a web-based GIS application. Alternatively, a decentralized storage solution like IPFS (InterPlanetary File System) can be used to store large amounts of GIS data on the Ethereum network (EIPFS). GeoBCT can also be used to create more effective food waste recycling programs by tracking the movement of food waste through the recycling process. For example, a geoblockchain can be used to monitor food waste movement from collection points to processing facilities and the quality and quantity of food waste processed at each stage of the recycling process. This could help to ensure that food waste is being recycled efficiently and effectively and that it is being used to its full potential.

A geoblockchain model for the food waste cycle may rely on IoT-based sensors to improve efficiency, sustainability, and traceability and provide new capabilities and applications. IoT-based sensors can be used to track the movement of components within the food waste cycle and receive real-time data on their characteristics. By tracking the movement of food and other resources through the supply chain, geoBCT can identify bottlenecks and inefficiencies in the distribution process, leading to more efficient use of resources and reducing food waste. Data recorded in a geoblockchain is more reliable and detailed than previous systems, allowing waste handling companies to examine it more thoroughly and obtain information on the most efficient collection and processing methods.

A blockchain-based management system (Re-waste project) in a CE model, such as the Re-waste project, could also benefit from implementing cloud computing, internet-based computing that relies on virtualization and the concept of computing as a utility. It provides users with access to shared data and processing resources on demand without the need for extensive management or interactions with service providers. According to the US National Institute of Standards and Technology (NIST), cloud computing involves configurable computing resources, such as networks, servers, storage, applications, and services, which can be quickly and easily provisioned and released (Mell & Grance 2011). The NIST also outlines four principal service models for cloud computing: Platform as a Service (PaaS), Software as a Service (SaaS), Infrastructure as a Service (IaaS), and four deployment models private cloud, public cloud, hybrid cloud, and community cloud released (Mell & Grance 2011).

One of the key roles of cloud-based services in a blockchain system for managing the food waste cycle is to provide a secure and scalable platform for storing data, including data related to the production, distribution, and recycling of food and other relevant data types to the food waste cycle. The integrated use of these technologies with Blockchain would allow waste handling companies and control authorities to have a large flow of certified data on each stage of the treatment process and to view and plan activities on a map. Each passage would be traced and displayed on a map, revealing the condition of the transport, the parties involved in the transaction and its exact location. The InterPlanetary File System (IPFS) can be integrated with cloud computing and Geoblockchain to improve the performance, reliability, and security of cloud-based applications and services. Geoblockchain can use IPFS to store and share geospatial data and other large files, improving the performance, reliability, and security of geospatial applications and services running in the cloud. Additionally, IPFS can also be used as a decentralized storage layer for cloud-based applications, reducing reliance on centralized storage systems and improving the application's resilience.

Cloud-based services can be used to process and analyze data in a blockchain system for managing the food waste cycle. For example, cloud-based services could be used to identify patterns and trends in data related to food waste and develop algorithms and machine learning models to predict and prevent food waste. Cloud-based services could also be used to analyze data or to enable the exchange of data between a blockchain system and other systems, such as supply chain management or logistics systems.

An Intelligent Decision Support System (IDSS) can be implemented to take GeoBCT one step further (fig.5). IDSSs are a combination of Artificial intelligence (AI) and decision support systems (DSSs) IDSSs can be particularly useful in complex or uncertain situations, helping to identify the most optimal outcomes through various leading methods that provide new computing assistance to operate in a complex environment (Sprague, 1980; Turban et al., 2005; Khelifa et al., 2018) They rely on advanced computing techniques such as knowledge-based systems, artificial neural networks, intelligent agents, fuzzy systems, evolutionary computing, genetic algorithms, rough sets, data mining, and process mining to analyze and process large amounts of data and provide recommendations or options similar to how humans might reason through a decision (Khelifa et al. , 2018).

