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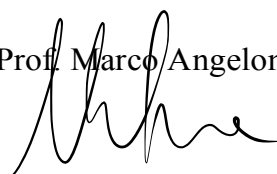
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Organizations, Food Bank, and Food
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Sara Damavandi actively participated in national and international conferences during her doctoral program, presenting her Doctoral Research Project. Below are key details of her conference contributions:

- **18th EIASM Conference** “Interdisciplinary on Intangibles, Intellectual Capital, and Sustainability: Reporting, Governance, and Value Creation”, September 21–22, 2023, Jagiellonian University, Krakow, Poland. Presentation Title: *Blockchain Technology on Food Recovery and Social Impact and Volunteer Distribution Management Sector: Theoretically Exploring Adoption Barriers (DEMATEL Method)*
- **Doctoral EBEN2023 Conference** “European Business Ethics Network Conference”, May 25, 2023, University of Bologna (Rimini Campus), Italy. Presentation Title: *Blockchain Technology in Food Recovery and Distribution: Social Impact and Volunteer Management*

- **Doctoral EBEN2023 Conference** “European Business Ethics Network Conference, May 26, 2023, University of Bologna (Rimini Campus), Italy. Presentation Title: *Digitalization Tools in Social Economy*
- **IRIS Network Conference** “Italian Research Institute on Social Enterprises”, June 16–17, 2022, University of Brescia, Department of Economic Management, Italy. Presentation Title: *Digitalization in Social Economy*

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Premise

Digitalization has profoundly transformed social economy organizations, serving as a growth-promoting trigger and innovation. My first doctoral research focused on systematically exploring digitalization's impact on the social economy. Employing a rigorous review of 40 articles via the PRISMA protocol and NVivo software for thematic classification, the study highlighted how digital tools empower organizations to achieve their objectives with enhanced confidence. Technologies like Big Data provide invaluable insights into social issues through advanced analytics, enabling targeted interventions. Similarly, Artificial Intelligence (AI) automates routine tasks and addresses complex social challenges, and blockchain technology offers transformative potential. Collectively, these tools drive transparency, cost reduction, informed decision-making, and innovation. My second doctoral research examined a Rough DEMATEL-based approach to identifying barriers to blockchain technology adoption in food bank supply chains. Blockchain technology (BCT) offers remarkable potential to enhance supply chain evaluations, especially in food banks, by improving operational transparency and efficiency. This study aimed to identify key barriers and understand their interrelationships. Input from academics and food bank supply chain (FBSC) experts was analyzed using the Decision-Making Trial and Evaluation Laboratory (DEMATEL) tool, a methodology adept at modeling causal relationships and interdependencies. Integrating rough theory with DEMATEL addressed subjectivity, ambiguity, and disputes in group decision-making. The findings revealed that the most critical barriers include a "lack of access to technology" (I1) and a "lack of organizational policy" (I2). These insights highlight the urgent need to bridge technological gaps by investing in accessible and user-friendly solutions. Addressing these challenges can significantly enhance the adoption and effectiveness of BCT in food supply chains, fostering resilience, efficiency, and innovation. In continuation of my research, I worked on another paper identifying the key barriers to the adoption of blockchain technology (BCT) in food supply chains (FSCs). The study explores the challenges hindering the development and deployment of BCT in this sector, with a focus on understanding the relationships among these barriers. First, the methodology design was A pairwise comparison survey form that was developed and distributed among academics and practitioners with expertise in supply chain management and BCT (n=20). Data analysis followed a four-step Rough Decision-Making Trial and Evaluation Laboratory (DEMATEL) process leading to the

identification of the overall importance of each barrier (prominence) and the causal or effect linkages (relations) between barriers within the BCT adoption landscape. Findings show that the most important weighted organizational, financial, and environmental barriers driving BCT adoption in FSCs were collaboration, coordination and communication in FSCs, cost of BCT implementation (F2), BCT customization costs (F3) being interrelated, affecting the lack of tools and standards. Other weaker interactions were identified such as the level of risk in FSCs with this effect having a large dependency on other factors. The practical implications of successful BCT adoption is dependent on addressing the cost of implementation and improving collaboration, coordination and communication in FSCs and improving the tools and standards available. Further actions need to be taken at industry level to develop cost-effective solutions built upon appropriate tools and standards that are accepted by all stakeholders. the Originality and value for this study demonstrates DEMATEL with Rough theory is a valuable tool for conceptualizing cause-and-effect interactions among the barriers influencing BCT adoption in FSCs.

Chapter 1. Introduction

The social economy holds a critical role in addressing societal challenges by prioritizing social well-being and sustainable development over profit maximization. This sector, encompassing organizations such as cooperatives, non-profits, social enterprises, and mutual societies, fosters social justice, democratic governance, and community cohesion (Moulaert & Ailenei, 2005; Defourny & Nyssens, 2010). Emerging in prominence after World War II, fueled by initiatives like the Marshall Plan, the social economy continues to evolve, emphasizing sustainability as vital for financial and social well-being (Renshaw & Krishnaswamy, 2009). Digitalization is a transformative force for the social economy, with technologies like Big Data, Artificial Intelligence (AI), and blockchain enhancing efficiency, transparency, and innovation (Wilts et al., 2021). These tools empower organizations to address social issues more effectively, foster collaboration, and adapt to societal shifts. AI and Big Data enable advanced analytics and decision-making, while blockchain enhances trust and reduces transaction costs (Chauhan et al., 2022). However, challenges such as limited access to technology, organizational readiness, and ethical concerns remain significant barriers to adoption (Dong & Yang, 2019; Gagliardi et al., 2020).

My first study conducts a systematic literature review (SLR) to explore the current research on digitalization in the social economy, addressing key questions: RQ1: Do digital technologies like Big Data, Blockchain, and Artificial Intelligence relate to the Social Economy? RQ2: What research has been conducted on adopting digitalization in social economy organizations? RQ3: How can digitalization's factors and capabilities contribute to enhancing the social economy? By examining 40 studies via the PRISMA protocol and NVivo software for thematic classification, the study highlighted how digital tools empower organizations to achieve their objectives with enhanced confidence. This research highlights key themes, gaps, and opportunities, establishing a foundation for future exploration. The findings underscore the need for tailored digital solutions, innovative experimental spaces, and sustainable income pathways to enable social economy organizations to thrive in a digitally integrated world (Gagliardi et al., 2021). This study makes a pioneering contribution by being the first to examine the impact of digital technologies on the social economy, offering a comprehensive understanding of digitalization and its implications. It serves as an invaluable resource for researchers, professionals, and practitioners, providing critical insights into technology adoption and its transformative role in strengthening the social economy. By systematically reviewing and analyzing key literature, the study lays a robust foundation for future research and identifies promising directions to advance knowledge in this evolving field.

In continuation of my research area, the literature review was instrumental in uncovering research gaps related to the application of blockchain technology within a specific area of the social economy, like the food bank system. The use of blockchain technology within the food bank system, a vital component of the social economy. It also shed light on the socio-economic implications of digitalization in this sector, particularly focusing on the accessibility and affordability of blockchain solutions for smaller or community-based food banks. Additionally, the review highlighted the need for research into how digitalization, especially blockchain, impacts relationships among key stakeholders—such as donors, volunteers, and recipients—and its potential to either improve or disrupt these dynamics. Ethical concerns, including data privacy, digital exclusion, and the equitable distribution of resources, were also recognized as critical areas for further exploration. By identifying these gaps, the literature review has provided a solid foundation for future research aimed at addressing the challenges and opportunities associated with the digitalization of food bank systems within the social economy.

For this study, I assessed Decision-Making Trial and Evaluation Laboratory (DEMATEL) and Rough A-based approach for Identifying Barriers to Blockchain Technology Adoption in Food Bank Supply Chains. Food banks exemplify the intersection of the social economy with broader supply chain systems, serving as models of efficiency, equity, and sustainability. By bridging the gap between surplus food supply and communities in need, they address food insecurity, reduce waste, and strengthen community resilience. Their integration into supply chains fosters partnerships among producers, distributors, and non-profits, ensuring efficient resource redistribution. Innovative technologies like blockchain and digital platforms enhance transparency, traceability, and accountability, further improving the efficiency of food redistribution. These efforts underscore the transformative role of food banks in reshaping supply chain systems to prioritize social economy and sustainability (Dowler & Lambie-Mumford, 2014; Tarasuk & Eakin, 2005). For this study, two key research questions are addressed: the first is, what are the key barriers to the adoption of blockchain technology in food bank supply chains? The second question explores, what are the interrelationships among these barriers?

In conducting another study, I focused on assessing the barriers to blockchain technology (BCT) adoption in food supply chains through a Rough DEMATEL analysis. Strengthening the linkages between food banks and food supply chains offers stakeholders an opportunity to create resilient systems capable of addressing food insecurity while advancing sustainability and fostering the social economy. Blockchain technology is revolutionizing food supply chains by enhancing transparency, efficiency, and trust. In the context of food supply chain, BCT provides innovative solutions for tracing donations, ensuring food safety, and automating processes through smart contracts (Tian, 2016; Saberi et al., 2019). Prominent examples, such as Walmart's IBM Food Trust platform and Carrefour's QR code tracing system, highlight BCT's potential to improve traceability and build consumer confidence (Kamath, 2018; CB Insights, 2020). These advancements can be adapted to food banking operations to track perishable items, streamline workflows, and minimize waste, aligning closely with sustainability objectives (Trevisan et al., 2024). However, the adoption of BCT in food bank supply chains (FBSC) and food supply chains (FSC) has its challenges. Technological, organizational, and policy barriers pose significant hurdles to widespread implementation (Liou & Tzeng, 2012). Overcoming these obstacles requires coordinated efforts from all stakeholders to develop strategies that address the unique complexities.

Over recent decades, concerns regarding food safety, quality, and the integrity of food labeling have increased, largely due to high-profile food scandals (Manning, 2016; Stranieri et al., 2021). This has led organizations to seek ways to track every aspect of a food product's journey and ensure data security and accessibility (Chen et al., 2021). Blockchain technology (BCT), with its decentralized platform and cryptographic validation, offers a promising solution to improve the transparency, reliability, and security of FSCs, addressing inefficiencies like information asymmetry and food recall issues (Raikwar et al., 2019; Bonetti et al., 2024).

This study shows how BCT can enhance the effectiveness and interoperability of FSCs, assuring data security and dependability (Kamath, 2018; Chen et al., 2021). However, successful implementation requires collaboration among FSC actors, overcoming barriers related to data privacy, technological constraints, and lack of knowledge or practical ability among stakeholders (Annosi et al., 2021). The study aims to address two key research questions: 1) What are the prominent barriers to adopting blockchain technology in the food supply chain? and 2) What are the relationships between these barriers? Successful BCT adoption depends on addressing the implementation costs, enhancing collaboration, coordination and communication in FSCs, and developing robust tools and standards. Further actions need to be taken at industry level to develop cost-effective solutions built upon appropriate tools and standards that are accepted by all stakeholders. The food bank system and the food supply chain share certain barriers to blockchain adoption while also facing distinct challenges, as discussed in detail in Chapter 3 and Chapter 4.

1.1. Thesis outline

This thesis is structured into five distinct chapters, each contributing to a cohesive exploration of the research topic. The first chapter introduces the research questions and establishes the foundational framework for the study. Chapter two presents the initial study of the doctoral program, offering a comprehensive literature review on the impact of digitalization on the social economy.

In chapter three, the focus shifts to assessing the barriers to blockchain technology adoption in food bank supply chains, utilizing a Rough DEMATEL-based approach. Building upon these insights, chapter four expands the investigation to examine barriers to blockchain adoption

within the broader context of food supply chains, employing a Rough DEMATEL analytical framework.

The final chapter concludes the research findings, discusses the study's limitations and implications, and provides a roadmap for future research.

Chapter 2. Exploring the Impact of Digitalization on the Social Economy: A Systematic Literature Review

2.1. Introduction

A social economy organization, as distinct organization, wields considerable economic influence in society Salamon & Geller (2007). It emphasizes the critical importance of sustainability for a country's financial and social well-being and makes significant social contributions (Renshaw & Krishnaswamy, 2009). The term "Social Economy" was used to emphasize the necessity of ethical economic development, especially during periods of social and economic imbalance (Mook & Quarter 2006). The term was further explored in Cummings' 1890 article, "Social Economy at the Paris Exposition." After the Second World War, there was a significant shift towards the Social Economy, thanks to the support of the Marshall Plan and

the resulting economic growth in Europe. The landscape of Social Economy Organizations (SEO) in Europe is quite diverse, including cooperatives, foundations, associations, mutual societies, and social enterprises that function like regular companies (Borzaga & Tortia, 2006). Definitions of the social economy often assume that sectors can interact (Quarter & Mook, 2018). The social economy encompasses a diverse range of organizations that prioritize social objectives and community well-being over profit maximization. It consists of voluntary, mutual societies, non-profit organizations, social enterprises, charities, and cooperative sectors, which are formally independent of the state. Their market activities serve to achieve social development goals that go beyond purely economic objectives. Therefore, the social economy should be seen as a distinct third sector (Moulaert & Ailenei, 2005).

The Social Economy Action Plan outlines several key initiatives to support the social economy (European Commission, 2021¹). 1. Developing social economy framework conditions. 2. Establishing a new EU Social Economy Gateway, which will offer a clear entry point for social economy stakeholders, relevant actors, and individuals seeking information on EU funding, policies, and initiatives. 3. Creating a new European Competence Centre for Social Innovation. Their focus is on social, cultural, and environmental goals rather than maximizing profits. These organizations are known for their dedication to social justice, democratic governance, and community well-being. They often reinvest any surplus back into their missions to address various societal challenges (Defourny & Nyssens, 2010). Between 2014 and 2020, over €2.5 billion from the EU budget was allocated to support the social economy. For the 2021-2027 period, the European Commission aims to increase this support, anticipating greater investment through the enhanced multiplier effect of Invest EU and additional backing for social impact and innovation. Other EU programs and national-level funding will also contribute to supporting the social economy. Strengthening past achievements is essential to address demographic, environmental, and digital challenges, particularly in the wake of the COVID-19 crisis. The plan outlines European support for the social economy up to 2030, in alignment with the European Pillar of Social Rights Action Plan (European Commission, 2020). The third sector, which is a vital part of the social economy, consists of a wide range of independent organizations. These organizations are separate from the government and for nonprofit businesses (Birchall, 2004). The third sector addresses gaps left by the public and private sectors, prioritizing social goals over profit to tackle issues such as poverty, inequality,

¹ European Commission in the Social Economy Action Plan <https://ec.europa.eu/social/main.jsp?catId=1537&langId=en>

and environmental degradation in innovative and community-focused ways. Operating on principles of solidarity and cooperation, third-sector organizations strengthen community bonds, enhance social capital, and contribute to the social fabric and economic stability of societies. Understanding their dynamics and contributions is essential for sustainable and equitable development (Defourny et al., 2010; Berardi et al., 2021).

Nonprofit organizations are another crucial component of the social economy. These entities operate for social, cultural, educational, or environmental purposes without distributing profits to owners or shareholders. They focus on addressing various societal issues such as poverty, health, education, and social services (Salamon, 1999). It's important to highlight the significance of core values such as social impact, participatory governance systems, and ethical business and governance models in guiding digitalization tools. Utilizing technologies such as AI and big data has the potential to revolutionize traditional business models. With the ability to personalize at a mass scale, companies can now choose sustainable inputs that meet their customers' needs. digital technologies are essential in the current social economy to facilitate networking and collaboration opportunities that go beyond physical constraints. digital technologies are essential in the current social economy to facilitate networking and collaboration opportunities that go beyond physical constraints (Galindo, et al., 2019).

This technological integration can lead to higher productivity and sustainability for both local and global economies and enterprises (Wilts et al., 2021). To fully understand technology's impact, it is imperative to consider cultural, organizational, and societal contexts, as Urbach and Röglinger emphasized in their 2018 research.

The social economy framework first prioritizes social objectives, and second, it acknowledges that different organizational models are suited to different needs and circumstances. Third, it recognizes that many social economy organizations operate across different sectors, blending public and private elements as needed. Finally, it is crucial for societies to confidently embrace a diverse range of organizational forms to cater to the needs of their citizens effectively and flexibly (Mook et al., 2015).

From a social economy perspective, the current era of digital platforms and advanced technology is bringing about significant changes. The rapid and widespread digital transformation is revolutionizing how we create, design, and utilize products and services, leading to significant changes in the socioeconomic landscape. Mounting pressure is on

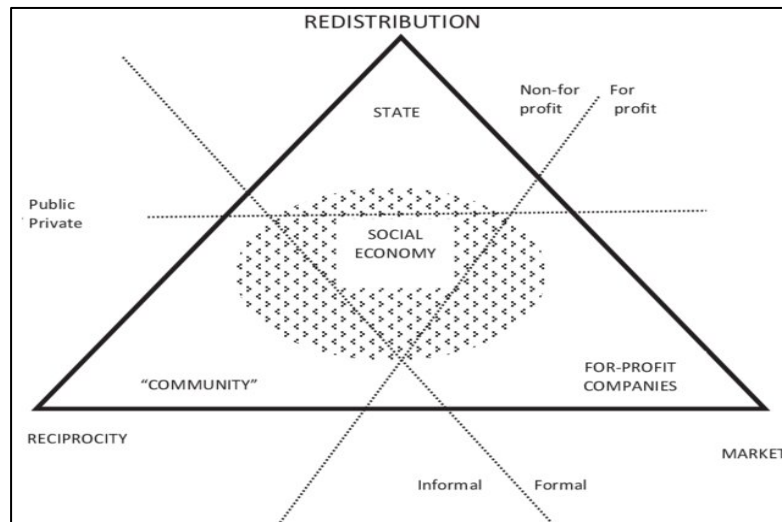
national governments and the EU to develop innovative policies that effectively support this transformation (Gagliardi et al., 2020).

According to Wilts et al. (2021), digital technologies, including artificial intelligence, encompass models and systems that carry out tasks related to human intelligence, such as reasoning and learning. These technologies can provide crucial support to organizations in applying social and economic principles. The process of digitalization is intended to enhance various areas of society, such as healthcare, education, job opportunities, entrepreneurship, agriculture, transportation, environmental protection, and natural resource management. This can lead to substantial benefits by boosting economic growth through improved efficiency, productivity, and competitiveness achieved with the use of digital technologies. It is crucial to modernize different economic sectors and activities while also gaining new competitive strengths and characteristics (Okhrimenko et al., 2019).

To proceed, social economy organizations to thrive, they need access to two key resources. Firstly, they require spaces to experiment and develop digital technologies, platforms, and advanced technological applications that cater specifically to their needs. Secondly, they need reliable pathways to income generation, which is essential for their smooth operation. It is worth noting that social economy organizations operate under unique circumstances that require careful consideration (Gagliardi et al., 2021).

According to Defourny and Nyssens (2012), social economy organizations have a unique role in the economy as they adhere to fundamental principles such as the market's basic rights, fair distribution of goods and services, and voluntary economic activity. These organizations operate in the third sector, bridging the gap in the economy where traditional businesses are unprofitable and social entities are unable to operate effectively (Figure 2-1).

Figure 2-1. Locating social economy organizations in the economy.



Source: Defourny & Nyssens (2012), p.11.

Incorporating technologies into the social economy is essential for progress. These technologies offer easy access to public services and create more job opportunities, driving economic growth. Ultimately, this leads to an overall improvement in the social welfare of individuals (Dong & Yang, 2019). According to Chauhan et al. (2022), modern technologies significantly impact the social economy. They improve operations, increase efficiency, reduce transaction costs, create job opportunities, and promote economic growth. Digitalization plays a vital role in providing essential public services, encouraging citizen engagement, and fostering economic growth. However, integrating Social Economy organizations with digitalization technologies like big data, blockchain, and artificial intelligence poses challenges that require attention from researchers, practitioners, and policymakers. Successfully addressing these challenges is crucial for a smooth integration of technology in the social economy. this paper aims to explore the current research literature on digitalization in the social economy. To guide our discussion, we have formulated the following research questions.

- **RQ1:** Do digital technologies like Big Data, Blockchain, and Artificial Intelligence relate to the Social Economy?

- **RQ2:** What research has been conducted on the adoption of digitalization in social economy organizations?

- **RQ3:** How can digitalization's factors and capabilities contribute to enhancing the social economy?

The contribution of this study includes research first of its kind to explore the impact of digital technologies on the social economy. Its main objective is to understand digitalization and its potential consequences comprehensively. The paper can be a useful resource for new researchers in related fields and offer more profound insights for professionals in profit organizations and the social economy. The findings of this study are also intended to be beneficial to academics and professionals interested in this area. By identifying and analyzing the most relevant papers, this review lays a strong foundation for future research and highlights some research directions that can help technology adopters better understand digitalization.

We will start by outlining the background information and references to primary sources that explain the reasons behind this shift. Second, it describes the methodology adopted for this study; the section presents the method used for this research, which is the (SLR). The third section reports the findings, which are further divided into Descriptive analysis, Discussion, and Integration. We then move on to discussing the results. Finally, in section 5, we conclude the paper by highlighting key findings and providing insightful recommendations for future research in this area. By identifying areas of potential research and highlighting gaps in existing knowledge, we aim to empower other researchers to continue exploring the effect of digital technologies on the social economy.

2.2. Methodology design

Systematic reviews are valuable research tools because they follow rigorous procedures to identify and analyze relevant data (Snyder, 2019). We followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Moher, 2009) approach to conduct an extensive assessment and gather relevant papers. This approach ensures that the review's findings and conclusions are reliable and unbiased, making them useful resources for decision-making (Oliveira & Lumineau, 2019). The PRISMA method has three essential stages: search strategy, screening criteria, and data extraction and synthesis. PRISMA (Preferred Reporting Items for Systematic Review and Meta-analysis) protocol (Shamseer et al., 2015), which is a widely accepted guideline for conducting systematic reviews (See Figure 2-2). We conducted our search on Scopus, a comprehensive database that covers a wide range of relevant literature

and has been used in several previous studies (Boon et al., 2019; Gusenbauer & Haddaway, 2020; Mehraein et al., 2023). This research utilizes a combination of literature review and NVivo-supported thematic template analysis as a methodology, as outlined by King and Brooks (2017). We created a template using NVivo software to organize the emerging data according to different levels of communication. This approach enabled us to systematically categorize and organize the themes identified in the studies, serving as the foundation for our coding procedure. This iterative process enabled us to create a final template that identified emerging themes and their interrelated patterns. We began our review by carefully selecting relevant keywords and search terms based on our objective and research questions. We also employed a snowball technique, carefully analyzing previous studies and foundational work to ensure a comprehensive understanding of the topic (Defourny & Develtere, 2009; Mehraein et al., 2023).to formulate our search queries, we utilized Boolean logic by integrating 'OR' and 'AND' connectors and extensively searched in keywords. For this study, the following initial Scopus search string was utilized:

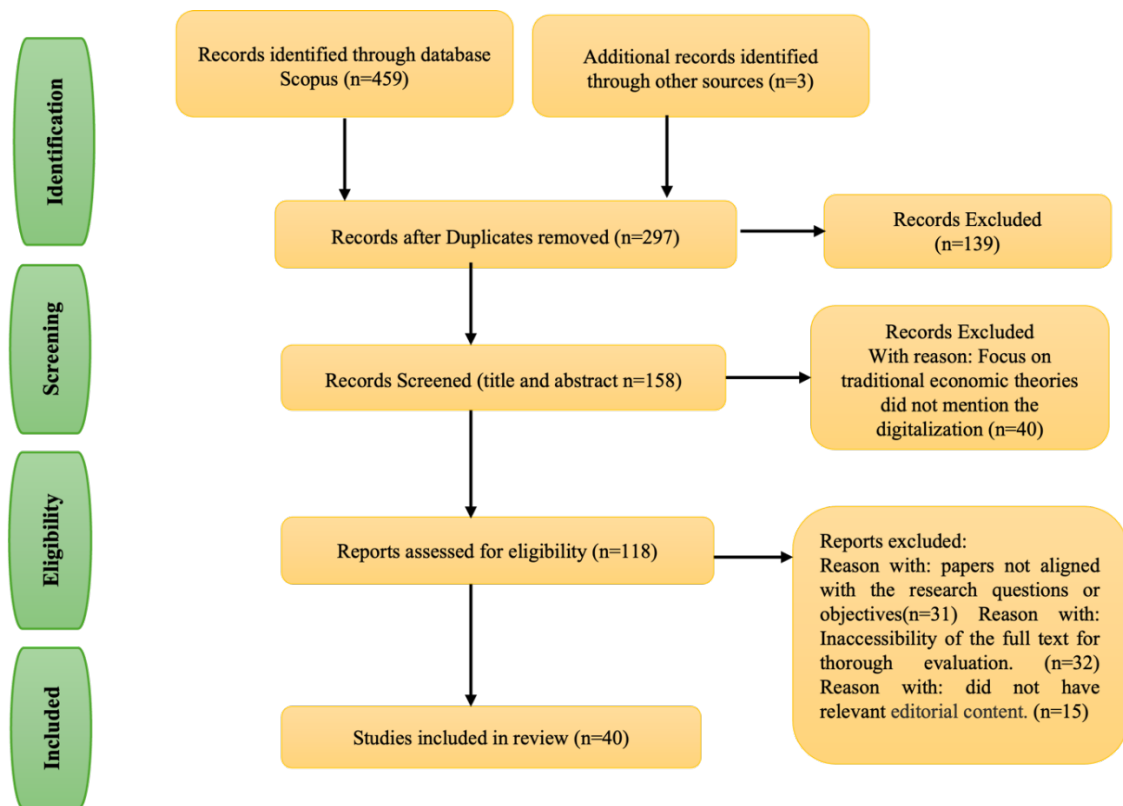
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( TITLE-ABS-KEY ( digital* OR "Digital Technology" OR "Artificial Intelligence" OR "Machine learning" OR "Web Intelligence" OR "Big data" OR blockchain OR "Internet of things" OR cybersecurity OR ICT OR "Artificial neural network" OR "Cloud computing" ) AND TITLE-ABS-KEY ( "Social Economy" OR nonprofit OR "Non-profit" OR "no profit" OR "non-profit" ) ) AND ( LIMIT-TO ( SUBJAREA , "BUSI" ) OR LIMIT-TO ( SUBJAREA , "SOCI" ) OR LIMIT-TO ( SUBJAREA , "ECON" ) ) AND ( LIMIT-TO ( DOCTYPE , "ar" ) ) AND ( LIMIT-TO ( PUBSTAGE , "final" ) ) AND ( LIMIT-TO ( LANGUAGE , "English" ) )
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In this process, we initially collected 459 documents on Scopus and identified three additional articles from other sources like google scholar First, we narrowed the scope of the review to a select number of articles to enable a thorough and in-depth analysis. We considered filtering the language of published articles to English for academic purposes. We limited the time frame of our search to articles published between 2014 and the end of 2022. We also focused on specific subject areas, specifically social sciences, business management, accounting, economics, econometrics, and finance. After removing duplicate entries, we carefully reviewed the titles, abstracts, and keywords. The screening process continued with the review of all 297 papers' titles and abstracts based on inclusion and exclusion criteria to

identify relevant studies that provided insight into the impact of digitalization tools on the social economy, and we then identified 158 papers.

We had valid reasons for excluding certain records and full-text articles in this section. Firstly, some papers were excluded because they focused on traditional economic theories without addressing digitalization tools. Additionally, some papers were not directly relevant to our research objectives and questions, falling outside the scope of our review. We also excluded editorial content as they did not meet the predefined inclusion criteria. Another factor was the unavailability of full-text articles; some papers lacked access to the complete text, and the provided abstracts or summaries were insufficient for a comprehensive evaluation. To maintain the integrity of our analysis, papers without accessible full texts were excluded. We searched the retrieved records by keywords, followed by a full-text evaluation to determine their relevance. There was strong agreement among authors (87%), and any disagreements were subsequently discussed and resolved. Ultimately, 40 articles were selected for the final analysis. Figure 2 provides details of our search process.

Figure 2-2. PRISMA Flow Diagram for systematic literature review.



