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Smart food-sharing platforms for social sustainability: a heuristic algorithm approach

Behzad Maleki Vishkaei[a] and Pietro De Giovanni[b,c,*]

[a] *Department of Management and Technology, Bocconi University, Milan, Italy*
[b] *SDA Bocconi School of Management, Milan, Italy*
[c] *DIR—Claudio Dematté Research Division, Sustainable Operations and Supply Chain Monitor, 20136, Milan, Italy*
E-mail: behzad.maleki@unibocconi.it [Maleki Vishkaei]; pietro.degiovanni@sdabocconi.it [De Giovanni]

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Abstract

This study examines how smart food-sharing platforms (SFSP) can help reduce food waste and suggests a method for using smart contracts to share extra food among different partners effectively. For smart contracts to work automatically and prevent food wastage, artificial intelligence systems can recognize how smart clauses should be executed. This will involve analyzing several factors like the selling price, expiration dates, offers from other partners, transport costs, wholesale price, shelf life, donation rates, and demand rates. The findings indicate that adopting an SFSP is an efficient solution for preemptively adopting redistribution strategies and improving social outcomes through donations as well as achieving positive environmental outcomes through reduced waste. However, we also identify cases in which reducing food waste to achieve social sustainability may negatively impact economic performance.

Keywords: artificial intelligence; blockchain; food waste; logistics; quality; smart contracts; social programs; sustainability

1. Introduction

Food waste is a major problem that happens at all stages of consumption and the food supply chain (FSC) and represents a big challenge for the industry in terms of environmental and social impacts (Sadraei et al., 2023). Apart from industrial waste, supermarkets contribute to 14% of global food waste each year, greatly affecting all sustainability aspects (EPA, 2018). According to the World Food Programme (2020) report, the annual food waste is about 1.3 billion tons with an approximated worth of one trillion US dollars. This amount is sufficient to feed more than two billion underfed people. Besides, the extra food production substantially adds carbon dioxide to the atmosphere generating unwanted emission effects. In developed countries, 40% of the food losses occur

*Corresponding author.

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at the retail and consumer stage and, as revealed in research done on a few supermarkets by Scholz et al. (2015), a high carbon footprint is associated with discarding fresh products, whereby about 1570 tons went to waste equivalent to 2500 tons CO_2 emission. The main causes of supermarket food waste are poor condition or nearing expiry planning for products as well as surplus inventory sold within its shelf life (Moser, 2020).

Conventional responses to decreased quality products involve giving discounts or selling them at salvage prices to other firms, for example, suppliers and end-users (Vishkaei et al., 2014; Farhangi et al., 2015). However, customers are more sensitive about the standards of perishable and fresh goods. Various strategies are proposed by the literature to deal with food expiration, including alternate shopping patterns, energy recovery, donations, incineration, anaerobic digestion, and composting as well as animal feeding (Eriksson and Spångberg 2017; Eriksson et al., 2015). In addition, involving outside organizations such as restaurants, charity groups, and food banks could be an effective way through which excess stock can be minimized before it becomes waste (Moser, 2020). Accordingly, food-sharing platforms are attracting increasing attention to overcome food waste, improve donations and sales management, reduce excess inventory, and enhance firms' image (Mazzucchelli et al., 2021). Food-sharing platforms relying on new digital technologies can contribute positively to the prevention of food waste and provoke social responsibility in terms of donations in the FSC (Michelini et al., 2020). Accordingly, supermarkets, as principal contributors to food spoilage, are required to invest more in sharing platforms. However, such collaboration necessitates additional activities, including accurate process development, defining relationship types and rules, and implementing new procedures (Moser, 2020).

To address the complexity of collaboration in downstream logistics and automated contracts between partners, emerging digital technologies offer promising solutions that facilitate the development of efficient food-sharing platforms with a high level of automation, trust, and accuracy for all players (De Giovanni, 2020). For example, smart contracts, executable code running on the blockchain, and efficiently enforce agreements between untrusted parties without the need for intermediaries. By automatically executing contracts based on predetermined criteria stored on the blockchain, they become trustable and readable by everyone; therefore, blockchain-based smart contracts facilitate logistics operations, including surplus inventory determination and distribution, thereby positively impacting the social and environmental aspects of the FSC (Ahmad et al., 2021). While artificial intelligence (AI) can make FSCs more adaptive and intelligent by varying the terms of the agreement according to different parameters and situations influencing the decisions of supermarket proprietors and other parties, these systems have been shown to be highly complex (De Giovanni, 2019). Therefore, this research seeks to find out how blockchain-based smart food-sharing platforms (SFSP), admitted along with AI, can decrease food waste in supermarkets by fostering collaboration between downstream partners. Specifically, it aims to explore how the adoption of an SFSP with blockchain-based smart contracts, alongside AI, can mitigate supermarket food waste by enhancing collaboration among downstream logistics partners while also being able to adjust the contractual terms according to the existing level of competition (De Giovanni, 2021). We develop a model for the SFSP accounting for different product quality levels to estimate and redistribute surplus inventory among various partners, such as other supermarkets, restaurants, online stores, and charities, at reasonable prices to minimize food loss. To achieve this, we devise a program that analyzes partners' inventory levels and other parameters, including donation

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rates, expiry dates, surplus inventory levels, market prices, and distribution prices, to execute smart contracts that allocate products from supermarkets to other parties based on agreement conditions.

The study also shows that adopting SFSP with AI-based smart contracts can help manage surplus inventory, which, in turn, leads to a reduction of waste, increased profits, and significant environmental sustainability effects. Developing an SFSP with smart contracts supports redistribution decisions concerning excessive stock levels within organizations (like retailers) dealing with large volumes of perishable commodities. Moreover, SFSPs accelerate collaboration among different partners by providing an agile and trustworthy platform capable of executing automated agreements. However, devising an efficient algorithm to consistently monitor different conditions based on various parameters is the key factor for developing an efficient SFSP. Besides, the earlier we can recognize surplus inventory, the greater our chance of decreasing food waste and revenue loss. Furthermore, implementing an SFSP improves economic, environmental, and social sustainability performance by increasing sales, reducing waste, and participating in donation programs. Supermarkets can benefit from enhancing their brand awareness by participating in donation programs via SFSPs. Nevertheless, the economic advantages of adopting an SFSP, considering social targets, are significantly lower than its economic gains in terms of environmental goals.

The remainder of this paper is structured as follows: Section 2 presents the literature review and highlights the research gap. Section 3 develops and formulates the model, incorporating various parameters and variables. Section 4 outlines a sample algorithm for the SFSP's smart contract implementation illustrated with a numerical example. In Section 5, we discuss the impact of the food waste management model and SFSP on Sustainable Development Goals (SDGs). Finally, Section 6 concludes with key findings, managerial insights, and suggestions for future research.

2. Literature review

We review the literature in two subsections: food waste management and the relationships between food waste and digital technologies. The first subsection examines the importance of food waste management, its impact on environmental, economic, and social sustainability, and strategies for reducing food waste. The second subsection focuses on the adoption of new technologies, such as sharing platforms, blockchain, smart contracts, and AI to mitigate food loss in supermarkets.

2.1. Food waste management

Food waste is a big problem that affects the whole world since it uses up resources and generates greenhouse gases when food is made but not eaten, which in turn goes to waste (Cicatiello et al., 2016). This directly connects with the concept of economic, environmental, and social aspects of sustainability. Globally, almost one-third of all food produced for human consumption is lost or wasted every year—with 40% coming from homes—so there is a need for models and scientific approaches to solve this issue (Ganguly and Robb, 2022). At every stage of the FSC—that is, wholesale, retail, food service industry, and households—food wastage consistently occurs, indicating that downstream partners like retailers and supermarkets, along with consumers, should play their part against the food waste (Özbük and Coşkun, 2020). Supermarkets act as important

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links between producers and final buyers, thus having authority over the entire distribution channel through their ordering systems up to selling points inclusive of storage facilities where different managerial decisions can lead to a loss, for example, pricing strategies may lead to overstocking products exceeding their expiration dates (Richards and Hamilton, 2022). Furthermore, demand fluctuations caused by phenomena like communication errors or seasonal changes generated by various market changes can also worsen the situation, exemplified by large quantities of food becoming uneatable if not properly managed in warehouses (Mahroof et al., 2022), especially due to the deterioration of quality over time (De Giovanni, 2024).

The current research shows that increasing store density makes grocery shopping more sustainable until a certain point beyond which it results in higher rates of food spoilage (Belavina, 2021). To control these losses, at the retailer level, good practices include but are not limited to rotating inventory, setting the correct case size according to the shelf life, as well as regularly checking if any items have exceeded their expiry dates (Akkas and Honhon, 2023). In this perspective, Yang et al. (2022) argue that prices based on both quality and information about products will boost demand while reducing wastage among stores. Furthermore, De Giovanni (2024) shows that how the adoption of high-quality standards including performance, product security, health and safety, and usability provides benefits in terms of sustainability of the whole business model. In the FSC policymakers should devise strategies according to changes in the quantity and quality of products (e.g., postharvest ripening and fully ripening agricultural products) to manage the food's on-shelf quality and potential for profit (Xie et al., 2023).

Moreover, the impact analysis of various types of food waste at supermarkets reveals that the negative environmental effects of such wastage are significantly higher among some products than others (Filimonau and Gherbin, 2017). Accordingly, supermarkets should distinguish between different groups of products to prioritize the most impactful categories for their food waste management plans. Accordingly, donation, anaerobic digestion, and incineration with energy recovery are highlighted as the most effective waste management options (Eriksson et al., 2015), which complement the traditional total quality management strategies with servitization: making some food available for social purposes signifies transforming a product to a (social) service, improving the overall quality of the business and reputation (De Giovanni, 2024).

Different strategies have been suggested to handle grocery retail food waste, which involves dynamic pricing and preventing organic waste from entering landfills through legislation. Dynamic pricing has shown much more effectiveness when it comes to reducing waste and making profits than other pricing mechanisms (Sanders, 2024). Also, people's shopping behavior can be greatly influenced by retailers and the related infrastructure; thus, there is a need for the creation of new urban areas for retailing groceries facilitated by technology to avoid household food waste (Lee, 2018). In other words, mitigating food waste requires the involvement of all players in the FSC, rather than focusing only on the consumers. This means responsibilities for reducing this issue should be extended to retailers as well as consumers (Aschemann-Witzel et al., 2023). In addition, collaboration among supply chain partners, particularly in logistics, can reduce product waste and profit loss due to the deterioration of food products (Beullens and Ghiami, 2022). Establishing connection and cooperation among stakeholders and partners in the FSC by defining accurate rules and policies leads to advantages for the whole supply chain in terms of food waste management that are not achievable by individual stakeholders (Nadeau and Koebele, 2023). However, lack of trust among FSC members remains a challenging obstacle, in addition to the need for extensive

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data analysis in B2B as well as B2C relationships to manage decision-making in quality and stockholding capabilities, among other strategic choices (De Giovanni, 2024). Digital platforms, together with technologies like blockchain coupled with smart contracts, have the potential to provide effective solutions for the redistribution of perishable goods so that supermarkets can reduce food wastage and possibly solve the food waste issue (Kör et al., 2022).

