Proceedings of the 5th European International Conference on Industrial Engineering and Operations Management
Rome, Italy, July 26-28, 2022

Blockchain-based Smart Contracts for Sustainable Food Waste Management and Collaborations

Behzad Maleki Vishkaei and Pietro De Giovanni
Department of Business and Management
LUISS University, Rome, Italy
bmalekivishkaei@luiss.it, pdegiovanni@luiss.it

Abstract

Food waste is a significant problem in modern society. It is well documented that about one-third of the food produced globally is lost or wasted, harming the firms' economic, environmental, and social sustainability. This problem is evident in supermarkets and restaurants, which are the most important wasters after households and agriculture. In most cases, supermarkets use new technologies to manage expiry dates, tackle food waste via implementing dynamic pricing and encourage customers to buy near-to-expired over fresher products. However, these practices are not sufficient to guarantee the achievement of sustainability. Supermarkets need to cooperate with more parties such as their counterparts (other supermarkets), restaurants, online selling platforms, fertilizer producers, and charities besides their general customers. This study introduces a framework that uses blockchain-based smart contracts to manage the cooperation between supermarkets and other parties with the goal of reducing food waste and seeking to achieve sustainable targets. A smart contract is an appealing feature of blockchain technology to facilitate and automatically execute the terms of an agreement once the specified conditions are met. We analyze the benefits that a smart contract grants to supermarkets to manage food waste in a sustainable way.

Keywords
Food Waste, Blockchain, Smart Contract, and Supermarkets.

1. Introduction
Food waste leads to significant environmental impact in terms of inefficient use of natural resources as well as an economic cost and also social and moral implications (Mattsson et al. 2018). Although 795 million people suffer from undernourishment, it is estimated that almost one-third of the food produced for human consumption is lost or wasted globally. So, it is an issue of importance to global food security (FAO 2011; FAO 2015). Food production causes greenhouse gas emissions along the entire food supply chain and wasting food means that those emissions are produced in vain (Scholz et al. 2015). Figure (1) estimates the percentage distribution of wasted food generation in the United States excluding the industrial sector based on the report of the U.S. Environmental Protection Agency (EPA). The supermarkets have a share of 14% in generating food waste which is noticeable. For supermarkets, there is a need for a change in waste management methods.

A regular way to manage defective items is selling them at a lower price which most the retailers are using considering the salvage value per defective item (Vishkaei et al. 2014; Maleki Vishkaei et al. 2014; Farhangi et al. 2015). Moreover, there are various types of traditional inventory control models that consider assumptions such as discounts and destructive testing acceptance sampling that are beneficiary for managing inventory levels (Pasandideh et al. 2014; Maleki Vishkaei et al. 2019). One of the food waste reduction practices is a collaboration with external partners, including restaurants and food banks. Those partners source from the supermarket's products that the supermarkets are unwilling to sell anymore, for two reasons. The first reason is that the products might almost have reached their expiration date and spoil, and they might look not quite perfect anymore. The second reason is that there might be too much stock in the store to be sold before the products reach their expiration date. But, collaborating with external partners usually leads to additional work for the managers (Moser 2020). Moreover, a collaboration between different parties including supermarkets, restaurants, small food services, and even consumers makes the operational activities become more complex (Almeida Oroski 2020). Using new technologies such as smart contracts can be helpful to manage these issues.

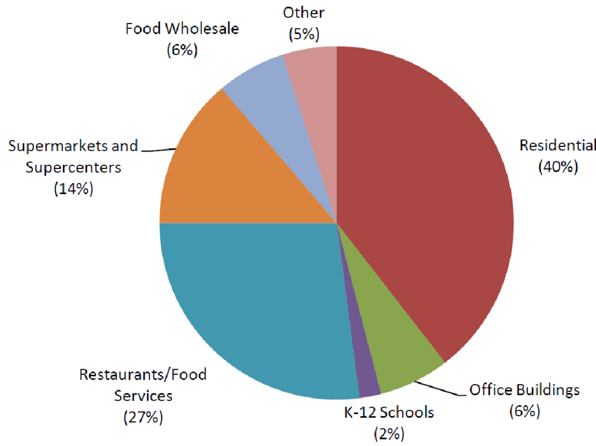

Figure 1. Percentage Distribution of Wasted Food Generation, Excluding the Industrial Sector (based on the report of Environmental Protection Agency, 2018)

The blockchain can carry out smart wholesale price contracts and Artificial Intelligence (AI) determines the best wholesale price to finalize the transactions. Blockchain technology determines the right amount to be shared among the firms, generating a smart contract (De Giovanni 2020a). Artificial intelligence uses centralized solutions to identify the best contract clauses to be used by the firms. The blockchain allows the complexity of smart contracts to be managed such that firms can easily use digitalization in their transactions (De Giovanni 2019). A smart contract is an executable code that runs on the blockchain to facilitate, execute and enforce the terms of an agreement between untrusted parties.