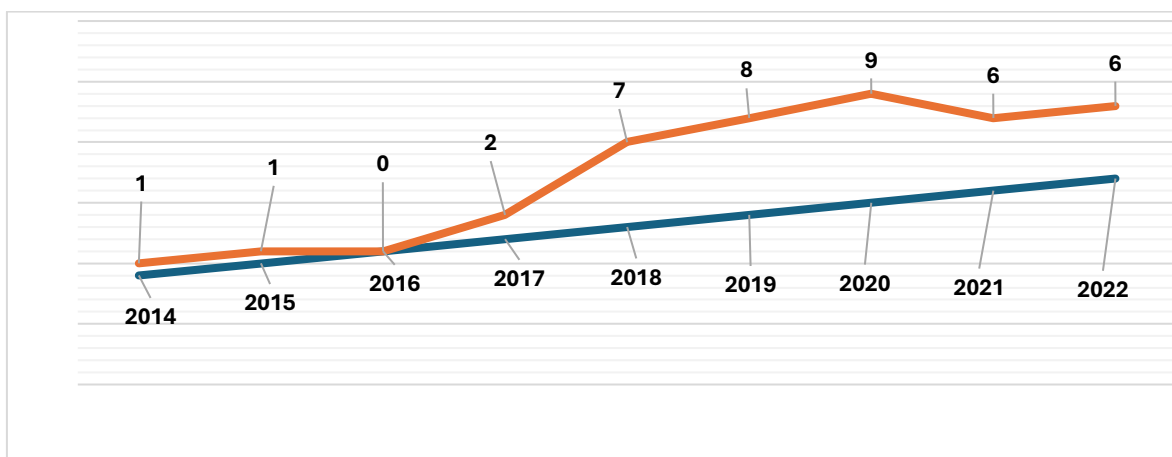
2.3. Results

2.3.1. Descriptive analysis

2.3.1.1. Publications by year

We specifically chose the period from 2014 to 2022 because prior to 2014, there was a lack of research on the impact of digital technologies on the social economy. Limiting the review to recent years ensures the inclusion of the most up-to-date data, theories, and findings. This period provides a sufficient volume of literature to perform a robust analysis while remaining manageable in scope. It also ensures that the findings are relevant to current technological and socio-economic contexts. Figure 2-3 shows that in the number of publications related to our selected topic during the review period. The growth of studies on this topic, especially between 2014 and 2017, is significant. After 2014, there was a significant increase in the number of publications. Over fifteen papers were published during the pandemic in 2020 and 2021. The rapid increase in the number of articles is to be expected as we are concentrating on an emerging research stream. During the COVID-19 pandemic, social economy organizations played a pivotal role in providing vital services and bolstering community resilience. This crisis drove the adoption of digital technologies as these organizations shifted to remote work and digital service delivery, sparking heightened interest and usage of digital tools within the social economy.

Figure 2-3. The number of papers published between 2014 and 2022.



2.3.1.2. Publication by kind of organizations

Our review focuses on studies on specific social economy organizations, like voluntary associations and social enterprises, as well as those covering the generic sector, including non-profits and third-sector entities. These studies offer detailed insights into the use of digital technology in social economy organizations. This review examined common trends and challenges faced by nonprofits, third-sector organizations, and the wider social economy as they adopt digital technologies. Among the various types of organizations examined, other forms of social economy were the focus of the most frequent studies, with 14 papers, while nonprofit organizations ranked second with 12 papers. Third-sector entities were the focus of six papers, and four papers examined both social enterprises and volunteer organizations, as shown in Figure 2-4.

Figure 2-4. The types of organizations examined in the social economy.



2.3.1.3. Geography map of scientific production

The map illustrated in

Figure 2-5

Figure 2-5 displays the geographic areas that have conducted research on digitalization and the social economy. The yellow areas indicate a low number of countries studied, while the darker green areas indicate a high number. Studies on digitalization in the social economy show that Russia has the highest number of articles among other European countries but still lags behind developed European countries. It has been observed that Russia's production of products with high R&D intensity is relatively low, as evident from the growth rate in its High-Technology Exports. However, the country ranks high in the National Cyber Security ranking. In terms of research publications, the majority of articles have been published by European authors, with Russia having the highest number of publications at 8 (21%), followed by Germany with 5 (12.5%), and Italy, Romania, and the UK with 3 (7.5%) each. (Table 2-1) Similar studies have also been conducted by authors from the USA and Canada. refer to (

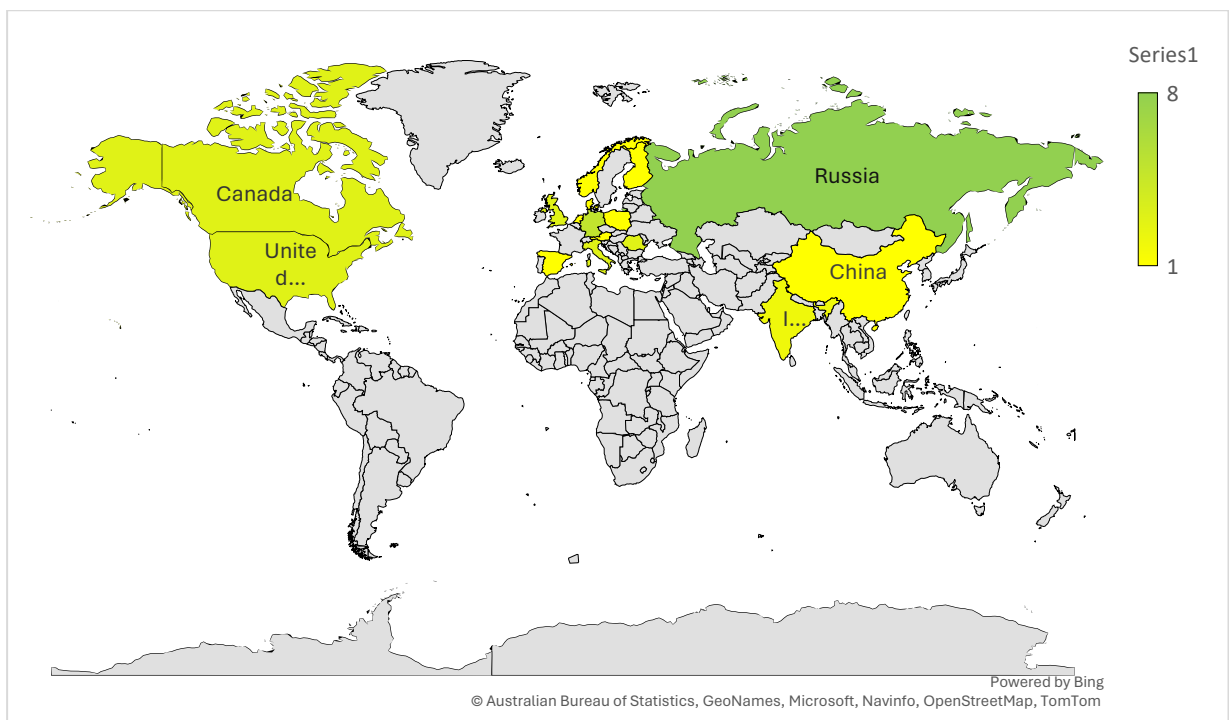
Figure 2-5) for a visual representation of the papers by geographic region.

Table 2-1. The papers by percentage geographic regions

Geographic Area	Percentage (%)
Holland	2.5
India	5
Canada	7.5
Russia	20
Italy	7.5
Romania	7.5
Spain	2.5
Thailand	2.5
China	2.5
Portugal	2.5
Poland	2.5

Germany	12.5
Finland	2.5
United States	7.5
Austria	2.5
Uk	7.5
Norway	2.5
Danmark	2.5

Figure 2-5. Geographic distribution by country.



2.3.1.4. Publication by research methods

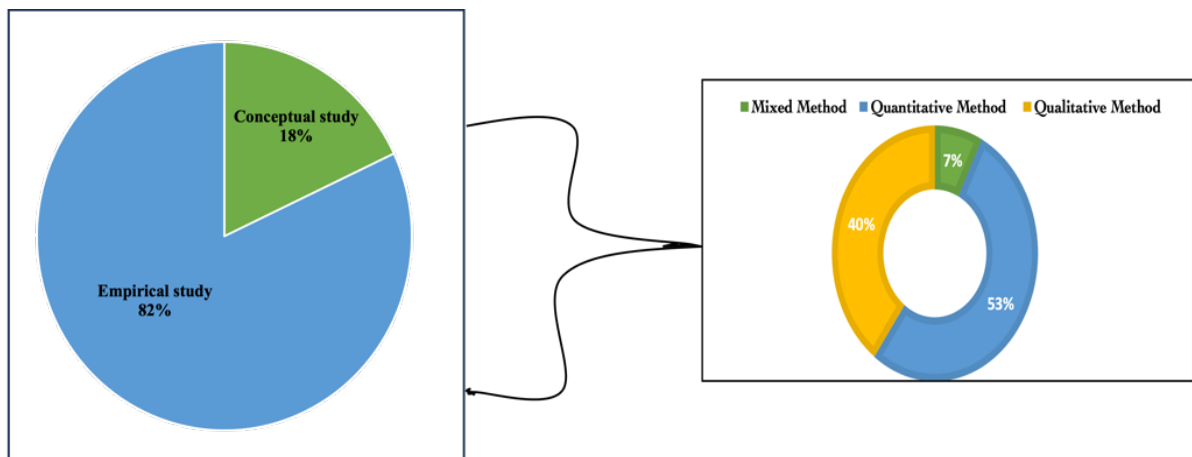
To understand how we classify papers, we examined the ratio of conceptual and empirical papers. Empirical papers concentrate on digitalization activities and processes that can be observed or measured using both qualitative and quantitative methods. On the other hand,

conceptual papers offer valuable insights, theories, frameworks, and criticisms on emerging technologies like AI and blockchain in the social economy. They provide a foundation for new ideas and offer a comprehensive understanding of the subject matter.

However, researchers face challenges in collecting and analysing real-world data due to debates on definitions. The analysis indicates that research on digitalization's impact on the social economy is a recent and rapidly growing trend. Such studies are mostly published in a limited number of journals on economics and marketing. Out of the 40 academic articles selected, 9 (18%) were conceptual, and 41 (82%) were empirical studies, as shown in

Figure 2-6 Among the 41 empirical studies, 21 (53%) used quantitative research methods, 16 (40%) used qualitative methods, and 3 (7%) used mixed research methods. In other words, the majority of research conducted in this field is quantitative, with surveys being the most commonly used research method. The relatively high proportion of conceptual articles indicates that the field is still in its early stages of development. After conducting empirical studies, researchers aim to identify and address significant challenges within different contexts of the social economy. Additionally, they analyse the digital tools used to enhance the social economy. This trend is supported by the existing literature on social economy and digitalization, as qualitative analysis has shown.

Figure 2-6. Overview of research methods used.

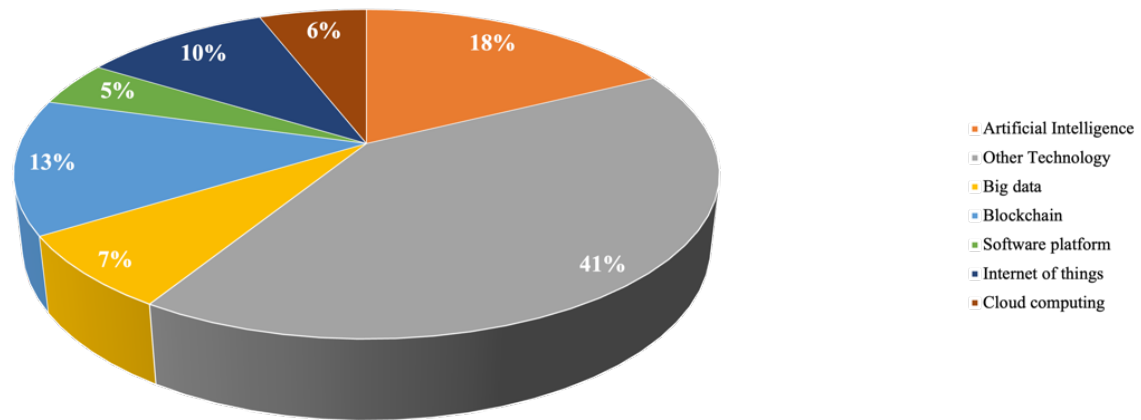


2.3.1.5. Publication by digitalization keywords

Digitalization can bring significant benefits to nonprofits and the social economy. It can improve efficiency by simplifying work processes, streamlining communication, and facilitating collaboration. Moreover, digitalization can help reduce labor costs by automating tasks, personalizing donations, increasing transparency, raising awareness, virtualizing marketing, and decentralizing services (Herbert, 2017).

Social economy organizations must utilize digital platforms and advanced technologies to boost their performance and decision-making capabilities. Social economy organizations must harness the power of digital platforms and advanced technologies to maximize their performance and decision-making capabilities. Our study shows that digital tools are essential, with other technologies being the most frequently utilized (at 41%), followed by artificial intelligence (at 18%). By utilizing these state-of-the-art tools, social enterprises can confidently drive their success and make a significant impact on the social economy. Figure 2-7 AI's economic impact has been both widely recognized and undeniable. With its unparalleled capacity to process vast amounts of data, AI enhances productivity, drives growth, streamlines processes, and supports more informed decision-making. The adoption of AI holds tremendous potential to accelerate economic growth and productivity, making it a game-changer for social economy organizations. As intelligent companies increasingly leverage digital technologies like artificial intelligence, big data, and blockchain, a new era of innovation and exploration has begun. The advancements in science and technology have disrupted conventional institutions, leading to globalization and digital transformation, thus paving the way for a new paradigm of human interaction. The second digitalization tool is the popular Blockchain technology can bring enormous positive development opportunities. Blockchain technology will significantly affect the SEO in NPO. this technology with 9 (13%). In general, Blockchain shows potential as a tool that can greatly influence the social economy and, respectively, the Internet of Things 7 (10%), the most frequently analyzed issue. But we also could find other essential topics, such as Cloud Computing 4 (6%), Software Platforms 3(5%), and Big Data 5 (7%).

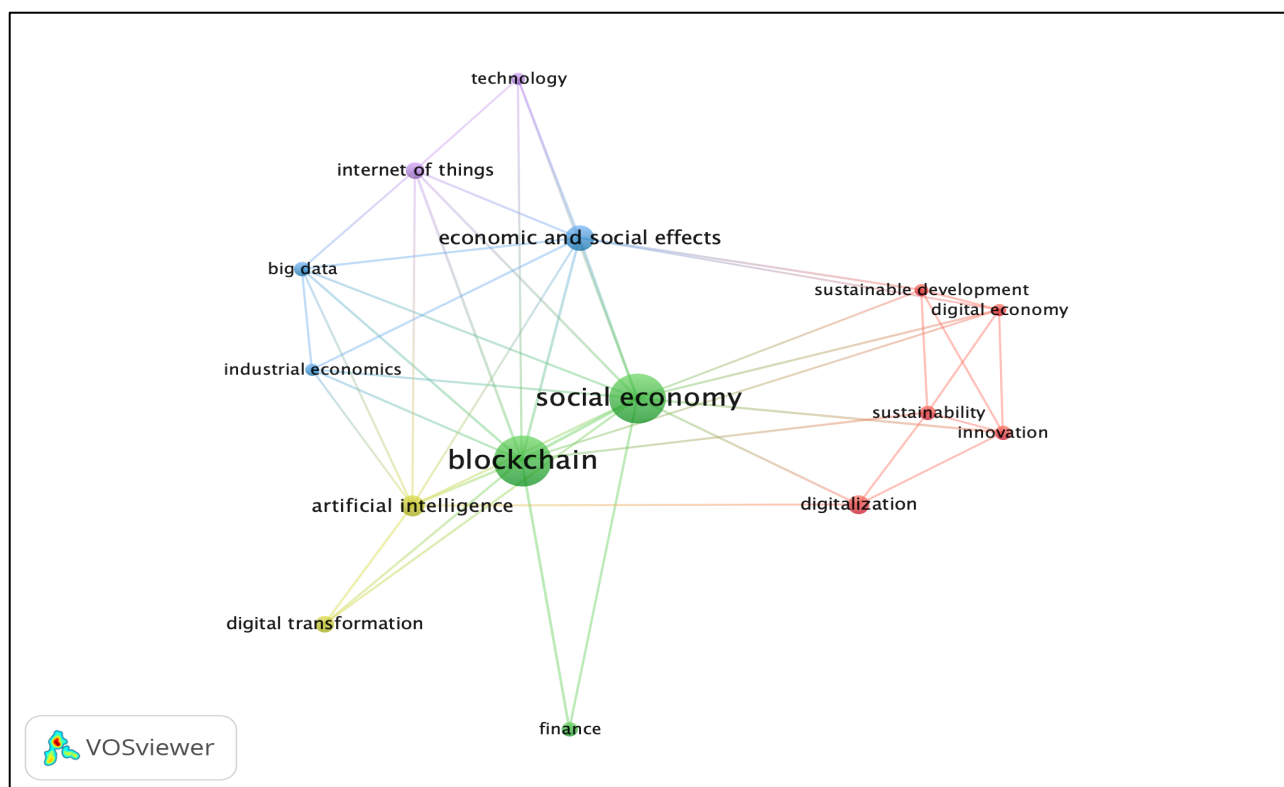
Figure 2-7 Digital technologies applied in papers.



2.3.1.6. Clustering and relation diagram of keyword frequency

The relation diagram in VOSviewer illustrates the strength and directionality of relationships between keywords based on their co-occurrence frequencies. Nodes represent keywords, and the thickness and color of the lines connecting them indicate the strength and nature of their associations. A thicker line between two keywords signifies a stronger relationship, suggesting frequent co-occurrence in the same documents. This diagram visually maps out the interconnections between different concepts and themes in the literature, providing insights into which keywords are central or peripheral within the research domain. The keyword co-occurrence in our analysis, as shown below, depicts four connected clusters, with social economy being the most central topic, followed by blockchain. Figure 2-8 shows a stronger relationship between social economy and blockchain and then the artificial intelligence keyword. The integration of AI and big data into the social economy represents a significant shift towards more data-driven and technologically advanced approaches, highlighting the increasing importance of digital transformation in driving economic and social innovation. Overall, both clustering and relation diagrams in VOSviewer enhance the visualization and exploration of keyword relationships, offering valuable tools for bibliometric analysis and literature mapping in research.

Figure 2-8. VOSviewer overlay visualization of the co-occurrence analysis of author keywords with factorial counting



2.3.1.7. The studies are organized by citation count across multiple journals

Table 2-2 presents a detailed overview of the most influential studies on digitalization and the social economy, ranked by citation count. The analysis of these studies reveals several key findings regarding the state of research in this emerging field.

The most cited study, "The Impact of Digitalization on Business Models" by Bouwman et al. (2018), with 539 citations, underscores the importance of understanding how digital technologies reshape business models across various sectors, including the social economy. This article's prominence suggests a strong scholarly interest in how organizations can adapt their strategies to leverage digitalization effectively. Similarly, "Introduction to Digitalization Cases" by Urbach and Röglinger (2018), with 226 citations, highlights the transformative impact of digitalization on organizational strategies and operations, further supporting the critical role of digitalization in redefining traditional business models. The study "A Framework to Make Charity Collection Transparent and Auditable Using Blockchain Technology" by Farooq et al. (2022), with 107 citations, illustrates a growing recognition of blockchain's potential to enhance transparency and trust within the social economy. The significant number of citations indicates that blockchain technology is considered a vital tool for addressing

accountability issues in charitable activities and nonprofit management. Multiple studies, such as "Challenges of Digital Transformation: The Case of the Non-Profit Sector" by Nahrkhalaji et al. (2018) and "Challenges of the Digital Transformation: Comparing nonprofit and Industry Organizations" by Vogelsang et al. (2021), highlight the specific barriers nonprofit organizations face in digital adoption. These studies, with 94 and 18 citations respectively, reveal key challenges like limited resources, resistance to change, and lack of digital skills, emphasizing the need for targeted strategies to support nonprofits in their digital transformation journeys. Several studies aim to develop strategic frameworks to assist organizations in navigating digital transformation. For example, "Fields of Action to Advance the Digital Transformation of NPOs" by Brink et al. (2020), with 17 citations, offers a structured approach to digital transformation for nonprofit organizations (NPOs). This focus on frameworks suggests a need for practical guidance on how these organizations can effectively implement digital strategies. Studies like "Digitalization, Social Entrepreneurship, and National Well-Being" by Torres and Augusto (2020) (76 citations) and "Global Trends in the Social Economy Development" by Stukalo and Simakhova (2021) (17 citations) examine the broader implications of digitalization on social enterprises and societal well-being. These articles explore how digital tools can drive social innovation, improve quality of life, and support sustainable development. the article "New Technologies and Digitization: Opportunities and Challenges for the Social Economy and Social Enterprises" by Gagliardi et al. (2020) (15 citations) and "Social and Economic Background of Digital Economy: Conditions for Transition" by Afonasova et al. (2020) (27 citations) delve into the specificities of how social economy organizations can harness digital tools, highlighting both opportunities and challenges.

Table 2-2. The list of studies organized by citation count across various journals.

Rank	Year	Title	Author(s)	Journal	TC ²
1	2018	The impact of digitalization on business models.	Bouwman, , et al.,	Digital Policy, Regulation and Governance, 20(2), 105-124	539
2	2018	Introduction to digitalization cases: how organizations rethink their business for the digital age.	Urbach, et al.,	Journal of Springer International Publishing.	226

² TC total citations.

		In digitalization cases: how organizations rethink their business for the digital age			
3	2022	A framework to make charity collection transparent and auditable using blockchain technology.	Farooq, et al.,	Computers & Electrical Engineering, 83, 106588.	107
4	2018	Challenges of digital transformation: The case of the non-profit sector	Nahrkhalaji, et al.,	International conference on industrial engineering and engineering management (IEEM) (pp. 1245-1249). IEEE.	94
5	2020	Fields of action to advance the digital transformation of NPOs– development of a framework.	Brink, et al.,	In International Conference on Business Informatics Research (pp. 82-97). Cham: Springer International Publishing.	17
6	2020	New technologies and digitisation: Opportunities and challenges for the social economy and social enterprises.	Gagliardi, et al.,	European Commission, Executive Agency for SMEs, DOI, 10, 667682.	15
7	2021	Challenges of the digital transformation Comparing nonprofit and industry organizations. In Innovation Through Information Systems: Volume I: A Collection of Latest Research on Domain Issues (pp. 297-312).	Vogelsang, et al.,	Journal of Springer International Publishing.	18
8	2020	Digitalization peculiarities of organizations: A case study	Vasilev, et al.,	Entrepreneurship and Sustainability Issues, 7(4), 3173	82
9	2018	Social and economic background of digital economy: conditions for transition.	Afonasova, et al.,	European Research Studies Journal, 21(Special issue 3), 292-302.	27
10	2020	Digitalisation, social entrepreneurship and national well-being.	Torres , et al.,	Technological Forecasting and Social Change, 161, 120279.	76
11	2021	Global trends in the social economy development.	Stukalo, et al.,	International economic policy, (34), 7-22.	17

2.4. Discussion and Integration

In this section, we are addressing three questions that need to be investigated further.

- **RQ1:** Do digital technologies like Big Data, Blockchain, and Artificial Intelligence relate to the Social Economy?

Blockchain technology significantly enhances transparency and accountability within the social economy. Its decentralized ledger system enables the creation of secure, transparent, and tamper-proof transaction records, fostering unwavering trust among stakeholders (Zheng et al., 2018). Blockchain has revolutionized financial systems with its use of cryptocurrencies. Its impact on companies, industries, information systems, and social relationships cannot be overstated. The experts are highly confident this technology will have far-reaching implications for customers, people, and organizational behavior, as well as AI and the Internet of Things. Innovations involve not only the introduction of new technical devices but also social and economic structures (Barker et al., 2020; Matt et al., 2023).

Digital technologies such as Big Data, Blockchain, and Artificial Intelligence (AI) have a profound impact on the social economy by significantly improving efficiency, transparency, and innovation. Big Data analytics empower social economy organizations to gain deeper insights into social issues, enabling them to target interventions more effectively. Through the analysis of extensive data, these organizations can pinpoint patterns, forecast outcomes, and allocate resources more efficiently, ultimately leading to the implementation of more impactful social programs. For instance, Big Data can track health trends in underserved communities, optimize supply chains for food banks, and measure the effectiveness of educational programs (Kitchin, 2014; Mougayar, 2016; Bridge et al., 2020).

According to a study by Zheng et al. (2018), blockchain technology offers substantial benefits for the social economy by ensuring transparency and accountability in transactions. This is particularly vital for social enterprises and non-profits, which rely heavily on trust and donor confidence. Blockchain enhances the traceability of donations, ensuring that funds are utilized appropriately, thereby increasing stakeholder trust. Additionally, blockchain facilitates secure and transparent contracts and transactions, which are essential for cooperatives and other social economy entities that operate on principles of fairness and equity.

Blockchain technology has revolutionized financial systems with its use of cryptocurrencies. Its impact on companies, industries, information systems, and social relationships cannot be overstated. The experts are highly confident that blockchain technology will have far-reaching implications for customers, people, and organizational behavior, as well as AI and the Internet of Things. Innovations involve not only the introduction of new technical devices but also social and economic structures (Barker et al., 2020). To achieve successful digital transformation, organizations must integrate modern technologies like IoT, blockchain,

Cloud Computing, and Data Analytics, and develop relevant digital skills and capabilities (Tsolakis et al., 2022; Lemieux, 2016; Dicuonzo et al., 2021).

Artificial Intelligence (AI) theoretically contributes to the social economy by offering advanced tools for automating routine tasks and providing sophisticated solutions to social problems. AI's predictive analytics and machine learning capabilities can improve decision-making processes, enabling social economy organizations to anticipate needs and respond proactively. This theoretical framework of enhanced responsiveness and adaptability is crucial for addressing dynamic social challenges. Additionally, AI's potential to personalize services, such as tailored educational programs or healthcare interventions, aligns with the theoretical concept of individualized care and support, promoting inclusivity and equity within the social economy (Vinuesa et al., 2020; Holzmann & Gregori 2023).

From a social impact perspective, these technologies have the potential to democratize access to information and resources, empower marginalized communities, and promote inclusivity. Big Data analytics can bring attention to disparities and direct resources to underserved populations, ensuring a fair distribution of social services. Blockchain can empower individuals by granting them control over their data and transactions, reducing reliance on intermediaries and improving financial inclusion. AI can offer customized solutions to social issues, such as tailored educational programs for disadvantaged students or optimized healthcare services for remote areas (Mittelstadt et al., 2016).

Social-purpose organizations can increase revenue and social impact by aligning trade and social activities through digitization, leading to greater financial independence and innovative organizational models (Alshawaaf & Lee, 2021). Likewise, digitization is crucial for economic growth and social progress in developed countries. Credit institutions and nonprofit organizations face sustainability and security challenges in integrating digital technology into their operations. New measures are necessary to ensure economic security in these sectors (Borkova et al., 2020; Sept 2020).

For instance, regarding the social economy and social economy enterprises in Italy, a recent survey on the digital transformation of the whole country's social economy highlights the fact that digital technologies are broadly diffused amongst Italian social economy enterprises and are often included in all their activities (23%), but still not deployed with a strategic purpose (34%). Nevertheless, a small portion of social economy enterprises still do not deploy any

digital technologies (one in eight social enterprises). Social economy enterprises are shaping the digital sphere through the use of a growing number of digital applications. This has resulted in the emergence of new ecosystems of organizations that are building a digital social economy. Digital social economy enterprises prioritize users or use technology for social goals. These innovations help users manage and leverage digital impact for societal benefit and transformation (Brülisauer, 2020; Balcerzak & Pietrzak, 2017).

According to the survey conducted by ISNET (2020)³ titled "Exploring the Impact of Digital Technologies on Social Economy Organizations," and published by the International Social Economy Network, definitively presents the perspectives of 500 Italian social enterprises. This includes 400 social cooperatives and 100 social enterprise ex-leges, providing clear insights into the potential impact of specific digital technologies on their organizations. The survey unequivocally reveals that social enterprises are increasingly embracing digital technologies due to their business-oriented characteristics, which undeniably contribute to economic sustainability by optimizing their business practices.