2.2. Food waste and new technologies

Food-sharing platforms can be impactful drivers for business innovation in the food industry, which aims to prevent food loss efficiently (Mattila et al., 2020). However, collecting and distributing surplus food between final consumers solely cannot be effective as it does not reduce extra production in the FSC. This is related to the fact that the new technologies employed allow for analysis, sharing of information, and automation of necessary procedures among other features. The literature shows that AI can be successfully designed to mitigate food waste at various stages of the FSC. For example, AI-based systems are being implemented to sort and classify waste, and the employment of AI in predicting demand and waste is surely one of the best practices in this domain (Kutyauripo et al., 2023). AI enables this via automation, efficiency, and scalability, while additionally entailing complex waste management at different stages of the FSC—collection and logistics, redistribution, sorting, recycling, and pricing (Onyeaka et al., 2023).

Besides, supply chains with various partners and leaders see the performance of the supply chain members enhanced through the use of blockchain-based information traceability systems, considering the level of collaboration and competition (Zhou et al., 2023). Despite the challenge posed by blockchain technology through scalability, privacy leakage, and high cost of adoption, this integration is expected to boost some other technologies: Internet of Things (IoT) and AI leverage sustainability goals in the agri-food system (Rana et al., 2021). For example, in smart cities, municipalities can make financial management of waste collection and engage volunteer citizens, store owners, and public agents through a blockchain-based system to improve social and environmental sustainability features (França et al., 2020). Blockchain, when coupled with IoT, improves traceability and transparency and reduces asymmetric information within the FSC, thus proving effective in the mitigation of food excess wastage or further spoilage (Pakseresht et al., 2023). Its potential lies in increasing the visibility of food inventories, tracing food flows, and sharing information among partners by lowering food loss (Rejeb et al., 2020).

Blockchain also addresses issues such as traceability, food fraud, recall, and waste, at the same time enhancing operational efficiency in terms of transaction time, cost, revenue, and overall performance (Li et al., 2023). The adoption of blockchain in the fresh produce supply chain enhances information sharing with a high level of traceability and responsiveness (Ma et al., 2023). However, effective governance, regulation, and education are essential for maximizing its adoption benefits since blockchain-based smart contracts facilitate food redistribution by automating transactions and agreements, eliminating ambiguity and distrust among partners, and reducing dependence on third-party intermediaries (Hu et al., 2020). Smart contracts are programmable, allowing for the execution of predefined policies among network partners, thus enhancing trust and transparency (Hasan et al., 2020).

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Therefore, according to the literature, retailers such as supermarkets remain responsible for a significant amount of waste in the FSC, which highlights the need to adopt new initiatives to mitigate this issue. The concept of the sharing economy is known as a promising solution for improving economic, social, and environmental sustainability in different industries. Accordingly, the use of sharing platforms for sharing physical and consumable products is booming worldwide (Muñoz and Cohen, 2017). However, communities mostly use food-sharing platforms to share extra food among individuals, rather than as an exercise in collaboration between businesses and companies. Using B2B food-sharing platforms is complex because of the notable number of perishable items in sales outlets such as supermarkets and their short shelf life, which impact food retailers' profitability. However, implementing new technologies, such as AI and blockchain-based smart contracts, can accelerate the adoption of B2B food-sharing platforms by increasing trust among firms and automating some processes aimed at reducing both food waste and revenue loss. To the best of our knowledge, no articles in the literature discuss B2B food-sharing platforms using this combination of technologies. The contribution of this paper is related to developing a model for a smart B2B food-sharing platform concerning a specific use case at supermarkets and other identical retailers aiming to reduce food waste. Moreover, the paper discusses the role of blockchain and AI in implementing a smart platform that can overcome the challenges of B2B food-sharing systems. Therefore, according to the importance of food waste as a global issue and the significant proliferation of food-sharing concepts, this study contributes a valuable model for implementing smart B2B food-sharing platforms.

In this study, we develop a sample algorithm for implementing an SFSP with smart contracts to reduce supermarket food waste by redistributing surplus inventory among partners at the downstream logistics of the FSC. AI analyzes data collected from various sensors or IoT devices to inform the algorithm layer of blockchain-based smart contracts. Parties involved in developing the automated redistribution strategy include minimarkets or supermarkets, restaurants, charities, and online shops, all of which benefit by having access to surplus inventory at reasonable prices, which helps reduce food waste.

3. Smart food-sharing platform

This section presents the assumptions, rules, and mathematical formulations required to define a model for identifying and redistributing extra inventory among other partners to reduce food waste at supermarkets. The supermarket serves as the central partner in the model, with other parties, such as restaurants and charities, collaborating in downstream logistics to redistribute surplus inventory using smart contracts, and when realizing the benefits of managing food waste efficiently, possibly enter into competition (De Giovanni, 2021). According to Amaral and Orsato (2023), digital sharing platforms can be effective if they can improve trust, facilitate information sharing and decision-making, distribute surplus food effectively, and decrease operational costs. The model that we provide in this paper covers all the aforementioned points by implementing a smart platform using AI and blockchain-based smart contracts. To redistribute surplus inventory, the AI algorithm monitors all conditions, including inventory levels, price offers, expiration dates, and donations. Blockchain technology ensures trustable transactions besides accurate data sharing. Automated smart contracts save time and energy by redistributing surplus inventory of a wide

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range of products before their spoilage. Moreover, SFSP facilitates donation activities to improve the social sustainability performance of the supermarkets. So, we provide a novel model for B2B food-sharing platforms with a high efficiency concerning the core performance factors of digital sharing platforms.

Moreover, this study focuses on solving the main challenges of B2B food-sharing systems that supermarket owners face using current models. The main challenges are related to additional work for the managers to collaborate with external partners (Moser 2020), complicated operations due to managing a noticeable number of items with different characteristics (Freitas et al., 2024), and intensive communication and exchange between parties to reach agreements (Horoś and Ruppenthal, 2021). Accordingly, this study develops a model for an SFSP to mitigate operation challenges using a trustable platform that collects data, shares information, and executes agreements automatically aiming to facilitate the decision-making procedure without being overwhelmed by redistribution operations.

3.1. Model description

Redistribution serves as a preventive strategy to mitigate food waste in the FSC while also reducing revenue loss associated with food spoilage. Additionally, supermarkets have the opportunity to collaborate with nonprofit organizations such as charities to fulfill their social responsibility by delivering surplus inventory to them. Consequently, SFSP can enhance FSC performance in terms of economic, environmental, and social sustainability. The main assumptions of our model are summarized as follows:

- Supermarkets order perishable products based on parameters such as wholesale price, discounts, transportation costs (ordering cost), and demand predictions. However, due to erratic demand rates and prediction errors, supermarkets may face surplus inventory that cannot be sold as anticipated. Therefore, prevention strategies are implemented to redistribute additional inventory before spoilage occurs.
- Supermarkets categorize the shelf life of each product into several quality levels. The quality and price of a product decrease as it approaches its expiry date. For instance, a perishable vegetable with a one-month shelf life may be categorized into four weeks, with the first week being of the highest quality, and the last week of the lowest quality.
- To prevent food waste and sales loss, supermarkets establish decision points within each quality level (excluding the first period) for each perishable product. If the predefined sales amount for a product at each quality level cannot be achieved, the unsold amount is considered surplus inventory for redistribution. Recognizing additional inventory at the initial quality levels allows supermarkets to potentially sell them at higher prices before expiry.
- Monitoring and identifying surplus inventory of various products at different quality periods is challenging for supermarkets. To address this, supermarkets implement an SFSP considering blockchain-based smart contracts to automatically redistribute products according to agreed-upon policies and rules with other partners.

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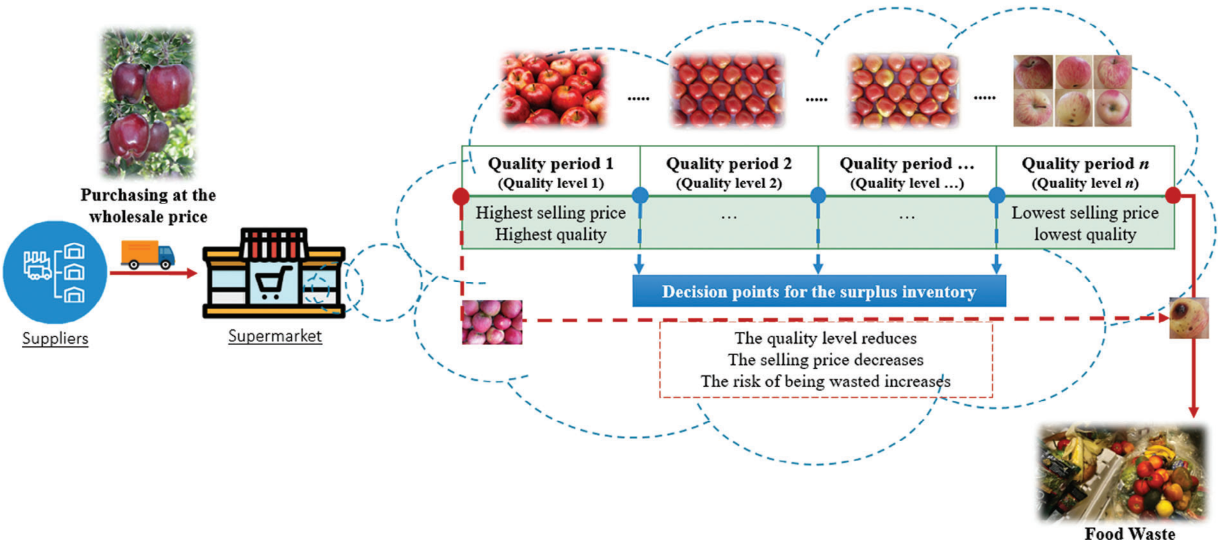

Fig. 1. Example of a perishable product considering different quality levels (source: authors).

- The new automated redistribution system collects data on inventory levels, expiry dates, freshness, market prices, and purchasing prices through sensors (IoT, e-nose, e-eye, etc.), inbound oracles, hardware oracles, and software oracles. An AI algorithm analyzes these data to examine agreement conditions and execute smart contracts automatically.