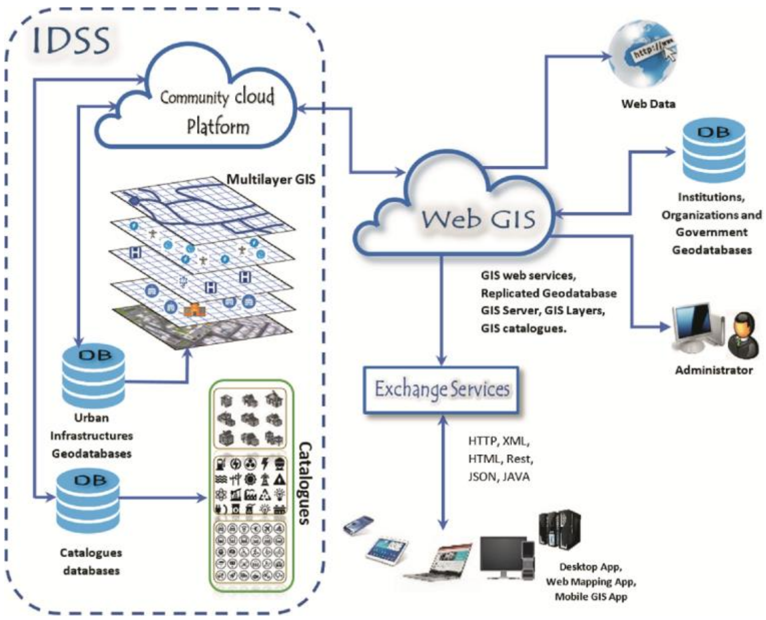

Figure 5 - Architecture of an IDSS integrating GIS and cloud computing for complex urban planning problems like the food-waste cycle. From: (Kelifa e al., 2018)

IDSS (Intelligent Decision Support Systems) can play a significant role in a geoblockchain system designed to manage the food waste cycle. The following outlines the potential uses of IDSS in this context:

Predictive Analytics: IDSS can analyze data within a geoblockchain system to identify patterns and trends and make predictions about future developments. This information can be used to help stakeholders make informed decisions and plan accordingly.

Optimization: IDSS can be used to optimize the food waste cycle by identifying areas for improvement and reducing waste which can lead to increased efficiency and reduced costs.

Decision Support: IDSS can provide decision support to users of a geoblockchain system for managing the food waste cycle. The system can provide recommendations and guidance based on data analysis and predictive analytics, which can help users make informed decisions.

5. DISCUSSION

The waste sector in Italy is a complex and sensitive issue, similar to other countries. The purpose of this research is to provide free access to information on the management of organic waste and the entire agri-food chain that is related to it. It is crucial to monitor the waste supply chain closely and openly as a valuable resource To reduce barriers and minimize environmental risks.

The starting point for this research was the analysis of the Track Chain 4.0 project (RQ1 and RQ2) and its revision and integration (RQ2) in a geoblockchain applied to the waste cycle (RQ3).

The Track-Chain 4.0 Research Project aims to accelerate the development of new models and organizational systems related to food safety within the supply chain. Through the acquisition of results, experiences, research data, documentation and technologies, the project introduces procedures that represent an advantage compared to a previous enterprise system. These procedures optimize the engagement of the assigned human resources, positively impacting the organization of the companies involved in the project and their relationship with the market.

In the two cases considered, the organization of the R&D project, considering the criteria for evaluating innovation according to the Frascati Manual and the Oslo Guidelines, required the two companies involved in the project to obtain tax benefits. A well-designed R&D project enabled companies to overcome one of the main barriers limiting the development of BCT projects applied to the EC, giving a partial response to RQ1.

The project has resulted in an increase in the quality perception of the food products involved and the dissemination of digital solutions for traceability and easier access to data. Additionally, the project has ensured the originality of reference data and identified necessary and potential application requirements for future design and prototyping. Overall, the project has contributed to increasing technical and economic competitiveness. All these elements correspond with part of the barriers identified by Ada et al.2021 and with the related technological solutions proposed to overcome them. So they respond at least partially to RQ1 and RQ2.

BCT providing transparent access to real-time information and supporting the implementation of the CE can work towards a more sustainable future. In the food waste sector, the smart contract could have various components that monitor interactions among stakeholders. These units work together to prevent any invalid transactions that may affect stakeholders. The stakeholders provide details used to verify transactions through the consensus algorithm, which all network participants follow. This approach promotes transparency and trust between the parties involved. Additionally, the system holds parties accountable and imposes penalties if they fail to meet the terms outlined in the Smart Contract.

Following a comprehensive examination of the Track-Chain 4.0 project, a geoblockchain model suitable for the food waste cycle has been suggested. The Re-Wast project can then be incorporated into this model once it has completed its testing phase, addressing research question 3 (RQ3).

The system could be built using the Ethereum network, utilizing Solidity, Ganache, and Truffle. This geoblockchain model, when integrated with waste tracking capabilities, could be useful in enforcing waste management regulations. As shown in Fig. 4, various roles in the food supply chain are identified, and their corresponding responsibilities are in a geoblockchain (as outlined in Table 5, according to Papantoniou 2020). The result of this prototype is a cloud-based geoblockchain web dashboard that participants can access throughout the supply chain process. In the development phase of this project, specific roles and profiles will be more clearly defined. The food waste cycle is just one part of the agri-food supply chain. But to efficiently manage the huge amount of data and processes involved in transitioning to a CE, it will be necessary to utilize a system that also incorporates a geoblockchain, artificial intelligence (AI), and a database (DB) for certification and validation purposes (RQ3).