A 2020 study by Grow revealed that social economy organizations in Italy, including social enterprises, require practical and legal assistance to effectively implement digital technologies. This aid can assist them in overcoming challenges that may arise during the process of digitalization. Consequently, these enterprises are urging the government and central administrations to prioritize skills and technologies as part of the incentives they provide. To achieve a successful digital transformation, organizations must integrate modern technologies such as IoT, blockchain, cloud computing, and data analytics while also developing the necessary digital skills and capabilities (Tsoulakis et al., 2022).

• **RQ2:** What research has been conducted on the adoption of digitalization in social economy organizations?

According to Gagliardi et al. (2020) assessing the current state of digital transformation in the social economy requires focusing on skills, technologies, and practices. This assessment will help identify education and learning needs, and policies should prioritize skills, education, and learning objectives. The social economy's capacity, skills, and competencies to navigate an

³Definition International Social Economy Network The survey conducted by ISNET (2020) <https://op.europa.eu/en/publication-detail/-/publication/2c17d0c2-3384-11eb-b27b-01aa75ed71a1/language-en>

increasingly digital world at all levels can be enhanced by doing so. A recent study by Yli-Viitala et al. (2020) focused on implementing and utilizing digitalization in the US manufacturing industry. Despite the lack of strong national policy initiatives reflective of a market-driven economy, Culture, and policy support digitalization in manufacturing. Digitalization has permanently affected the social economy, triggered a management revolution and decentralized financial technologies. According to Kumaret al. (2022) study, Expanding the digital community can create a more inclusive European economy that tackles 21st-century challenges with advanced technologies and platforms. A combination of AI and blockchain technology is a global trend with significant potential in the business and economics sectors. Research indicates that social economy organizations face considerable challenges in adopting digital technologies, such as limited resources, inadequate expertise, and resistance to change. Overcoming these obstacles requires enhancing digital literacy, fostering a supportive organizational culture, and ensuring strong leadership commitment. Furthermore, the findings highlight the critical need to create an environment conducive to digital transformation, where dedicated leadership can effectively drive this transition (Vogelsang et al., 2021). The digitalization significantly impacts operational efficiency and social outcomes, which has been a focal point of research. Empirical studies demonstrate that digital technologies can greatly enhance the efficiency of social economy organizations by streamlining processes and reducing administrative burdens. For instance, digital platforms can help improve coordination and communication among staff and volunteers, resulting in more efficient service delivery (Chui et al., 2012). Furthermore, the use of digital tools can enhance monitoring and evaluation processes, allowing organizations to measure the impact of their interventions more accurately and make data-driven decisions (Torres & Augusto 2020; Skivko, 2021).

Digital tools significantly enhance the operational efficiency of social enterprises. Their findings highlight the capacity of digital technologies to streamline processes and reduce administrative burdens, enabling organizations to devote more resources to their core mission (Chui et al., 2012; Krueger & Haytko 2015).

According to Bellakhal and Mouelhi (2020), integrating digital tools into operations can have several advantages. It can improve human resource management, reduce expenses, and contribute to substantial economic growth. Digitizing processes enables social enterprises to access financing opportunities and cut costs associated with communication, administration,

and commerce. These benefits can significantly enhance performance within the social economy organizations.

A recent study by Alshawaaf and Lee, 2021, research and innovation (R&I) are crucial for digital transformation in the social economy. However, R&I is not fully utilized due to a lack of structure and systemization. Social economy organizations must implement digitalization strategies and integrate digital technologies to address challenges. This requires proper support and guidance. Organizations can expand both physically and virtually by creating digital intellectual resources. The European Social Economy Summit held in May 2021 recognized the social economy as the new way of doing business and the future business model for Europe. Social economy organizations (SEOs) in European countries consist of around 2.8 million entities, such as cooperatives, mutual benefit societies, associations, foundations, and social enterprises. These organizations have created over 13 million jobs. The Commission will conduct a thorough study to gain a comprehensive understanding of the social economy in the EU. This study will involve both qualitative and quantitative data collection. (Social Economy Europe Report, 2022). Digital technologies are vital for non-profit organizations to grow; as per a 2019 study by Chunakov et al., these technologies offer effortless access to information and feedback mechanisms, which in turn reduces the need for expensive marketing tools. Thus, non-profits can fully leverage the power of digital technologies to achieve their goals. It is evident that data must undergo transformation to become suitable for analysis. Analysts often encounter challenges or barriers in integrating various datasets commonly utilized by third sector and social economy organizations. Therefore, implementing new digital solutions is imperative to determine how data can be captured, stored, and managed to augment non-profit entities' accountability and data analysis (Farooq & Abid, 2020; Calderon & Ribeiro 2024).

Digitalization poses theoretical challenges regarding how technology affects organizations and individuals and how it is adopted by organizations, as noted by Leviäkangas & Kauppila (2020). While we acknowledge the limitations and challenges in digitalizing the social economy, for further research, while the implementation of digital technology in developing economies is complex, it holds significant potential benefits. For international companies, particularly those in the food chain industry, digitalization can help attract more clients by improving efficiency, transparency, and customer engagement. By leveraging digital tools, these companies can better meet consumer demands, streamline supply chains, and enhance their competitive edge in the global market. Overall, prioritizing social issues in future research

and understanding the multifaceted impact of digital technology are essential for fostering an inclusive and equitable digital transformation within the social economy. This approach ensures that digital advancements contribute to broader social goals and address the unique challenges faced by diverse social economy organizations.

• **RQ3:** How can digitalization's factors and capabilities contribute to enhancing the social economy?

Blockchain technology introduces a new framework for trust and transparency in the social economy. Its decentralized ledger system ensures transparent, immutable, and verifiable transactions, which is essential for maintaining stakeholder trust. This transparency can enhance governance models in social economy organizations, ensuring ethical management and fair resource distribution (Zheng *et al.*, 2018).

Theoretically, AI capabilities support adaptive and personalized service delivery within the social economy. AI's machine learning and predictive analytics can customize services to individual needs, promoting inclusivity and equity. This aligns with theoretical concepts of personalized social support, enabling more effective and responsive interventions (Vinuesa *et al.*, 2020). Digital technologies enable social economy organizations to expand their operations and foster innovation. AI and Big Data can assist in identifying emerging social issues and swiftly developing innovative solutions. Blockchain can aid in establishing decentralized networks and partnerships, allowing for collaborative approaches to social challenges on a broader scale (Gupta *et al.*, 2020). AI provides powerful tools to address complex social problems and boost operational efficiency effectively. From personalized education programs to predictive maintenance in social housing, AI-driven solutions substantially elevate the effectiveness of social economy initiatives (Vinuesa *et al.*, 2020).

As per Kaplan and Haenlein's (2019) definition, Artificial intelligence (AI) refers to a system's ability to interpret external data accurately, learn from it, and use that knowledge to achieve specific goals and tasks through adaptable adaptation. Nonprofit organizations, specifically museums, are embracing digitization, such as AI, to leverage the potential of digital technology. This approach aims to enhance social value for their audiences and promote cross-cultural understanding. Some of them have already succeeded in finding new ways of interaction and information sharing through this modern approach. Digital platforms and blockchains impact work, goods and services, money, finance, and governance. They offer

incredible possibilities, and it is recommended that their impacts be managed actively to ensure they align with people-centered development and sustainability. (Brülisauer, 2020; Jones & Wynn, 2021). Integrating digital technology into nonprofit organizations and other social economy entities is a key strategy for bridging the gap between technological advancement and social welfare. Achieving this goal relies heavily on comprehensive management education at all levels (Gagliardi et al., 2020). The use of digital platforms and advanced technologies can have a positive impact on the social economy by automating processes, streamlining operations, and creating innovative social services. Collaborating with stakeholders in environments like social clusters and creative spaces helps modernize social economy organizations. Nonprofit organizations must have a well-defined digital strategy, as emphasized in the 2018 Italia Nonprofit Report titled "Third Sector and Digital Transformation." Embracing digital transformation can break down the boundaries of nations, promote globalization, and bridge the gap between science, education, production, and the market (GROW, 2020; Kosa ; Dhliwayo 2024 ; Berardi et al., 2023).

Digital technology has brought about significant changes in the world, and one of the most crucial technologies is big data. It facilitates the acquisition of essential information and effective decision-making by accumulating datasets. Numerous studies have examined the impact of digitalization on both for-profit and non-profit organizations. The phenomenon of big data is commonly identified as the proliferation of data generated using digital technologies, which is an information asset characterized by a high volume, velocity, and variety. It requires specific technology and analytical methods for its transformation into value (De Mauro et al., 2016). European industry has a strong foothold in both advanced digital technologies and traditional sectors. This puts them in a good position to capitalize on opportunities presented by technologies such as the Internet of Things, big data, advanced manufacturing, robotics, 3D printing, blockchain, and artificial intelligence (Karnitis and Karnitis, 2017). Blockchain, initially popularized by the rise of cryptocurrencies, has gained significant recognition as a powerful technological tool. Its potential extends far beyond financial and economic sectors, proving valuable across a wide range of applications. (Ghilal & Nach, 2019).

These theoretical frameworks create valuable insights into the dynamics of digital technology within the social economy. They highlight the transformative potential and the challenges that must be addressed for inclusive and sustainable development.

2.5. Conclusion

2.5.1. Value/Originality

The value and originality of research in social economy and digitalization in its unparalleled capacity to innovate solutions that leverage digital technologies to foster inclusive growth, enhance social cohesion, and advance sustainable development goals. Our study demonstrates that digital tools are crucial for the success of social economy organizations, enabling them to operate more efficiently, expand their reach, and achieve their missions effectively. Technologies like artificial intelligence, blockchain, and cloud computing empower these organizations to make informed decisions, improve transparency, reduce costs, engage stakeholders more effectively, and foster innovation. As a result, they can adapt more quickly to changing environments and achieve their objectives with greater confidence and sustainability. our study is the first of its kind to explore the impact of digital technologies on the social economy. Its primary objective is to understand digitalization and its potential effects comprehensively. we conducted a systematic literature review to explore the potential applications of digital technologies within the social economy. After reviewing relevant articles, we addressed existing shortcomings and inconsistencies in the literature, providing a more holistic understanding of the topic. Our assessment identifies key research gaps, which serve as the main contribution of this study. It shows that Digitalization is a key driver of economic progress, enhancing efficiency, reducing transaction costs, and expanding access to global markets. Both developed and developing nations must embrace digitalization to succeed in today's competitive market. Developing countries can leverage digitalization to narrow the gap with their more developed counterparts. However, integrating these technologies poses ethical and social challenges. Therefore, it is crucial to implement digital technologies in ways that align with the principles of social justice and inclusivity. Non-profit organizations can experience direct positive impacts by aligning their social missions with well-planned, long-term strategies and by making use of customized digital platforms and advanced technologies. This research presents valuable opportunities for further studies. This field holds promise in shaping a more equitable and digitally empowered future for social economy organizations through interdisciplinary collaboration and research on how digital transformation influences organizational dynamics, community resilience, and social capital formation.

2.5.2. Limitations of the research

While there are promising avenues for future research, the current literature on digitalization in the social economy faces several notable limitations. The rapid evolution of digital technologies poses a challenge, as findings can quickly become outdated, requiring ongoing updates to maintain relevance. Language bias is another issue, as many non-English publications are excluded, potentially missing valuable insights from diverse regions. Additionally, restricted access to full-text articles and proprietary data can limit the comprehensiveness of reviews. The diversity in the size, scope, and resources of social economy organizations also makes it difficult to generalize results across different contexts. Addressing these limitations is crucial for advancing the field effectively. This study itself has certain limitations, including publication bias, sample selection bias, inconsistent data interpretation, and the combination of qualitative and quantitative studies. Publication bias is a common issue in systematic reviews, where studies with positive results are more likely to be published. Furthermore, while this study makes significant contributions, it focuses solely on the academic perspective using rigorous methods, which may lead to the exclusion of relevant studies due to strict inclusion criteria. The literature review's findings may not be fully generalizable across all social economy organizations due to the diversity in organizational structures, sizes, missions, and geographic locations. The impact of digitalization can vary significantly depending on these factors, and the review may not capture the nuanced differences across various types of social economy entities, such as cooperatives, non-profits, and social enterprises. On the other hand, digitalization is a rapidly evolving field, with new technologies and practices constantly emerging. The reviewed literature may not capture the most recent developments or trends in digital adoption within the social economy. As a result, some of the study's findings may become outdated or less relevant over time.

2.5.3. Future Research

Future research in the social economy and digitalization should prioritize longitudinal studies to track the long-term impacts of digital transformation on various organizations within the sector. This approach can reveal sustainability trends, the evolution of digital practices, and the overall effectiveness of these technologies in enhancing organizational efficiency and social impact. Additionally, comparative studies across different types of social economy

organizations, such as NGOs, cooperatives, and social enterprises, can help identify sector-specific challenges and best practices, providing tailored strategies for digital integration. Another critical area for future research is how digital technologies can enhance the efficiency, reach, and effectiveness of social services, as well as their ability to foster social innovation. Researchers should investigate the specific ways in which digital tools contribute to improved service delivery, greater community engagement, and more inclusive economic growth. It is crucial to assess the broader societal implications of digitalization, such as changes in social capital, community cohesion, and the empowerment of marginalized groups. By understanding these impacts, future research can inform the development of digital strategies that maximize positive social outcomes. We have some research questions as suggestions for future studies. These questions aim to address various dimensions of digitalization's impact on the social economy, providing a roadmap for future research. First, how do various digital technologies (such as AI, blockchain, IoT, and others) uniquely influence social economy organizations' operational efficiency and effectiveness? A case study approach across different social economy companies could be used to explore this question in research methodology. Second, what are the barriers to digitalization for social economy organizations, and how can these be effectively mitigated? Future research could investigate the common obstacles faced by social economy organizations in adopting digital tools and strategies to overcome them.

The ultimate suggestion for future research on Blockchain Technology (BCT) barriers in food bank (FB) systems, a crucial component of the social economy, is essential for unlocking their full potential in combating food insecurity and reducing waste. Operating within complex networks of donors, distribution centers, and beneficiaries, food banks rely on transparency and efficiency to maximize their impact. BCT offers transformative solutions, such as real-time tracking, enhanced food safety, and streamlined operations. However, adoption is often hindered by significant challenges, including high implementation costs, limited technical expertise, and organizational resistance. Exploring these barriers through focused research can yield actionable insights to overcome these obstacles and foster a supportive environment for BCT integration. By addressing these challenges, food banks can leverage blockchain to enhance their operational effectiveness, ensuring greater accountability and sustainability in their mission to serve vulnerable communities.

Chapter 3. A Rough DEMATEL-Based Approach for Identifying Barriers to Blockchain Technology Adoption in Food Bank Supply Chains

3.1. Introduction

Food banks serve as a vital link between the social economy and efforts to address food insecurity. As part of the social economy, food banks operate with the dual objective of mitigating hunger and reducing food waste, aligning with broader societal goals of equity and sustainability. They exemplify how social economy initiatives can complement traditional market mechanisms by redistributing surplus food from producers, retailers, and consumers to those in need. This redistribution process fosters inclusivity and strengthens community

resilience, as food banks not only address immediate needs but also contribute to long-term food security (Defourny & Nyssens, 2012).

Food banks (FBs) have been established worldwide to address food insecurity while also working to reduce food waste (Dowler & Lambie-Mumford, 2014). They are nonprofit organizations that collect food donations from various sources such as producers, distributors, retailers, consumers, and farmers, and then distribute the food to those in need through a network of community agencies (Tarasuk & Eakin, 2005; Feeding America, 2021). The first food bank, St. Mary's Food Bank (SMFB), was founded by John Van Hengel in 1967 in Phoenix, Arizona, USA (Mook et al., 2020). By 2020, food banks affiliated with the European Food Banks Federation (FEBA) had redistributed approximately 860,000 tons of food, helping around 12.8 million people (Akkerman et al., 2023; FEBA, 2021). These organizations are vital in reducing food waste by redirecting surplus food from industrial processing and retail sales to those in need (Trevisan et al., 2024). FEBA, along with other European food banks, plays a significant role in food waste reduction and poverty alleviation. The organization relies on corporate donations, public food collection, and mechanisms such as the Fund for European Aid to the Most Deprived (FEAD), which is linked to the European Union's agricultural policies (Capodistrias et al., 2022). Recently, food banks have started receiving additional donations from businesses seeking to minimize waste, furthering their role in food recovery and reducing food insecurity (Capodistrias et al., 2022). The operational challenges of food banks include issues with transparency, traceability, and efficient management of food donations. Blockchain technology (BCT) offers a promising solution by providing an immutable, decentralized ledger that ensures transparency and traceability in food donation processes (Tian, 2016; Kamilaris et al., 2019). By utilizing BCT, food banks can track perishable items more effectively, ensuring that they are safely distributed to recipients while reducing waste (Carrefour & Lefebvre, 2021). Furthermore, BCT's ability to create smart contracts can streamline operations by automating agreements among donors, food banks, and recipients, reducing administrative overhead and potential errors (Saber et al., 2019). Several companies, such as Walmart and Carrefour, have already successfully integrated BCT into their supply chains to improve traceability and reduce fraud. Walmart, for example, uses the IBM Food Trust platform to track food products, significantly reducing the time needed to trace the source of contamination from seven days to just 2.2 seconds (Kamath, 2018). Carrefour has implemented BCT to trace food products like free-range chickens, eggs, and milk, allowing

consumers to access detailed product information via QR codes (Kamilaris et al., 2019; CB Insights, 2020).

Figure 3-1. Distribution system management in FBSC

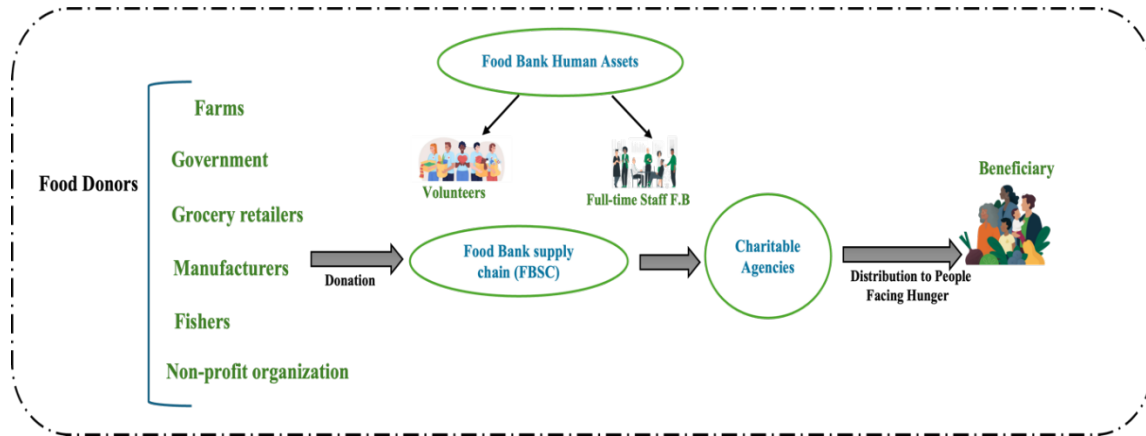


Figure 3-1 illustrates the flow of resources and relationships within FBSC, focusing on the roles of assorted stakeholders and the flow from donation sources to beneficiaries. The arrows indicate the movement of food and resources from various sources (Government, Grocery Retailers, Manufacturers, Fishers, and Non-profit Organizations) to the FBs. From there, the food and resources are distributed to the beneficiaries. The top part of the diagram shows the two main human resources that FBs rely on: Volunteers and Full-time Staff, who are essential in managing the operations and ensuring the effective distribution of food to beneficiaries. FBs often face transparency, traceability, and efficient management challenges concerning donations and resources. With its immutable and decentralized ledger, blockchain offers a possible fix by ensuring a clear, unchangeable record of every transaction and movement within the SC (Tian, 2016; Kamilaris et al., 2019). In order to reduce food waste throughout the FSC, the European Union has recently implemented a variety of initiatives, including member state commitments to reduce food waste by 30% (Ghahremani-Nahr et al., 2023).

Despite the potential benefits of BCT, food banks face several barriers to its adoption. These barriers include technological challenges, lack of infrastructure, limited resources, regulatory constraints, and a lack of awareness among volunteers and other stakeholders (Ghahremani-Nahr et al., 2023). To address these challenges, the study employs the Decision-Making Trial and Evaluation Laboratory (DEMATEL) technique, which helps identify and assess the

relationships between these barriers (Fontela & Gabus, 1976). DEMATEL is particularly useful for understanding the interdependencies and feedback loops among various barriers, making it an effective tool for complex systems analysis (Liou & Tzeng, 2012; Zhang & Ma, 2020). The study also integrates rough set theory with DEMATEL to account for subjectivity and ambiguity in expert opinions during group decision-making processes. This approach helps prioritize the most significant barriers to BCT adoption in the food bank supply chain (Liou & Tzeng, 2012). By identifying and analyzing these barriers, the study aims to provide a roadmap for successfully implementing BCT in food banks, thereby enhancing the efficiency, traceability, and transparency of their operations. Given that it is practically impossible to address every barrier at once, decision-making techniques could be useful for determining the relative relevance of different barriers. A DEMATEL is a useful tool to conceptualize the structure of cause-and-effect interactions among the constituents of a complex system (Fontela & Gabus, 1976). In order to pinpoint the important obstacles and comprehend how they relate to one another, we employ the DEMATEL technique. This approach stands out by effectively capturing and quantifying the causal links between various barriers, offering an advantage over other decision-making techniques like Interpretive Structural Modeling (ISM) and the Analytic Hierarchy Process (AHP). DEMATEL's strength lies in its ability to model interdependencies and feedback loops, making it particularly valuable for complex systems analysis. Rough theory and DEMATEL are combined in this study to gather data from groups to address subjectivity, disputes, and ambiguity in expert opinions during group decision-making processes (Liou & Tzeng, 2012; Zhang & Ma, 2020; Kao & Lo, 2022). and proposes an integrated evaluation method for analysing interactions within FBSC using DEMATEL and rough set theory (Fontela & Gabus, 1976).

The contribution of this study is that we examine the relationships among barriers affecting the adoption of blockchain technology (BCT) in FBSC, ranking their perceived prominence and evaluating their cause-and-effect dynamics. Also in this study, we analyze data from academics and practitioners involved in food bank supply chains (FBSCs) and blockchain technology in Italy. To achieve this, we utilize the Decision-Making Trial and Evaluation Laboratory (DEMATEL) method, a robust tool for conceptualizing and visualizing cause-effect relationships within complex systems. DEMATEL is particularly effective in mapping intricate causal connections and illustrating the interplay between various system components. In the next phase of our study, we integrate rough set theory, a mathematical framework introduced by Pawlak (1982), to enhance and refine our analysis. This combination

allows for a more comprehensive understanding of the barriers and their interdependencies. DEMATEL, as highlighted by Shieh and Huang (2010), is especially suitable for investigating FBSCs and the challenges they face, making it a valuable approach for this research.

Here are the two research questions we are pursuing:

RQ 1. What barriers exist for blockchain adoption in the supply chain of food banks?

RQ 2. What are the relationships between the barriers?

3.2. Theoretical background

An overview of the key ideas supporting this research is given in this section, including FBSC issues, blockchain within SC, and adoption barriers identified to blockchain in the FBSC. It is shown in Table 3-1.

3.2.1. Food banks supply chain issues

It is hard for FBs to effectively organize and distribute resources when the supply and request are ambiguous. Variations in donation quantity, timing, and quality often create imbalances, leading to either shortages or surpluses of food. These inconsistencies hinder effective distribution and can strain the ability of FBs to meet community needs consistently (Alkaabneh et al., 2021). As non-profit organizations, FBs can prove significant in the struggle against hunger by performing as aggregates of surplus food from multiple sources, such as supermarkets, growers, and grocers, that have various shelf lives (from new produce to prepared food), and distributing it to the underprivileged (Tanksale et al., 2024).

FBs play an essential contribution in promoting food security by dispensing millions of pounds of complimentary food and drink to vulnerable communities. They operate as critical intermediaries, channeling surplus food from donors to those who are in need. This effort aids in mitigating food waste and offers short-term relief for food-insecure populations (Tarasuk et al., 2020). FB has grown globally since the 1980s, and as a subsidiary of the World Food Bank Network, there are currently operational food banking groups in over 30 countries. Certain FBs use a "front-line" approach, distributing food to recipients straight. The others function as

"warehouses," providing food to front-line organizations and other intermediaries like food stores (Ghahremani-Nahr et al., 2023).

A study was carried out in 2013 by Ross and associates to examine the nutritional value of food that was provided by six FBs in California. The study found that while the FBs were making progress in distributing healthier food, more effort was needed to sustain this positive trend. The research focused on the quality of the food being delivered Instead of the quantity (Rivera et al., 2023). Many FBs depend heavily on volunteers and donations, which can fluctuate in availability and quality. Addressing these issues requires a combination of better planning, technological investment, and cross-sector collaboration to improve the SC for FBs' resilience and effectiveness (Baglioni et al., 2017).

FBs are humanitarian efforts to address both worries about food waste, which is primarily caused by retailers and generally caused by the proximity of its best-before date, and the different types of food insecurity experienced by certain sections of the population, which develop during periods of a social and economic crisis. The FB food rescue and delivery supply chain adapts to both environmental and socioeconomic crises (Martins et al., 2024).

However, A significant portion of FBs' operations relies on the assistance of volunteers. According to Paço and Agostinho (2012), volunteers receive no compensation and are faced with numerous worthwhile opportunities vying for their time, money, and attention.

Therefore, what drives volunteers to give their time to FBs is something that organizations need to know. Furthermore, De Boeck et al. (2017) suggested that handling perishable food items and communicating with food donors may provide difficulties and problems when working with volunteers who lack appropriate training in food safety and a pertinent understanding of food logistics (Rivera et al., 2023). As highlighted by FAO (2020), the complexity of managing these constraints alongside demand surges leads to operational inefficiencies and hinders the sustainability of FBs. According to Ogazon et al. (2022), FBs need to change to deal with the fallout from unforeseen circumstances like natural or man-made disasters. For instance, the recent COVID-19 pandemic significantly worsened food insecurity worldwide, prompting FBs to intensify their efforts to maintain service and adapt to the challenging situation (Rivera et al., 2023). According to Martins et al. (2019), governmental and public financing and donations are more predictable than contributions from private organizations and individuals, despite being essential sources of supply for FBs. These

private donations are essential to guarantee stable operations, but they pose challenges due to the uncertainty of supply, and these challenges include the varying donor capacity to provide equipment, the variety of goods donated, as well as the receipt of unforeseen and perhaps unwelcome presents.

3.2.2. Blockchain within Supply Chains

BCT, primarily developed for crypto assets like Bitcoin, has gained attention as a solution to challenges. This decentralized digital ledger ensures that transactions cannot be changed after the fact by recording them over a computer network (Nakamoto, 2008). Utilizing BCT can help prevent opportunistic behavior and lessen the uncertainty brought on by changes in the political, economic, regulatory, or behavioral spheres. This technology is becoming increasingly prevalent beyond the finance sector, particularly in SCM. In this context, BCT usage is anticipated to increase at a rate of 87% each year, and by 2023, its market value is likely to have grown from \$45 million in 2018 to over \$3.3 billion.

This growth reflects BCT's potential to enhance transparency, security, and traceability across several industries, especially SC operations (Köhler & Pizzol, 2020; Chang et al., 2019).