Figure 1 illustrates the quality levels of a perishable product, such as apples. The supermarket purchases a batch of apples at wholesale price from a supplier and considers n quality periods for it. The quality of the apples gradually decreases from the highest level during the first period to the lowest level during the last period. The surplus inventory is recognized at the end of each quality period for redistribution based on inventory levels and actual sales. Managing surplus inventory during the initial stages is crucial to prevent food waste, as selling surplus items near expiry becomes increasingly difficult.

Figure 2 illustrates how the SFSP functions in identifying surplus inventory of products and redistributing them among other partners using smart contracts. In other words, the supermarket adopts a smart sharing platform to circulate information and financial credits and automatically redistribute extra inventory of perishable products using new technologies. The required information and data are collected through smart sensors and blockchain oracles to feed the AI algorithm of the sharing platform and consequently analyze agreement conditions and execute smart contracts between partners. These partners may include other minimarkets and supermarkets in the same region, restaurants and fast-food establishments, online stores offering discounted products, as well as charities or other organizations to which the supermarket can donate the surplus inventory. The algorithm for implementing smart contracts takes into account various parameters, such as inventory levels, expiry dates, donation rates, and prices to prioritize distribution among other partners.

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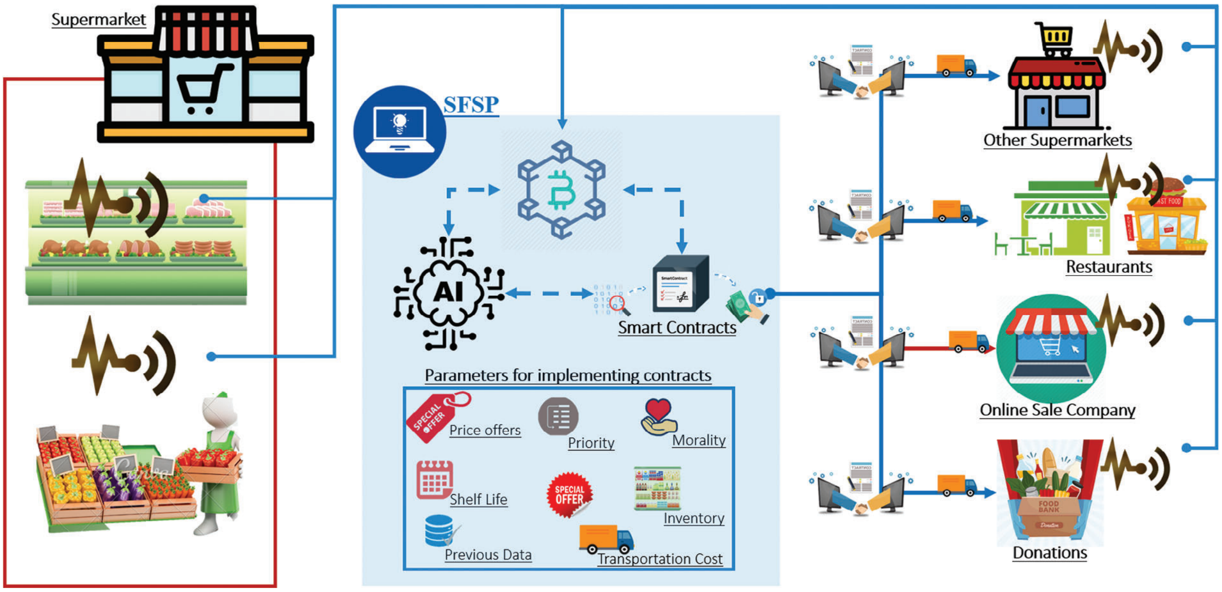

Fig. 2. Example of implementing the SFSP with blockchain-based smart contracts for redistributing surplus inventory at supermarkets (source: authors).

According to Fig. 2, the main technologies we define for the SFSP include AI, blockchain, and smart contracts. Blockchain technology helps exchange and transfer data among various parties without compromising security with a high level of transparency. This leads to a trustworthy shared platform, thus facilitating the efficient traceability of information and products. AI analyzes the collected data and considers different policies and rules to evaluate the agreement conditions for implementing smart contracts and executing multitask analyses. This process considers a significant number of parameters and decision variables within a reasonable time frame. Finally, to adopt a smart sharing platform that can facilitate decision-making procedures for all parties, we use smart contracts that automate the agreement process and reach a consensus for redistributing surplus inventory when predefined conditions are met. All the aforementioned technologies create an agile food-sharing platform capable of identifying extra inventory, finding the right partners for redistribution, and automatically implementing the contracts among them in a reasonable time. The SFSP, with AI, blockchain, and smart contracts, can be an efficient tool for reducing food waste as it can simultaneously manage the surplus inventory of numerous perishable products that have a short shelf life.

3.2. *Model formulation*

To formulate the model and devise the profit function, we need to define the parameters and decision variables. Accordingly, k, l, f, h, and i are the indices indicating "other supermarkets," "restaurants," "charities," "online platforms," and "products," respectively. We use g to indicate the number of products, n_i, to define the number of quality levels, c_i as the unit cost, D_i as the total demand

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rate (ordering amount from the supplier), and W_i as the total wasted amount of product i. d'_{ij} is the estimated demand for product i and quality period j, whereas d_{ij} is the real demand, and s_{ij} is the unit selling price of product i for the proposed period. I^S_{ij}, and I^{Minsur}_{ij} indicate the surplus inventory level and the minimum acceptable level that can be considered as surplus inventory for product i at the beginning of the quality period j. Moreover, we define I^M_{ijk}, I^R_{ijl}, I^O_{ijh}, and I^C_{ijf} as the inventory level of minimarket k, restaurant l, online platform h, and charity f for product i at the beginning of the quality period j, respectively.

To analyze the needs of other partners, we should consider their maximum inventory capacity; we indicate this parameter for minimarket/supermarket k with $I^{M_{max}}_{ik}$, restaurant l with $I^{R_{max}}_{ik}$, charity f with $I^{C_{max}}_{ik}$, and online store h with $I^{O_{max}}_{ih}$. Moreover, each of the partners offers a maximum price for purchasing the surplus inventory for product i at the beginning of quality period j, which we define for the minimarkets, restaurants, and online shops using p'_{ijk^M}, p'_{ijl^R}, and p'_{ijh^O}. Besides, p_{ijk^M}, p^R_{ijl}, and p^O_{ijh} indicate the real purchasing price the AI algorithm defines for the smart contracts, considering the limitations for the minimarkets/supermarkets, restaurants, and online stores, respectively. Note that the price of the products suggested by partners is an exogenous parameter that they define according to the information they collect from the market and the average price they usually pay to buy the same quality products. After that, AI rejects the offers that are lower than the minimum price defined by the supermarket (considering the minimum revenue) and then sorts and prioritizes the remaining collaborators according to the best price offers to dedicate the surplus inventory to them. In the next section, we provide a sample algorithm for these calculations. Finally, to calculate the total profits, we add TR' and TR which are the total estimated profit and total real profit of the supermarket. TR'_i and TR_i indicate the same values for a specific product, i, and TR'_{ij} and TR_{ij} are again the total profits related to product i, but for quality period j. The decision variables for executing the smart contracts are Q^M_{ijk}, Q^R_{ijl}, Q^C_{ijf}, and Q^O_{ijh}, which are defined by AI, and indicate the amount of surplus inventory of product i that will be sent to minimarket k, restaurant l, online platform h, and charity f at the beginning of the quality period j. The execution of smart contracts and the record of transactions on the blockchain allow the players to demonstrate the transactions and prove their contribution to the reduction of food waste. Furthermore, the supermarkets use blockchain records to prove their social contributions by providing food to charities, whose communication to the eco-system can still be done using AI tools.

The total purchasing cost the supermarket pays to the supplier for product i is c_iD_i, and its total revenue expectation for this product during period j equals $s_{ij}d'_{ij}$. So, Equation (1) calculates the total expected profit of the supermarket considering all products and periods. Moreover, we can use Equations (2) and (3) to obtain the total profit for the specific product i and the total profit for product i and the quality period j, respectively.

$$TR' = \sum_{\forall i} \sum_{j=1}^{n_i} s_{ij} d'_{ij} - \sum_{\forall i} c_i D_i, \tag{1}$$

$$TR'_i = \sum_{j=1}^{n_i} s_{ij} d'_{ij} - c_i D_i, \tag{2}$$

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$$TR'_{ij} = s_{ij}d'_{ij} - c_i d'_{ij} = \left(s_{ij} - c_i\right) d'_{ij}. \tag{3}$$

To calculate the total real profit of the supermarket, we should consider $\sum_{\forall i}\sum_{\forall k}\sum_{j=2}^{n_i} p^M_{ijk}Q^M_{ijk}$, $\sum_{\forall i}\sum_{\forall l}\sum_{j=2}^{n_i} p^R_{ijl}Q^R_{ijl}$, and $\sum_{\forall i}\sum_{\forall h}\sum_{j=2}^{n_i} p^O_{ijh}Q^O_{ijh}$ as the total revenue the supermarket gains from the minimarkets, restaurants, and online markets respectively, besides the total costs it pays to the supplier (c_iD_i) as well as its revenue from general customers ($\sum_{\forall i}\sum_{j=1}^{n_i} s_{ij}d_{ij}$). Therefore, Equation (4) calculates the total profit of the supermarket. Accordingly, we can calculate TR for the specific product i using Equation (5) and for product i and quality period j ($j \neq 1$ as there is no revenue at the beginning of the first period) using Equation (6).

$$TR = \sum_{\forall i}\sum_{j=1}^{n_i} s_{ij}d_{ij} + \left(\sum_{\forall i}\sum_{\forall k}\sum_{j=2}^{n_i} p^M_{ijk}Q^M_{ijk} + \sum_{\forall i}\sum_{\forall l}\sum_{j=2}^{n_i} p^R_{ijl}Q^R_{ijl} + \sum_{\forall i}\sum_{\forall h}\sum_{j=2}^{n_i} p^O_{ijh}Q^O_{ijh}\right) - \sum_{\forall i} c_iD_i, \tag{4}$$

$$TR_i = \sum_{j=1}^{n_i} s_{ij}d_{ij} + \left(\sum_{\forall k}\sum_{j=2}^{n_i} p^M_{ijk}Q^M_{ijk} + \sum_{\forall l}\sum_{j=2}^{n_i} p^R_{ijl}Q^R_{ijl} + \sum_{\forall h}\sum_{j=2}^{n_i} p^O_{ijh}Q^O_{ijh}\right) - c_iD_i, \tag{5}$$

$$TR_{ij} = (s_{ij} - c_i)d_{ij} + \sum_{\forall k}(p^M_{ijk} - c_i)Q^M_{ijk} + \sum_{\forall l}(p^R_{ijl} - c_i)Q^R_{ijl} + \sum_{\forall h}(p^R_{ijh} - c_i)Q^O_{ijh,} \tag{6}$$