Participants	**Responsibilities**
GeoBlockchain-Administrator	Administrator has full privileges to the private GeoBlockchain (Hyperledger Fabric and ArcGIS Enterprise)
GeoBlockchain food-waste collection centre	Participant that is added to GeoBlockchain with controlled roles only for waste collection
GeoBlockchain-waste transport	Participant that is added to GeoBlockchain with controlled roles only for waste trasport
GeoBlockchain Re-Waste	Participant that is added to GeoBlockchain with controlled roles only for Re-Waste Process
GeoBlockchain- transport agricultural soil improvers	Participant that is added to GeoBlockchain with controlled roles only for soil improvers trasport
GeoBlockchain soil improvers distribution	Participant that is added to GeoBlockchain with controlled roles only for soil improvers distributiont
GeoBlockchain farmers	Participant that is added to GeoBlockchain with controlled roles only for New virgin (raw) material (produced for waste)
GeoBlockchain recycled agricultural product distribution	Participant that is added to GeoBlockchain with controlled roles only for recycled product (new virgin materiale) distributiont
GeoBlockchain Production	Participant that is added to GeoBlockchain with controlled roles only for new food production/trasformation (food industry)
GeoBlockchain food products- distribution	Participant that is added to GeoBlockchain with controlled roles only for agri-food product distribuitiont
GeoBlockchain-food products transport	Participant that is added to GeoBlockchain with controlled roles only for food trasport
GeoBlockchain trusted organization	The main authority (local and national) and authority in the blockchain that controls policies, rules, and roles
Geoblockchain consumer	Participant that is added to GeoBlockchain individually or collectively, both for data verification purposes and for data input (production of novel food waste)
GeoBlockchain food- Waste collection centers	.... closing of the cycle......

Table5 – Food-Waste GeoBlockchain Participants and responsibilities

The implementation of smart sensors in the collection, transportation, and processing of organic waste management is proposed in this study. The sensors will facilitate the traceability of food waste, agricultural products, and soil improvers. Furthermore, the creation of an application that utilizes QR code scanning to trace the movement of recycled materials from producers to consumers could be developed. The app will allow users to access information about all stakeholders involved by scanning a QR Code.

The case study is quite specific, but even if it represents only a segment of the broader waste cycle, especially the food waste cycle, its analysis implies the response to problems of a much more general nature. The food waste industry is complex and involves various types of waste that must be processed before disposal. Many small production units often generate this waste, making it difficult to track it back from the source. In order to address these challenges, a distributed database is needed to allow participants in the food waste supply chain to store data chronologically and provide real-time information to address these challenges. This database should incorporate information about the type and quality of food waste and traceability data through both physical and digital documents. In Europe, certifications that promote sustainable food waste management are essential.

Implementing Blockchain in the food waste industry can help improve the certification process for the type of food waste being sent for treatment by providing a certificate of origin, reducing illegal practices, and meeting the legislative requirement. The food waste supply chain consists of several steps, beginning with waste generation and ending with its disposal or reuse. An important aspect of this process is the waste generation stage, which lays the foundation for the subsequent steps and influences their efficiency and effectiveness. One way to improve this step is by using a traceable system like Blockchain, which can increase resource efficiency, improve capacity utilization, reduce damage to the ecosystem, and prevent illegal disposal practices.

Blockchain technology can improve waste management logistics by eliminating redundant flows and reducing the likelihood of data input errors. Additionally, it can be utilized to monitor the quality of food waste and unexpected occurrences, such as the disposal of non-food items, through the use of RFID transponders, which enable electronic identification and tracking of food waste generated by households.

BCT in the food waste industry can help to improve efficiency, reduce costs, and support sustainable waste management practices. Table 6 summarizes the potential benefits of using Blockchain during different stages of the food waste treatment process.

The Internet of Things (IoT) is frequently utilized in the waste management industry, where sensors can be employed during various stages such as collection, transportation, transformation, disposal, and recycling. However, traditional traceability systems utilizing the IoT are based on a “centralized server-client paradigm”, leading to vulnerabilities in data modification and management and difficulties in addressing data fragmentation and central controls (Vishkaei et al., 2022). Blockchain technology

(BCT) holds the potential to tackle these issues and enhance transparency and security in the agriculture supply chain by facilitating the exchange of information in a transparent and unalterable manner.

Process	Organization through Blockchain
acquisition of food waste	Certification of the type and quantity of food waste with automatic issuance of documents
temporary storage	Control of storage process. Efficient storage management
processing	Monitoring the process. Ensure compliance with standards in production
logistics	Prevent redundant flows and input data error

Table 6 - Organization through Blockchain during the various stages of the food waste treatment process.

6. CONCLUSION

This study aimed to define a theoretical framework for implementing blockchain technology in food waste recycling within a Circular Economy perspective. BCT has been introduced in the food supply chain in recent years, and there are no consolidated applications to the food waste sector.

Through three research questions and the development of a case study, this work has tried to address these research gaps. A literature review and the analysis of a business model (Track Chain 4.0) finds the main barriers to implementing BCT and circular economy (CE) within the food-waste supply chain but also highlights the potential of digital technologies and more effective process management to overcome these challenges answering to the first RQ.