Transparent information on BCT ledgers can significantly improve the source of products, chains of custody, authenticity, and operational processes (Montecchi et al., 2019). BCT is also effectively utilized in financial sectors to track assets and enable seamless information sharing among all participants (Jellason et al., 2024). BCT is an immutable shared ledger used to track assets and record transactions; its key features are decentralization, immutability, security, and smart contracts, which can bring significant benefits to SCs when used properly (Kshetri, 2018). According to Bosona & Gebresenbet (2013), food traceability is a component of logistics management that requires obtaining, conserving, and sharing complete data about an animal or material used to create food, feed, or food at all stages of the FSC. This allows us to inspect the goods for quality and safety. Good traceability ensures accurate product movement recording, enabling companies to understand their SC, make wise choices, and steer clear of any quality hazards (Duan et al., 2020). BCT is attractive because it should enable secure, robust, and trustworthy solutions and enhance traceability and transparency in comparison to existing technology or management systems (Liu et al., 2019, George et al., 2019). The World Bank report indicates that BCT can enhance transparency in FSC, but this potential remains

limited in the absence of government support to encourage adoption and integration (World Bank, 2020). BCT offers significant advantages by enabling secure, decentralized transactions among multiple, potentially unreliable parties (Pearson et al., 2019; Yuan et al., 2019). Its appeal lies in its ability to deliver robust, reliable, and secure solutions, fostering trust among stakeholders. BCT's potential to improve transparency and traceability significantly surpasses that of existing technologies and management systems, providing a more efficient and accountable approach to operations (George et al., 2019; Kamilaris et al., 2019; Liu et al., 2019). Smart contract governance and process regulations can help manage actor certification, approval, and process access for BCT in SC. A smart contract's SC type, position, and triggers may cause changes to actor data. Without a consensus-building method, actors are powerless to change the regulations (Maurer, 2017). Procurement is another area where smart contract applications are being used. A smart contract between two trading partners can allow end users across the line of business to legally update the automated record of products bought, sold, and delivered in real-time. (Saber et al., 2019). Since one of the primary structural issues in FBs is the lack of transparency in tracking donations and the distribution of food, BCT's decentralized and immutable ledger makes sure that each transaction and movement within the SC is recorded in a tamper-proof manner and this transparency allows all stakeholders, including donors, FBs, and recipients, to have a clear and accurate view of the flow of goods, thus reducing the risk of mismanagement and fraud (Tian, 2016; Saber et al., 2019). Furthermore, FBs frequently encounter difficulties associated with inefficiencies in resource allocation and distribution. Integrating smart contracts within BCT systems can automate agreements and processes, ensuring more efficient resource distribution according to predefined rules. This capability is especially valuable for FBs, where timely distribution of perishable goods is crucial for minimizing waste and maximizing the impact of donations (Carrefour & Lefebvre, 2021). Indeed, BCT's decentralized nature reduces dependency on central authorities, which is often a limitation in traditional FB operations. By enabling peer-to-peer transactions and direct interactions between donors and recipients, BCT can streamline operations and reduce administrative burdens, leading to more responsive FB management (Kamilaris et al., 2019). BCT platforms like Bitcoin and Ethereum are known for their relatively slow transaction speeds and high operational costs. These limitations pose substantial challenges for companies looking to implement BCT solutions throughout their entire SC, potentially reducing the technology's overall effectiveness and return on investment (Tian, 2017). BCT's decentralized nature makes it an ideal tool for combating fraud in SCs; As an example, ever ledger, a BCT-based platform, effectively tracks the provenance of diamonds to

significantly lower the risk of fraud, and unethical practices. Through BCT, ever ledger creates a secure digital record of each diamond's attributes, ensuring authenticity, preventing counterfeiting, and promoting ethical sourcing practices in the diamond industry (Kshetri, 2018; Saberi et al., 2019).

3.2.3. Identifying barriers to adopting blockchain technology in the food bank supply chains

3.2.3.1. Technological barrier (external views)

The adoption of new technology is often fraught with challenges, and BCT is no exception. To fully realize the benefits of this technology, it is essential to first overcome these obstacles. All participating parties must thoroughly make sense of these challenges and strategically outline how to address them. This section explored both the external and internal barriers within the FBSC, as shown in Figure 3-3 and Table 3-1.

Robust internet connectivity and IT infrastructure are critical for the successful adoption of blockchain. However, in some cases, an organization's IT infrastructure may be inadequate, or access to the necessary technology may be impractical (Kouhizadeh et al., 2021). Studies by Queiroz et al. (2019) and Sabari et al. (2019) identified several barriers to blockchain implementation, including high costs, lack of technological infrastructure, resistance to change, and interoperability issues. These challenges indicate that while blockchain holds great promise, its adoption is far from straightforward.

The implementation of BCT in the SC could mean lower transaction numbers but higher transaction times. Managing the required environmental and social information is difficult due to the kind, place, and volume of the data. Despite BCT's reputation for having a safe and decentralized structure, recent system breaches and hacks in the cryptocurrency space have raised questions about how vulnerable it is (Yli-Huumo et al., 2016).

3.2.3.2. Organizational Policy Barrier

Another significant barrier is the absence of organizational policy. Organizations must be proactive in defining policies that guide the implementation of new technologies like

blockchain. By doing so, they can confidently adopt these technologies and reap their many benefits. Clear guidelines on the proper usage of such technologies and when and where they are most effective give organizations a competitive edge and help them overcome limitations that may hold them back (Saber et al., 2019). With the right policies in place, organizations can confidently embrace new technologies and take full advantage of their potential (Yadav et al., 2020).

3.2.3.3. Infrastructure, facilities, and human resources barrier

Lack of infrastructure, facilities, and human resources in internal barriers FBs face significant challenges in their day-to-day operations due to the limited availability of crucial resources like manpower, scarcity of collection, handling operations, and distribution facilities, and lack of well-developed infrastructure (Dubey et al., 2022; Hecht et al., 2019). A report by the Food Research & Action Center (FRAC) highlights that many FBs struggle with inadequate staffing levels and high turnover rates. This can lead to inconsistent service and operational inefficiencies (FRAC, 2022). According to research published in the Journal of Hunger & Environmental Nutrition, training gaps and a lack of specialized skills among staff can affect the management of food resources and overall operational effectiveness; the non-profit sector, including FBs, often faces challenges in maintaining a well-trained workforce. (Hunger & Environmental Nutrition, 2021). According to a study by Feeding America, many FBs operate in facilities that are either too small or poorly equipped to handle the volume of food they need to distribute (Feeding America, 2020). The scarcity of these resources acts as a major barrier, making it tough for them to operate effectively. Adopting new technology systems could be a valuable solution to overcome these barriers. (Millar et al., 2020; Hermsdorf et al., 2017).

3.2.3.4. Financial Resources Barrier

Likewise, in Feeding America, financial constraints often limit the ability of FBs to expand their programs or add new services, such as nutrition education or emergency assistance, thus reducing their overall impact (Feeding America, 2020). Another significant barrier to the internal sector is the lack of financial resources in FBs. FBs require surplus food, labor, funding, and numerous other resources for their function. One of the significant barriers is finding enough money to support FBs' expansion and operation. Stated that food rescue organizations

are hindered by a lack of funds and that one of the biggest problems they encounter is a lack of financial support (Kouhizade et al., 2021). Organisations incur fees for information collecting through FBs and system conversion. Moreover, implementing sustainable practices is expensive. Companies have limited money to implement this technology (Tarasuk et al., 2005; Frasz et al., 2015).

3.2.3.5. Regulation and legislation about donated food barrier (external views)

In the external barriers segment of the FBSC, there is a regulation and legislation barrier concerning donated food. Donated food is a critical resource for providing sustenance to those in need, but it's essential to recognize the challenges that come with it. The low nutritional value, limited shelf life, and uncertain SCs in FBs are unacceptable, and we must take immediate action to address them. We need to identify, develop, and traceability more effective strategies to improve the quality and accessibility of donated food, such as BCT to implement innovative technologies and techniques and establish a reliable SC system. This will enhance the positive impact of donated food to help make certain that every person has access to nutritious and healthy food (Millar et al., 2020; Alkaabneh et al., 2021).

3.2.3.6. Awareness among volunteers regarding food waste/loss and food bank roles barrier

Another challenging external barrier in the FBSC is the lack of awareness among volunteers regarding food waste, loss, and the critical role FBs play. Raising awareness about these issues is essential, as volunteers may have limited knowledge in this area. Additionally, the diverse and varying skill sets among volunteers can present challenges (Akkerman et al., 2023; Annosi et al., 2021). The amount of food waste that happens at different points in the SC, from production to distribution, is something that many volunteers are ignorant of. This lack of understanding can lead to inefficiencies in sorting, storage, and distribution processes within FBs. A study by Garrone et al. (2014) highlighted that FBs often rely on volunteer labor, but insufficient training and awareness can result in unintentional food waste, undermining the mission of food redistribution efforts. Technologies such as BCT could play a vital role in decreasing food waste by increasing awareness and enhancing food recovery initiatives. These

processes provide transparency and traceability across the FSC, helping to optimize resource allocation and minimize loss (Dubey et al., 2022; Ardra et al., 2022; Frasz et al., 2015).

Table 3-1. Framework of internal and external barriers to blockchain adoption in the FBS

Barriers	Sub-barriers	Description. Literature Content	Sources
I -Internal	1.Lack of access to technology	IT infrastructure and the internet are crucial resources for the deployment of BCT. Sometimes an organization's IT infrastructure is inadequate, or access to technology is not practicable.	(Kouhizadeh et al.,2021).
	2.Lack of organizational policy	Organizations must be proactive in defining policies that guide the implementation of new technologies like blockchain. By doing so, they can confidently adopt these technologies and reap their many benefits. Clear guidelines on the proper usage of such technologies, when and where they are most effective, give organizations a competitive edge and help them overcome limitations that may hold them back. With the right policies in place, organizations can confidently embrace new technologies and take full advantage of their potential.	(Saberi et al., 2019), (Yadav et al., 2020).
	3. Lack of infrastructure, facilities, and human resources	FBs face notable challenges in their day-to-day operations due to the limited availability of crucial resources like manpower, lack of collection and distribution facilities, handling & operations, lack of well-developed infrastructure. The scarcity of these resources serves as a formidable barrier, making it tough for them to operate effectively. Adopting new technology systems could be useful.	(Dubey & Tanksale 2022); Hecht & Neff ,2019) ; (Millar, et al., 2020) ; Hermsdorf et al., 2017).
	4.Lack of financial resources	For FBs to operate, they need money, labour, extra food, and a number of other resources. Finding enough money to keep FBs open and growing is one of the largest challenges. claimed that one of the biggest challenges faced by food rescue organizations was obtaining funding, and that this posed a barrier to their operations. Organizations pay for information gathering via FBs and system modifications. Moreover, it costs money to put sustainable methods into effect. Businesses lack the funding necessary to use this technology.	(Tarasuk, & Eakin, 2005); (Frasz, et al., 2015).
2 -External	5.lack of regulation and legislation pertaining to donated food.	Donated food is a critical resource for providing sustenance to those in need, but it's essential to recognize the challenges that come with it. The low nutritional value, limited shelf life, and uncertain SCs in FBs are unacceptable, and we must take immediate action to address them. We need to identify, develop, and traceability more effective strategies to improve the quality and accessibility of donated food, such as implementing innovative technologies and techniques and establishing a reliable supply chain system. This will enhance the positive impact of donated food to help make certainthat every individual has access to healthy and nutritious food.	(Millar, et al., 2020) ; (Alkaabneh, et al., 2021).
	6.Lack of awareness	Raising awareness among volunteers about the issue of food recovery and food waste in food banks is	(Annosi&Kostoula,2021) ; (Akkerman et al., 2023).

	among volunteers regarding food waste/loss and food bank roles	crucial, as their knowledge on this subject may be limited. The skills of volunteers are diverse and uncertain. It's critical to note that implementing digital processes can significantly decrease food waste and improve food recovery.	Dubey & Tanksale, 2022) ; (Ardra, & Barua, 2022); (Frasz, et al., (2015).
	7.Lack of government support for implementing blockchain technology	The government faces various obstacles in the process of collecting information through food banking and transitioning to a new system. One of the significant challenges is the cost associated with adopting sustainable practices. Due to limited financial resources, many countries are unable to invest in BCT. Another obstacle is the lack of standardisation and suitable tools, criteria, and techniques for implementing BCT and assessing sustainability output in the government. However, by overcoming these challenges, the government can enhance its operations and assist in to a more sustainable future.	Kouhizadeh, et al., 2021). Tarasuk, & Eakin, 2005). (Frasz, et al., (2015).

3.2.3.7. Government support for implementing blockchain technology barrier

The lack of government support for implementing BCT is a significant barrier. A study conducted by the Food Agriculture Organization (FAO) highlights that BCT can greatly improve transparency and efficiency but notes that the high costs and lack of government incentives limit adoption in sectors like FBs (FAO, 2020). According to a report by the World Economic Forum, many FBs cannot afford the upfront costs of BCT, and without government support, these barriers are unlikely to be overcome (WEF, 2022). A report by the European Commission emphasizes that regulatory frameworks supported by governments can facilitate the adoption of BCT by ensuring consistency and addressing legal challenges (European Commission, 2022).

Indeed, Governments face various obstacles in the process of collecting information through food banking and transitioning to a new system. One significant challenge is the cost associated with adopting sustainable practices. Due to limited financial resources, many countries are unable to invest in blockchain technology. Another challenge is the lack of standardization and proper methods, tools, measurements, and procedures for deploying blockchain technology and monitoring sustainability performance in the government. However, by overcoming these

challenges, the government can enhance its operations and contribute to a more sustainable future. (Frasz et al., 2015; Kouhizadeh, et al., 2021; Liu et al., 2020; Tarasu et al., 2005).

3.3. Research Methodology

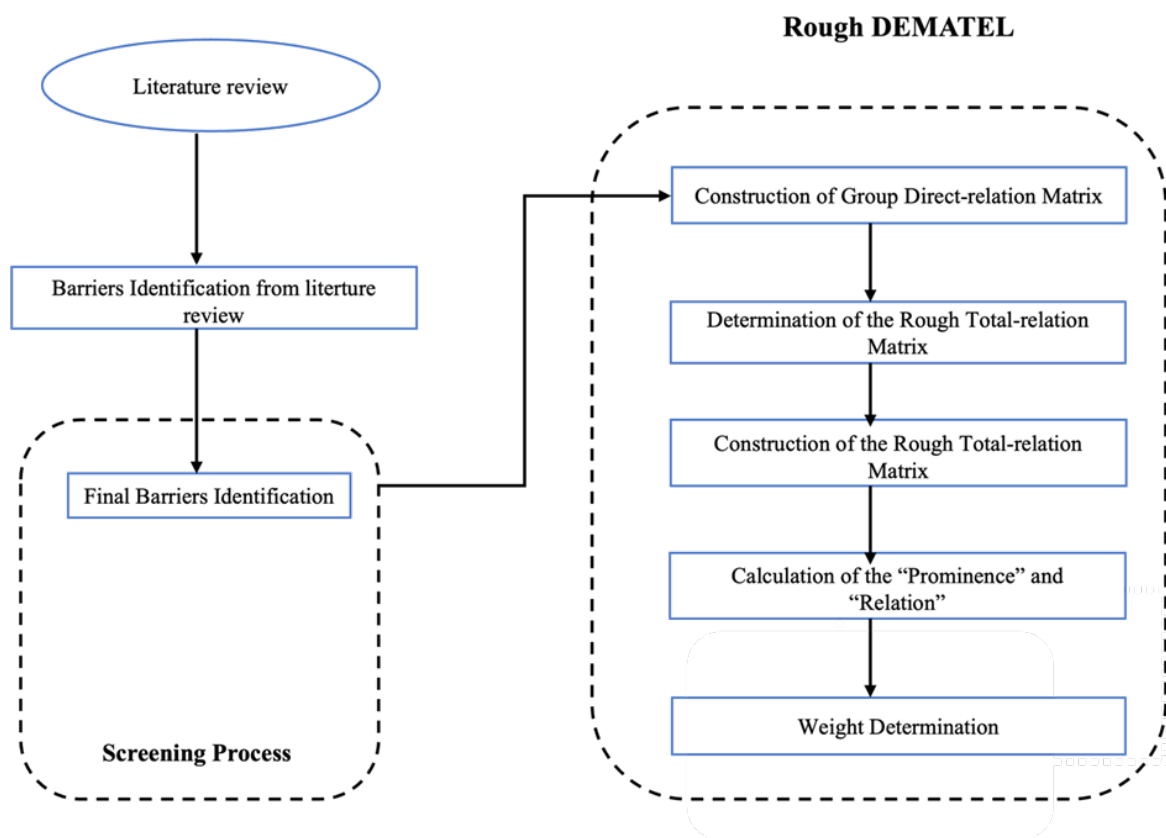
This paper had two main objectives. First, it aimed to recognize the barriers involved. Secondly, it sought to understand the interrelationships among these barriers. The DEMATEL methodology's resulting outputs are relationship diagrams. This process demonstrates that after identifying barriers, the preparation involves four steps in a set rough DEMATEL. The first step involves the Construction of a group direct relation matrix. The second part is the Determination of the rough total relation matrix. The third step is the Construction of the rough total relation matrix. Finally, the process involves the Calculation of the “Prominence” and “Relations”. Figure 3-2 illustrates the research process outlined in this method. The sample, participant information, and the DEMATEL technique are all included in this section.

3.3.1. DEMATEL methodology

It can be daunting to analyze so many interconnected barriers or causes. Methods for defining the linkages and priorities of several elements include MCDM techniques. In Figure 3-2, DEMATEL is a helpful method for conceptualizing the framework of cause-and-effect linkages among the components of a complex system (Fontela & Gabus, 1976). When expressing the connections between various system components, DEMATEL provides a useful method for visualizing the structure of intricate causal linkages (Song & Cao, 2017). DEMATEL can identify key variables, both independent and dependent, and the connections between them in a cause-and-effect network. It can also process the degree to which these elements interact and impact one another. Pairwise comparisons are used in DEMATEL to visualize direct and indirect correlations while also examining the causal dependency structure among the elements that have been identified. It is a helpful methodology for investigations using mind mapping. The DEMATEL methodology determines each barrier's prominence and aids in organizing the causal linkages among the barriers that have been identified (Fu et al., 2012; Lee et al., 2010). SC experts have employed two well-established methodologies, the analytic hierarchy process (AHP) (Saaty, 1988) and interpretive structural modeling (ISM) (Mandal and Deshmukh, 1994), to organize and assess a variety of defined obstacles or factors.

These two approaches do, however, have certain drawbacks. ISM is unable to determine the entire influence of each element, while AHP ignores the interactions between the barriers. The capacity of DEMATEL to map out and quantify the causal linkages among various obstacles is one of its main advantages (Tzeng et al., 2007; Biswas and Gupta, 2019). Also, unlike methods such as Failure Mode and Effects Analysis (FMEA), which typically treat barriers as independent factors, DEMATEL explicitly models the interdependencies and feedback loops, offering a more comprehensive analysis of the factors involved (Fontela and Gabus, 1976).

Figure 3-2. Research process



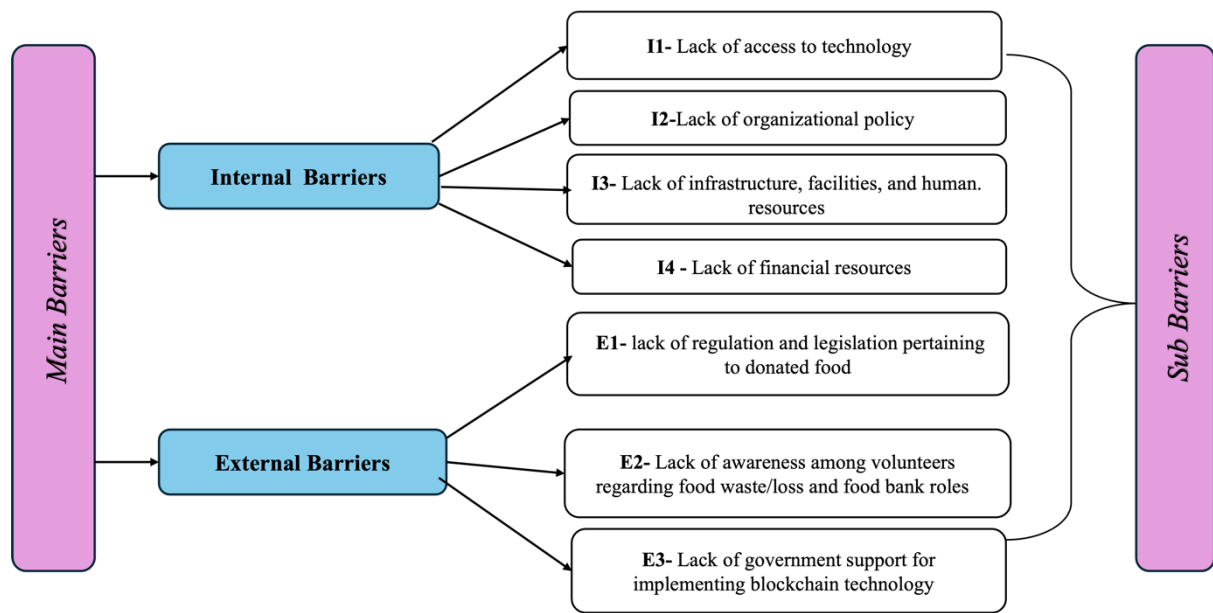
See Appendix 1.

This paper combines the rough theory with DEMATEL to collect data to address disagreements, individuality, and ambiguity in judgments by experts during group decision-making processes. This method could lead to more reliable and accurate results (Mao et al., 2020; Shojaei et al., 2023). Figure 3-2 illustrates the research methodology process.

3.3.2. Collection of data

The BCT's innovation and the shortage of adoption instances in FBSC restrict a wide-ranging study. In order to assess the barriers, we thus chose a sample of respondents that includes experts from academia and industry who are familiar with BCT and the FBSC. In order to assess the barriers, we thus chose a sample of respondents that includes experts from academia and industry who are familiar with BCT and the FBSC. To achieve our research objective, we identified several barriers to the adoption of BCT in the FBSC. We reviewed relevant articles and pinpointed four Internal barriers and three external barriers. Table 3-1 illustrates the references of this review. These barriers were analyzed and compared to explore any Causes and Effects relationships among them. Figure 3-3 illustrates the main barriers and sub-barriers within the process of relationships. We used to a Comparison Pairwise Form to explore the cause-and-effect relationships between the identified barriers. We asked the participants to evaluate the influence of each factor on one another using pairwise comparisons. Survey forms were also utilized by academics and practitioners. For each barrier, the academic experts or practitioners give their opinion about the influence and effectiveness of barriers on another barrier, and similarly for all barriers using a multiple-choice questionnaire using a scale of from one to five: No Influence (0), Low Influence (1), Medium Influence (2), High Influence (3), subsequent to Very High Influence (4). Essentially, what the text describes is taking the judgments provided by multiple experts (in the form of $n \times n$ matrices), and then calculating the average of these matrices to create a single aggregated influence matrix. This step is common in group decision-making or influence modeling to combine multiple perspectives into a unified view (Liu et al., 2018).

Figure 3-3. Main barriers and sub-barriers in the relationship process



3.3.3. Sample and respondent information

We invited thirteen experts from one of the networks of FBs (Banco Alimentare) in Italy. They were internal and external stakeholders of an Italian FB. The practitioners worked mostly in consulting and leadership roles, such as managers and consultants, and were involved in the FBSC. Indeed, The Banco Alimentare organization has established an extensive and efficient network across Italy. This decentralized system relies on regional FBs to handle the gathering, distribution as well as storage of food to those in need. Banco Alimentare also has a crucial function in decreasing food waste through strategic partnerships within businesses and nonprofit organizations. Moreover, it collaborates closely with government agencies and European Union initiatives, such as the European Food Banks Federation (FEBA), to further enhance its reach and impact, feeding millions of people annually across the country. This network in Italy consists of 21 regional FBs that operate independently (Banco Alimentare Onlus, 2020, Annual Report; Lambie-Mumford & Dowler 2014).

We also considered the eight academic respondents to be active researchers in the food industry, SCM, and BCT, mainly university doctoral students, researchers, and professors. Academics had an average work experience of 8.12 years, with a standard deviation of 6.70. The average employment experience among practitioners was 13.61 years, with a standard deviation of 6.70 years. Both research groups demonstrated an adequate understanding of BCT and/or

sustainable FBSC. Table 3-2 shows information on respondents from academic and practitioner individuals).

Table 3-2. Information from respondents

No	Practitioner /Academic	Role	Department/Organization Category	Years of Experiences within Research & Work
1	Practitioner	Administrative Staff in Food Bank Supply chain	The Italian Food Bank Network	1
2	Practitioner	Food Bank's Executive Director	The Italian Food Bank Network	15+
3	Practitioner	Advisor (member of the Board of Directors) of the Food Bank)	The Italian Food Bank Network	1
4	Practitioner	Technology, IT aspects Expert	The Italian Food Bank Network	15
5	Practitioner	Marketing and sales	The Italian Food Bank Network	15
6	Practitioner	Advisor for food pantry	The Italian Food Bank Network	15
7	Practitioner	Volunteer at the Food Bank	The Italian Food Bank Network	15
8	Practitioner	Advisor for Food pantry	The Italian Food Bank Network	15
9	Practitioner	Administrative Manager	The Italian Food Bank Network	15+
10	Practitioner	Administrative employee	The Italian Food Bank Network	15
11	Practitioner	Director of food bank	The Italian Food Bank Network	27
12	Practitioner	Technology, IT aspects Expert	The Italian Food Bank Network	10
13	Practitioner	Advisor for Food pantry	The Italian Food Bank Network	18
14	Academic	Professor	Center of Philanthropy & Nonprofit Innovation	20+
15	Academic	Associate Professor	Economics	16+
16	Academic	Doctoral Condidate	Logistics	7
17	Academic	Doctoral Student	Operations Management	10
18	Academic	Doctoral Student	Economic	2
19	Academic	Doctoral student	Supply chain	3
20	Academic	Phd Scholar	Business Sciences	3
21	Academic	Master Student	Food Industry	4

3.3.4. Rough DEMATEL

Since its introduction by Pawlak in 1982, the rough model theory has developed into a mathematical studies technique that is becoming more and more linked with decision-making approaches. It has been used in conjunction with several key decision-making method, like the Best-Worst method (Haqbin et al., 2021), The approach for sorting preferences based on likeness to the best alternative The Technique for Order Preference by Similarity to Ideal

Solution (TOPSIS) (Chakraborty, 2022; Song et al., 2014), AHP (Gigović et al., 2017), and ANP (Li and Wang, 2018).

In group decision-making processes, rough theory is particularly useful for aggregating group information to address conflicts, subjectivity, and ambiguity in judgments (Mao et al., 2020), resulting in more accurate and dependable results. The steps of Song and Cao's (2017) rough DEMATEL approach are outlined below. As stated by (Mao et al., 2020), rough theory helps decrease the ambiguity and subjectivity that result from differing opinions during a group decision-making process by combining group data. Based on (Zhu et al. 2015).

See Appendix 1.

3.4. Result

3.4.1. Direct relation and normalization matrix

show the decision-maker's direct-relation matrix in addition to the group direct-relation matrix and the formulae were subsequently utilized to convert the opinions into approximated numbers. Similarly, the approximate numerical forms for the remaining judgements in the group direct-relation matrix were determined. The Table 3-3 depicted the decision-maker's direct-relation matrix. In addition, Table 3-4 illustrates to the group direct-relation matrix. This matrix was subsequently normalized (

Table 3-5) to ensure consistency and comparability across criteria, enabling a balanced evaluation of their relationships. The normalization process refines the data, allowing for a more accurate analysis of the interactions and dependencies among the elements in the decision-making framework.

Table 3-3. The first decision maker's direct-relation matrix

BARRIES	I1	I2	I3	I4	E1	E2	E3
I1	0	4	4	0	0	4	0
I2	1	0	2	0	0	4	0
I3	4	3	0	0	0	4	0
I4	4	2	4	0	0	3	0
E1	2	2	1	0	0	3	3
E2	4	4	4	0	0	0	0
E3	3	3	2	0	0	3	0

3.4.2. Total-Relation Matrix and Influence Analysis

Table 3-6 presents the rough total-relation matrix, showcasing both the upper and lower normalisation values calculated using the MMULT matrix approach. This matrix effectively captures the interrelationships among criteria, providing a comprehensive view of their influence on each other. The upper and lower normalisation helps to standardise the data, ensuring consistency and comparability while highlighting the range of potential values for each criterion within the rough set framework. It can be acquired by using the formula (3-34)–(3-36).