At the beginning of each quality period (decision points regarding the surplus inventory), the purchasing levels of the other partners are limited according to their maximum inventory capacity. Therefore, we need to consider constraints (7)–(10) for the maximum possible allocation of the additional inventory of product i at the beginning of quality period j for minimarket/supermarket k, restaurant l, online store h, and charity f, respectively.

$$Q^M_{ijk} \leq \left(I^{M_{max}}_{ik} - I^M_{ijk}\right) \qquad \forall i,\ j\,(j \neq 1),\ k, \tag{7}$$

$$Q^R_{ijl} \leq \left(I^{R_{max}}_{il} - I^R_{ijl}\right) \qquad \forall i,\ j\,(j \neq 1),\ l, \tag{8}$$

$$Q^O_{ijh} \leq \left(I^{O_{max}}_{ih} - I^O_{ijh}\right) \qquad \forall i,\ j\,(j \neq 1),\ h, \tag{9}$$

$$Q^C_{ijf} \leq \left(I^{C_{max}}_{if} - I^C_{ijf}\right) \qquad \forall i,\ j\,(j \neq 1),\ f. \tag{10}$$

Furthermore, the supermarket can consider offering other partners a discount (r_{dis}) to motivate them to purchase the surplus inventory. Accordingly, we can define the selling price as equal to $(1 - r_{dis})s_{ij}$. However, this is the minimum price (the SFSP does not accept an offer lower than this price), and if the offer from a partner is higher than this value, the SFSP will consider the highest

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price. Partners can suggest a higher price as a competitive option to be prioritized on receiving the surplus inventory from the supermarket. To satisfy these assumptions, we define constraints (11)–(13), which emphasize that the minimum price is $(1 - r_{dis})s_{ij}$, but the agreement will be based on the maximum price offer from the other partners.

$$p^{M}_{ijk} = \max\left\{(1 - r_{dis})s_{ij},\ p'^{M}_{ijk}\right\} \qquad \forall i,\ j\,(j \neq 1),\ k, \tag{11}$$

$$p^{R}_{ijl} = \max\left\{(1 - r_{dis})s_{ij},\ p'^{R}_{ijl}\right\} \qquad \forall i,\ j\,(j \neq 1),\ l, \tag{12}$$

$$p^{O}_{ijh} = \max\left\{(1 - r_{dis})s_{ij},\ p'^{O}_{ijh}\right\} \qquad \forall i,\ j\,(j \neq 1),\ h. \tag{13}$$

The SFSP only redistributes surplus inventory, and there will be an agreement to distribute the products only if there is extra inventory for a product at a decision point (at the beginning of a quality period). Therefore, considering j' is the quality period for which the SFSP calculates and analyzes, the maximum possible surplus inventory level at period j' will be $\sum_{j=1}^{j'-1}(d'_{ij} - d_{ij})$ and if $\sum_{j=1}^{j'-1}(d'_{ij} - d_{ij} - \sum_{\forall h} Q^{O}_{ijh} - \sum_{\forall k} Q^{M}_{ijk} - \sum_{\forall l} Q^{R}_{ijl} - \sum_{\forall f} Q^{C}_{ijf}) < 0$, it means there is no surplus inventory for redistribution at the beginning of period j'. Accordingly, inequality (14) shows the maximum possible amount of product i that can be dedicated to other partners through smart contracts at the beginning of period j' in which $j' \neq 1$ (there is no surplus inventory at the beginning of the first period) and $Q^{O}_{i1h} = Q^{M}_{i1k} = Q^{R}_{i1l} = Q^{C}_{i1f} = 0$ (as there is no surplus inventory in the first period, there is no redistribution in this period as well).

$$Q^{O}_{ij'h} + Q^{M}_{ij'k} + Q^{R}_{ij'l} + Q^{C}_{ij'f} \leq \sum_{j=1}^{j'-1}\left(d'_{ij} - d_{ij} - \sum_{\forall h} Q^{O}_{ijh} - \sum_{\forall k} Q^{M}_{ijk} - \sum_{\forall l} Q^{R}_{ijl} - \sum_{\forall f} Q^{C}_{ijf}\right). \tag{14}$$

Additionally, the supermarket sets a minimum threshold for product i as the surplus inventory. If the amount of additional inventory falls below this specified value, the SFSP assumes the risk of potentially selling them in the next quality period. Therefore, surplus inventory will exist for product i at the beginning of period j' only if $\sum_{j=1}^{j'-1}(d'_{ij} - d_{ij} - \sum_{\forall h} Q^{O}_{ijh} - \sum_{\forall k} Q^{M}_{ijk} - \sum_{\forall l} Q^{R}_{ijl} - \sum_{\forall f} Q^{C}_{ijf}) \geq I^{Minsur}_{ij'}$.

Another important factor in the supermarket's decisions is related to the social sustainability practice of donations. To achieve this goal, the SFSP allocates a portion of the surplus inventory to charity. The minimum and maximum amounts of this donation for product i at the beginning of period j are defined in constraint (15).

$$d^{min}_{ij} I^{S}_{ij} \leq \sum_{\forall f} Q^{C}_{ijf} \leq d^{max}_{ij} I^{S}_{ij} \ \forall j,\ j \neq 1,\ j \neq n. \tag{15}$$

Note that there is no donation for the first period ($j = 1$) as there is no surplus inventory at the beginning of the first period. Moreover, for the final period ($j = n$), the algorithm considers the maximum donation ($d^{max}_{ij} = 100\%$) based on the capacity of the charities because after this period,

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whatever remains from the products will be wasted. So, in Equations (15)–(17), we ignore the first and last periods ($j \neq 1,\ j \neq n$). Accordingly, we can define the amount of donation of product i at the beginning of period j as follows:

$$\sum_{\forall f} Q^{C}_{ijf} = \left\{\begin{array}{lr} \sum_{\forall f}\left(I^{C_{max}}_{if} - I^{C}_{ij}\right) & \text{if } x_j = 1,\ u_j = 0,\ j \neq 1,\ j \neq n \\ d^{min}_{ij} I^{S}_{ij} & \text{if } x_j = 0,\ u_j = 0,\ j \neq 1,\ j \neq n \\ d^{min}_{ij} I^{S}_{ij} + d^{max}_{ij}\left(I^{S}_{ij} - \left(\sum_{\forall k} Q^{M}_{ijk} + \sum_{\forall l} Q^{R}_{ijl} + \sum_{\forall h} Q^{O}_{ijh}\right) - d^{min}_{ij} I^{S}_{ij}\right) & \text{if } x_j = 0,\ u_j = 1,\ v_j = 1,\ j \neq 1,\ j \neq n \\ \sum_{\forall f}\left(I^{C_{max}}_{if} - I^{C}_{ij}\right) & \text{if } x_j = 0,\ u_j = 1,\ v_j = 0,\ j \neq 1 \\ d^{min}_{ij} I^{S}_{ij} + \left(I^{S}_{ij} - \left(\sum_{\forall k} Q^{M}_{ijk} + \sum_{\forall l} Q^{R}_{ijl} + \sum_{\forall h} Q^{O}_{ijh}\right) - d^{min}_{ij} I^{S}_{ij}\right) & \text{if } x_j = 0,\ u_j = 1,\ v_j = 1,\ j = n \\ \sum_{\forall f}\left(I^{C_{max}}_{if} - I^{C}_{ij}\right) & \text{if } x_j = 0,\ u_j = 1,\ v_j = 0,\ j = n \\ 0 & \text{Otherwise} \end{array}\right\}. \tag{16}$$

In Equation (16), x_j, u_j, and v_j are binary variables in which $x_j = 1$ if $\sum_{\forall f}(I^{C_{max}}_{if} - I^{C}_{ij}) \leq d^{min}_{ij} \times I^{S}_{ij}$, which means the inventory capacity of the charities at the beginning of period j is lower than the minimum donation amount, $u_j = 1$ if $I^{S}_{ij} - (\sum_{\forall k} Q^{M}_{ijk} + \sum_{\forall l} Q^{R}_{ijl} + \sum_{\forall h} Q^{O}_{ijh}) - x_j \sum_{\forall f}(I^{C_{max}}_{if} - I^{C}_{ij}) - (1 - x_j)\ d^{min}_{ij} I^{S}_{ij} > 0$, indicating that at the beginning of period j there is surplus inventory after the redistribution considering the minimum donation, and $v_j = 1$ if $\sum_{\forall f}(I^{C_{max}}_{if} - I^{C}_{ij}) - d^{min}_{ij} I^{S}_{ij} > d^{max}_{ij}(I^{S}_{ij} - (\sum_{\forall k} Q^{M}_{ijk} + \sum_{\forall l} Q^{R}_{ijl} + \sum_{\forall h} Q^{O}_{ijh}) - d^{min}_{ij} I^{S}_{ij})$ which means for period j, after the first round of donations (minimum donation) and redistribution, the remaining inventory capacity of the charities is greater than the maximum possible donation amount. So, the first term in Equation (16) indicates the total donation amount at the beginning of period j if the available capacity of the charities is lower than the minimum donation the supermarket is considering for this period. In that case, the SFSP donates an amount equal to the available capacity of the charities. In the second term, the available capacity of the charities is greater than the minimum donation amount. However, after distributing the surplus inventory, there is no more extra inventory to donate. Therefore, the total donation for this period equals the minimum level the supermarket considers for its social responsibility. The third term in Equation (16) is similar to the second term, except that after redistribution, there is extra inventory at the supermarket for product i, and the remaining capacity of the charities exceeds the maximum donation rate the supermarket considers for this period. Similarly, in the fourth term in the proposed equation, there is extra inventory after distribution, but the available capacity of the charities is lower than the maximum donation rate. We can also consider this condition for the final quality period, in which although the maximum donation rate equals 100%, there is not enough inventory capacity at the charities, and SFSP can donate only up to their available capacity. The fifth term in Equation (16) is related to the final quality period when there is surplus inventory after distribution as well as enough inventory capacity at the charities to donate the entire remaining surplus inventory to them. The total donations for the first, fourth, and sixth terms equal the maximum available capacity of the charities. In other words, the supermarket satisfies the total demand of the charities in the proposed conditions through the SFSP. Therefore, we can revise Equations (16) and (17) as some of the conditions in Equation (16) dominate other

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conditions.