The Re-Waste project has the potential to address the primary barriers and facilitate the shift towards CE in the post-consumption phase of the agri-food supply chain. It was highlighted as BCT plays a crucial role in ensuring the identity and data integrity of various nodes in the food-waste supply chain and can be used to create a decentralized and immutable record of the entire food supply chain, including recycling, answering the second RQ. The application of BCT in the Re-Waste project, integrated with the Track-Chain 4.0 model, enables the attainment of tax benefits and facilitates key enablers such as transparency and accountability.

As regard the third and final RQ, it was shown that the integration of BCT, GIS technology (Geoblockchain), and other digital technologies, such as IoT, CPS, BDA, CC, 3DP, RFID, and AI, can further enhance traceability, increase efficiency and manage organic product distribution and make food-waste recycling more efficient. In particular, the integration of GIS technology into the Re-Waste project enhances the traceability of food waste throughout the waste chain and supports compliance with EU food traceability legislation also in the subsequent production phase of agricultural products obtained from food waste. Geo-BCT can also allow for the localization of local producers and create a network for consumers to know where to buy organic products closest to them, as well as for large retailers to promote "zero kilometres" products.

In conclusion, the application of GIS and blockchain technology in the agri-food chain and the recycling phase with projects like Re-Waste can support the closure of the cycle and align with the principles of CE. However, this work represents only the starting point, and further research is necessary to fully develop the potential of blockchain and GIS in the food waste recycling sector. Future research will be crucial in operationalizing the theoretical framework proposed in this study and adapting it to different contexts, such as the recycling of the municipal organic waste in smart cities. Additionally, it will be necessary to conceptualize and test the most effective system to introduce a mechanism of rewards and penalties for network members tailored to specific contexts.

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Department
of Business and Management
Course of Management of Circular Economy

Blockchain Application to the CE: the recycling of agri-food waste
EMPIRICAL RESEARCH

Expanded Abstract

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ABSTRACT

This study analyzes the potential applications of Blockchain Technology (BCT) to the entire agri-food supply chain, from food production to food waste recycling in agriculture, in line with the Circular Economy (CE) model. The aim is to evaluate the possible and future adoption of blockchain technologies in terms of the benefits they could bring to this sector and how they can be combined with the Track Chain 4.0 project (by the Centro di Ricerche e Studi dei Laghi CRSL) and the Re-Waste project (by Tuscia University), and the improvements they would create for supporting food waste recovery and the CE.

1. INTRODUCTION

The consumption of resources available on our planet has reached completely unsustainable levels, and food waste is one of the main factors in this process. In 2022, the global volume of food waste was estimated to reach over 1.6 billion tons, with almost one-third of all food produced being wasted (FAO, 2022). Food waste generates greenhouse gasses (3.3 billion tonnes of CO_2 equivalent released into the atmosphere annually) and contributes to global warming. The direct economic consequences of food wastage (excluding fish and seafood) amount to about $750 billion annually. (FAO, 2022).

The European Circular Economy Action Plan recognizes the circular economy (CE) as a key component of a larger transition towards climate neutrality and long-term economic stability. Companies that adopt a CE approach can reap several environmental benefits, including waste recovery and reuse, resource efficiency, circular inputs, and reduced carbon dioxide emissions. (Maranesi & De Giovanni, 2020). Therefore the CE has been proposed as a way to address the negative consequences of traditional economic activities and promote sustainability, but there are challenges to its implementation. The idea behind this research is to link the Track-Chain 4.0 model, which aims to enhance the efficiency in the food supply chain of companies through innovation, with the Re-Waste project, which seeks to recycle food waste sustainably within a Circular Economy perspective.

The goal is to create a new, effective, and systematic process at the industrial, training, productive, and organizational levels. The interdisciplinary design model considers Blockchain's latest protocols and ICT systems, the need to establish new relationships between project participants, and a corporate training and development process. All elements developed within the project are transferable to other businesses or projects.

The research will address the following questions through a comprehensive literature review, relevant case studies (the Track-Chain 4.0 project), and a theoretical framework for the implementation of Blockchain and GIS technology in the Re-Waste project:

- RQ1 What are the key enablers or barriers that can impact the success of a circular economy project on the food waste supply chain using blockchain technology?
- RQ2 What is the role of blockchain technology in enhancing the efficiency of the food waste recycling process within a Circular Economy perspective?
- RQ3 How can Geographic Information Systems (GIS) be integrated with blockchain technology in a food waste recycling project?

This work aims to be one of the first to assess the possible benefits of applying blockchain technology in the food-waste sector from a circular and sustainable economy perspective. The three proposed research questions (RQs) summarize the main barriers to introducing this technology in this area and highlight the role and opportunities it could represent. The objective is to identify the most effective solutions and construct a theoretical framework for implementing blockchain technology in food waste recycling within a Circular Economy context (Re-Waste Project).