After constructing the approximate total-relation matrix T , the sums of the columns y_j and rows x_i were calculated (

Table 3-7). These sums provide valuable insights into the overall ‘influence’ dynamics among the criteria. Specifically, the row sums represent the degree to which each criterion influences others, while the column sums indicate the extent to which each criterion is influenced by others. By identifying the most influential and dependent criteria, this analysis enhances our understanding of their roles and interconnections in the decision-making process. The "Prominence" m_i and "Relation" n_i are basically determined by taking the total of the columns Y_j are converted into crisp values ($X_i Y_j$). After obtaining the rough total-relation matrix T , the sum of rows X_i and the sum of columns Y_j (see

Table 3-7) are calculated with the formulae (3-37), (3-38).

3.4.3. Prominence and Relation of Barriers

I1 (3.6135) stands out as the most impactful and prominent barrier, with a strong positive relationship between X and Y (0.1821). This indicates that addressing this barrier may have a significant and reinforcing effect on the system. I2 and I3 also have high values for both Final Crisp Value and Prominence, and their positive relationships suggest that addressing them may also lead to improvements in the system. These barriers include (lack of access to technology, Lack of organizational policy, and Lack of infrastructure, facilities, and human resources) making it a cause despite its limited overall significance, indicating its active role in influencing other barriers. In contrast, E1 has the strongest negative relationship (-0.3539), This suggests that efforts to address this barrier require a balancing act, and then E2 and E3 also show negative relationships, but their negative impacts are weaker compared to E1. **Table 3-8** shows the approximate total-relation matrix T .

3.4.4. Normalized Weights and Ranking of Barriers

Table 3-9 identifies the importance ranking and normalized weights of the barriers. This showed the top five ranked by order of importance as (I1) Lack of organizational access to technology and Lack of organizational policy, (I2) and lack of governance support for BCT implementation (E3) and moreover, the factors cited of least importance were (E1) lack of regulation and legislation about donated food, (E2) lack of awareness among volunteers regarding food waste/loss and bank roles and (I4) lack of financial resources.

I1 and I2 stand out as the most critical barriers, with the highest ω_i and w_i values. These barriers should be prioritized in any intervention, as they have the greatest overall impact and relative importance. I3 is also significant, ranked 4th in terms of ω_i , but slightly less impactful than I1, and I2. E1 is ranked 7th, with the lowest w_i value (0.1325), suggesting it is the least influential barrier. While it may still require attention, it is less critical than the others. I4, E2, and E3 are ranked in the middle (5th, 6th, and 3rd, respectively). These barriers should not be ignored, but they are less critical than I1 and I2. The data highlights that I1, I2, and I3 are the most critical barriers to address, given their high ω_i and w_i values. E1 is the least significant and should be considered a lower priority. I4, E2, and E3 fall in the middle, requiring attention but not as urgently as the top-ranked barriers.

Figure 3-4 visualizes the normalized weights of the barriers (I1, I2, I3, I4, E1, E2, E3), with the height of each orange bar reflecting its relative importance. The exact weights, displayed above each bar, provide a quantitative measure of each barrier's significance within this study, enhancing clarity and interpretation. Notably, barriers I1, I2, E3, emerge as the most critical, indicating their dominant influence and priority in addressing the challenges highlighted in this study. In contrast, barriers such as E1 (0.1325) and E2 (0.1361) demonstrate lower normalized weights, suggesting a reduced impact on the overall system.

Figure 3-4. Weights diagram

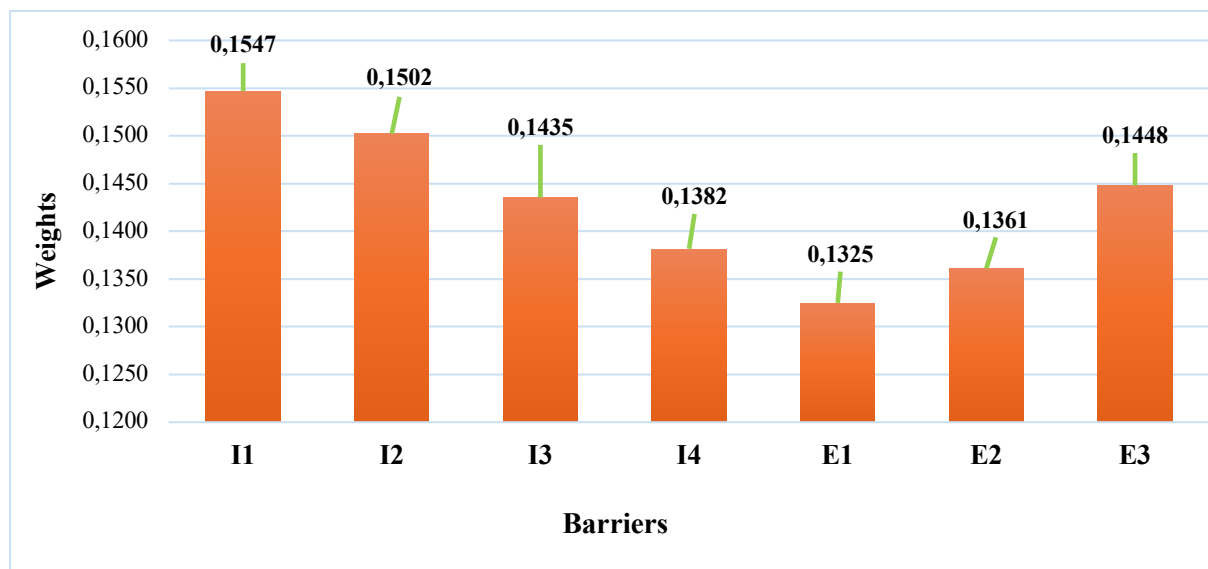


Table 3-4. The rough group direct-relation matrix

Barriers	I1	I2	I3	I4	E1	E2	E3
I1	[0.0000, 0.0000]	[1.8186, 3.2600]	[1.7305, 3.2076]	[1.3424, 3.0724]	[1.6838,3.3281]	[1.4919, 3,2486]	[1.2090, 2.8690]
I2	[1.8029, 3.5333]	[0.0000, 0.0000]	[1.4219, 2.9943]	[1.3329, 2.8724]	[1.2576,2.8814]	[1.5152, 3.1843]	[1.5443, 3.3905]
I3	[1.7881, 3.1119]	[1.6967, 3.2381]	[0.0000, 0.0000]	[1.6510, 3.1676]	[0.9614,2.4419]	[1.8029, 3.0776]	[1.3305, 3.0586]
I4	[1.8029,3.5333]	[1.5514, 3.1062]	[1.7062, 3.3719]	[0.0000, 0.0000]	[0.7319,2.3019]	[1.4862, 2.7729]	[1.4186, 2.8486]
E1	[1.5062,3.2814]	[1.7376, 3.2257]	[1.3405, 2.9086]	[1.0914, 2.9724]	[0.0000,0.0000]	[1.2614, 2.1400]	[1.8000, 3.5300]
E2	[1.6500,3.2100]	[1.4400, 3.1700]	[1.7000, 3.3100]	[1.1400, 2.9700]	[0.8700,2.7100]	[0.0000, 0.0000]	[1.0100, 2.7900]
E3	[1.6900,3.2300]	[1.6900, 3.2500]	[1.4400, 3.0700]	[1.3800, 3.0000]	[1.8000,3.1600]	[1.3500, 2.9700]	[0.0000, 0.0000]

Table 3-5. The normalized rough group direct-relation matrix

Barriers	I1	I2	I3	I4	E1	E2	E3
I1	[0.0000,0.0000]	[0.0643,0.1153]	[0.0612,0.1135]	[0.0475,0.1087]	[0.0596,0.1178]	[0.0528,0.1149]	[0,0428,0.1015]
I2	[0.0638,0.1250]	[0.0000,0.0000]	[0.0503,0.1059]	[0.0472,0.1016]	[0.0445,0,1020]	[0.0536,0.1127]	[0,0546,0.1200]
I3	[0.0633,0.1101]	[0.0600,0.1146]	[0.0000,0.0000]	[0.0584,0.1121]	[0.0340,0.0864]	[0.0638,0.1089]	[0,0471,0.1082]
I4	[0.0638,0.1250]	[0.0549,0.1099]	[0.0604,0.1193]	[0.0000,0.0000]	[0.0259,0.0814]	[0.0526,0.0981]	[0,0502,0.1008]
E1	[0.0533,0.1161]	[0.0615,0.1141]	[0.0474,0.1029]	[0.0386,0.1052]	[0.0000,0.0000]	[0.0446,0.0757]	[0,0637,0.1249]
E2	[0.0584,0.1136]	[0.0510,0.1122]	[0.0602,0.1171]	[0.0403,0.1051]	[0.0308,0.0959]	[0.0000,0.0000]	[0,0357,0.0987]
E3	[0.0598,0.1143]	[0.0598,0.1150]	[0.0510,0.1086]	[0.0488,0.1061]	[0.0637,0.1118]	[0.0478,0.1051]	[0,0000,0.0000]

Following the creation of the approximate total-relation matrix T , the sums of the columns Y_j and rows X_i were determined in **Error! Reference source not found.** The sum of the rows X_i and the sum of the columns y_j in **Error! Reference source not found.** were subsequently transformed into crisp values (x_i and y_j) in order to calculate the prominence (m_i) and relation (n_i) values. **Error! Reference source not found.** displays the crisp values.

Table 3-6. The rough total-relation matrix

Barriers	I1	I2	I3	I4	E1	E2	E3
	Lower	Lower	Lower	Lower	Lower	Lower	Lower
I1	0,0272	0,0870	0,0826	0,0667	0,0759	0,0741	0,0634
I2	0,0861	0,0254	0,0719	0,0656	0,0618	0,0738	0,0730
I3	0,0867	0,0828	0,0250	0,0766	0,0525	0,0840	0,0667
I4	0,0858	0,0769	0,0807	0,0204	0,0443	0,0727	0,0683
E1	0,0763	0,0830	0,0687	0,0575	0,0192	0,0653	0,0812
E2	0,0784	0,0709	0,0781	0,0572	0,0468	0,0206	0,0532
E3	0,0838	0,0832	0,0735	0,0680	0,0802	0,0696	0,0226

Table 3-7. Summation of the columns y_j and rows x_i .

Barriers	X_i	Y_j
I1	[0.5243, 2.0035]	[0.4769, 1.9200]
I2	[0.5092, 1.9446]	[0.4576, 1.9100]
I3	[0.4806, 1.9093]	[0.4743, 1.8397]
I4	[0.4120, 1.8356]	[0.4490, 1.8255]
E1	[0.3808, 1.7241]	[0.4512, 1.8374]
E2	[0.4599, 1.7803]	[0.4052, 1.8452]
E3	[0.4284, 1.8735]	[0.4809, 1.8930]

Table 3-8. shows the "Prominence" and "Relation" Crisp values.

Barriers	Final Crisp Value		Prominence	Relation
	X	Y	X+Y	X-Y
I1	3,6135	3,4314	7,0448	0,1821
I2	3,4416	3,4031	6,8447	0,0385
I3	3,3429	3,1950	6,5379	0,1479
I4	3,1392	3,1560	6,2952	-0,0169
E1	2,8362	3,1900	6,0262	-0,3539
E2	2,9834	3,2142	6,1976	-0,2308
E3	3,2453	3,3505	6,5958	-0,1052

Table 3-9. The importance, normalized weights, and rankings of the barriers.

BARRIERS	ω_i	W_i	RANKING
I1	7,047184	0,1547	1
I2	6,844819	0,1502	2
I3	6,539578	0,1435	4
I4	6,295243	0,1382	5
E1	6,036575	0,1325	7
E2	6,201863	0,1361	6
E3	6,596673	0,1448	3

3.4.5. Threshold Analysis and Network Visualization

Following the approach of Mao *et al.*, (2020), a threshold q was determined in order to identify the significant relationships between the barriers in (T^*). The values 2.1475 and 0.2566 represent the mean and standard deviation, respectively, of all components in T^* . Furthermore, Threshold T^* is used to simplify the direct influence matrix by eliminating less significant or weaker influences, keeping only the stronger relationships. After calculating the average influence matrix (based on multiple expert inputs), a threshold is set to retain only influences that are greater than or equal to this threshold. T^* serves as a filter to eliminate weaker connections in the direct influence matrix, focusing the analysis on the more significant relationships (see Figure 3-5). The choice of T^* is critical, as it directly affects the complexity and clarity of the resulting model (Tzeng and Huang, 2011).

Figure 3-5. Significant relationships after the threshold analysis

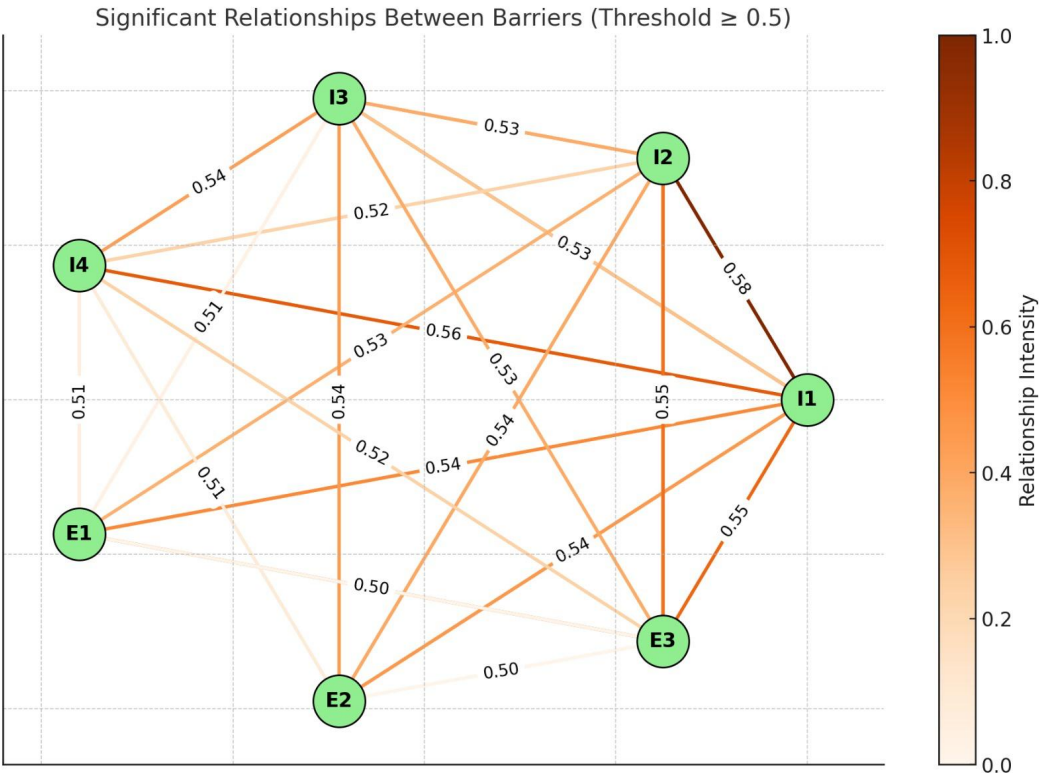


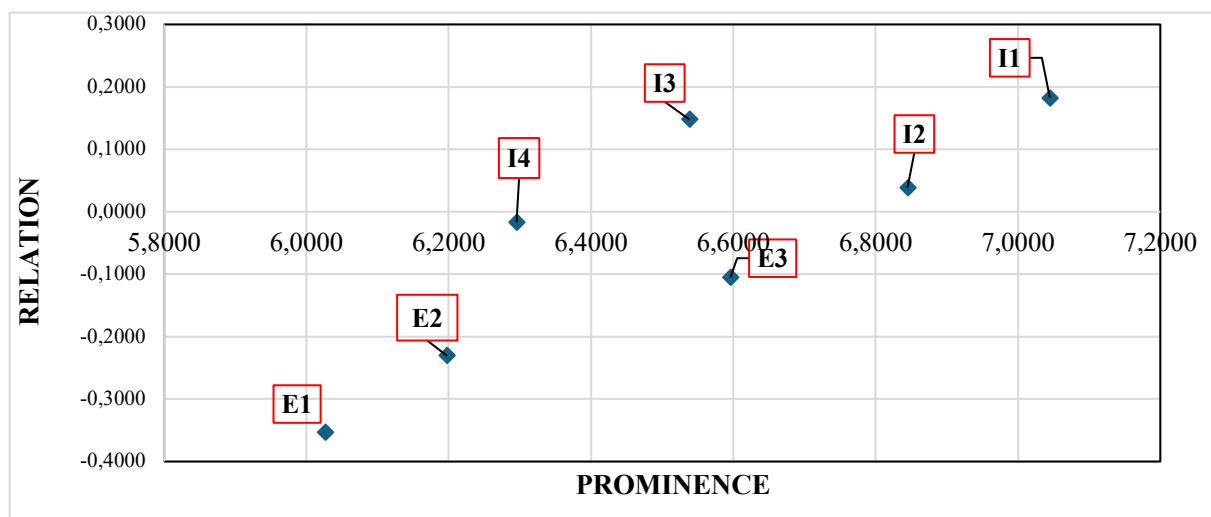
Figure 3-5 the nodes represent the barriers, and the edges indicate significant connections, with their intensity reflected in the thickness and dark orange color of the lines. This visualization highlights more interactions and provides a broader view of the relationships between barriers. It clarifies the most critical interactions, providing a clear and comprehensive understanding of the relationships between the barriers. the network graph illustrating the significant relationships between the barriers (I1, I2, I3, I4, E1, E2, and E3) with a threshold of 0.5. The nodes represent the barriers, and the edges reflect the relationships exceeding the threshold. The intensity of the relationships is depicted through the thickness and color of the edges, with darker and thicker edges indicating stronger relationships. This visualization helps clarify the interactions and dependencies between the barriers. Let me know if further adjustments are needed. In contrast, the T2 shows no interaction, reflecting its relatively weak connection with other barriers. In contrast, E1 and E2 shows no interaction, reflecting its relatively weak connection with other barriers.

3.4.6. Strategic Insights from the Causal Diagram

The causal diagram (Figure 3-6) (Relation-Prominence) highlights the relationships and significance of the barriers (I1, I2, I3, I4, E1, E2, E3) within the system. Barriers with high prominence, such as I1, I2, and I3, play a critical role in shaping the system's performance. Among

these, I1 stands out as the most prominent barrier with a strong positive relation, indicating that addressing it will have a substantial and reinforcing impact on the system. Similarly, I2 and I3 also exhibit high prominence and positive relations, suggesting that resolving these barriers will lead to significant improvements. In contrast, I4 has moderate prominence and a near-neutral relation, indicating a less critical role compared to the top three barriers. On the other hand, barriers E1, E2, and E3 show negative relations, indicating potential challenges when addressing them. E1, in particular, has the strongest negative relation, suggesting that efforts to resolve this barrier may lead to opposing effects, requiring a cautious and balanced approach. While E2 and E3 also exhibit negative relations, their impacts are less severe than E1 but still demand careful consideration. Overall, the diagram suggests prioritizing the resolution of I1, I2, and I3 to achieve the most significant positive impact while adopting strategic and cautious approaches to manage barriers with negative relations, such as E1, E2, and E3.

Figure 3-6. The Causal Diagram (Relation-Prominence)



3.5. Discussion

The relation value groups obstacles into cause or effect groups, as described in the steps of the rough DEMATEL process. The barrier in question belonged to the cause group in circumstances with a positive relation value. Otherwise, the relation value was negative, which is the effect group's barrier that applies. Therefore, the functionality of the obstacles depends on the operation of the other barriers. The findings revealed that Lack of access to technology (I1), Lack of organizational policy (I2), and Lack of infrastructure, facilities, and human resources (I3) were the primary drivers of other barriers, as they had positive relation values (n_i). Of these, Lack of infrastructure, facilities, and human resources management (I3) emerged as the most critical factor, with a prominence value of

0.1479, indicating its significant influence. Table 4 illustrates the normalized weights and the importance barriers. “lack of financial resources” (I4), “lack of regulation and legislation about donated food” (E1), “lack of awareness among volunteers regarding food waste/loss and bank roles” (E2), and “lack of government support for implementing blockchain technology” (E3) were the causal barrier of least importance with the lowest prominence value (mi).

The most significant issue identified is the lack of access to technology (I1). Technological barriers can influence organizational policy challenges, which in turn affect supply chain (SC) barriers. Organizational barriers often serve as a bridge between technological and SC challenges. For example, the immaturity of blockchain technology (BCT) as a critical technological concern may create hesitation among stakeholders or managers, potentially impacting their commitment to and support for its implementation within food bank supply chains (FBSC) (Iansiti & Lakhani, 2017; Saberi et al., 2019). Technological and FBSC-related barriers emerge as the most critical categories requiring focused attention. Addressing technological barriers (I1), as an internal challenge, is a priority for mitigating SC obstacles and advancing BCT adoption in the FBSC. Tackling these technological challenges within organizational policies can significantly reduce broader FBSC barriers (Tian, 2017). Furthermore, limited awareness among volunteers about food waste and the vital role of FBs remains a crucial external barrier that also requires immediate action.

Nevertheless, the lack of expertise and knowledge makes effect hesitate to change to new systems. This leads to a relationship mediated between a lack of management commitment and support. The adoption of BCT can help them raise updated awareness among volunteers about all issues in FBs. (Alexander & Smaje, 2008; Davis, 1989). Additionally, this barrier has a low relative prominence compared to the other barriers, however, this could be owing to a lack of influence over this barrier (E2). Nonetheless, certain studies in the FBSC literature may be somewhat compared to the findings of the current investigation. For example, food banks faced multiple unprecedented hurdles as a result of the pandemic and were not immune to the effects of the COVID-19 issue. Due to the various social restrictions imposed, many FBs and their forefront organizations faced significant challenges, a shortage of human resources like volunteers, both essential to the daily operations of FBs and their frontline partners, created a substantial strain on their ability to function effectively.

Moreover, several frontline organizations that were collecting food from the Polish FB were forced to temporarily close due to tight regulations and a shortage of volunteers. As a result, the Polish FB redistributed less food in the spring of 2020, because of a limit of food but because of the organizations' lack of personnel to redistribute it (Capodistrias, 2022). On the other hand, governments encounter several challenges when collecting information through FBs and transitioning

to a new system. One major challenge is the high cost of adopting sustainable practices, which many countries struggle to afford due to limited financial resources, making investment in BCT difficult.

Further, the lack of standardization, as well as the unavailability of relevant methods, tools, measurements, and procedures for deploying BCT and monitoring sustainability functioning, is a substantial challenge. However, by overcoming these obstacles, the government may improve its operations and make a significant contribution to a more sustainable future (Kouhizadeh et al., 2021). Nevertheless, BCT enables more effective monitoring and enforcement of food safety standards by supplying a clear, Tamper-proof record of food transactions. Policymakers can use these records to ensure that FBs comply with regulations, potentially reducing the incidence of foodborne illnesses and policymakers can also leverage the transparency provided by BCT to encourage the adoption of best practices in food distribution. For example, BCT data can help identify inefficiencies or bottlenecks in the SC, informing policy decisions to improve food security (Casino et al., 2019). FBs can use BCT to generate accurate and detailed reports for donors, showcasing the impact of their contributions. This capability is particularly important for attracting and retaining large donors, including corporate sponsors and institutional funders (Sabeti et al., 2019).

Likewise, Policymakers can introduce tax incentives for donations made through BCT-verified platforms, ensuring that contributions are tracked and used efficiently. This could encourage more substantial and more frequent donations to FBs (Zyskind et al., 2015). The use of BCT in FBs can improve sustainability by enabling precise tracking of food donations and distributions, ultimately reducing waste and improving resource allocation. Sabeti et al. (2019) discuss how BCT can enhance resource management and support sustainability in non-profit settings. If the results of implementing BCT in FBs show reduced waste and better management of food resources, it would not only reinforce existing sustainability theories but also extend them by demonstrating how BCT can serve as a powerful tool for achieving sustainability goals in non-profit settings.

3.5.1. Managerial implications

BCT is perceived as too complex or underdeveloped, leaders may be hesitant to invest resources, thereby slowing down the adoption process. Organizations need to first focus on upskilling their workforce and establishing a clear understanding of BCT's capabilities before attempting widespread adoption (Sabeti et al., 2019). Leaders need to align their strategic goals with adoption, ensuring that any technological investments align with long-term organizational objectives (Tian,2017). To successfully implement BCT in FBSC, managers must foster strong partnerships with stakeholders and establish clear agreements on data governance and information-sharing protocols. These

measures are crucial for ensuring seamless blockchain integration across the supply chain (Queiroz & Wamba, 2019). Organizational resistance to change, including insufficient managerial support or a reluctance to embrace new technologies, can significantly hinder the successful adoption of BCT in supply chains. Addressing these barriers requires securing leadership commitment, offering comprehensive training, and fostering a culture of innovation. Such efforts not only help overcome internal resistance but also enhance collaboration with supply chain partners—an essential factor for the transparent and decentralized functionality of BCT systems (Queiroz & Wamba, 2019; Kshetri, 2018).

To address the lack of Organizational Policy (I2), managers should develop clear policies for data governance, information sharing, and blockchain implementation to align technological adoption with organizational goals. Strong leadership support is essential to drive innovation, ensure strategic alignment, and communicate policies effectively across all levels. For the Lack of Access to Technology (I1), managers must prioritize upskilling employees and volunteers through targeted training programs to enhance technological proficiency. Partnerships with tech providers or non-profits can help access affordable solutions, such as cloud-based platforms or blockchain-as-a-service (BaaS), reducing implementation costs. To overcome the Lack of Infrastructure, Facilities, and Human Resources (I3), managers should streamline operations and invest in critical infrastructure, such as upgraded storage facilities and smart logistics systems, to improve efficiency. Collaborating with government agencies, non-profits, and private stakeholders can secure funding and resources, including manpower, transportation, and distribution support.

3.6. Conclusion, limitation, and Future Research Direction

This study aimed to identify and analyze the interrelationships among barriers to adopting blockchain technology (BCT) in the food bank supply chain (FBSC). These barriers were categorized into internal and external groups, and the rough group DEMATEL technique was applied to evaluate their interactions. The methodology effectively revealed the relationships between barriers, providing a clear understanding of their influence. By addressing the blockchain technology gap, this study highlights opportunities to enhance the adoption and effectiveness of supply chain innovations. Furthermore, the establishment of robust organizational policies can create a supportive framework for integrating new technologies. The findings offer valuable insights for practitioners and policymakers to prioritize actions, overcome barriers, and strengthen the efficiency and resilience of supply chains.

It should be noted that this study has limitations such as the potential challenge in generalizing the findings across all FBSC. The specific barriers to blockchain adoption identified through the Rough DEMATEL-Based Approach may vary depending on the size, structure, and operational practices of different food banks. As a result, the insights gained might not be universally applicable to all organizations within this sector. Furthermore, Barriers to adoption may differ significantly across various geographic regions, influenced by local regulations, technological infrastructure, and cultural attitudes toward digital innovation. This limitation suggests that the findings may not be entirely relevant or applicable in all contexts. Likewise, it offers novel insights into the integration of BCT within the FBSC, particularly by identifying and analyzing the theoretical adoption barriers. Future research could explore tailored solutions to overcome adoption barriers across different regions and countries, considering variations in technological infrastructure, regulatory frameworks, and cultural attitudes toward BCT. Additionally, studies could investigate how BCT enhances transparency and trust within the FBSC, particularly in tracking donations, financial flows, ensuring food safety, and minimizing waste. Examining the regulatory implications of BCT adoption, with a focus on data privacy, security, and compliance with food safety standards, is another critical avenue for future research. Longitudinal studies are also essential to monitor the adoption of BCT in FBSCs over time, identifying key factors that drive sustained use and assessing the long-term impacts on supply chain efficiency and food security.

Besides that, we recommend exploring implementing BCT decision models that align sector-specific needs with suitable design features. Additionally, longitudinal studies could assess the long-term impact of overcoming adoption barriers on key supply chain performance metrics, such as traceability, efficiency, and sustainability. Incorporating advanced methodologies, such as hybrid multi-criteria decision-making approaches or machine learning techniques, could further enhance the precision and depth of barrier analysis in future studies. This limitation indicates that the findings may not be fully relevant or applicable across all contexts. However, the study provides valuable insights into the integration of blockchain technology (BCT) within food bank supply chains (FBSC), particularly by identifying and analyzing theoretical adoption barriers. Additionally, barriers to adoption can vary significantly across different geographic regions, shaped by factors such as local regulations, technological infrastructure, and cultural attitudes toward digital innovation.