$$\sum_{\forall f} Q^C_{ijf} = \begin{cases} \sum_{\forall f}\left(I^{C_{max}}_{if} - I^C_{ij}\right) & \text{if } x_j = 1,\ u_j = 0,\ j \neq 1,\ j \neq n \text{ or } x_j = 0,\ u_j = 1,\ v_j = 0,\ j \neq 1 \text{ or } x_j = 0,\ u_j = 1,\ v_j = 0,\ j = n \\ d^{min}_{ij} I^S_{ij} & \text{if } x_j = 0,\ u_j = 0,\ j \neq 1,\ j \neq n \\ d^{min}_{ij} I^S_{ij} + d^{max}_{ij}\left(I^S_{ij} - \left(\sum_{\forall k} Q^M_{ijk} + \sum_{\forall l} Q^R_{ijl} + \sum_{\forall h} Q^O_{ijh}\right) - d^{min}_{ij} I^S_{ij}\right) & \text{if } x_j = 0,\ u_j = 1,\ v_j = 1,\ j \neq 1,\ j \neq n \\ d^{min}_{ij} I^S_{ij} + \left(I^S_{ij} - \left(\sum_{\forall k} Q^M_{ijk} + \sum_{\forall l} Q^R_{ijl} + \sum_{\forall h} Q^O_{ijh}\right) - d^{min}_{ij} I^S_{ij}\right) & \text{if } x_j = 0,\ u_j = 1,\ v_j = 1,\ j = n \\ 0 & \text{Otherwise} \end{cases} \quad (17)$$

We can utilize Equation (18) to formulate the total waste of product i at the end of its shelf life. This value depends on the difference between the order quantity of the product (D_i) at the beginning of the planning horizon and the total sales amount ($\sum_{j=1}^{n_i} d_{ij}$) during its shelf life to general customers, as well as other partners, including other supermarkets and minimarkets ($\sum_{\forall k}\sum_{j=2}^{n_i} Q^M_{ijk}$), restaurants and fast-food establishments ($\sum_{\forall k}\sum_{j=2}^{n_i} Q^R_{ijl}$), and online stores ($\sum_{\forall k}\sum_{j=2}^{n_i} Q^O_{ijh}$), in addition to the amount the supermarkets consider for donation ($\sum_{\forall k}\sum_{j=2}^{n_i} Q^C_{ijf}$).

$$W_i = D_i - \sum_{j=1}^{n_i} d_{ij} - \sum_{\forall k}\sum_{j=2}^{n_i} Q^M_{ijk} - \sum_{\forall l}\sum_{j=2}^{n_i} Q^R_{ijl} - \sum_{\forall f}\sum_{j=2}^{n_i} Q^C_{ijf} - \sum_{\forall h}\sum_{j=2}^{n_i} Q^O_{ijh}. \quad (18)$$

Now, considering a tax rate for wasted products (V_t) and a social value for donation in terms of revenue (V_s) that helps to improve the supermarket's brand recognition, we can revise the supermarket's total profit from Equation (4) to Equation (19).

$$TR = \sum_{\forall i}\sum_{j=1}^{n_i} s_{ij} d_{ij} + \left(\sum_{\forall i}\sum_{\forall k}\sum_{j=2}^{n_i} p^M_{ijk} Q^M_{ijk} + \sum_{\forall i}\sum_{\forall l}\sum_{j=2}^{n_i} p^R_{ijl} Q^R_{ijl} + \sum_{\forall i}\sum_{\forall h}\sum_{j=2}^{n_i} p^O_{ijh} Q^O_{ijh}\right)$$
$$+ V_s \sum_{\forall i}\sum_{\forall f}\sum_{j=2}^{n_i} Q^C_{ijf} - \sum_{\forall i} c_i D_i - V_t \sum_{\forall i} W. \quad (19)$$

Therefore, in this section, we have highlighted the key roles and restrictions to consider when devising an SFSP algorithm that uses smart contracts, following the assumptions of our model for managing food waste. A supermarket may apply redistribution as a measure of facing high levels of waste while, at the same time, increasing the overall income earned and reducing the impact. By collecting and analyzing required data and information using sensors, blockchain oracles, and AI technology, it is possible to execute smart contracts between different partners at the downstream logistics for redistributing surplus inventories at the beginning of each quality period. The model we discuss in this paper is related to a sample algorithm for executing smart contracts in an SFSP and it does not necessarily cover all conditions in the real world. However, we can extend the model to include different real circumstances and challenges retailers may face in managing their food surplus inventory. In this section, we developed all required formulas to run the sample algorithm and there is no need for any additional formulas as long as nothing changes to the main assumptions.

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However, the formulation of the model is in a way that brings the possibility of developing the algorithm concerning a larger number of supermarkets and partners as well as further assumptions and constraints. In addition, the platform's efficiency depends on the service quality of the blockchain system providers and the information technology support systems in real cases. In the next section, we will utilize the aforementioned parameters, formulas, and decision variables to present a sample algorithm for our model.

4. Algorithm for SFSP

Smart contracts are programs that automatically execute agreements between partners when predefined conditions are met. The interfaces with AI systems allow smart contracts to continuously update according to the new and variable situations of the ecosystem. The program consists of a set of policies and rules to make decisions for executing contracts among all partners without the need for a third party. In this section, we will first develop a sample program to check the possible conditions for executing smart contracts based on the parameters, decision variables, functions, and constraints discussed in the previous section. Then, we will provide a numerical example to illustrate the functionality of the algorithm for the SFSP. From the perspective of executing smart contracts, this algorithm can monitor different agreement conditions and, according to them, automatically implement blockchain-based smart contracts among different partners. Some of the main rules that AI considers by analyzing the data collected by blockchain are as follows:

- The algorithm defines each product's surplus inventory according to its quality level and shelf life. Then, AI checks the agreement conditions of smart contracts only for redistributing the indicated items that the supermarket needs to reduce their inventory levels before decomposition.
- The partners should have sufficient inventory capacity to receive the surplus inventory. Otherwise, the algorithm does not consider them as potential targets for redistribution.
- The algorithm only considers partners that offer a unit price higher than a predefined value that the supermarket automatically defines according to the market data.
- The algorithm redistributes the surplus inventory according to a priority list based on the price offers or other factors like distance and donations.
- The algorithm implements smart contracts between supermarkets and charities, considering a predefined percentage for donating surplus inventory. AI dedicates the extra inventory to the charities equally or according to a priority list that it calculates based on their inventory levels.

Overall, the proposed model helps to automatically implement blockchain-based smart contracts in a B2B platform to overcome challenges that retailers like supermarkets usually face in managing their surplus inventory concerning a reasonable time and cost. SFSP facilitates redistributing products when supermarket owners are overwhelmed with making decisions about their surplus inventory due to a profound number of items with different shelf lives. Therefore, SFSP results to be a trustable and efficient tool to automatically monitor and execute agreements between partners to prevent food waste.

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4.1. Algorithm

The algorithm begins by determining the surplus inventory of the products at the decision points, which occur at the beginning of each quality level period. To calculate this surplus, anticipated sales, actual sales, and a minimum acceptable surplus inventory are considered. The SFSP then allocates a portion of this surplus to charities and distributes the remaining inventory among other partners capable of accepting products. The algorithm sorts partner requests based on offered prices, though prioritization can also consider factors such as distance, previous collaboration, and business type.

Subsequently, the surplus inventory is distributed starting with the highest priority partner, considering inventory limitations. This process continues until all surplus inventory is allocated. If surplus inventory remains unclaimed, it is allocated to charities based on the maximum donation rate set by the supermarket. Additionally, if the product is in its final quality period, the entire remaining batch is earmarked for donation to prevent waste.

These steps outline the main process of the algorithm. It is important to note that this is just one example of potential rules and policies for implementing SFSP in supermarket partnerships for food waste management. Prioritization of partners for surplus distribution can vary based on different conditions, not just product prices. Additionally, factors such as quality levels, discount rates, and donation rates, may differ for each product based on demand, revenue, shelf life, and environmental impact.

Algorithm for executing the blockchain-based smart contract:

Consider $i = 1$ and $j' = 2$.

Run the following steps for product type i and quality period j':

Step A. If $\sum_{j=1}^{j'-1}(d'_{ij} - d_{ij} - \sum_{\forall h} Q^O_{ijh} - \sum_{\forall k} Q^M_{ijk} - \sum_{\forall l} Q^R_{ijl} - \sum_{\forall f} Q^C_{ijf}) \geq I^{Minsur}_{ij'}$ then

calculate $I^S_{ij'} = \sum_{j=1}^{j'-1}(d'_{ij} - d_{ij} - \sum_{\forall h} Q^O_{ijh} - \sum_{\forall k} Q^M_{ijk} - \sum_{\forall l} Q^R_{ijl} - \sum_{\forall f} Q^C_{ijf})$ as the surplus inventory for distributing among other partners. Go to Step B.

Otherwise $j' = j' + 1$,

If $j' < n_i$ then repeat this step for new j'

Otherwise $i = i + 1$,

If $i > g$, then, stop the algorithm

Otherwise, repeat this step for the new i

End if

End if

End if

Step B. At the beginning of period j, create a priority list for product i, including all the possible partners. Remove the partners from this list who offer a price lower than $(1 - r_{dis})s_{ij'}$.

Step C. Sort the list based on the price offers ($p^M_{ij'k}$, $p^R_{ij'l}$, $p^O_{ij'h}$; $\forall k, l, h$) in which the partners with higher prices have the highest priority (they will acquire the first ranks). If there are similar price offers, prioritize them according to other elements that are important for the supermarket manager, such as their past collaboration and transportation costs.

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Step D. Consider the minimum donation rate for the charities, and accordingly dedicate $d_{ij'}^{min} \times I_{ij'}^{S}$ to charities. If $\sum_{\forall f}(I_{if}^{C_{max}} - I_{ij'}^{C}) \leq d_{ij'}^{min} \times I_{ij'}^{S}$, then dedicate the maximum possible amount, which equals $\sum_{\forall f}(I_{if}^{C_{max}} - I_{ij'}^{C})$.

Step E. Calculate the maximum possible dedication to each of the partners in the priority list using the following equations:

$$Q_{ij'k}^{M} \leq \left(I_{ik}^{M_{max}} - I_{ij'k}^{M}\right) \qquad \forall k \ (if\ it\ exists\ in\ the\ list),$$

$$Q_{ij'l}^{R} \leq \left(I_{il}^{R_{max}} - I_{ij'l}^{R}\right) \qquad \forall l \ (if\ it\ exists\ in\ the\ list),$$

$$Q_{ij'h}^{O} \leq \left(I_{ih}^{O_{max}} - I_{ij'h}^{O}\right) \qquad \forall h \ (if\ it\ exists\ in\ the\ list).$$

Step F. Dedicate the remaining surplus inventory which after donation equals $(1 - d_{ij'}^{min})I_{ij'}^{S}$ or $I_{ij'}^{S} - \sum_{\forall f}(I_{if}^{C_{max}} - I_{ij'f}^{C})$ to the list according to their inventory capacity and rank (start from the top of the list).