Once the pre-defined rules have been met, the system releases digital assets to all or some of the involved parties with lower transaction fees compared to traditional systems that require a trusted third party to enforce and execute the terms of an agreement (Alharby and Van Moorsel 2017). Smart contracts represent programs stored on the blockchain with terms of the agreement between participants of waste management processes. They automatically execute and trigger events after meeting predetermined criteria in the agreement. Also, they assist the stakeholders in performing business operations in a faster, cheaper, and more secure way compared to traditional systems that require intermediaries to commit to the business operations (Ahmad et al. 2021). Blockchain generates smart contracts according to the real strategies that each member sets; thus, it offers an opportunity to incentivize firms to behave cooperatively and make the interests of the whole partners (De Giovanni 2020b).

1.1 Objectives
The aim of this study is to analyze using smart contracts to improve collaboration between the supermarket and other parties such as minimarkets, restaurants, online stores, and charities with the goal of reducing food waste and increasing the profit of the supermarket. So, this study tries to answer the following questions:

- Can smart contracts be helpful for food waste management at supermarkets?
- How does the supermarket should take care of the shelf-life periods of the products?
- When does the supermarket need to make decisions regarding the surplus inventory?
- What rules should be considered for executing the agreements using smart contracts?

2. Literature Review
Waste, loss, or spoilage of food is an efficiency issue that has attracted increasing attention from the media, researchers, politicians, companies, and the general public in recent years. Food waste is not just a problem, but also a solution to other problems, such as public health or economic profit, and the complexity of the food waste issue also links it to the three parts of sustainable development: economics, social issues, and environmental impact. Supermarkets represent an important link between producers and consumers, with potential influence over large parts of the food supply chain (Eriksson 2015).

There are good articles that investigated food waste problems and issues. Cicatiello et al. (2016) measured the extent of food waste in retailing as well as its environmental, social, and economic value. Brancoli et al. Eriksson et al. (2015) investigated and compared the effect on greenhouse gas emissions of different food waste management scenarios representing different levels in the waste hierarchy in the city of Uppsala, Sweden.

They performed a life cycle assessment for six waste management scenarios including landfill, incineration, composting, anaerobic digestion, animal feed, and donations. Brancoli et al. (2017) analyzed the impacts of food waste at a supermarket in Sweden to investigate which waste fractions have the largest environmental impacts and what part of the waste life cycle is responsible for the majority of the impacts. Tonini et al. (2018) developed a bottom-up life cycle assessment method to quantify the environmental impacts of the avoidable food waste generated by four sectors of the food supply chain in the United Kingdom, namely processing, wholesale and retail, food service, and households. Marrucci et al. (2020) studied a new waste management system in the supermarket highlighting the importance of recycling, particularly in the context of the circular economy. They focused on organic matter, as the category producing the most waste and compared composting and anaerobic digestion. Özbük and Coşkun (2020) provided a critical systematic review that aims to identify the potential causes of food waste at the downstream entities of the food supply chain and provides a coherent and integrated knowledge basis of these factors.

A preventive strategy for food waste is redistribution. The redistribution of food is not always successful due to small amounts of food surpluses and misunderstandings amongst the parties. For the store owners, it can be difficult to manage the redistribution on time, especially for highly perishable products. Such practices require intensive communication and exchange between the two parties, which is more difficult to achieve for larger retail chains or for retailers with a greater physical distance to food banks (Horoś and Ruppenthal 2021). Smart contracts utilize protocols and user interfaces to facilitate all steps of the contracting process, which almost obviates the ambiguity of contractual clauses in text or their implementation. Smart contracts aim to reduce transaction costs imposed by principals, third parties, or the tools of transactions (Hu et al. 2020). The contract layer makes the blockchain programmable and enables the inclusion of different scripts, smart contracts, and algorithms with the help of which complex transactions can be carried out on the blockchain (Alladi et al. 2020).