Studying the barriers to Blockchain Technology (BCT) adoption in food bank (FB) systems is essential due to their critical role in addressing food insecurity and reducing waste. By identifying these challenges—such as high implementation costs, limited technical expertise, and resistance to change—organizations can develop strategies to overcome them, enabling BCT to enhance efficiency, transparency, and traceability in food bank operations.

Understanding these barriers also allows for the creation of tailored, low-cost solutions that fit the unique constraints of food banks, which often rely on limited resources and volunteer support. Insights gained can not only improve food security and waste reduction within FB systems but also inform broader efforts in digital transformation across nonprofit supply chains, guiding policymakers and technology providers to better support socially driven operations.

To wrap up this chapter, I would like to highlight that during my time as a visiting scholar at the University of Worcester Polytechnic Institute (WPI), I focused on assessing the design and implementation of blockchain technology within food bank supply chains. Our work involved evaluating critical questions related to its feasibility, impact, and potential for improving efficiency and transparency in these systems. We have evaluated several models related to blockchain adoption implementation, highlighting areas that require further in-depth study and exploration.

Chapter 4. Assessing Barriers to Blockchain Technology Adoption in the Food Supply Chain: A Rough DEMATEL Analysis

4.1. Introduction

Food supply chain (FSCs) encompasses various stakeholders, including producers, transport companies, wholesalers, distributors, and consumers (Coppolino et al., 2020). In recent decades, concerns regarding food safety, quality, the honesty of supply chain participants, and the accuracy of food labelling have grown, largely due to several high-profile food scandals (Manning, 2016; Stranieri et al., 2021). As a result, organisations are expected to track every aspect of a food product's journey and gather all relevant data about its movement through FSCs in an accessible and secure way (Chen et al., 2021). Blockchain technology (BCT), a decentralised platform allows direct peer-to-peer transactions while validating information via cryptography (Raikwar et al., 2019), offers a significant advancement in addressing these concerns by providing secure, reliable, and transparent solutions offering substantial improvements over traditional technologies and management systems

delivering an advancement in providing secure, reliable, and trustworthy solutions (George et al., 2019; Jellason et al., 2024; Liu et al., 2019;), and is poised to revolutionise FSCs (Queiroz et al., 2020). BCT is also a powerful tool for addressing critical challenges, such as information asymmetry and inefficiencies in food recalls (Bonetti et al., 2024; Zhao, 2019).

Recent pilot projects have demonstrated that BC provides an irreversible and standardized database for traceability systems, (Astill et al., 2019; Creydt and Fischer, 2019; Collart and Canales, 2021), improving supply chain management effectiveness and interoperability across chain participants (Casino et al., 2019; Kamath, 2018) and assuring the security and dependability of the data (Chen et al., 2021; Tian, 2016). Several studies concentrating on FSC have emphasized that blockchain technology improves the traceability of products (Bonetti et al., 2024; Feng et al., 2020; Patelli and Mandrioli, 2020; Vu et al., 2021). However, FSC actors must also possess the necessary knowledge and practical abilities to guarantee successful implementation (Müller and Gaudig, 2011; Köhler and Pizzol, 2020). Integrating digital technologies such as BCT into FSC requires close collaboration among all actors to overcome various certain barriers to success. These challenges include concerns over data privacy, sharing sensitive information and technological barriers such as the storage capacity and connectivity constraints (Jagtap and Duong, 2019; Astill et al., 2019; Annosi et al., 2021). The adoption of smart technologies, especially for tracking food and commodities, is expected to boost industry digitalisation whereby tracking underpins product safety, security, and sustainability. Major food retailers, such as Walmart, have already leveraged BCT to improve the traceability of products like Mexican mangoes and Chinese pork, enhancing supply chain management of product quality and food safety (Creydt and Fischer, 2019; Stranieri et al., 2021). Nonetheless, the FSC could still benefit from further integration of BCT (Di Vaio and Varriale, 2020; Kamble et al., 2019). The adoption of smart technologies, especially for tracking food and commodities, is expected to accelerate the digitalisation of the industry, with BCT playing a vital role in ensuring product safety, security, and sustainability (Bonetti et al., 2024).

Notably, BCT could play a significant role in this process (Bonetti et al., 2024). Quick-response codes (QR codes), radio frequency identification (RFID), near-field communication (NFC), online certification and digital signatures, sensors and actuators, and cell phones are just a few of the digital technologies across FSCs that can be linked via BCT (Kamilaris et al., 2019). The UN Food Systems 2021 Summit, also known as the Tokyo Nutrition for Growth (N4G), emphasized the urgent need to change the policies and strategies used to feed the world during the Twentieth Century. At the summit, it was proposed that taking decisive action to transition the food system is imperative to achieve universally accessible, affordable, healthy, environmentally friendly, economically viable, and socially sustainable diets (Amentae and Gebresenbet, 2021; Ringler et al., 2021).

The contribution of this paper is to analyse industry and academic stakeholder perspectives on the barriers that impede the development of BCT for the FSCs, ranking their perceived prominence and evaluating the cause-and-effect relationships. We apply the Decision-Making Trial and Evaluation Laboratory (DEMATEL) method, a powerful technique for conceptualising the structure of cause-effect relationships in complex systems. DEMATEL is particularly effective in representing intricate causal connections and illustrating the relationships between various system components. In the subsequent phase of our study, we incorporate rough set theory, a mathematical approach originally introduced by Pawlak (1982), to further refine our analysis. In this study the following research questions are explored:

Research question 1: What are the barriers to adopting blockchain technology in the food supply chain, and their prominence?

Research question 2: What are the relationships identified between the barriers?

The paper is organised as follows: Section 2 provides the conceptual background and literature review. Section 3 outlines the research methodology adopted for the study in detail. Section 4 presents the results and analysis. Section 5 discusses the findings, and Section 6 concludes with the research's conclusions, implications, and limitations.

4.2. Theoretical background

4.2.1. Blockchain technology adoption within food supply chains

The production of processed foods with longer shelf lives requires complex procedures (Duan et al., 2020). The FSC involves highly interconnected network of producers, shipping companies, dealers, distributors, and consumers (Coppolino et al., 2020). Table 4-1 presents the stages of the retail FSC, by name of actors, detailing each process involved from provider to consumption.

Table 4-1 The process of food supply chain system

Num	The Stage of Food Supply Chain	Description
1	Provider	Information about the Record transactions with farmers, including crop, pesticide, fertilizer, and machinery info.
2	Producer	Information about the farm, including farming practices, crop cultivation, weather conditions, and animal welfare.
3	Processing	Information about the factory and its equipment, the processing methods used, batch numbers, etc. The financial transactions that take place with the producers and distributors are recorded too.
4	Distribution	Information about the transportation, it is important to track shipping details, storage conditions like temperature and humidity, and time in transit method etc. All transactions between the distributors and with the final recipients (i.e., retailers) are written on the blockchain.
5	Retailer	Detailed information about each food item is listed on the chain, including its quality, quantity, expiration date, storage conditions, and time spent on the shelf.
6	Consumer	In the last step of the process, consumers can use their internet-connected mobile phones or a web application to scan a QR code linked to a food item. This will provide them with detailed information about the product, including its producer, provider, and retail store.

BCT is a shared, immutable ledger that records transactions and tracks assets. Its key features are decentralisation, immutability, security, and smart contracts, which can bring significant benefits to FSC when used properly, and BCT has multiple advantages for enhancing food traceability systems (Astill et al., 2019; Collart and Canales, 2021). Blockchain-based traceability systems enable FSC entities to store transaction data, providing customers with access to information verifying product authenticity (Pandey et al., 2022). Schmidt and Wagner (2019) state that BCT can limit opportunistic behaviour and the impact of uncertainty related to potential regulatory, political, economic, or behavioural changes. BCT's potential to improve transparency and traceability significantly surpasses that of existing technologies and management systems, providing a more efficient and accountable approach to FSC operations (George et al., 2019; Kamilaris et al., 2019; Liu et al., 2019; Tran et al., 2024). BCT offers an unprecedented level of visibility and traceability for fresh produce and other food products (Li et al., 2023) and is an effective tool to promote sustainability (Saber et al., 2019).

BCT stands out among emerging digital innovations as a transformative tool with the capability to reshape and realign business operations across multiple economic sectors including FSCs (Schneider et al., 2020, Sabbagh et al., 2024). Tiscini et al., (2020) emphasize BCT's potential for sustainable business model innovation in agri-food, using a small Italian winery as a case study. Italian wine supply was also the case utilised by Sabbagh et al., (2024) to explore BCT adoption. Digital solutions

are essential for improving the coordination of organisations in the FSC. By aligning and linking all points of contact and influence, including people, processes, information, knowledge, and strategies, these solutions can facilitate the efficient and effective flow of material, money, information, and knowledge to meet customer needs supporting organisations that adopt these solutions to stay competitive and meet the demands of the market (Annosi et al., 2021; Stevens and Johnson, 2016).

The BCT ledger is shared among all nodes in the network, and each node can access the most recent version of the ledger (Jellason et al., 2024). Likewise, the reliable traceability system in BCT relies on the safe collection and storage of data at every stage of the production process. This enhances safety in production and helps in managing failures or breakdowns effectively (Bonetti et al., 2024; Li et al., 2023; Patelli and Mandrioli, 2020). Thus, digital technologies, such as BCT, can facilitate the sharing of information required to manage and control various issues along the FSC. This includes the timely transfer of foods and ingredients, ensuring the safety of food products throughout the supply chain, and guaranteeing an adequate shelf life for the end-user. Similarly, digital solutions facilitate producers to align supply-demand dynamics so that retailers can more easily meet customers' demands preventing oversupply (Annosi et al., 2021; Corallo et al., 2020).

4.2.2. Identifying barriers to the adoption blockchain technology in food supply chains

Four types of barriers have been synthesized from the literature: technological barriers, organisational barriers, financial constraints and environmental barriers. Access to technology connectivity and internet coverage (external) are fundamental requirement for successful BCT adoption and are a significant challenge in some regions (Astill et al. 2019; Kouhizadeh, et al., 2021; Kumar et al., 2022). Likewise, lack of internal connectivity within organisations and its websites is a barrier whether organisational IT infrastructure is poor, or technology access is impractical (Astill et al. 2019; Kouhizadeh, et al., 2021; Kumar et al., 2022). Additionally, organisations must obtain legal permission from governments to use cryptocurrencies for blockchain transactions as they are illegal in many countries (Andoni et al., 2019; Kouhizadeh et al., 2021; Morkunas et al., 2019). The absence of centralised authorities and regulations has increased the chances of using these technologies for fraudulent purposes. Existing laws or regulations, particularly after the advent of new disruptive technologies need to be updated (Chen et al.,2020; Kumar et al., 2022; Reyna et al.,2018; Singh et al.,2020).

In FSCs, it is essential to have interoperability between stakeholders and appropriate legislation for data sharing and storage and availability of tools and standards for BCT implementation and data analysis is essential. Currently, there are no unified regulations for the organised use of emerging

technology and their data in the FSC, resulting in some stakeholders having limited or no access to information (Kumar et al., 2022; Sharma et al., 2022; Zhao et al., 2019). For food products to be monitored for safety and quality management, food traceability is essential (González-Mendes et al., 2024; Wang and Scrimgeour, 2023). The lack of tools and standards for implementing BCT and data analysis in FSCs may be a significant barrier as these are essential for implementing and measuring sustainability performance within organisations (Kumar et al., 2022; Sharma et al., 2022; Zhao et al., 2019). Another potential barrier is the lack of knowledge and expertise, so ensuring trained employees who understand modern technologies is critical to allow FSC organisations to implement BCT (Crosby et al., 2016; Guo and Liang, 2016; Kouhizadeh et al., 2021; Kumar et al., 2022; Sharma et al., 2022; Zhao et al., 2019).

A further challenge that emerged during the review of the extant literature is the lack of financial support through grants and incentives (government and market) see Kouhizadeh et al., (2021). Information collection through the FSC and conversion to new systems also imposes costs on organisations (Baralla et al., 2019; Kouhizadeh et al., 2021). Likewise, there are high development costs for BCT design and customization arising from high labour/expertise costs for blockchain development, maintenance, and high insurance/ risk coverage premiums (Okorie et al., 2022; Baralla et al., 2019). Also, adopting sustainable practices may be costly and many organisations have limited financial resources to allow them to adopt BCT. Implementing these technologies also relies on continuous maintenance of the environment, power supply, and storage after implementation, with technologies associated with BCT for FSC mainly consisting of biosensors, which are expensive (Baralla et al., 2019; Kouhizadeh et al., 2021). The other barriers found from the extant literature are associated with weak collaboration, communication, and coordination between FSC actors who may have different even contradictory strategic and operational goals and targets operational incentives/ objectives and priorities; other reasons that impede collaboration. (Behnke and Janssen, 2019; Caro et al., 2018; Kamble et al., 2019; Kshetri, 2018; Kouhizadeh et al., 2021). Finally risks in the FSC such as uncertainty, volatility, perceptions of the risk of adopting BCT and trust are barriers that need to be considered (Nurgazina et al., 2021). These factors have been collated in Table 4-2.

Table 4-2 Identified barriers to the adoption of blockchain technology in food supply chains

Main Barriers	Sub Barriers	Sources
Technological Barriers	T1- Lack of external internet connectivity and coverage and ability to access external technology. T2- Lack of internal connectivity and coverage within the organisation and its websites	Astill <i>et al.</i> , (2019); Kouhizadeh <i>et al.</i> , (2021); Kumar <i>et al.</i> , (2022). Astill <i>et al.</i> , (2019); Kouhizadeh <i>et al.</i> , (2021); Kumar <i>et al.</i> , (2022).
Organisational Barriers	O1-Lack of legislation for data sharing and data storage. O2-Lack of tools and standards for BCT implementation and data analysis O3-Lack of knowledge and expertise O4-Lack of access to legal permissions for the use of cryptocurrencies	Chen <i>et al.</i> , (2021); Kumar <i>et al.</i> (2022). Reyna <i>et al.</i> , (2018); Singh <i>et al.</i> , (2020); Kumar <i>et al.</i> , (2022); Sharma <i>et al.</i> , (2022); Zhao <i>et al.</i> , (2019) Crosby <i>et al.</i> , (2016); Guo and Liang, (2016); Kouhizadeh <i>et al.</i> , (2021); Kumar <i>et al.</i> , (2022); Sharma <i>et al.</i> , (2022); Zhao <i>et al.</i> , (2019) Andoni <i>et al.</i> , (2019); Kouhizadeh <i>et al.</i> , (2021); Morkunas <i>et al.</i> , (2019).
Financial Constraints	F1-Weak financial support via grants/incentives for BCT adoption F2- Cost of BCT implementation and maintenance F3- Cost of bespoke design and customisation of BCT systems	Kouhizadeh <i>et al.</i> , (2021) Baralla <i>et al.</i> , (2019); Kouhizadeh <i>et al.</i> , (2021). Baralla <i>et al.</i> , (2019); Okorie <i>et al.</i> , (2022).
Environmental Barriers	E1- Lack of collaboration, communication, and coordination in FSCs E2- Risk in FSCs	Behnke and Janssen, (2019); Caro <i>et al.</i> , (2018); Kamble <i>et al.</i> , (2019); Kshetri, (2018); Kouhizadeh <i>et al.</i> , (2021).Nurgazina <i>et al.</i> , (2021)

4.3. Methods and materials

Firstly, we identified key "barriers" to adopting BCT in the FSC through a structured literature search (see section 2.2). This led to the identification of four main barriers and eleven sub-barriers (Table 2). Based on the findings of this review, we created a survey to be administered to a selected group of experts from both academia and practitioners to explore the cause-and-effect relationships among the identified barriers. Respondents evaluated the influence and effectiveness of each barrier on all other barriers, considering them separately, and responded using a Likert scale with five levels of influence: no influence (0), low influence (1), medium influence (2), high influence (3), and very high influence (4). This approach had two main objectives. First, it aimed to identify the importance of each individual barrier (prominence). Secondly, it sought to understand the interrelationships among these barriers (relations). A rough DEMATEL analysis was carried out on the data to highlight the prominence of each barrier and the relationship among them. Figure 4-1 illustrates the research process outlined here.

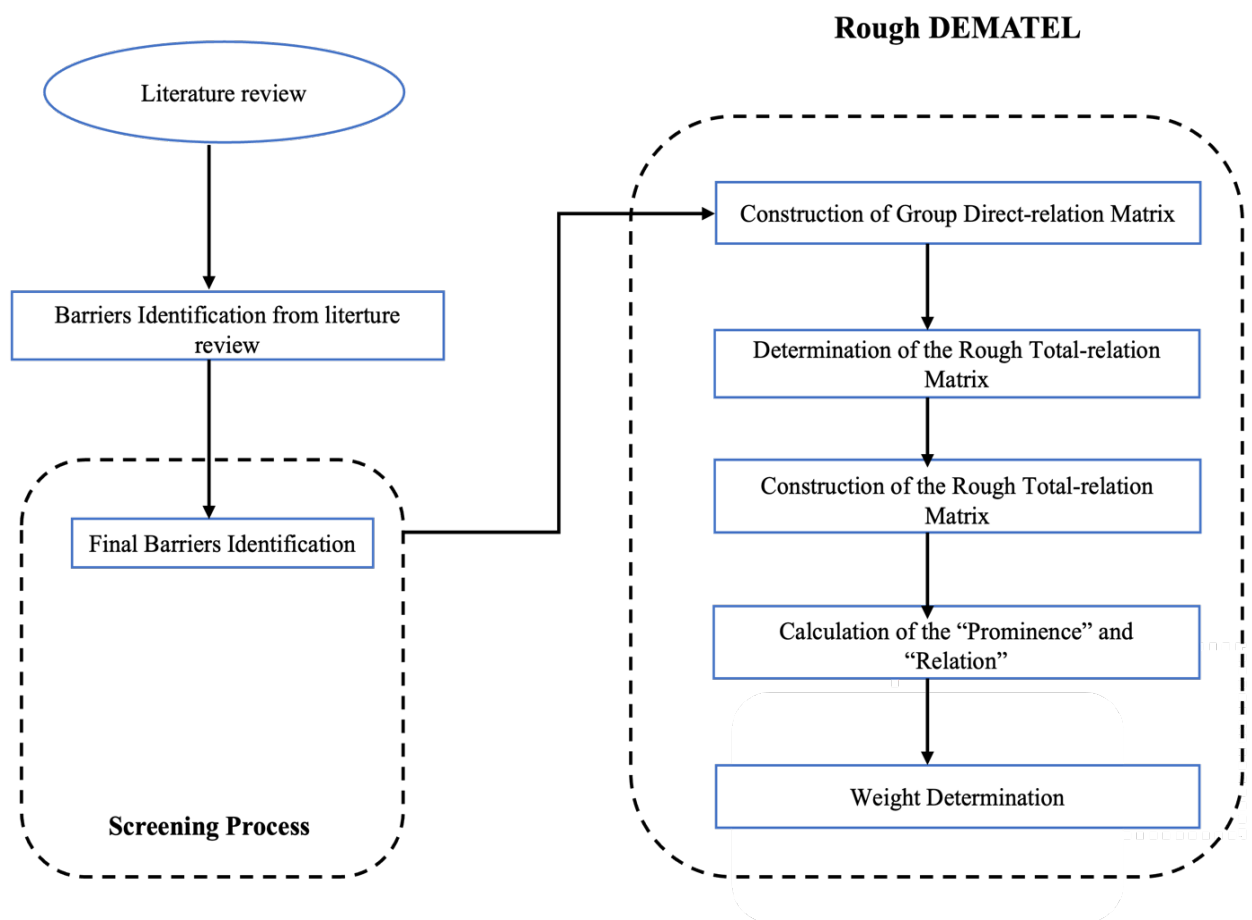
4.3.1. DEMATEL methodology

It can be daunting to analyse so many interconnected barriers or causes. DEMATEL is a helpful method for conceptualising the framework of cause and effect linkages among components of a complex system (Fontela & Gabus, 1976). When expressing the connections between various system components, DEMATEL provides a useful method for visualising the structure of intricate causal linkages (Song and Cao, 2017). DEMATEL can identify key variables, both independent and dependent, and the connections between them in a cause-and-effect network. It can also process the degree to which these elements interact and impact one another. Pairwise comparisons are used in DEMATEL to visualise direct and indirect correlations while also examining the causal dependency structure among the elements that have been identified. The DEMATEL methodology determines each barrier's prominence and aids in organising the causal linkages among the barriers that have been identified (Fu *et al.*, 2012; Lee *et al.*, 2010). SC experts have employed two well-established methodologies, the analytic hierarchy process (AHP) (Saaty, 1988) and interpretive structural modelling (ISM) (Mandal and Deshmukh, 1994), to organise and assess a variety of defined obstacles or factors. These two approaches do, however, have certain drawbacks. ISM is unable to determine the entire influence of each element, while AHP ignores the interactions between the barriers. The capacity of DEMATEL to map out and quantify the causal linkages among various obstacles is one of its main advantages (Tzeng *et al.*, 2007; Biswas and Gupta, 2019). Also, unlike methods such as

Failure Mode and Effects Analysis (FMEA), which typically treat barriers as independent factors, DEMATEL explicitly models the interdependencies and feedback loops, offering a more comprehensive analysis of the factors involved (Fontela and Gabus, 1976).

This paper combines the rough theory with DEMATEL to collect data to address disagreements, individuality, and ambiguity in judgements by experts during group decision making processes. This method could lead to more reliable and accurate results (Mao *et al.*, 2020; Shojaei *et al.*, 2023). Figure 4-1 illustrates the research methodology process. The steps are now explained. The four steps followed are outlined in the Supplementary File.

Figure 4-1 Research methodology process



4.3.2. Collection of data and survey participants

The University of Lincoln Research Ethics Committee approved the study prior to the start of data collection (ethics reference: 2024_17610). In order to assess the barriers, we chose a sample of respondents that includes experts from academia and practitioners who are familiar with BCT and FSCs. To address our research questions, we identified four barriers and eleven sub-barriers to the

adoption of BCT in the FSC (Table 2) which were analysed and compared to explore any relationships between them. The survey was developed, piloted and then completed by participants who were asked to evaluate the influence of each factor on another using pair-wise comparisons via a multiple-choice questionnaire using a scale of from one to five: No Influence (0), Low Influence (1), Medium Influence (2), High Influence (3), following Very High Influence (4). Essentially, the judgments were provided in the form of $n \times n$ matrices, and then calculating the average of these matrices to create a single aggregated influence matrix. We invited academics ($n=13$) and agri-food industry practitioners ($n=7$) to complete the questionnaire (Table 4-3). Both sub-groups demonstrated an adequate understanding of BCT and FSC in their responses.

Table 4-3 Information on study respondents

No.	Practitioner /Academic	Role	Academic Department/Organisation Category
1	Academic	Professor	Food Science
2	Academic	Professor	Computer Science
3	Academic	Senior Lecturer	Sustainable Agri-Food
4	Academic	Lecturer	Engineering
5	Practitioner	Food systems risk manager	Food Science/Regulation
6	Academic	Associate Professor	Supply Chain Management and Logistics
7	Academic	Professor	Systems Engineering
8	Practitioner	Founder of food safety consultancy business	Food Science and Supply Chain Management
9	Practitioner	Director of agriculture consultancy business and visiting professor	Supply Chain Management and Logistics
10	Academic	Associate Professor	Food Science and Supply Chain Management
11	Academic	Senior Lecturer	Banking and Finance
12	Practitioner	Principal environmental health officer	Food Regulation
13	Academic	Senior Lecturer	Food Safety Management and Supply Chains
14	Practitioner	Industry advisor and researcher	Food Safety Management and Supply Chains
15	Practitioner	Compliance manager	Supply Chain Management
16	Academic	Senior Lecturer	Sustainability and International Business
17	Academic	Senior Lecturer	Supply Chain Management
18	Academic	Senior Lecturer	Supply Chain Management and Logistics
19	Academic	Senior research fellow	Computer Science and Innovation
20	Practitioner	Consultant	Food Science and Supply Chain Management

4.3.3. Rough DEMATEL

Since its introduction by Pawlak in 1982, the rough model theory has developed into a mathematical studies technique that is becoming more and more linked with decision-making approaches. It has been used in conjunction with several key decision making method, like the Best-Worst method (Haqbin et al., 2021), The approach for sorting preferences based on likeness to the best alternative The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) (Chakraborty, 2022; Song et al., 2014), rough Analytical Hierarchy Process - AHP (Gigović et al., 2017), and rough Analytical Network Process - ANP (Li and Wang, 2018). In group decision-making processes, rough theory is particularly useful for aggregating group information to address conflicts, subjectivity, and ambiguity in judgments (Mao et al., 2020), resulting in more accurate and dependable results. The steps of Song and Cao's (2017) rough DEMATEL approach are outlined below. As stated by Mao et al., (2020), rough theory helps decrease the ambiguity and subjectivity that result from differing opinions during a group decision-making process by combining group data. Based on (Zhu et al. 2015), define the following terms in relation to rough numbers:

The four steps followed are outlined in the Supplementary File. And See Appendix 2.