2. LITERATURE REVIEW AND THEORETICAL FRAMEWORK

The Circular Economy (CE) and Blockchain Technology (BCT) have been widely acknowledged as crucial elements for sustainable development and waste reduction, with the potential to transform the traditional linear economic model and promote closed-loop systems and resource efficiency. Despite growing interest in these areas, there is a significant research gap in the intersection of CE, Blockchain, and food waste, particularly in the post-consumption phase of the agri-food supply chain (Ada et al., 2021; Agnusdei & Coluccia, 2022; Baralla et al., 2023). The shift towards the CE requires re-evaluating traditional business models to identify more sustainable solutions and requires digital transformation progress, like e-commerce and Industry 4.0 (De Giovanni, 2022). To fully understand the benefits of BCT, firms need to analyze the strategic changes required, estimate the economic outcomes, and assess the implications for the entire supply chain network (Saberi et al., 2018; De Giovanni, 2022). In operations and supply chain management, BCT can increase transparency, verify the authenticity of raw materials and goods, and ensure traceability and risk mitigation (De Giovanni, 2022).

As regards the first RQ, several studies (Ada et al., 2021; Rejeb et al., 2023; Laouar et al., 2019) have identified challenges in implementing a circular economy in the food supply chain. The first requirement for project development is its financial sustainability, which is particularly critical for R&D projects. However, advanced technologies such as Industry 4.0 and blockchain technology (BCT) can overcome these challenges and promote sustainability in the food supply chain. However, the high implementation costs and lack of incentives for businesses throughout the food chain pose difficulties in the widespread adoption of BCT. In Italy, the diffusion of BCT in small and medium-sized enterprises (SMEs) is hindered by the complexity of administrative procedures, the difficulty in obtaining financing, and the lack of understanding of the technology by clients. A survey by the Smart Agri-food Observatory of the Politecnico di Milano (2020) found a growing interest in blockchain-based applications in the food tracking and certification sector in Italy. However, many companies have made Industry 4.0 investments mainly to take advantage of financial and fiscal opportunities rather than effectively utilizing a new technology. In conclusion, a BCT food waste recycling project that aims to align with a circular and sustainable economy perspective must overcome numerous barriers and take advantage of the economic and tax incentives provided for innovative R&D projects by Italian and European legislation.

As regards the second RQ, a comprehensive examination of the existing literature has been performed to comprehend the new perspectives that technologies such as the Blockchain (BCT) and Circular Economy (CE) have opened for companies in the food waste recycling sector. Research conducted in January 2023 using the keywords "Blockchain and Circular Economy" found 175 papers on the Web of Science (WOS) and 187 on Scopus, which shows a significant number of publications on the topic and demonstrates the links between these emerging research streams. These findings provide new insights into the potential benefits of implementing a circular economy using blockchain technology. Most of the studies focus on the role of blockchain technology in sustainable supply chain management for the agri-food sector within the circular economy framework. Among original research papers, only a few studies have explored the challenges firms face in adopting business models at the intersection of Circular Economy (CE) and digitalization. No studies have applied BCT to food waste from a circular economy perspective.The literature analysis shows that the research on this sector is still in its early stages and is fragmented across interdisciplinary fields (Rejeb et al., 2023). There is a lack of knowledge in economics, econometrics, finance, business, management, and accounting. This lack of knowledge challenges companies as it requires integration with technical-scientific skills, which are not always available in SMEs.

As regards the third and final RQ, Geospatial Blockchain or GeoBlockchain, as defined by Papantoniou (2020), refers to the combination of Blockchain and Geographic Information Systems (GIS) to "identify spatial trends of blockchain transactions". GeoBlockchain solutions use a crypto-spatial coordinate system to provide an immutable spatial context that is not present in traditional blockchains, allowing GIS technologies to track geographical and spatial behaviours within the Blockchain (Papantoniou and Hilton, 2021). Research on the implementation of GIS technology with Blockchain is limited. A search conducted in January 2023 using the keywords "Blockchain AND Geographic Information Systems" produced 47 results on Scopus and 28 papers on WOS Expanding the search to include "Blockchain AND GPS" produced 104 papers on Scopus and 58 on WOS, with many of these being conference papers and reviews but only a few original articles. None of the articles specifically deal with food waste.Regarding the research question (RQ3), most of the analyzed articles approached the topic in general terms and were in the field of mathematics, computer science, and engineering. Only a small percentage (3%) was in the subject area of Business and Management (Scopus, January 2023), but with articles that were not relevant to the study. The few articles of real interest (i.e. Xie et al., 2022 or Baralla et al., 2018, 2021) provide extremely technical contributions. However, some explore the applications of GPS-GIS and blockchain technologies in the agri-food industry and may be relevant to the topics being considered. Literature review shows that BCT can be successfully integrated with GPS GIS technology, the Internet of Things, RFID sensors, and automation (AI) and can potentially improve circularity and food waste recycling programs. However, the actual applications of these technologies are still relatively few, and there are no reference studies or experiences to evaluate the effects of their implementation in the food-waste chain.