Step G. *If* all the surplus inventory is dedicated, then

$$j' = j' + 1$$

If $j' < n_i$ then go to step A
Otherwise, $i = i + 1, \ j' = 2$,
If $i>g$, then, stop the algorithm
Otherwise, repeat the algorithm for new i
End if
End if
Otherwise
If $j' < n_i$ then

Dedicate d_{ij}^{max} percent of the remaining surplus inventory to the charities according to their available inventory capacity (if there is no inventory capacity for them, the remaining surplus inventory will be kept for the next period).

Otherwise

Dedicate the whole remaining surplus inventory to the charities according to their available inventory capacity (if there is no inventory capacity for them, the remaining surplus inventory will be kept for the final period).

End if
End if

Step H. If $j' = n_i$ then

Calculate the total donations, waste, and total profit of the supermarket related to product i as follows:

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For $j = 1 : n_i$ calculate

$$\sum_{\forall f} Q^C_{ijf} =$$

$$\begin{cases} \sum_{\forall f}\left(I^{C_{max}}_{if} - I^C_{ij}\right) & \text{if } x_j = 1,\ u_j = 0,\ j \neq 1,\ j \neq n \text{ or } x_j = 0,\ u_j = 1,\ v_j = 0,\ j \neq 1 \text{ or } x_j = 0,\ u_j = 1,\ v_j = 0,\ j = n \\ d^{min}_{ij} I^S_{ij} & \text{if } x_j = 0,\ u_j = 0,\ j \neq 1,\ j \neq n \\ d^{min}_{ij} I^S_{ij} + d^{max}_{ij}\left(I^S_{ij} - \left(\sum_{\forall k} Q^M_{ijk} + \sum_{\forall l} Q^R_{ijl} + \sum_{\forall h} Q^O_{ijh}\right) - d^{min}_{ij} I^S_{ij}\right) & \text{if } x_j = 0,\ u_j = 1,\ v_j = 1,\ j \neq 1,\ j \neq n \\ d^{min}_{ij} I^S_{ij} + \left(I^S_{ij} - \left(\sum_{\forall k} Q^M_{ijk} + \sum_{\forall l} Q^R_{ijl} + \sum_{\forall h} Q^O_{ijh}\right) - d^{min}_{ij} I^S_{ij}\right) & \text{if } x_j = 0,\ u_j = 1,\ v_j = 1,\ j = n \\ 0 & \text{Otherwise} \end{cases}$$

EndFor

- Total Donations $= \sum_{\forall f} \sum_{j=2}^{n_i} Q^C_{ijf}$
- $W_i = D_i - \sum_{j=1}^{n_i} d_{ij} - \sum_{\forall k} \sum_{j=2}^{n_i} Q^M_{ijk} - \sum_{\forall l} \sum_{j=2}^{n_i} Q^R_{ijl} - \sum_{\forall f} \sum_{j=2}^{n_i} Q^C_{ijf} - \sum_{\forall h} \sum_{j=2}^{n_i} Q^O_{ijh}$
- $TR_i = \sum_{j=1}^{n_i} s_{ij} d_{ij} + (\sum_{\forall k} \sum_{j=2}^{n_i} p^M_{ijk} Q^M_{ijk} + \sum_{\forall l} \sum_{j=2}^{n_i} p^R_{ijl} Q^R_{ijl} + \sum_{\forall h} \sum_{j=2}^{n_i} Q^O_{ijh}) - c_i D_i + V_s \sum_{\forall f} Q^C_{ijf} - V_t W_i$

Otherwise, go to step A.
End if

4.2. Numerical example

To discuss the proposed algorithm in more detail, we provide a numerical example to clarify the calculations. Consider a supermarket that defines four quality levels for one of its perishable products (apples), in which each quality period lasts one week, and the shelf life of the product is 28 days (four weeks). At the beginning of the planning horizon for this specific product, the supermarket orders 220 kg of apples at the cost of €1 per kg, which is the wholesale price. According to previous data regarding the demand for apples and the suggestion coming from the AI system, the manager expects to sell 100, 60, 40, and 20 of it at prices of €5.5, €4.5, €3.5, and €2.5 per kg for the first, second, third, and last quality periods, respectively. If everything goes based on the initial plan, the total revenue of the supermarket from selling apples during its shelf life can reach €1010 (with a profit of €790 considering a wholesale price equal to €1 per kg). The supermarket cannot reduce the amount of the order as it will lose the wholesale price, and it prefers this amount to ensure all its customers are satisfied (because of the erratic demand rate).

After the supermarket receives the batch from the supplier, we consider the assumption that the real sales to the general customers are 80, 70, 15, and 10 kg during the first, second, third, and last quality periods. So, the supermarket has an overestimation of 20, 25, and 10 for the first, third, and last periods, respectively, and it underestimates the demand by 10 kg for the second period. The supermarket manager only considers the surplus inventory if the additional amount is greater than 5 kg ($I^{M insur}_{ij} = 5$; considering $i = 1$ for apple). Accordingly, the cumulative surplus inventory of the first and third quality periods (decision points at the beginning of the second period and the beginning of the last period) equals 20 and 35 kg, respectively. If the supermarket does not redistribute the extra inventory, it will have a total revenue equal to €832.5 (a profit equal to €612.5) and 45 kg of wasted apples. Moreover, considering a waste tax rate equal to €0.5 per

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kg, its profit decreases to €590. Hereby, AI helps substantially increase the opportunity to allocate extra inventory to reduce food waste and increase social recognition.

Now, considering the redistribution strategy, the supermarket can mitigate food waste besides reducing its revenue loss due to food spoilage. The other partners implementing smart contracts include four supermarkets, three restaurants and fast-food outlets, one online store, and two charities for donations. In Table 1, we summarize the required information of all the partners regarding the inventory level and affordable prices at each of the quality levels for executing the smart contracts. This table shows that collaborating with other partners involves some complexities in terms of their expectations regarding the price and their vacant capacity for receiving surplus products from the supermarket. Moreover, some of them may not be interested in purchasing the extra inventory of low-quality products. For example, other supermarkets may prefer to purchase from other suppliers to benefit from the wholesale price rather than buying the same products from their rivals. So, they may offer prices to the core supermarket that are even lower than the wholesale price. Additionally, restaurants may refuse to buy products that are close to their expiry dates, because it affects the quality of their dishes. Considering the aforementioned points, in addition to the significant number of items we need to manage during a short time, indicates the need to adopt SFSP using new technologies with an adequate number of partners for redistributing surplus inventory immediately after recognition.

The supermarket allocates surplus inventory to other partners based on their ranking determined by price offers. In the case of identical offers, additional factors such as distance and past collaboration are considered for prioritization. Table 2 displays partners' inventory levels at the onset of quality periods 2 and 4, along with their priority based on other indicators when their price offers are comparable. According to this table, at the end of each quality period, when the core supermarket redistributes the surplus inventory, some of the partners may not have the inventory capacity for collaboration. This may be related to the erratic demands of their products. So, postponing the redistribution of the extra inventory can lead to an increased risk of a lack of collaborators during subsequent quality periods. This point emphasizes the importance of identifying the surplus inventory and deciding on it during a convenient period. Besides, it clarifies the need to have adequate partners on the SFSP to ensure there is sufficient inventory capacity for redistributing. Additionally, when prioritizing partners as recipients of surplus inventory, some may be found to have identical scores in terms of price offers. In such cases, the algorithm should consider other factors to rank them, such as transportation costs, collaboration in previous periods, and the probability of wasting the products at the destinations.

Note that the supermarket allocates donations evenly among charities, with minimum and maximum donation rates set at 10% and 20%, respectively. Additionally, a 20% discount threshold is established, wherein price offers below €4.4, €3.6, €2.8, and €2 per kg are not accepted for quality periods 1, 2, 3, and 4, respectively. Moreover, during the final period, the supermarket aims to donate the entire remaining surplus inventory to charities, recognizing that no further opportunities exist to mitigate food waste beyond this point. Then, according to the aforementioned data, we run the algorithm we discussed in Section 3.2.

Table 3 shows the outputs of the algorithm and indicates the value of the decision variables. Accordingly, at the beginning of quality period 2, the SFSP distributes the surplus inventory among other partners, with the maximum amount allocated to partners 8 and 3 based on their inventory level and ranking. Moreover, at the beginning of the last quality period, the maximum dedication

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Table 1
Purchasing price offers and the maximum inventory capacity of the partners for apples

Downstream logistics parties		Price offers (euros per kg)				Maximum storage capacity (kg)			
		Period 1	Period 2	Period 3	Period 4	Period 1	Period 2	Period 3	Period 4
Other supermarkets	Partner 1	4.8	3.8	2.5	–	15	13	4	–
	Partner 2	4.6	4.05	3	1.9	10	8	6	4
	Partner 3	4.4	3.9	3.1	1.5	18	14	12	3
	Partner 4	4.5	3.7	2.9	2.3	14	9	5	2
Restaurants and fast Foods	Partner 5	4.9	3.8	3.2	–	9	8	4	–
	Partner 6	4.3	3.75	2.8	–	10	6	4	–
	Partner 7	4.7	3.2	3.2	–	14	11	8	–
Online market	Partner 8	4.5	4.1	2.8	2.3	30	18	14	10
Charities	Partner 9	–	–	–	–	18	14	12	8
	Partner 10	–	–	–	–	20	14	10	7

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Table 2
Inventory level of partners and prioritizing them in the case of similar price offers

Downstream logistics parties		Inventory level at the beginning of periods (kg)		Ranking (excluding price offers)	
		Period 2	Period 4	Period 2	Period 4
Other supermarkets	Partner 1	6	–	8	–
	Partner 2	5	1	1	3
	Partner 3	8	0	7	4
	Partner 4	6	0	3	2
Restaurants and fast foods	Partner 5	2	–	2	–
	Partner 6	3	–	5	–
	Partner 7	6	–	6	–
Online market	Partner 8	8	1	4	1
Charities	Partner 9	5	1	–	–
	Partner 10	6	2	–	–

Table 3
Outputs of running the algorithm for redistributing surplus inventory

Downstream logistics parties		Agreements (kg)	
		Period 2	Period 4
Other supermarkets	Partner 1	–	–
	Partner 2	3	–
	Partner 3	5	–
	Partner 4	–	2
Restaurants and fast foods	Partner 5	–	–
	Partner 6	–	–
	Partner 7	–	–
Online market	Partner 8	10	9
Charities	Partner 9	1	2
	Partner 10	1	2

is related to the online store. In the second period, there are more partners to distribute the extra inventory and, accordingly, the donation amount is lower than in the last period. The increment in donations is also related to the characteristic of the last period, after which there is no chance of redistribution, and the remaining products will be wasted. So, the supermarket considers the maximum possible donation at this stage. However, as the partners are not interested in products of lower quality, and charities have a limited capacity for products close to their expiry date, a part of the product is wasted at the end of the fourth period. This reveals the importance of having plans for surplus inventory when it is of better quality and finding a sufficient number of partners to decrease the risk of wasting food in the final period.