The core of smart contracts is algorithm contracts, that is, the parties reach an agreement on the contents of the contract and perform the contracts according to the behaviors written in certain computer algorithms (Bai et al. 2018). Furthermore, blockchain smart contracts can offer programmability to ensure the execution of business logic with ordered execution of transactions according to a predefined set of rules and policies, in a way that is open and trusted by all actors and organizations who are interacting with the blockchain network (Hasan et al. 2020). Smart contracts have several advantages including reducing risks, cutting down administration and service costs, and improving the efficiency of business processes (Zheng et al. 2020).

Although there has been much discussion on food waste, to the best of our knowledge, there is no research that analyses using smart contracts to provide an agile decision-making system about the surplus inventory and food waste at supermarkets. This study aims to devise some rules to reach agreements (using smart contracts) between the supermarket and the other parties including minimarkets, restaurants, online stores, and charities (for donation) to reduce food waste as well as to decrease the lost income of the supermarket because of unsold foods.

3. Model Description

Consider a supermarket that buys the products from its suppliers based on its prediction regarding the selling amounts during the shelf lives of the products. The Supermarket usually buys the goods more than a specific amount from the suppliers to benefit from the wholesale price and reduce the transportation cost. The selling periods of each product are categorized based on the quality of the items in terms of the number of remaining days before their expiration date. For instance, consider the shelf life of a product is four weeks and it is divided into four periods with the length of one week. In other words, the supermarket divides the shelf life of the product into four quality levels. The highest quality level with the highest selling price belongs in the first week and the quality of the proposed product will reduce during the remaining weeks. The second and third quality levels belong to the second and third weeks respectively and the supermarket considers the lowest quality level for the last week with the lowest selling price.

The error in selling prediction may result in food waste in the supermarket. To avoid waste, the supermarkets usually offer more discounts for the products that are near their expiration dates or donate them. Despite using these strategies, a huge amount of food is being wasted in supermarkets each year. It seems that they need better strategies to avoid food waste as well as sales losses. One of the main reasons that the supermarkets cannot decide quickly about the surplus products is that there are many types of products in a supermarket and deciding regarding the surplus inventories based on the selling rates and the expiry dates is time-consuming. Therefore, automating this process using the new technologies and smart contracts can be helpful for the supermarkets to act more agile regarding the surplus inventory before that they are wasted. Moreover, they can cooperate with more organizations and partners to minimize food waste by deciding about the surplus inventory at the least time.

Figure (2) shows an example of a supermarket that purchases a product such as apples at wholesale price from the supplier and divides the shelf life of the product into n periods (considering n quality levels for the product). The product has the highest quality during the quality period 1 and has the lowest quality in the quality period n. If it cannot sell the products before the end of period n, the remaining products will be wasted. The supermarket has a prediction regarding the amount of product that it can sell during each quality period. So, at the end of each period (at the beginning of the next period), it needs to make a decision about the surplus inventory.

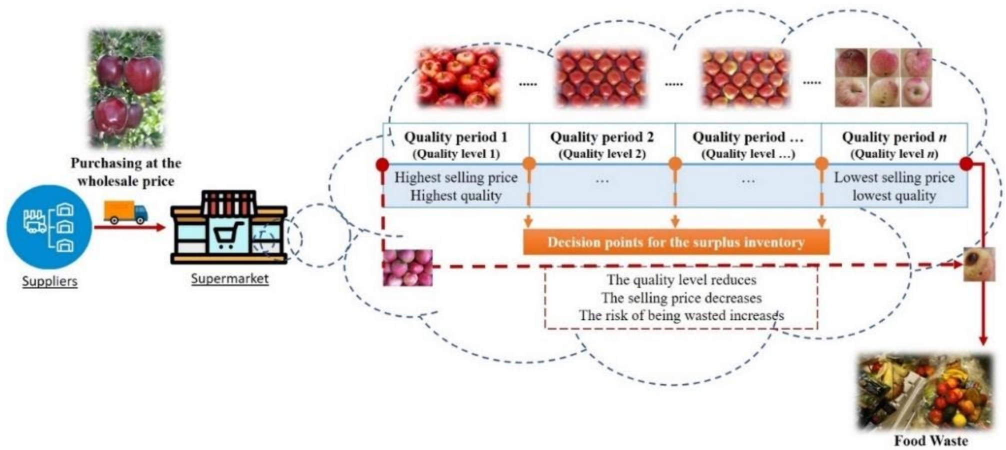

Figure 2. An example for selling a product at a supermarket considering different quality levels.