3. RESEARCH METHODOLOGY

The research methodology involves three successive steps. First, the research questions were examined using literature studies. The second step consists of analyzing the possible applications of the GIS and blockchain technology to a theoretical case study: the Re-Waste project. The third and final step involves a discussion of how the combination of technological and business innovations proposed in the Re-Waste project can overcome the main barriers previously identified by responding to the three research questions.

4. CASE STUDY

The re-Waste project proposes a circular economy approach to enhance organic waste in Lazio, turning it into a resource for agriculture. The significant waste in the agri-food chain includes waste from collective restaurant distribution and consumption phases and agri-food products. The proposed system aligns with the circular economy and the European 2020 objective of self-disposal of organic waste by producers ("zero waste").

This research project highlights the potential of using food waste as a sustainable source of bioactive products and soil improver in a circular economy and sustainable agriculture. Food waste contains valuable biomolecules such as phytochemicals, bioactive phenolic compounds, oligosaccharides, and minerals that can alter critical physiological processes in crops (Ceccarelli et al., 2022). The study demonstrates that the Smart Cara CS10 device can effectively reduce the volume and weight of food waste while producing high-quality organo-mineral fertilizer and soil improver. The results suggest that the solid residues obtained have the potential to improve soil characteristics, stimulate the innate immune system of plants, and meet production needs on a company scale with increased yields, improved nutrient efficiency, biocontrol, crop protection, and increased tolerance to abiotic stress (Savatin, 2022; Ceccarelli et al., 2022).

To respond to the first RQ have been identified the key barriers that can impact the success of a circular economy project like Re-Waste, which aims to use blockchain technology to improve the food waste supply chain:

- difficulties associated with the investments required to acquire new technologies;
- lack of adequate I.C.T. tools and staff with inadequate I.C.T. knowledge;
- limited (traditional) business models and leadership;
- poor penetration capacity in new markets;
- cultural barriers and limited adoption of blockchain technology in the Italian SMEs.

Track Chain 4.0 model was identified as a solution to overcome these barriers. This model, developed by the Centro di Ricerche e Studi dei Laghi (CRSL)[14] digital hub, provides companies with the necessary technical knowledge and training in advanced technologies such as Blockchain, IoT, big

[14] Founded in 2017, CRSL – Centro Ricerche e Studi dei Laghi, is a relatively young but highly dynamic reality that has received prestigious accreditations: It is a spin-off of the Carolina Albasio High School of Castellanza, and is one of the founders of the POLO UNIVERSITARIO METIS Foundation. CRSL is registered in the National Research Registry file of MIUR and is certified by Unioncamere as a 4.0 Technology Transfer Center (CTT). As 4.0 CTT, CRSL has developed a series of new technologies to be transferred as part of the subsidies on innovative assets; this is an extension of the activities of CRSL, which aims to implement some services related to the issues of its 8 Departments, in terms of innovation, process quality, safety, environment and energyhttps://www.crslaghi.net/en/

data, and artificial intelligence. The Track Chain 4.0 model can enable farms/companies interested in Re-Waste technology to receive tax advantages and organize or reorganize their production processes to implement the BCT. This project aligns with points 1.32 and 1.33, and 2.8 of the Frascati Manual 2015 (the activity must be novel, creative, uncertain, systematic, transferable, and/or reproducible - OECD, 2015; 2018). The two firms to which the Track Chain 4.0 model was applied, Cannoleria Siciliana and Pastificio Pasta, faced various challenges in implementing blockchain technology but were able to overcome them. In these Firms, Track Chain 4.0 transformed the business organization and developed new models and methodologies for data security and validation, improving the efficiency of the two companies' production processes. However, the biggest barrier to overcome is cultural, as many Italian SMEs still have traditional management models. But it is necessary for top management to perceive the efficiency of production processes and for consumers to understand the traceability of products to make the innovations permanent. Using BCT guarantees transparency throughout the supply chain and communicates the products' real quality to customers (Ruzza, Morandini & Chielli , 2022).

BCT can allow farms to collect food waste treated with Re-Waste technology and trace the obtained organic products. As evidenced by the literature review, there is currently a lack of research studies or specific initiatives that detail the application of BCT to the food waste cycle from a CE perspective. The development of the Re-Wast project can allow for filling at least in part the gap and responding to the second RQ. However, to effectively implement the theoretical framework presented in this study, it is crucial to accurately identify and contextualize the challenges and key facilitators involved in integrating blockchain technology for monitoring the circular lifecycle of food waste. The waste-supply chain focuses on developing a modular architecture that enables fast system configuration. The distributed ledger layer acts as a decentralized data management system, enabling the storage and retrieval of data and ensuring its legal validation. According to Laouar et al. (2023), a model (Fig 1) was developed with the main components and actors of a blockchain-based food-waste management system. The contribution of blockchain usage will be discussed for each phase.