Furthermore, the supermarket donates 6 kg to charities through the SFSP. In this numerical example, after implementing the preventive strategy, the total revenue increases from €832.5 to €931.45, with the profit increasing from €590 to €711.45, considering waste tax $V_t = €0.5$ per kg and the social value of donations $V_s = €1$ per kg. The waste tax is related to the fine that

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Table 4
Comparing the outputs of the numerical example for different scenarios

	Traditional waste management system without SFSP	SFSP with AI, blockchain, and smart contracts	SFSP with AI, blockchain, and smart contracts, including donations
Total revenue (euro)	832.5	923.45	931.45
Total profit (euro)	590	703.45	711.45
Total waste (kg)	45	14	10
Donations (kg)	–	–	6
Waste tax (euro)	22.5	7	5
Social value (euro)	–	–	6

governments and municipalities define to mitigate food waste aiming to overcome its negative environmental impacts due to the addition of methane in landfills and the emissions related to waste transportation. The social value is related to the positive impact that social responsibilities such as donations have on the brand image of supermarkets and, in the long term, it affects their revenue by increasing the number of loyal customers and sales. In other words, we can interpret V_s as the average revenue per kg donation that in the long term the supermarket gains by increasing its total sales. Additionally, social responsibility improves the relationships between partners and enhances community engagement, leading to an increase in the overall value proposition of the FSC.

In this example, the food waste is reduced from 45 to 10 kg. Accordingly, Table 4 compares the main outputs of the numerical example for three different conditions: without SFSP, implementing SFSP without donations, and implementing SFSP with donations. The results show that not only does the waste management system help increase profit and reduce total waste, but donations as a social responsibility can decrease food waste and improve the supermarkets' profits. Moreover, the economic gains related to environmental targets and food waste reduction are greater than the economic advantages of social sustainability, such as donations. However, social activities related to donations can improve the connection between organizations and society to improve their brand awareness.

Furthermore, the long-term usage of SFSP helps to better understand the inventory circulation among different partners. Then, by analyzing the inventory and financial flows, the system can improve itself by reducing surplus inventory and mitigating the risk of food spoilage. Besides, by extending the network and collaborating with more partners, such as nonprofit organizations and charities, the platform can be more effective in terms of improving social sustainability aspects. In addition, extending the SFSP to other parts of the food value chain reduces food waste in different stages of the supply chain and, consequently, mitigates environmental issues like carbon emissions.

5. Advantages of a smart food-sharing platform

In this section, we develop three scenarios to highlight the benefits of implementing an SFSP. Specifically, we model the following situations:

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Scenario 1: Traditional waste management system without AI, blockchain, and smart contracts. In this scenario, the supermarket implements a traditional waste-management system in which the quality is determined by operators who manage inspections manually and visually, without the support of digital technologies. Prices are determined through traditional agreements between the supermarket and other parties, without considering demand patterns. In this scenario, the supermarket owner is overwhelmed by having to manage too many items before they are wasted at the end of their shelf life. The lack of adopting an SFSP causes many challenges, such as identifying surplus inventories, finding proper partners for each item, negotiating prices, and redistributing, which leads to more food waste and revenue loss compared to other scenarios.

Scenario 2: SFSP with AI, blockchain, and smart contracts. In this scenario, the supermarket transitions from a traditional to a smart food waste-management system by implementing an SFSP with AI to detect food quality over time and decide whether to sell it in the supermarket to other players or to keep it in stock for future periods. Transactions with other players are managed through smart contracts that collect information from the AI system and update contractual terms. All transactions are recorded on the blockchain. So, in this scenario, the sharing platform facilitates collaboration among different partners to automatically redistribute the surplus inventory during convenient periods and at reasonable times. The smart sharing platform will also increase the chance of finding more collaborators and reduce the risk of wasting food because of the limited capacity of the partners. SFSP works as a trustworthy tool with a high level of traceability and agility in implementing smart contracts.

Scenario 3: SFSP with AI, blockchain, and smart contracts, including donations. In addition to Scenario 2, Scenario 3 uses information recorded in the blockchain to create social awareness and effectively communicate the supermarket's contributions to society. This creates indirect benefits, as the ecosystem recognizes the social value created by the supermarket and has evidence of this value by accessing information on public blockchain systems. By implementing this scenario, the supermarket not only benefits from all the advantages the SFSP provides in the previous scenario but also improves its social sustainability performance by donating a part of the surplus inventory as its social responsibility. In this case, the SFSP offers more opportunities to find social partners, such as charities, and circulate appropriate information about their need for donations. This enhances the brand awareness of the supermarket as an indirect advantage, besides helping to mitigate food waste and, accordingly, waste tax.

The analysis displayed in Table 4 suggests that while adopting technologies such as AI, blockchain, and smart contracts can bring substantial economic benefits to firms by reducing food waste, the same cannot be said for social initiatives such as donating surplus inventory to charities. In fact, the transition from Scenario 1 to Scenario 2 yields substantial improvements in both total revenues and total profits, showcasing the significant impact of implementing SFSP with AI, blockchain, and smart contracts. However, moving from Scenario 2 to Scenario 3, the enhancements are relatively minor, indicating that the addition of donations does not lead to significant further economic gains. Specifically, the total revenue from Scenario 2 to Scenario 1 indicates a 10.89% increase, for example, [(923.45 − 832.5) / 832.5], while the shift from Scenario 3 to Scenario 2 shows an increase of 0.86%, for example, [(931.45 − 923.45) / 923.45]. Similarly, total profit

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results increase by 19.29% when moving from Scenario 2 to Scenario 1, for example, [(703.45 − 590) / 590] and by 1.14% when moving from Scenario 3 to Scenario 2 [(711.45 − 703.45) / 703.45].

A similar discussion can be pursued for food waste and waste tax: the transition from Scenario 2 to Scenario 3 reveals relatively minor improvements, suggesting that the addition of donations has little impact on reducing them. For instance, total waste decreases by 68.89% when moving from Scenario 1 to Scenario 2, for example, [(45 − 14) / 45], while the shift from Scenario 1 to Scenario 3 shows a 77.78% reduction, which is negligible compared to the impact of Scenario 2. This clearly translates into lower taxes when using SFSP only to reduce waste.

Our results demonstrate that while the implementation of advanced technologies in Scenario 2 leads to significant reductions in total waste and waste tax and a significant increase in profits and revenues, the addition of donations in Scenario 3 contributes only marginally to further reductions in these areas. There are several reasons why social donations may not bring significant economic advantages. Donating surplus inventory can incur various atypical direct costs for a firm, exemplified by transportation, handling, and administration, as well as some indirect costs linked to the opportunity costs: not selling those products at their full price results in a direct loss of potential revenue and, although donations to charities may offer tax deductions, the financial benefit from these deductions may not entirely offset the value of the donated inventory.

Moreover, the next challenge for firms will be bonding social responsibility and environmental sustainability goals alongside economic objectives. In such cases, the decision to donate surplus inventory may be motivated more by ethical considerations and corporate social responsibility than purely economic factors, which need to be appropriately communicated, perceived by the stakeholders, and evaluated by society as a whole. More specifically, firms that seek to reduce food waste using smart systems should link their results to *SDG1: No poverty* and *SDG 2: Zero hunger*. Nowadays, roughly a third of the world's food is wasted, and supermarkets are responsible for a significant portion of food waste globally. Moreover, the rapid increase in the world's population could soon be too big to feed itself, a fact that is likely to affect poverty in terms of food prices adversely. So, food waste management programs at supermarkets such as the SFSP can have a positive impact on reducing food spoilage, food scarcity, food prices, and poverty. Currently, societies are wasting a third of food despite the fact that there are parts of the world in which people are struggling with hunger, malnutrition, and starvation. So, besides SFSP's aim of moving toward sustainable agriculture development, it is also a potential means of mitigating hunger.

Similarly, all players around the FSC should pursue *SDG 17: Partnerships for the goals*. The latter strengthens the need to revitalize global partnerships to ensure sustainable development and efficient food-waste management. Accordingly, SFSP with AI and blockchain-based smart contracts can facilitate collaboration among different partners in the global FSC. Implementing this technology and strategy at supermarkets by involving downstream logistics partners can be developed into other steps of the FSC aiming to mitigate food waste at all stages of the global value chain, thus leading to *SDG 12: Responsible consumption and production*. Finally, firms in the FSC need to be supported by a well-functioning infrastructure (e.g., AI and blockchain require 5G technology to work properly) as well as contributions from all players, such as restaurants, online shops, and nonprofit organizations. Therefore, firms can render smart food-waste management effective only when pursuing *SDG 9: Industry, innovation, and infrastructure* and *SDG 11: Sustainable cities and communities*.

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6. Conclusions

This paper develops a model for adopting an SFSP at supermarkets using such new technologies as blockchain, AI, and smart contracts. The model allows SFSP to make a decision about redistributing the surplus inventory of perishable products to partners downstream of the food value chain, which can be given by other supermarkets, minimarkets, restaurants, online stores, and charities for donations. Redistribution serves as a preventive strategy to mitigate food waste from supermarkets. However, the decision about redistribution has to be made by the supermarket owner prior to inventory expiration, which is complex given the varied range of products with their respective shelf life. An SFSP, with blockchain-based smart contracts, fosters trust among partners and automates redistribution agreements, necessitating precise policies and rules based on data collected through sensors, IoT, and blockchain oracles on quality, expiration dates, prices, donation rates, demand rates, etc. AI is then essential to manage this complexity and update smart contract clauses when situations change. For example, in the event of rapid quality deterioration linked to a malfunctioning refrigeration system in a warehouse.

Considering all these factors, our analysis demonstrates that identifying surplus inventory during the initial stages (initial quality periods) increases the likelihood of distribution before expiration, thereby improving profit, reducing food waste, enhancing social sustainability through donation programs, and reducing energy consumption and greenhouse gas emissions. However, it highlights the challenges that social sustainability can entail for firms. While the adoption of SFSP with AI, blockchain, and smart contracts creates important advantages for firms aiming exclusively to reduce food waste, the economic advantages for such firms can be significantly high. Nonetheless, when social targets (exemplified by donating surplus inventory to charities) are implemented, the economic advantages for firms are less significant.

Overall, our study reveals the importance of adopting B2B SFSP to manage surplus inventory by redistributing it among other partners. SFSPs can help overcome the challenges related to the profound number of perishable items, time shortage, and collaboration by automating all processes, from identifying extra inventory to reaching agreements between parties and dedicating the products. This smart platform also facilitates collaboration among partners to ensure there is enough inventory capacity to redistribute products before they are wasted. Otherwise, finding partners and negotiation procedures will be time-consuming without a significant result in food-waste reduction. Moreover, SFSP improves social sustainability performance by engaging different nonprofit organizations, such as charities, for donation programs. Besides, collaboration in donating a part of surplus inventory can mitigate food waste when there is no capacity or interest from other partners to redistribute all surplus inventory. So, SFSP, with AI, blockchain, and smart contracts, is an agile and trustworthy tool for developing new initiatives to overcome food waste in organizations such as supermarkets.