To decide about the surplus inventory, the supermarket can cooperate with other parties using the new technologies including smart contracts. There are other supermarkets or minimarkets in the region that may be interested to buy the surplus inventory with a specific quality level. This is the same for the restaurants and fast-food shops that are looking to buy their materials from the supermarket at a reasonable price. Moreover, the supermarket can also cooperate with an online store that provides the products with different levels of quality considering discounts. It also can cooperate with charities or donation platforms to donate a part of the extra food to people who really need them.

Figure 3 indicates the cooperation between the supermarket and other parties regarding the surplus inventory considering blockchain and smart contracts for executing agreements between them based on various data including the expiration date, morality, price, and priority. Automating the process of selling the surplus inventory helps to transfer them in an agile way before losing the quality and being wasted at the supermarket. It also helps supermarkets increase their profit instead of having wasted products at the end of the evaluation period.

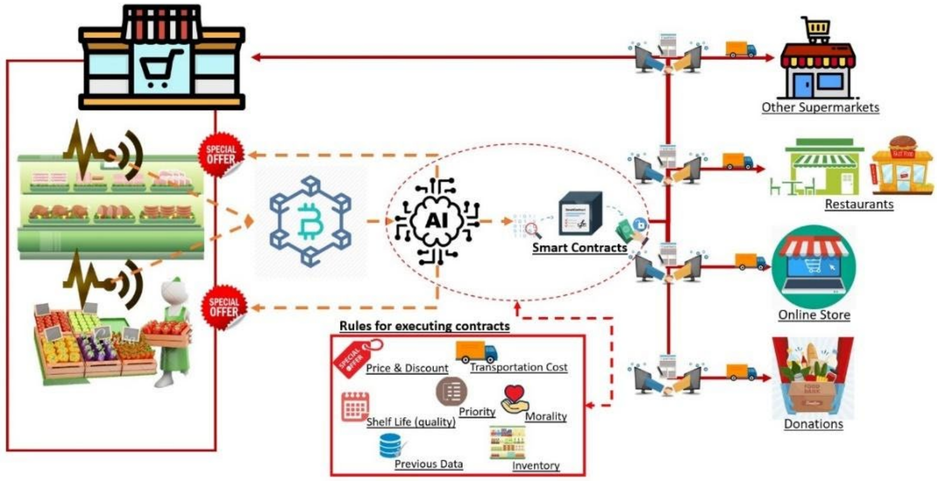

Figure 3. Using smart contracts for executing agreement regarding the surplus inventories.

There is no doubt that being agile about making the right decision for the surplus inventory especially for the products that have a shorter shelf life can help to reduce the food waste in supermarkets and using smart contracts is a good solution to achieve this goal. But for implementing this platform that connects different partners together for selling the surplus inventory requires accurate rules that should be defined to automate the execution of agreements between them considering various situations. To define the proposed rules, the following questions should be answered about the supermarket and the other partners:

- When is the proper time for selling the surplus inventory?
- At which level the inventory of a product is considered surplus?
- At which level of inventory and at which price do other partners need to make an order?
- When should the supermarket donate the extra products and how much should be considered?
- What is the priority of the supermarkets to sell the surplus inventories to their partners?
- How the revenue of the supermarkets and the other partners should be considered?

To answer the proposed questions, we need to define some parameters that indicate the inventory levels, selling price, purchasing price, quality of the products, and the decision periods. The parameters and decision variables are described in Table (1).

4. Model Formulation

This section formulates the mathematical model for deciding about the surplus inventory at the beginning of each quality period. The supermarket pays the supplier for buying product *i* which equals $c_i D_i$ and anticipates to sell them during the quality period *j* with the price s_{ij} and the quantity P'_{ij} which leads to a revenue $s_{ij} P'_{ij}$. So, the total revenue that the supermarket anticipates for the predefined evaluation period equals the following equation.

$$TR' = \sum_{\forall i} \sum_{j=1}^{n_i} s_{ij} P'_{ij} - \sum_{\forall i} c_i D_i \qquad (1)$$

Considering equation (1) for a specific product (product *i*), the equation can be revised as follows.

$$TR'_i = \sum_{j=1}^{n_i} s_{ij} P'_{ij} - c_i D_i \qquad (2)$$

This equation can be calculated for a specific quality period such as *j* as follows.