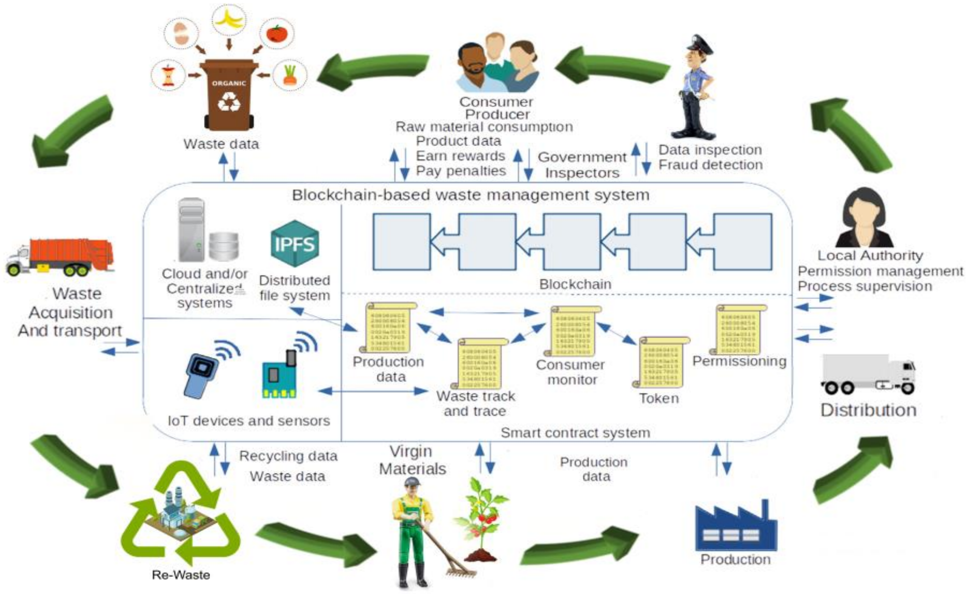

Figure 1 – Representation of the main components and actors of a blockchain-based management system (Re-waste project) in a CE model (after Baralla et al. 2023. modified and redesigned)

If initially thought of as a standalone project, a project like Re-Waste can only find its full application if inserted within the whole agri-food-waste chain in a Circular Economy model. Blockchain technology (BCT) is sufficiently evolved to allow its effective application both in the process of recycling food waste and in the subsequent production by farms and agri-food companies.

The Project Track Chain 4.0 utilized the Ethereum permissionless platform; however, there are several other options available as well. Ethereum can also function as a private platform with a configurable feature. But considering that Ethereum, on September 15, 2022, has reduced its electrical energy requirement by at least 99.84% to 99.99% by changing its production method, we can consider using Ethereum also for the implementation of the Re-waste project.

The Re-Waste project development shows that Geographic Information Systems (GIS) can be integrated with BCT in a food waste recycling supply chain responding to the third and final RQ Specialized open-source Application Programming Interfaces (APIs) such as QGIS and GRASS GIS can be utilized to visualize and manage cartographic data within a geoblockchain using standardized methods such as eXtensible Markup Language (XML) and Javascript Object Notation (JSON). The web3.js library and IPFS can be used to interact with GIS data stored on the Ethereum network. IoT-based sensors can be used to track the movement of food waste in the recycling process. Cloud computing can provide a secure platform for storing data and improving the performance and security of cloud-based applications. IPFS can also be integrated with cloud computing and geoblockchain to improve performance and reliability. This integration would allow waste-handling companies to have access to certified data on each stage of the recycling process.

5. DISCUSSION

The waste sector in Italy is a complex and sensitive issue, similar to other countries. The purpose of this research is to provide free access to information on the management of organic waste and the entire agri-food chain that is related to it. It is crucial to monitor the waste supply chain closely and openly as a valuable resource To reduce barriers and minimize environmental risks.

The starting point for this research was the analysis of the Track Chain 4.0 project (RQ1 and RQ2) and its revision and integration (RQ2) in a geoblockchain applied to the waste cycle (RQ3).

In the two cases considered, the organization of the R&D project, considering the criteria for evaluating innovation according to the Frascati Manual and the Oslo Guidelines, required the two companies involved in the project to obtain tax benefits. A well-designed R&D project enabled companies to overcome one of the main barriers limiting the development of BCT projects applied to the EC, giving a partial response to RQ1.