4.4. Result

4.4.1. Determining the interrelationships among the barriers

Our research is to develop an integrated evaluation method for adopting BCT in FSCs, assessing the interactions and interrelationships of barriers using DEMATEL and rough theory. This involved submitting a (Pairwise Comparison Questionnaire) , the frame is created by utilising a specific scale (as described in Step 1), including six practitioners who are experts in the FSC and fourteen academic people. The Table 4-4 and

Table 4-5 depicted the decision-maker's direct-relation matrix in addition to the group direct-relation matrix and the formulae were subsequently utilised to convert the opinions into approximated numbers.

$$\underline{Lim} (A_k) = \frac{1}{m_L} \sum \{P \in \underline{Apr} (A_k)\} \quad (4-48)$$

Table 4-4. The first decision maker's direct-relation matrix

Expert	O1	O2	O3	O4	F1	F2	F3	T1	T2	E1	E2
O1	0	4	3	4	3	4	4	4	4	4	2
O2	4	0	3	3	3	3	3	1	1	3	3
O3	1	3	0	1	2	3	3	1	1	2	2
O4	2	2	2	0	0	2	2	0	0	0	0
F1	1	1	1	1	0	4	4	1	1	1	1
F2	3	3	3	3	3	0	3	3	3	3	3
F3	1	3	3	2	3	3	0	1	1	3	2
T1	0	0	0	2	3	3	3	0	3	0	0
T2	1	2	0	1	3	2	2	4	0	1	2
E1	1	2	1	1	1	2	2	1	1	0	3
E2	1	1	1	1	2	1	1	1	1	3	0

Table 4-5. The rough group direct-relation matrix

	O1	O2	O3	O4	F1	F2	F3	T1	T2	E1	E2
O1	[0.0452, 1.0660]	[0.1072, 1.2745]	[0.1102, 1.2660]	[0.1049, 1.1544]	[0.0955, 1.2182]	[0.1238, 1.3271]	[0.1088, 1.3342]	[0.0861, 1.1105]	[0.0792, 1.0911]	[0.1146, 1.3527]	[0.1113, 1.2441]
O2	[0.1016, 1.1552]	[0.0626, 1.1846]	[0.1281, 1.2771]	[0.1061, 1.1521]	[0.1101, 1.2238]	[0.1433, 1.3262]	[0.1392, 1.3432]	[0.0923, 1.1128]	[0.0941, 1.0899]	[0.1356, 1.3470]	[0.1212, 1.2405]
O3	[0.0974, 1.1146]	[0.1158, 1.2307]	[0.0550, 1.1332]	[0.0784, 1.0973]	[0.0943, 1.1832]	[0.1574, 1.2922]	[0.1110, 1.2932]	[0.0659, 1.0587]	[0.0687, 1.0428]	[0.1240, 1.3003]	[0.1014, 1.1929]
O4	[0.0698, 0.9383]	[0.0676, 1.0195]	[0.0613, 1.0075]	[0.0248, 0.8443]	[0.0523, 0.9643]	[0.0691, 1.0684]	[0.0644, 1.0532]	[0.0411, 0.8831]	[0.0375, 0.8588]	[0.0587, 1.0683]	[0.0536, 0.9773]
F1	[0.0705, 1.0870]	[0.0874, 1.2084]	[0.0827, 1.2011]	[0.0677, 1.0853]	[0.0391, 1.0724]	[0.1150, 1.2718]	[0.1042, 1.2777]	[0.0697, 1.0630]	[0.0657, 1.0435]	[0.0925, 1.2691]	[0.0856, 1.1684]
F2	[0.0759, 1.0940]	[0.0977, 1.2175]	[0.1051, 1.2175]	[0.0809, 1.0946]	[0.0940, 1.1747]	[0.0573, 1.1826]	[0.1045, 1.2827]	[0.0705, 1.0626]	[0.0749, 1.0450]	[0.1111, 1.2889]	[0.0899, 1.1786]
F3	[0.0757, 1.1092]	[0.1103, 1.2376]	[0.1135, 1.2340]	[0.0777, 1.1043]	[0.1013, 1.1815]	[0.1255, 1.3024]	[0.0523, 1.1952]	[0.0744, 1.0700]	[0.0720, 1.0480]	[0.1049, 1.2986]	[0.0910, 1.1786]
T1	[0.0716, 1.0452]	[0.0829, 1.1668]	[0.0862, 1.1619]	[0.0605, 1.0441]	[0.0696, 1.1149]	[0.0917, 1.2275]	[0.0859, 1.2265]	[0.0326, 0.9466]	[0.0910, 1.0217]	[0.0956, 1.2406]	[0.0813, 1.1918]
T2	[0.0537, 0.9892]	[0.0882, 1.0893]	[0.0765, 0.9885]	[0.0610, 0.9885]	[0.0667, 1.0542]	[0.0921, 1.1715]	[0.0823, 1.1597]	[0.0872, 0.9878]	[0.0313, 0.8813]	[0.1013, 1.1942]	[0.0814, 0.0669]
E1	[0.1019, 1.762]	[0.1115, 1.2079]	[0.1108, 1.0772]	[0.0854, 1.0772]	[0.0862, 1.1473]	[0.1166, 1.2520]	[0.1029, 1.2458]	[0.0807, 1.0519]	[0.0760, 1.0319]	[0.0571, 1.1766]	[0.1153, 1.1771]
E2	[0.0802, 1.0400]	[0.0979, 1.1402]	[0.0931, 1.1345]	[0.0703, 1.0233]	[0.0846, 1.0893]	[0.1103, 1.1750]	[0.0976, 1.1918]	[0.0705, 0.9938]	[0.0696, 0.9741]	[0.1108, 1.2073]	[0.0451, 1.226]

Table 4-6. The normalized rough group direct-relation matrix

	O1	O2	O3	O4	F1	F2	F3	T1	T2	E1	E2
O1	[0.0452, 1.0660]	[0.1072, 1.2745]	[0.1102, 1.2660]	[0.1049, 1.1544]	[0.0955, 1.2182]	[0.1238, 1.3271]	[0.1088, 1.3342]	[0.0861, 1.1105]	[0.0792, 1.0911]	[0.1146, 1.3527]	[0.1113, 1.2441]
O2	[0.1016, 1.1552]	[0.0626, 1.1846]	[0.1281, 1.2771]	[0.1061, 1.1521]	[0.1101, 1.2238]	[0.1433, 1.3262]	[0.1392, 1.3432]	[0.0923, 1.1128]	[0.0941, 1.0899]	[0.1356, 1.3470]	[0.1212, 1.2405]
O3	[0.0974, 1.1146]	[0.1158, 1.2307]	[0.0550, 1.1332]	[0.0784, 1.0973]	[0.0943, 1.1832]	[0.1574, 1.2922]	[0.1110, 1.2932]	[0.0659, 1.0587]	[0.0687, 1.0428]	[0.1240, 1.3003]	[0.1014, 1.1929]
O4	[0.0698, 0.9383]	[0.0676, 1.0195]	[0.0613, 1.0075]	[0.0248, 0.8443]	[0.0523, 0.9643]	[0.0691, 1.0684]	[0.0644, 1.0532]	[0.0411, 0.8831]	[0.0375, 0.8588]	[0.0587, 1.0683]	[0.0536, 0.9773]
F1	[0.0705, 1.0870]	[0.0874, 1.2084]	[0.0827, 1.2011]	[0.0677, 1.0853]	[0.0391, 1.0724]	[0.1150, 1.2718]	[0.1042, 1.2777]	[0.0697, 1.0630]	[0.0657, 1.0435]	[0.0925, 1.2691]	[0.0856, 1.1684]
F2	[0.0759, 1.0940]	[0.0977, 1.2175]	[0.1051, 1.2175]	[0.0809, 1.0946]	[0.0940, 1.1747]	[0.0573, 1.1826]	[0.1045, 1.2827]	[0.0705, 1.0626]	[0.0749, 1.0450]	[0.1111, 1.2889]	[0.0899, 1.1786]
F3	[0.0757, 1.1092]	[0.1103, 1.2376]	[0.1135, 1.2340]	[0.0777, 1.1043]	[0.1013, 1.1815]	[0.1255, 1.3024]	[0.0523, 1.1952]	[0.0744, 1.0700]	[0.0720, 1.0480]	[0.1049, 1.2986]	[0.0910, 1.1786]
T1	[0.0716, 1.0452]	[0.0829, 1.1668]	[0.0862, 1.1619]	[0.0605, 1.0441]	[0.0696, 1.1149]	[0.0917, 1.2275]	[0.0859, 1.2265]	[0.0326, 0.9466]	[0.0910, 1.0217]	[0.0956, 1.2406]	[0.0813, 1.1918]
T2	[0.0537, 0.9892]	[0.0882, 1.0893]	[0.0765, 0.9885]	[0.0610, 0.9885]	[0.0667, 1.0542]	[0.0921, 1.1715]	[0.0823, 1.1597]	[0.0872, 0.9878]	[0.0313, 0.8813]	[0.1013, 1.1942]	[0.0814, 0.0669]
E1	[0.1019, 1.762]	[0.1115, 1.2079]	[0.1108, 1.0772]	[0.0854, 1.0772]	[0.0862, 1.1473]	[0.1166, 1.2520]	[0.1029, 1.2458]	[0.0807, 1.0519]	[0.0760, 1.0319]	[0.0571, 1.1766]	[0.1153, 1.1771]
E2	[0.0802, 1.0400]	[0.0979, 1.1402]	[0.0931, 1.1345]	[0.0703, 1.0233]	[0.0846, 1.0893]	[0.1103, 1.1750]	[0.0976, 1.1918]	[0.0705, 0.9938]	[0.0696, 0.9741]	[0.1108, 1.2073]	[0.0451, 1.226]

Similarly, the approximate numerical forms for the remaining judgements in the group direct-relation matrix were determined. Formula (4-21), and

Table 4-5 illustrates the rough group's direct-relation matrix, which quantifies the direct influence of one criterion on another within the group. This matrix was subsequently normalized to ensure consistency and comparability across criteria, enabling a balanced evaluation of their relationships. The normalization process refines the data, allowing for a more accurate analysis of the interactions and dependencies among the elements in the decision-making framework.

Table 4-6 presents the normalized rough group direct-relation matrix, where the values are scaled to ensure that the total influence of any barrier (the sum of a row or column) does not exceed a value of 1. This normalization is achieved by dividing each value by the largest row sum in the initial unnormalized matrix, ensuring consistency in scale and facilitating comparability across barriers.

Table 4-7. The rough total-relation matrix

	O1	O2	O3	O4	F1	F2	F3	T1	T2	E1	E2
O1	[0.0452, 1.0660]	[0.1072, 1.2745]	[0.1102,1.2660]	[0.1049,1.1544]	[0.0955, 1.2182]	[0.1238,1.3271]	[0.1088, 1.3342]	[0.0861,1.1105]	[0.0792,1.0911]	[0.1146, 1.3527]	[0.1113, 1.2441]
O2	[0.1016, 1.1552]	[0.0626, 1.1846]	[0.1281,1.2771]	[0.1061,1.1521]	[0.1101, 1.2238]	[0.1433,1.3262]	[0.1392, 1.3432]	[0.0923,1.1128]	[0.0941,1.0899]	[0.1356, 1.3470]	[0.1212, 1.2405]
O3	[0.0974, 1.1146]	[0.1158, 1.2307]	[0.0550,1.1332]	[0.0784,1.0973]	[0.0943, 1.1832]	[0.1574,1.2922]	[0.1110, 1.2932]	[0.0659,1.0587]	[0.0687,1.0428]	[0.1240, 1.3003]	[0.1014,1.1929]
O4	[0.0698, 0.9383]	[0.0676, 1.0195]	[0.0613,1.0075]	[0.0248,0.8443]	[0.0523,0.9643]	[0.0691,1.0684]	[0.0644, 1.0532]	[0.0411,0.8831]	[0.0375,0.8588]	[0.0587, 1.0683]	[0.0536, 0.9773]
F1	[0.0705, 1.0870]	[0.0874, 1.2084]	[0.0827,1.2011]	[0.0677,1.0853]	[0.0391,1.0724]	[0.1150,1.2718]	[0.1042, 1.2777]	[0.0697,1.0630]	[0.0657,1.0435]	[0.0925, 1.2691]	[0.0856, 1.1684]
F2	[0.0759, 1.0940]	[0.0977,1.2175]	[0.1051,1.2175]	[0.0809,1.0946]	[0.0940, 1.1747]	[0.0573,1.1826]	[0.1045, 1.2827]	[0.0705, 1.0626]	[0.0749,1.0450]	[0.1111, 1.2889]	[0.0899, 1.1786]
F3	[0.0757, 1.1092]	[0.1103,1.2376]	[0.1135,1.2340]	[0.0777,1.1043]	[0.1013, 1.1815]	[0.1255,1.3024]	[0.0523, 1.1952]	[0.0744, 1.0700]	[0.0720,1.0480]	[0.1049,1.2986]	[0.0910, 1.1786]
T1	[0.0716,1.0452]	[0.0829,1.1668]	[0.0862,1.1619]	[0.0605,1.0441]	[0.0696, 1.1149]	[0.0917,1.2275]	[0.0859, 1.2265]	[0.0326, 0.9466]	[0.0910,1.0217]	[0.0956, 1.2406]	[0.0813, 1.1918]
T2	[0.0537,0.9892]	[0.0882, 1.0893]	[0.0765,0.9885]	[0.0610,0.9885]	[0.0667,1.0542]	[0.0921,1.1715]	[0.0823, 1.1597]	[0.0872, 0.9878]	[0.0313,0.8813]	[0.1013, 1.1942]	[0.0814,0.0669]
E1	[0.1019,1.762]	[0.1115, 1.2079]	[0.1108,1.077]2	[0.0854,1.0772]	[0.0862, 1.1473]	[0.1166,1.2520]	[0.1029, 1.2458]	[0.0807, 1.0519]	[0.0760,1.0319]	[0.0571, 1.1766]	[0.1153,1.1771]
E2	[0.0802, 1.0400]	[0.0979, 1.1402]	[0.0931,1.1345]	[0.0703,1.0233]	[0.0846, 1.0893]	[0.1103, 1.1750]	[0.0976, 1.1918]	[0.0705, 0.9938]	[0.0696,0.9741]	[0.1108, 1.2073]	[0.0451,1.226]

Table 4-7 presents the rough total-relation matrix, showcasing both the upper and lower normalization values calculated using the MMULT matrix approach. This matrix effectively captures the interrelationships among criteria, providing a comprehensive view of their influence on each other. The upper and lower normalization helps to standardize the data, ensuring consistency and comparability while highlighting the range of potential values for each criterion within the rough set framework. It can be acquired by using the formula (4-34)–(4-36).

Table 4-8. Row and column sums of the rough total-relation matrix

	x_i		y_j	
	Lower	Upper	Lower	Upper
O1	0,8435	11,7149	1,0869	13,4388
O2	1,02909	13,0059	1,2340	13,4523
O3	1,0225	12,9261	1,0693	12,9391
O4	0,8176	11,6654	0,6003	10,6828
F1	0,8936	12,4238	0,8801	12,7477
F2	1,2021	13,5967	0,9617	12,8456
F3	1,0531	13,6031	0,9985	12,9725
T1	0,771	11,3407	0,8487	12,3279
T2	0,7599	11,128	0,8217	11,6919
E1	1,1061	13,7436	1,0443	12,648
E2	0,9769	12,5903	0,9299	11,9918

After constructing the approximate total-relation matrix T , the sums of the columns y_j and rows x_i were calculated and are presented in Table 4-8. These sums provide valuable insights into the overall influence dynamics among the criteria. Specifically, the row sums represent the degree to which each criterion influences others, while the column sums indicate the extent to which each criterion is influenced by others. By identifying the most influential and dependent criteria, this analysis enhances our understanding of their roles and interconnections in the decision-making process.

Table 4-9. The Prominence and Relation values

Final Crisp Value				
Barriers	X	Y	Prominence (m_i)	Relation (n_i)
O1	20,9576	26,2454	47,2030	-5,2877
O2	24,5505	26,2731	50,8236	-1,7225
O3	24,3210	24,7681	49,0890	-0,4471
O4	20,8251	18,5926	39,4177	2,2325
F1	22,9007	24,2230	47,1237	-1,3224
F2	26,2732	24,5027	50,7759	1,7705
F3	26,3007	24,8705	51,1712	1,4302
T1	19,9633	23,0247	42,9880	-3,0614
T2	19,4074	21,2604	40,6678	-1,8530
E1	26,7181	23,9264	50,6445	2,7917
E2	23,3662	22,0803	45,4465	1,2859

The "Prominence" m_i and "Relation" n_i are basically determined by taking the total of the columns Y_j are converted into crisp values ($X_i Y_j$). After obtaining the rough total-relation matrix T, the sum of rows X_i and the sum of columns Y_j (See Table 4-8) are calculate with the formula (37), (38).

Table 4-9 highlights the analysis results of the barriers reveals their varying roles in the framework based on their prominence and relation values. (O1) has moderate prominence and slightly negative relation, indicating it is more of an effect that depends on other barriers. (O2) exhibits high prominence and slightly negative relation, suggesting it is an effect but with greater overall importance in the system. (O3) stands out with high prominence and a nearly neutral relation, showing that it is both influenced by and influential toward other barriers, highlighting its balanced role in the system. In contrast, (O4) has low prominence but a positive relation, making it a cause despite its limited overall significance, indicating its active role in influencing other barriers.

(F1) has moderate prominence and a slightly negative relation, identifying it as an effect with a moderate level of importance. (F2) and (F3) both show high prominence and positive relation values, making them causes, with (F3) being the most prominent and influential among all barriers. Transitioning to technical barriers, (T1) and (T2) exhibit low prominence and negative relation values, categorizing them as effects that are relatively dependent on other barriers. Finally, (E1) has high prominence and a strongly positive relation to environmental barriers. In contrast, (E2) has moderate prominence and a positive relation, indicating it also

serves as a cause, though with slightly less influence than (E1). This distribution underscores the interconnectedness of barriers and the need to prioritize causes like (F3) and (E1) to address framework challenges effectively.

Table 4-10. The importance and the normalised weights of the barriers considered.

Barriers	w_i	W_i	Ranking
O1	47,49828288	0,092040931	6
O2	50,85276852	0,098541166	2
O3	49,09107566	0,095127403	5
O4	39,48085866	0,076504976	11
F1	47,14226909	0,091351057	7
F2	50,8067384	0,09845197	3
F3	51,19115725	0,099196886	1
T1	43,09683685	0,083511924.	9
T2	40,71002905	0,07888683	10
E1	50,72134868	0,098286504	4
E2	45,4647238	0,088100353	8

Table 4-10 identifies the importance ranking and normalized weights of the barriers. This showed the following top five ranked by order of importance (F3) Cost of bespoke design and customisation of BCT systems, (O2) Lack of tools and standards for BCT implementation and data analysis, (F2) Cost of BCT implementation and maintenance, (E1) Lack of collaboration, communication, and coordination in FSCs and (O3) Lack of knowledge and expertise. The factors cited of least importance were (O4) Lack of access to legal permissions for the use of cryptocurrencies and (T2) Lack of internal connectivity and coverage within the organisation and its websites.

Figure 4-2. Weights diagram

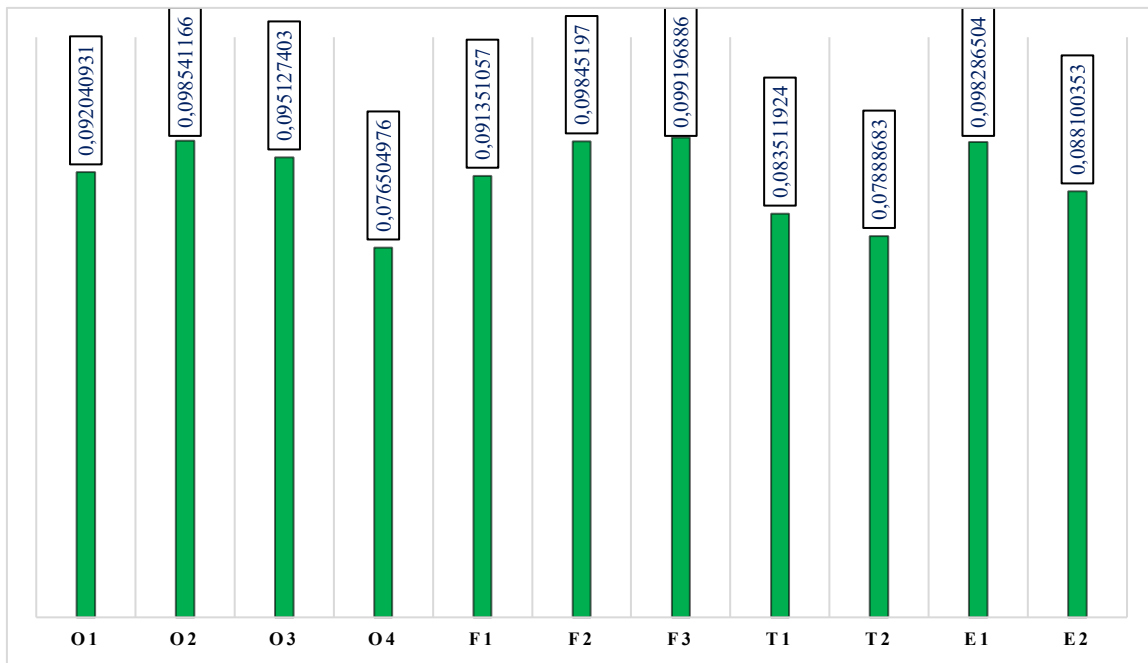
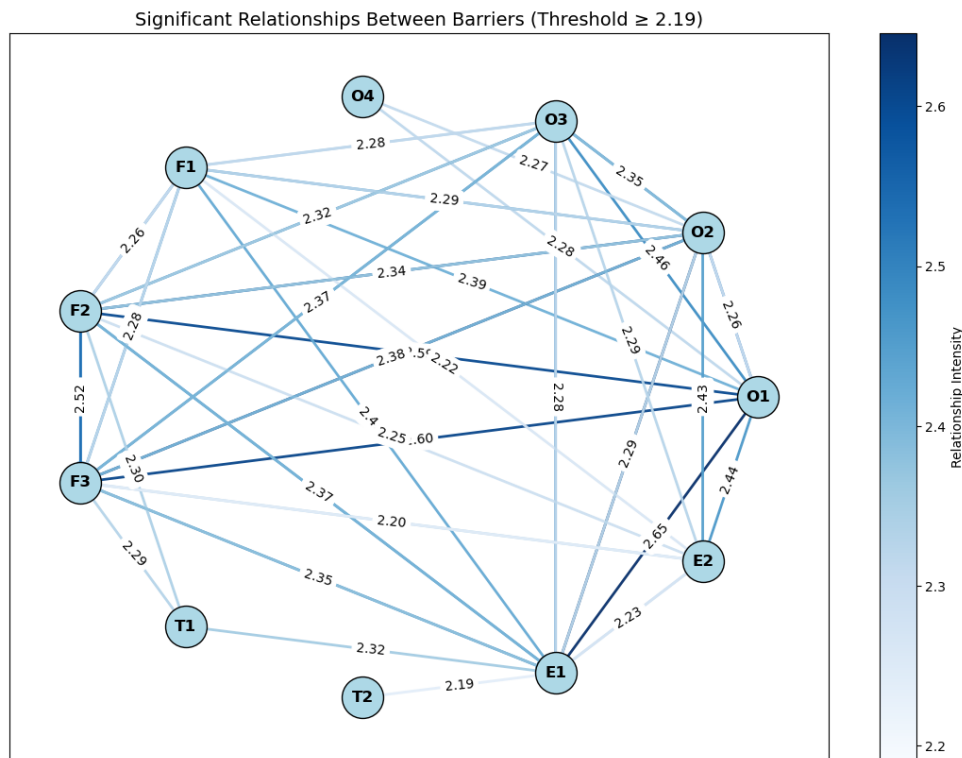


Figure 4-2. visualizes the normalized weights of barriers (O1, O2, O3, O4, F1, F2, F3, T1, T2, E1, and E2), with the height of each green bar reflecting its relative importance. The exact weights, displayed above each bar, provide a quantitative measure of each barrier's significance within this study, enhancing clarity and interpretation. Notably, barriers F3, O2, E1, and F2 emerge as the most critical, indicating their dominant influence and priority in addressing the challenges highlighted in this study. In contrast, barriers such as O4 (0.0765) and T2 (0.0789) demonstrate lower normalized weights, suggesting a reduced impact on the overall system. This visualization effectively identifies barriers requiring immediate focus (F3, O2, E1, F2) and those with a less critical role. See Equation (46)-(47).

Figure 4-3. Significant relationships after the threshold analysis

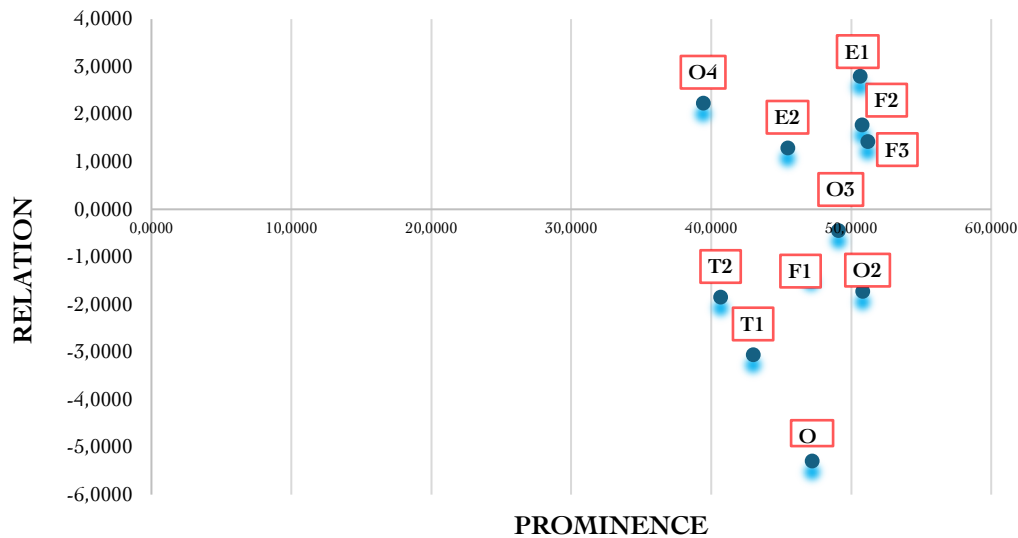


Following Mao et al. (2020), a threshold q was determined in order to identify the significant relationships between the barriers in (T^*). The values 2.1475 and 0.2566 represent the mean and standard deviation, respectively, of all components in T^* . Furthermore, Threshold T^* is used to simplify the direct influence matrix by eliminating less significant or weaker influences, keeping only the stronger relationships. After calculating the average influence matrix (based on multiple expert inputs), a threshold is set to retain only influences that are greater than or equal to this threshold. T^* serves as a filter to eliminate weaker connections in the direct influence matrix, focusing the analysis on the more significant relationships. The choice of T^* is critical, as it directly affects the complexity and clarity of the resulting model (Tzeng & Huang 2011).

Figure 4-3 the nodes represent the barriers, and the edges indicate significant connections, with their intensity reflected in the thickness and color gradient of the lines. This visualization highlights more interactions and provides a broader view of the relationships between barriers. It clarifies the most critical interactions, providing a clear and comprehensive understanding of the relationships between the barriers. The connections involving barriers (O1), (F2), (F3), and (E1) stand out with significant intensity, indicating their strong influence within the food supply

chain. In contrast, the barrier (T2) shows no interaction, reflecting its relatively weak connection with other barriers.

Figure 4-4. The Causal Diagram (Relation-Prominence)



The Causal diagram provides a strategic roadmap for prioritizing actions. It helps decision-makers understand the underlying dynamics of the system and focus their efforts on high-impact barriers, ensuring a more efficient allocation of resources and a greater likelihood of success in overcoming the challenges to blockchain implementation. The Causal Diagram (Figure 4-4) depicts the interrelationships between barriers to blockchain adoption throughout the food supply chain. It identifies the most significant impediments and their impact on the system. "The level of collaboration, communication, and coordination in the food supply chain" (E1) is identified as the most significant barrier. This research emphasizes the importance of stakeholder contact and effective communication in facilitating blockchain technology adoption. Without sufficient coordination, even the best technical solutions may fail to accomplish their intended impact, making this obstacle a primary target for overcoming adoption barriers. Following E1, the hurdles "Lack of access to legal permissions for the use of cryptocurrencies" (O4) and "High cost of blockchain technology implementation and maintenance" (F2) are similarly high, indicating severe regulatory and financial restrictions. These hurdles highlight the need for clearer legal frameworks and more cost-effective blockchain technologies to enable wider use.

In contrast, the analysis shows that some barriers have a lower impact on the whole system. The least significant barriers are "lack of status of legislation for data sharing and data storage"

(O1), "lack of external and internal connectivity, coverage, and access to external technology" (T1), and "lack of internal connectivity and coverage within organizations and websites" (T2). Their limited impact suggests that, while these issues may provide hurdles, they are not imminent impediments to blockchain adoption. These findings suggest that resources should be directed toward eliminating the most significant hurdles, such as E1, O4, and F2, in order to achieve real progress. By focusing on high-priority issues, stakeholders can lay the groundwork for addressing secondary challenges.

4.5. Discussion

This study investigates and evaluates the crucial barriers to adopting blockchain technology (BCT) in the food supply chain (FSC), offering valuable insights into their impact relationship. Our study integrates rough theory with the DEMATEL approach, presenting a robust framework for decision-making. Rough theory, a statistical methodology adept at managing data variability, has gained prominence for its ability to refine group-based analyses. Its integration with decision-making processes has become increasingly significant, especially for tackling subjectivity, ambiguity, and imprecise judgments often encountered in expert opinions during group evaluations. As noted, prior in the rough DEMATEL phases, the relation value separated the barriers into cause and effect groups. When the relation value was positive, the barrier in issue fell into the cause group. If the relation value was negative, the barrier was assigned to the effect group. As a result, the barrier was dependent on how the other barriers operated. The research findings and results indicated that (E1) "The level of collaboration, communication, and coordination in the food supply chain," (O4) "Lack of access to legal permissions for the use of cryptocurrencies," (F2) "Lack of the Cost of BCT implementation and maintenance", (E2) "The level of risk in the supply chain", (F3) "The Cost of bespoke design and customisation of BCT systems," caused the other barriers because they showed a positive relation value (r_{ij}). These barriers are deeply interconnected, highlighting the need for a comprehensive approach to address them. These barriers exhibit high prominence, indicating their significant influence on the adoption process. Moreover, fostering stakeholder collaboration and addressing financial constraints have emerged as critical areas for targeted intervention. Effective stakeholder collaboration is crucial, as poor communication can undermine even the most robust technical solutions. Prioritizing these aspects ensures a cohesive approach to overcoming barriers and enhancing the adoption of blockchain. On the

other hand, the effect barriers were (O2) "lack of availability of tools and standard for blockchain technology implementation and data analysis," (F1) "lack of weak financial support through grants/ incentives for blockchain technology adoption," (T1) "lack of external internet connectivity, coverage, and ability to access to external technology" (T2) "lack of external internet connectivity, coverage within the organization and with its websites" and (O1) "the lack of statues of legislation for data sharing and data storages" showed the negative relation value (mi). (T1) and (T2) have lower prominence and function as effects, reflecting their dependence on more influential factors.