This research and the related model formulations are based on some assumptions that can inspire future research to continue contributing to this framework. First, developing a model for other stages of the FSC and considering upstream partners can provide a more comprehensive analysis. For instance, the impact of adopting SFSP on order decisions and the relationships between the supermarkets and their suppliers can be an interesting topic to extend the usage of this platform to other stages of the food value chain. In fact, future research can build networks in the FSC that look into the implementation of SFSP with AI, blockchain, and smart contracts to reduce food

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waste and create social value. Second, devising algorithms considering additional parameters (e.g., packaging, ordering periods, tax rates for wasted products) can address more complex conditions. Third, while this study focuses on blockchain and AI, exploring other technologies such as drones and the metaverse for simulating and transferring products can be valuable. Finally, this model can be validated empirically using real data and highlighting the amplitude of the benefits firms and supply chains can obtain when dealing with smart food waste reduction.

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References

Ahmad, R. W., Salah, K., Jayaraman, R., Yaqoob, I., & Omar, M., 2021. Blockchain for waste management in smart cities: A survey. *IEEE Access* 9, 131520–131541.

Akkas, A., & Honhon, D., 2023. Determining maximum shipping age requirements for shelf life and food waste management. *Production and Operations Management* 32, 7, 2173–2188.

Amaral, D. G., & Orsato, R. J., 2023. Digital platforms for food waste reduction: the value for business users. *Business Strategy and the Environment* 32, 4, 1373–1387.

Aschemann-Witzel, J., Randers, L., & Pedersen, S., 2023. Retail or consumer responsibility?—Reflections on food waste and food prices among deal-prone consumers and market actors. *Business Strategy and the Environment* 32, 4, 1513–1528

Belavina, E., 2021. Grocery store density and food waste. *Manufacturing & Service Operations Management* 23, 1, 1–18.

Beullens, P., & Ghiami, Y., 2022. Waste reduction in the supply chain of a deteriorating food item–Impact of supply structure on retailer performance. *European Journal of Operational Research* 300, 3, 1017–1034.

Cicatiello, C., Franco, S., Pancino, B., & Blasi, E., 2016. The value of food waste: an exploratory study on retailing. *Journal of Retailing and Consumer Services* 30, 96–104.

De Giovanni, P., 2019. Digital supply chain through dynamic inventory and smart contracts. *Mathematics* 7, 12, 1235.

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De Giovanni, P., 2020. Blockchain and smart contracts in supply chain management: a game theoretic model. *International Journal of Production Economics* 228, 107855.

De Giovanni, P., 2021. A dynamic supply chain game with vertical coordination and horizontal competition. *International Transactions in Operational Research* 28, 6, 3117–3146.

De Giovanni, P., 2024. The modern meaning of "quality": analysis, evolution and strategies. *The TQM Journal* 36, 9, 309–327.

Eriksson, M., & Spångberg, J., 2017. Carbon footprint and energy use of food waste management options for fresh fruit and vegetables from supermarkets. *Waste Management* 60, 786–799.

Eriksson, M., Strid, I., & Hansson, P. A., 2015. Carbon footprint of food waste management options in the waste hierarchy–a Swedish case study. *Journal of Cleaner Production* 93, 115–125.

Farhangi, M., Niaki, S. T. A., & Maleki Vishkaei, B., 2015. Closed-form equations for optimal lot sizing in deterministic EOQ models with exchangeable imperfect AC quality items. *Scientia Iranica* 22, 6, 2621–2633.

Freitas, M. D. F., de Almeida Oroski, F., & Alves, F. C., 2024. Food waste-reducing platforms: unpacking the barriers and strategies to their implementation in Brazil. *Journal of Material Cycles and Waste Management* 16, 1690–1703.

Filimonau, V., & Gherbin, A., 2017. An exploratory study of food waste management practices in the UK grocery retail sector. *Journal of Cleaner Production* 167, 1184–1194.

França, A. S. L., Neto, J. A., Gonçalves, R. F., & Almeida, C. M. V. B., 2020. Proposing the use of blockchain to improve the solid waste management in small municipalities. *Journal of Cleaner Production* 244, 118529.

Ganguly, S., & Robb, D. J., 2022. An analytical model to characterize consumption and wastage of fresh fruit and vegetables in households. *European Journal of Operational Research* 300, 1, 151–163.

Hasan, H. R., Salah, K., Jayaraman, R., Ahmad, R. W., Yaqoob, I., & Omar, M., 2020. Blockchain-based solution for the traceability of spare parts in manufacturing. *IEEE Access* 8, 100308–100322.

Horoś, I. K., & Ruppenthal, T., 2021. Avoidance of food waste from a grocery retail store owner's perspective. *Sustainability* 13, 2, 550.

Hu, K., Zhu, J., Ding, Y., Bai, X., & Huang, J., 2020. Smart contract engineering. *Electronics* 9, 12, 2042.

Kör, B., Krawczyk, A., & Wakkee, I., 2022. Addressing food loss and waste prevention. *British Food Journal* 124, 8, 2434–2460.

Kutyauripo, I., Rushambwa, M., & Chiwazi, L., 2023. Artificial intelligence applications in the agrifood sectors. *Journal of Agriculture and Food Research* 11, 100502.

Lee, K. C., 2018. Grocery shopping, food waste, and the retail landscape of cities: The case of Seoul. *Journal of Cleaner Production* 172, 325–334.

Li, K., Lee, J. Y., & Gharehgozli, A., 2023. Blockchain in food supply chains: A literature review and synthesis analysis of platforms, benefits and challenges. *International Journal of Production Research* 61, 11, 3527–3546.

Ma, S., Dan, B., Li, M., & Zhou, M., 2023. To be traceable and responsive: blockchain adoption and information sharing in a fresh produce supply chain. *International Transactions in Operational Research* 31, 6, 4174–4198.

Mahroof, K., Omar, A., & Kucukaltan, B., 2022. Sustainable food supply chains: overcoming key challenges through digital technologies. *International Journal of Productivity and Performance Management* 71, 3, 981–1003.

Mattila, M., Mesiranta, N., & Heikkinen, A., 2020. Platform-based sustainable business models: REDUCING food waste in food services. *International Journal of Entrepreneurship and Innovation Management* 24, 4–5, 249–265.

Mazzucchelli, A., Gurioli, M., Graziano, D., Quacquarelli, B., & Aouina-Mejri, C., 2021. How to fight against food waste in the digital era: key factors for a successful food sharing platform. *Journal of Business Research* 124, 47–58.

Michelini, L., Grieco, C., Ciulli, F., & Di Leo, A., 2020. Uncovering the impact of food sharing platform business models: a theory of change approach. *British Food Journal* 122, 5, 1437–1462.

Moser, C., 2020. Managerial practices of reducing food waste in supermarkets. In *Food Waste Management: Solving the Wicked Problem*. Palgrave Macmillan, Cham, pp. 89–112.

Muñoz, P., & Cohen, B., 2017. Mapping out the sharing economy: a configurational approach to sharing business modeling. *Technological Forecasting and Social Change* 125, 21–37.

Nadeau, N., & Koebele, E. A., 2023. Collaborating to reduce food waste: building collaborative advantage in local food systems. *Renewable Agriculture and Food Systems* 38, e32.

Onyeaka, H., Tamasiga, P., Nwauzoma, U. M., Miri, T., Juliet, U. C., Nwaiwu, O., & Akinsemolu, A. A., 2023. Using artificial intelligence to tackle food waste and enhance the circular economy: maximising resource efficiency and minimising environmental impact: a review. *Sustainability* 15, 13, 10482.

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Özbük, R. M. Y., & Coşkun, A., 2020. Factors affecting food waste at the downstream entities of the supply chain: a critical review. *Journal of Cleaner Production*, 244, 118628.

Pakseresht, A., Yavari, A., Kaliji, S. A., & Hakelius, K., 2023. The intersection of blockchain technology and circular economy in the agri-food sector. *Sustainable Production and Consumption* 35, 260–274.

Rana, R. L., Tricase, C., & De Cesare, L., 2021. Blockchain technology for a sustainable agri-food supply chain. *British Food Journal* 123, 11, 3471–3485.

Rejeb, A., Keogh, J. G., Zailani, S., Treiblmaier, H., & Rejeb, K., 2020. Blockchain technology in the food industry: a review of potentials, challenges and future research directions. *Logistics* 4, 4, 27.

Richards, T. J., & Hamilton, S. F., 2022. Inventory management and loss in beer retailing. *Agribusiness* 38, 3, 461–485.

Sadraei, R., Biancone, P., Lanzalonga, F., Jafari-Sadeghi, V., & Chmet, F., 2023. How to increase sustainable production in the food sector? Mapping industrial and business strategies and providing future research agenda. *Business Strategy and the Environment* 32, 4, 2209–2228.

Sanders, R. E., 2024. Dynamic pricing and organic waste bans: a study of grocery retailers' incentives to reduce food waste. *Marketing Science*. 43, 2, 289–316.

Scholz, K., Eriksson, M., & Strid, I., 2015. Carbon footprint of supermarket food waste. *Resources, Conservation and Recycling* 94, 56–65.

Vishkaei, B. M., Pasandideh, S. H. R., & Farhangi, M., 2014. The %1 100 screening economic order quantity model under shortage and delay in payment. *Scientia Iranica* 21(6), 2429–2435.

Yang, C., Feng, Y., & Whinston, A., 2022. Dynamic pricing and information disclosure for fresh produce: an artificial intelligence approach. *Production and Operations Management* 31, 1, 155–171.

Xie, R., Zhang, Y., Luo, H., Yu, P., & Chen, Z., 2023. Optimizing decisions for post-harvest ripening agricultural produce supply chain management: a dynamic quality-based model. *International Transactions in Operational Research* 30, 6, 3625–3653.

Zhou, Y., Fu, Y., Wang, K., Min, J., & Zhang, X., 2024. Competition in the online platform: impacts of blockchain technology adoption. *International Transactions in Operational Research* 31, 6, 4105–4127.

Environmental Protection Agency. 2018. 2018 Wasted food report. https://www.epa.gov/sites/default/files/2020-11/documents/2018_wasted_food_report-11-9-20_final_.pdf (accessed 14 February 2024).

World Food Programme. 2020. 5 facts about food waste and hunger. https://www.wfp.org/stories/5-facts-about-food-waste-and-hunger (accessed 29 April 2024).

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