The project has resulted in an increase in the quality perception of the food products involved and the dissemination of digital solutions for traceability and easier access to data. Additionally, the project has ensured the originality of reference data and identified necessary and potential application requirements for future design and prototyping. Blockchain technology can improve waste management logistics by eliminating redundant flows and reducing the likelihood of data input errors. Additionally, it can be utilized to monitor the quality of food waste and unexpected occurrences, such as the disposal of non-food items. This can be achieved through the use of RFID transponders, which enable electronic identification and tracking of food waste generated by households. The Internet of Things (IoT) and related sensors can be employed during various stages, such as collection, transportation, transformation, disposal, and recycling. However, traditional traceability systems utilizing the IoT are based on a "centralized server-client paradigm", leading to vulnerabilities in data modification and management and difficulties in addressing data fragmentation and central controls (Vishkaei et al., 2022). Blockchain technology (BCT) holds the potential to tackle these issues and enhance transparency and security in the agriculture supply chain by facilitating the exchange of information in a transparent and unalterable manner. Overall, the project has contributed to increasing technical and economic competitiveness. BCT providing transparent access to real-time information and supporting the implementation of the CE can work towards a more sustainable future. In the food waste sector, the smart contract could have various components that monitor interactions among stakeholders. These units work together to prevent any invalid transactions that may affect stakeholders. The stakeholders provide details that are used to verify transactions through the consensus algorithm, which all network participants follow. This approach promotes transparency and trust between the parties involved. Additionally, the system holds parties accountable and imposes penalties if they fail to meet the terms outlined in the Smart Contract. All these elements correspond with part of the barriers identified by Ada et al. (2021) and with the related technological solutions proposed to overcome them. So they respond to RQ1 and RQ2.

Following a comprehensive examination of the Track-Chain 4.0 project, a geoblockchain model suitable for the food waste cycle has been suggested. The Re-Wast project can then be incorporated into this model once it has completed its testing phase, addressing research question 3 (RQ3).

The system could be built using the Ethereum network, utilizing Solidity, Ganache, and Truffle. This geoblockchain model, when integrated with waste tracking capabilities, could be useful in enforcing waste management regulations. The result of this prototype is a cloud-based geoblockchain web dashboard that participants can access throughout the supply chain process. In the development phase of this project, specific roles and profiles will be more clearly defined. The food waste cycle is just one part of the agri-food supply chain. But to efficiently manage the huge amount of data and processes involved in transitioning to a CE, it will be necessary to utilize a system that also incorporates a geoblockchain, artificial intelligence (AI), and a database (DB) for certification and validation purposes (RQ3).

The case study is quite specific, but even if it represents only a segment of the broader waste cycle, especially the food waste cycle, its analysis implies the response to problems of a much more general nature. Implementing Blockchain in the food waste industry can help improve the certification process for the type of food waste being sent for treatment by providing a certificate of origin, reducing illegal practices, and meeting the legislative requirement.

6. CONCLUSION

This study aimed to define a theoretical framework for implementing blockchain technology in food waste recycling within a Circular Economy perspective. BCT has been introduced in the food supply chain in recent years, and there are no consolidated applications to the food waste sector.

Through three research questions and the development of a case study, this work has tried to address these research gaps. A literature review and the analysis of a business model (Track Chain 4.0) finds the main barriers to implementing BCT and circular economy (CE) within the food-waste supply chain but also highlights the potential of digital technologies and more effective process management to overcome these challenges answering to the first RQ.

The Re-Waste project has the potential to address the primary barriers and facilitate the shift towards CE in the post-consumption phase of the agri-food supply chain. It was highlighted as BCT plays a crucial role in ensuring the identity and data integrity of various nodes in the food-waste supply chain and can be used to create a decentralized and immutable record of the entire food supply chain, including recycling, answering the second RQ. The application of BCT in the Re-Waste project, integrated with the Track-Chain 4.0 model, enables the attainment of tax benefits and facilitates key enablers such as transparency and accountability.

As regard the third and final RQ, it was shown that the integration of BCT, GIS technology (Geoblockchain), and other digital technologies, such as IoT, CPS, BDA, CC, 3DP, RFID, and AI, can further enhance traceability, increase efficiency and manage organic product distribution and make food-waste recycling more efficient. In particular, the integration of GIS technology into the Re-Waste project enhances the traceability of food waste throughout the waste chain and supports compliance with EU food traceability legislation also in the subsequent production phase of agricultural products obtained from food waste. Geo-BCT can also allow for the localization of local producers and create a network for consumers to know where to buy organic products closest to them, as well as for large retailers to promote "zero kilometres" products.

In conclusion, the application of GIS and blockchain technology in the agri-food chain and the recycling phase with projects like Re-Waste can support the cycle's closure and align with CE's principles. However, this work represents only the starting point, and further research is necessary to fully develop the potential of Blockchain and GIS in the food waste recycling sector. Future research will be crucial in operationalizing the theoretical framework proposed in this study and adapting it to different contexts, such as the recycling of the municipal organic waste in smart cities. Additionally, it will be necessary to conceptualize and test the most effective system to introduce a mechanism of rewards and penalties for network members tailored to specific contexts.

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