The normalized weights of the barriers provide a quantitative ranking, reinforcing the need to focus on the top-ranking challenges. Barriers like (F3), (F2), (O2), and (E1) consistently rank high, confirming their importance. These findings align with the broader literature, which often identifies cost, lack of standards, and poor communication as primary obstacles to blockchain adoption. In contrast, while not insignificant, barriers like (O4) and (T2) have relatively lower weights, suggesting they pose more localized challenges that do not significantly affect the overall system dynamics. The interdependencies between barriers underscore the complexity of the blockchain adoption process in FSCs. The rough total-relation matrix reveals how certain barriers influence others, either amplifying or mitigating their effects. For example, improving E1 (Lack of collaboration, communication, and coordination) can significantly enhance the system's capacity to tackle other challenges, such as cost-related barriers (F2 and F3) and technical hurdles (T1 and T2). This interconnectedness highlights the importance of adopting a systemic approach that prioritizes high-impact barriers while simultaneously addressing their interrelated effects.

4.5.1. Managerial implications

The study offers useful insights for managers and decision-makers looking to overcome barriers to BCT implementation in FSCs. The novelty of BCT, a common technological barrier, can hinder organizational readiness and management commitment. If BCT is perceived as too complex or underdeveloped, managers may hesitate to invest resources, slowing down the adoption process. Managers must align their strategic goals with adoption, ensuring that any technical investments are consistent with long-term corporate goals (Tian, 2017). To address the absence of standardized tools and frameworks for blockchain deployment (O2), industry-wide collaboration is required. Managers should collaborate with technology vendors, industry

consortiums, and research institutes to create uniform rules and compatible solutions. Clear procedures for blockchain deployment and data analysis can help accelerate acceptance. Furthermore, improving communication and collaboration among supply chain stakeholders (E1) can help to develop trust and coordination, overcoming resistance and ensuring the smooth incorporation of blockchain technologies. To address regulatory hurdles, such as a lack of legal approvals for cryptocurrencies (O4), managers should actively engage with lawmakers to create a favorable framework for blockchain adoption. Advocating for clear policies that protect data security and compliance while encouraging innovation is critical. Improved internal and external connectivity within companies. Prioritizing financial challenges, such as high implementation and maintenance costs, is crucial. Policymakers can support blockchain adoption by offering subsidies, tax incentives, or funding programs to ease initial setup costs and encourage wider adoption.

To perform BCT in FSC, managers must connect strongly with stakeholders and reach clear data governance and information-sharing protocol agreements. This will make blockchain implementation more successful throughout the supply chain (Queiroz & Wamba, 2019). Organizational resistance to change, such as limited managerial support or a workplace culture resistant to adopting new technologies, can significantly hinder the successful implementation of BCT in SCs. Addressing these barriers requires a concerted focus on securing leadership commitment, offering comprehensive training, and fostering a culture of innovation. These efforts help organizations embrace change and enhance collaboration with supply chain partners, a critical aspect of BCT systems' transparent and decentralized nature (Queiroz & Wamba, 2019; Kshetri, 2018). The managerial implications of this study offer practical guidance for overcoming barriers to blockchain technology (BCT) adoption in food supply chains (FSCs). First and foremost, managers should prioritize fostering effective collaboration and communication among stakeholders, including farmers, distributors, manufacturers, and retailers. The study highlights that poor coordination can undermine even the most robust technical solutions, making it essential to establish shared blockchain standards and protocols. Developing a common understanding and agreement on BCT can facilitate seamless data exchange and improve overall supply chain transparency. By focusing on these critical areas, managers can significantly enhance the likelihood of successful BCT implementation in the food supply chain.

4.5.2. Practical implications

The implications for practice are that organizations need to first focus on upskilling their workforce and establishing a clear understanding of BCT's capabilities before attempting widespread adoption (Saber et al., 2019). Practical implications include fostering industry-wide partnerships among stakeholders, such as farmers, distributors, manufacturers, and retailers, to develop shared blockchain standards and protocols. Such collaboration enables seamless data exchange across platforms, ensuring efficient and effective blockchain adoption. Moreover, by prioritizing cybersecurity and data protection, the industry can establish best practices that build trust in blockchain solutions, promoting widespread adoption while mitigating fraud and data breach risks. This study emphasizes the need for targeted strategies to overcome blockchain adoption barriers in FSCs. Policymakers and industry stakeholders should prioritize reducing the cost of blockchain systems (F3) and establishing clear implementation tools and standards (O2). Concurrently, fostering collaboration among stakeholders (E1) is critical for ensuring alignment and mitigating resistance to adoption. Additionally, addressing regulatory challenges (O4) and improving infrastructure connectivity (T2) will support long-term scalability and sustainability. By focusing on these high-impact barriers and leveraging the insights from the causal relationships, stakeholders can create a conducive environment for blockchain technology to transform the food supply chain. By addressing these high-impact barriers and utilizing insights from their causal relationships, stakeholders can foster an environment that enables blockchain technology to revolutionize the food supply chain.

4.6. Conclusions and future research agenda

Blockchain technology can dramatically improve transparency in the food supply chain by ensuring that everybody involved has access to identical, unedited data. This study provides a comprehensive analysis of the barriers to adopting blockchain technology in food supply chains and By integrating rough theory with DEMATEL, it provides a nuanced understanding of how barriers interact, distinguishing between causes and effects highlighting critical obstacles such as high costs for implementing blockchain technology, lack of standardized tools, and insufficient collaboration among stakeholders. By addressing these high-impact barriers, stakeholders can unlock significant opportunities for blockchain integration, enhancing

transparency, efficiency, and trust in food supply chains. By identifying and ranking barriers such as poor collaboration, communication, and coordination (E1), financial constraints (F2), and lack of legal permissions for cryptocurrencies (O4), the findings emphasize the need for a collaborative and systemic approach. Stakeholders, including farmers, manufacturers, and retailers, are encouraged to establish shared blockchain standards and protocols, fostering seamless data exchange and operational efficiency. Furthermore, its findings could help stakeholders in designing targeted strategies to overcome the identified barriers and facilitate blockchain adoption in the food supply chain. By understanding the relationships between these barriers, stakeholders such as policymakers, technology providers, and supply chain participants can focus on collaborative efforts to enhance communication, address financial constraints, and develop standardized tools and legal frameworks. This approach not only accelerates the adoption process but also ensures a robust implementation, ultimately leading to greater transparency, efficiency, and trust across the food supply chain.

Blockchain technology adoption in food supply chains necessitates a strategic approach that goes beyond technical considerations. For future research, we recommend that scholars explore the effects of implementing BCT decision models in this process because they assist in matching various needs with appropriate design features. Moreover, Future research could examine the evolution of hurdles to blockchain adoption in food supply chains over time, especially as the technology matures and adoption increases. Longitudinal studies could also measure the long-term impact of removing these obstacles on supply chain performance parameters like traceability, efficiency, and sustainability. Comparative investigations across industries could reveal contextual factors impacting blockchain adoption. Furthermore, incorporating modern methodologies, such as hybrid multi-criteria decision-making approaches or machine learning techniques, may improve the accuracy of barrier analysis. Finally, investigating the role of new technologies, such as IoT and AI, in supplementing blockchain may provide a more comprehensive view of technological integration in food supply chains.

Chapter 5. Conclusion

our studies highlight the transformative potential of digitization in advancing the social economy. By incorporating digital tools such as artificial intelligence, blockchain, and cloud computing, social economy organizations can enhance operational efficiency, increase transparency, and strengthen stakeholder engagement. These technological advancements empower organizations to adapt to dynamic environments, fostering innovation, inclusive growth, and social cohesion. Moreover, the integration of digital solutions supports sustainability goals, making their adoption essential for achieving long-term success and effectively addressing societal challenges.

However, the digitalization of the social economy is not without its challenges. The rapid evolution of digital technologies necessitates continuous updates to existing research and practices. Addressing these limitations is critical for maximizing the potential benefits of digitalization in the social economy.

Our study highlights the complexities blockchain adoption within the food bank supply chain (FBSC), which operates within the framework of the social economy. We identify and analyze the intricate interrelationships between adoption barriers in the FBSC, with a particular focus on Blockchain Technology (BCT). By categorizing these barriers into internal and external groups and applying the Rough DEMATEL technique, we uncover critical insights into how these challenges interact. Our findings emphasize the need for strong organizational policies to foster a supportive environment for BCT integration, which can enhance supply chain innovation and resilience. Furthermore, investigating the role of BCT in improving transparency and trust in FBSC operations such as donation tracking, food safety, and waste reduction will be essential.

In this study, I identified key barriers to adopting blockchain technology (BCT) in food bank supply chains (FBSC) through a structured literature review. This process resulted in the identification of two main categories and seven sub-barriers. Based on these findings, I developed a survey targeting a selected group of experts from both academia and industry in Italy to explore the cause-and-effect relationships among the identified barriers. A convenience sample of experts was selected, comprising 13 academics and seven practitioners.

For future research, longitudinal studies are also necessary to assess the long-term impact of BCT on supply chain efficiency and food security. While the study's limitations, such as regional and organizational differences, may influence the findings, it provides a solid foundation for future research and encourages further advancements in BCT adoption within FBSCs.

My third study highlights the significant potential of Blockchain Technology (BCT) to enhance traceability and transparency within food supply chains (FSCs). Encouraging stakeholders including farmers, manufacturers, and retailers to establish shared and trusted BCT standards and protocols can facilitate seamless data exchange and improve operational efficiency. By understanding and addressing the interconnections among adoption barriers, stakeholders can focus on collaborative efforts to enhance communication, overcome financial constraints, and develop standardized tools and legal frameworks. This approach not only accelerates BCT adoption but also ensures robust and effective implementation, fostering greater transparency, efficiency, and trust across the supply chain.

In terms of geographical context, this research was conducted under the ethical approval granted by the Research Ethics Committee of the University of Lincoln in the UK. Compliance with ethical standards was ensured throughout the study, from design to data collection, reinforcing the integrity and reliability of the research findings. Also, I selected a convenience sample of experts with expertise in BCT and food supply chains (FSCs), consisting of 13 academics and 7 practitioners. This study expanded the scope, identifying four main categories and eleven sub-barriers. Moreover, the percentage of respondents between academics and practitioners was evenly balanced in both the Italy and UK studies.

In my view, future research can delve into the development of BCT decision models tailored to meet the diverse needs of different sectors within FSCs, focusing on specific design features. Longitudinal studies are essential to evaluate the long-term impact of overcoming adoption barriers on supply chain performance metrics such as traceability, efficiency, and sustainability. Additionally, incorporating advanced methodologies such as hybrid multi-criteria decision-making techniques and machine learning could refine the analysis of barriers, offering more accurate and actionable insights. These advancements will contribute to building a resilient and innovative food supply chain capable of adapting to the evolving demands of global markets.

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Supplementary file

Appendix 1. Title of the Appendix to the Chapter 3

Step 1. Establishing matrix Z, the average initial direct-relation matrix

Consider the system requirements are: $B = \{B_1, B_2, B_3, \dots, B_n\}$. all characteristics are rated on a five-point scale: No Influence (0), Very Low Influence (1), Low Influence (2), High Influence (3), and "Very High Influence" (4). Due to the DEMATEL method's properties, the diagonal members of the matrix have a value of 0. The components of matrix Z is computed outlined below:

$$z_{ij} = (1/H) \sum_{k=1}^H x_{ij}^k \quad (3.1)$$

Where x_{ij} is the non-negative valued matrix for the k -th answer, x_{ij}^k is the degree of influence of criterion i on criterion j with regard to the k -th answer, H is the total amount of

experts, n is the number of criteria, and x_{ij}^k is the degree of influence supplied by criterion i to criterion j .

where x_{ij}^k is the degree to which the criterion i influences the criterion j with regard to the k -th response, H is the number of experts, n is the number of criteria, X_k is the not negative matrix for the k -th response, and x_{ij} is the degree to which the criterion i influences the criterion j . The first direct relation matrix ($Z_{n \times n}$) is then built in the manner described below:

$$Z = \begin{bmatrix} z_{11} & z_{12} & \cdots & z_{1n} \\ z_{21} & z_{22} & \cdots & z_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ z_{n1} & z_{n2} & \cdots & z_{nn} \end{bmatrix} \quad (3.2)$$

Where z_{ij} denotes the strength of indicator i 's effect over a measure j .

Step 2. Making the normalized original direct-relation matrix (Matrix D). The equation that follows is used to calculate a normalized initial direct-relation matrix, or Matrix- D :

$$S = 1 / (\max_{1 \leq i \leq n} \sum_{j=1}^n z_{ij}) \quad (3.3)$$

$$D = Z'S \quad (3.4)$$

Step 3. Making a factor's total-influence matrix (Matrix T)

The following formula is utilized to calculate a factor's total-influence matrix, or matrix T :

$$T = D(I - D)^{-1} \quad (3.5)$$

Whereby, (I) refer to an identity matrix.

Step 4. Computing the values of D , R , $R+D$, and $R-D$

Below describes how the numbers are computed: D is the sum of the matrix T 's columns, D_j indicates the other criteria's both direct and indirect effect on criterion j , R is the sum of the

matrix T 's rows, and R_i indicates the both the direct and indirect impact of criterion (i) on the other criteria. subsequently, $R_i - D_j$ illustrates the net impact of criterion I, while $R_i + D_j$ shows the significance of criterion (i).

Proposition 1. If A represent a set of n classes $\{A_1, A_2, \dots, A_n\}$ that cover each object in U , P be a random object from U , and U be the entire universe including all objects. The classes to that the item belongs are represented with $\forall P \in U, A_k \in R$, and $1 \leq k \leq n$ if the categories are classified as $\{A_1 < A_2 < \dots < A_n\}$. The category A_k 's lower and upper approximations, in addition to its boundary region, are defined as:

$$\underline{Apr}(A_k) = \{P \in U | R(P) \leq A_k\} \quad (3.6)$$

$$\overline{Apr}(A_k) = \{P \in U | R(P) \geq A_k\} \quad (3.7)$$

$$(A_k) = \{P \in U | R(P) \neq A_k\} = \{P \in U | R(P) > A_k\} \cup \{P \in U | R(P) < A_k\} \quad (3.8)$$

Proposition 2. Given the corresponding upper and lower the boundaries, A_k might be defined as an approximate value $RN(A_k)$:

$$\underline{Lim}(A_k) = \frac{1}{M_L} \sum \{P \in \underline{Apr}(A_k)\} \quad (3.9)$$

$$\overline{Lim}(A_k) = \frac{1}{M_U} \sum \{P \in \overline{Apr}(A_k)\} \quad (3.10)$$

$$RN(A_k) = [\underline{Lim}(A_k), \overline{Lim}(A_k)] \quad (3.11)$$

Here, M_L and M_U have been the total number of objects in Apr , correspondingly.

Proposition 3. The difference across both the lower and upper limits is expressed through the rough border intervals. $\overline{Lim}(A_k) - \underline{Lim}(A_k) = RN(A_k)$

Proposition 4. The following mathematical operations are carried out for the two rough numbers, $RN(\alpha) = [\underline{Lim}(\alpha), \overline{Lim}(\alpha)]$ and $RN(\beta) = [\underline{Lim}(\beta), \overline{Lim}(\beta)]$

$$RN(\alpha) + RN(\beta) = [\underline{Lim}(\alpha) + \underline{Lim}(\beta), \overline{Lim}(\alpha) + \overline{Lim}(\beta)] \quad (3.12)$$

$$RN(\alpha) - RN(\beta) = [\underline{Lim}(\alpha) - \underline{Lim}(\beta), \overline{Lim}(\alpha) - \overline{Lim}(\beta)] \quad (3.13)$$

$$RN(\alpha) \times RN(\beta) = [\underline{Lim}(\alpha) \times \underline{Lim}(\beta), \overline{Lim}(\alpha) \times \overline{Lim}(\beta)] \quad (3.14)$$

$$\frac{RN(\alpha)}{RN(\beta)} = \left[\frac{\underline{Lim}(\alpha)}{\underline{Lim}(\beta)}, \frac{\overline{Lim}(\alpha)}{\overline{Lim}(\beta)} \right] \quad (3.15)$$

$$\mu \times RN(\alpha) = [\mu \times \underline{Lim}(\alpha), \mu \times \overline{Lim}(\alpha)] \quad (3.16)$$

Proposition 5. Utilize one of the following equations to convert a rough number into a crisp value:

$$W_k^e = \frac{\tilde{C}_k^e}{\sum_{k=1}^n \tilde{C}_k^e} \quad (3.17)$$

$$\tilde{C}_k^e = \min_k \{w_k^{e*L}\} + \chi_k^e \times (\max_k \{w_k^{e*U}\} - \min_k \{w_k^{e*L}\}), k = 1, 2, \dots, n \quad (3.18)$$

$$\chi_k^e = \frac{w_k^{e*L} \times (1 - w_k^{e*L}) + w_k^{e*U} \times w_k^{e*U}}{1 - w_k^{e*L} + w_k^{e*U}} \quad (3.19)$$

Appendix 2: Title of the Appendix to the Chapter 4

Step 1: Formulation of direct-relation matrix for crisp group

Based on expert responses the direct-relation matrix M_1 of the first decision maker can be produced using Equation 20.

The direct-relation matrix M_k for the k -th experts is generated by: The k -th expert's direct-relation matrix is M_k produced through the following equation:

$$M_k = \begin{bmatrix} 0 & r_{12}^k & \cdots & r_{1n}^k \\ r_{21}^k & 0 & \cdots & r_{2n}^k \\ \vdots & \vdots & \ddots & \vdots \\ r_{n1}^k & r_{n2}^k & \cdots & 0 \end{bmatrix}, \quad k = 1, 2, \dots, m \quad (4-20)$$

The k -th expert's perceptive evaluation is represented by r_{ij}^k for the i th items. wherein r_{ij}^k is the k -th expert's exact assessment of the i th element's influence on the j -th element, and m , n , and n are the numbers of experts, elements, and experts, respectively. Impact regarding the j -th component, wherein m , and n indicate the number of components and experts, respectively.

To create the group's direct-relation matrix $\tilde{R}$, utilized the following:

The direct-relation matrix of the group $\tilde{R}$:

$$\tilde{R} = \begin{bmatrix} 0 & r_{12}^{\sim k} & \cdots & r_{1n}^{\sim k} \\ r_{21}^{\sim k} & 0 & \cdots & r_{2n}^{\sim k} \\ \vdots & \vdots & \ddots & \vdots \\ r_{n1}^{\sim k} & r_{n2}^{\sim k} & \cdots & 0 \end{bmatrix} \text{ where : } r_{ij} = \{r_{ij}^1, r_{ij}^2, \dots, r_{ij}^k, \dots, r_{ij}^m\} \quad (4-21)$$

$$\underline{Apr}(r_{ij}^k) = \cup \{P \in U \mid J(P) \leq r_{ij}^k\} \quad (4-22)$$

$$\overline{Apr}(r_{ij}^k) = \cup \{P \in U \mid J(P) \geq r_{ij}^k\} \quad (4-23)$$

Step 2: Establishment of the rough group's direct relationship matrix

Assume that there are m types of opinions from experts for every component relation.

$J = \{r_{ij}^1, r_{ij}^2, \dots, r_{ij}^k, \dots, r_{ij}^m\}$ has been arranged in the subsequent order: $r_{ij}^1 < r_{ij}^2 < \dots < r_{ij}^k < \dots < r_{ij}^m$. P is a randomised element of U . The following describes the lower and upper approximations of r_{ij}^k : the lower approximation illustrates Equation (22) and the upper approximation depicts Equation (23).

The judgement r_{ij}^k may be expressed as a rough number with lower limit $\underline{Lim}(r_{ij}^k)$ and upper limit $\overline{Lim}(r_{ij}^k)$ outlined below:

$$\underline{Lim}(r_{ij}^k) = \frac{\sum_{m=1}^{N_{ijL}} x_{ij}}{N_{ijL}} \quad (4-24)$$

$$\overline{Lim}(r_{ij}^k) = \frac{\sum_{m=1}^{N_{ijU}} y_{ij}}{N_{ijU}} \quad (4-25)$$

x_{ij} and y_{ij} indicates both lower and upper approximation for r_{ij}^k . The numerical values of objects that are contained in the lower and higher approximations of r_{ij}^k , Correspondingly, are denoted by the words N_{ijL} and N_{ijU} . In the direct relation matrix M_k , all of the crisp judgements r_{ij}^k are converted to rough values (Zhai et al., 2009). $RN(r_{ij}^k)$ is then given can be obtained using Equations. (4-2) -(4-5),

$$RN(r_{ij}^k) = [\underline{Lim}(r_{ij}^k), \overline{Lim}(r_{ij}^k)] = [r_{ij}^{kL}, r_{ij}^{kU}] \quad (4-26)$$

Where the rough number $RN(r_{ij}^k)$ in the direct relation matrix of value k-th has lower and upper bounds, denoted, respectively, by r_{ij}^{kL} and r_{ij}^{kU} . The degree of ambiguity is donated by the boundary region's interval. Moreover, the rough number will be more accurate the narrower the boundary region's interval (song and Cao, 2017). Thus, it is possible to derive an approximate sequence $RN(\tilde{r}_{ij})$ as follows:

$$RN(\tilde{r}_{ij}) = \{[r_{ij}^{1L}, r_{ij}^{1U}], [r_{ij}^{2L}, r_{ij}^{2U}], \dots, [r_{ij}^{mL}, r_{ij}^{mU}]\} \quad (4-27)$$

Using rough computation methods, one may compute the average rough interval $\overline{RN(\tilde{r}_{ij})}$:

$$\overline{RN(\tilde{r}_{ij})} = [r_{ij}^L, r_{ij}^U] \quad (4-28)$$

$$r_{ij}^L = \left(\sum_{k=1}^m r_{ij}^{kL} \right) / m \quad (4-29)$$

$$r_{ij}^U = \left(\sum_{k=1}^m r_{ij}^{kU} \right) / m \quad (4-30)$$

r_{ij}^L and r_{ij}^U are lowers and upper restrictions of rough number $[r_{ij}^L, r_{ij}^U]$ represented, wherein m is the number of judgements.

The next thing represents the process of the rough group direct-relation matrix R able to be constructed as follows:

$$R = [\overline{RN(\tilde{r}_{ij}^k)}]_{n \times n} = \begin{bmatrix} [0, 0] & [r_{12}^L, r_{12}^U] & \cdots & [r_{1n}^L, r_{1n}^U] \\ [r_{21}^L, r_{21}^U] & [0, 0] & \cdots & [r_{2n}^L, r_{2n}^U] \\ \vdots & \vdots & \ddots & \vdots \\ [r_{n1}^L, r_{n1}^U] & [r_{n2}^L, r_{n2}^U] & \cdots & [0, 0] \end{bmatrix} \quad (4-31)$$

Step 3: Make a roughly total-relation matrix

To normalise the element scales into comparable scales, apply the linear scale transformation formula. The normalised rough group direct-relation matrix R' is created by following these steps:

$$R' = [\overline{RN(r_{ij})}]_{n \times n} = \begin{bmatrix} \overline{RN(\tilde{r}_{11})}' & \overline{RN(\tilde{r}_{12})}' & \cdots & \overline{RN(\tilde{r}_{1n})}' \\ \overline{RN(\tilde{r}_{21})}' & \overline{RN(\tilde{r}_{22})}' & \cdots & \overline{RN(\tilde{r}_{2n})}' \\ \vdots & \vdots & \ddots & \vdots \\ \overline{RN(\tilde{r}_{n1})}' & \overline{RN(\tilde{r}_{n2})}' & \cdots & \overline{RN(\tilde{r}_{nn})}' \end{bmatrix} \quad (4-32)$$

Moreover, the rough total-relation matrix (T) can be generated using:

$$\overline{RN(r_{ij})}' = \frac{\overline{RN(\tilde{r}_{ij})}}{\tau} = \left[\frac{r_{ij}^L}{\tau}, \frac{r_{ij}^U}{\tau} \right], \tau = \max_{1 \leq i \leq n} (\sum_{j=1}^n r_{ij}^U) \quad (4-33)$$

The approximate total-relation matrix, T , is capable of being created as follows:

$$T = [t_{ij}]_{n \times n}, \quad (4-34)$$

$$t_{ij} = [t_{ij}^L, t_{ij}^U], \quad (4-35)$$

$$T^S = [t_{ij}^S]_{n \times n} = R^S (I - R^S)^{-1}, s = L, U. \quad (4-36)$$

In the total-relation matrix T , the lower and upper boundaries of the rough range t_{ij} are denoted by t_{ij}^L and t_{ij}^U , correspondingly, whereas I is the element of the matrix.

The rough interval's lower and upper limitations, as represented by the total-relation matrix T . t_{ij} are denoted by t_{ij}^L and t_{ij}^U , respectively, with I as the value of the matrix.

Step 4: Calculation of the “prominence” and “relation” values

After getting the preliminary total-relation matrix T , we must calculate the sums of rows X_i and columns Y_j . The sums of the columns are represented by x_i and y_j in the rough total-relation matrix using the equations below. An approximate total-relation matrix is represented by the sum of rows and columns.

$$X_i = [x_i^L, x_i^U] = [\sum_{j=1}^n t_{ij}^L, \sum_{j=1}^n t_{ij}^U] \quad (4-37)$$

$$Y_j = [y_j^L, y_j^U] = [\sum_{i=1}^n t_{ij}^L, \sum_{i=1}^n t_{ij}^U] \quad (4-38)$$

x_i^L and x_i^U are the upper and lower limitations of the interval's rough x_i . Similarly. y_j^U and y_j^L are the upper and lower restrictions and of the rough interval Y_i . To effectively determine the (Prominence) and (Relation), it is necessary to convert the X_i and Y_j into crisp values. A "the roughness" of X is calculated as follows:

(1) Normalisation of data

$$\tilde{x}_i^L = (x_i^L - \min_i x_i^L) / \Delta_{min}^{max} \quad (4-39)$$

$$\tilde{x}_i^U = (x_i^U - \min_i x_i^L) / \Delta_{min}^{max} \quad (4-40)$$

$$\Delta_{min}^{max} = \max_i x_i^U - \min_i x_i^L \quad (4-41)$$

Where $\tilde{x}_i^L$ and $\tilde{x}_i^U$ are the normalised from of the x_i^L and x_i^U corresponding.

(2) Identify the overall normalized in crisp value

$$\alpha_i = \frac{\tilde{x}_i^L \times (1 - \tilde{x}_i^L) + \tilde{x}_i^U \times \tilde{x}_i^U}{1 - \tilde{x}_i^L + \tilde{x}_i^U} \quad (4-42)$$

Computing the final crisp values x_i for X_i

$$x_i = \min_i x_i^L + \alpha_i \Delta_{min}^{max} \quad (4-43)$$

Likewise, we may calculate the final crisp values y_i for Y_i . The vector m_i , termed Prominence, is created by adding x_i to y_i . Similarly, the vector n_i named Relation, is created by deducting x_i to y_i .

$$m_i = x_i + y_j, \quad i = j \quad (4-44)$$

$$n_i = x_i - y_j, \quad i = j \quad (4-45)$$

The vector m_i indicates prominence, while the vector n_i gauges the relationship. Prominence indicates the importance of the criterion. As an outcome, the higher its prominence value, the more significant the criterion is in relationship to the other criteria. Relationships separate the criteria into cause-and-effect groups. When a criterion has a positive relation value, it is assigned to the cause group. In contrast, if the relation value is negative, the criterion is classified as an effect. In such cases, the criteria would involve reliant on the activities of the additional requirements. As per Song and Sakao in 2018 mapping the data set of prominence and relation values yields the causal diagram.

Step 5: Assess the weight of adoption barriers in the FSC.

The relevance of the criteria is computed as follows:

$$\omega_i = \sqrt{m_i^2 + n_j^2} \quad (4-46)$$

Moreover, the significance of the criterion can be normalised as follows.

$$W_i = \frac{\omega_i}{\sum_{1 \leq i \leq n} \omega_i} \quad (4-47)$$

Based on Song and Cao, (2017) each criterion's weight indicates how important it is in relation to the others.