$$TR'_{ij} = s_{ij} P'_{ij} - c_i D_i \qquad (3)$$

In equation (1), the first term calculates the total income that the supermarkets predict to gain from the sale of products, and the second term is related to the total cost that the supermarket pays to the supplier. Equation (4) can be used to calculate the real profit of the supermarket based on the amounts that it sells to different partners.

$$TR = \sum_{\forall i} \sum_{j=1}^{n_i} s_{ij} Q_{ij} + \sum_{\forall k} \sum_{\forall i} \sum_{j=2}^{n_i} p_{ijk}^{M} Q_{ijk}^{M} + \sum_{\forall l} \sum_{\forall i} \sum_{j=2}^{n_i} p_{ijl}^{R} Q_{ijl}^{R} + \sum_{\forall i} \sum_{j=2}^{n_i} Q_{ij}^{O} - c_i \left(D_i + \sum_{\forall f} \sum_{\forall i} \sum_{j=2}^{n_i} Q_{ijf}^{C}\right) \quad (4)$$

The first term calculates the income that is gained from the general customers, the second term shows the total income from the other partners, and the third term calculates the total cost related to donations and purchasing costs from the supplier. To discuss it in more detail, equations (5) to (7) show the total profit that the supermarket gains by cooperating with the minimarkets, restaurants, and the online store respectively. Equation (8) calculates the total cost of the donation.

$$TR_{ik}^{M} = \sum_{\forall k} \sum_{\forall i} \sum_{j=2}^{n_i} p_{ijk}^{M} Q_{ijk}^{M} \quad (5)$$

$$TR_{il}^{R} = \sum_{\forall l} \sum_{\forall i} \sum_{j=2}^{n_i} p_{ijl}^{R} Q_{ijl}^{R} \quad (6)$$

$$TR_{i}^{O} = \sum_{\forall i} \sum_{j=2}^{n_i} p_{ij}^{O} Q_{ij}^{O} \quad (7)$$

$$TC_{if}^{C} = \sum_{\forall f} \sum_{\forall i} \sum_{j=2}^{n_i} c_i Q_{ijf}^{C} \quad (8)$$

Table 1. Parameters and Decision Variables

Indices and Parameters:	
m: Number of minimarkets r: Number of restaurants d: Number of charities $\boldsymbol{n_i}$: Number of quality periods for product i g: Number of products $\boldsymbol{c_i}$: The cost of product i per unit $\boldsymbol{W_i}$: Wasted amount of product i $\boldsymbol{D_i}$: Amount of product i that has been bought from the supplier $\boldsymbol{q_{ij}}$: Quality level of product i for quality period j $\boldsymbol{d_{ij}^{min}}$: The minimum donation rate of product i at the beginning of the quality period j $\boldsymbol{d_{ij}^{max}}$: The maximum donation rate of product i at the beginning of the quality period j $\boldsymbol{P'_{ij}}$: Selling prediction for product i during the quality period j $\boldsymbol{P_{ij}}$: Selling amount of product i during the quality period j $\boldsymbol{I_{ij}}$: Inventory of the supermarket for product i at the beginning of quality period j $\boldsymbol{I_{ij}^{S}}$: Surplus inventory of the supermarket for product i at the beginning of quality period j $\boldsymbol{I_{ij}^{Minsur}}$: The minimum level of the inventory for product i that is not sold till the beginning of the quality period j and can be considered as surplus inventory. $\boldsymbol{I_{ijk}^{M}}$: Inventory of minimarket k for product i at the beginning of the quality period j $\boldsymbol{I_{ijl}^{R}}$: Inventory of restaurant l for product i at the beginning of the quality period j $\boldsymbol{I_{ij}^{O}}$: Inventory of the online store for product i at the end of the quality period j $\boldsymbol{I_{ijf}^{C}}$: Inventory of charity f for product i at the beginning of the quality period j $\boldsymbol{I_{ik}^{M_{max}}}$: Maximum inventory level of minimarket k for product i $\boldsymbol{I_{il}^{R_{max}}}$: Maximum inventory level of restaurant l for product i $\boldsymbol{I_{i}^{O_{max}}}$: Maximum inventory level of the online store for product i	$I_{if}^{C_{max}}$: Maximum inventory level of charity f for product i s_{ij}: Selling price for product i during quality period j at the supermarket p'^{M}_{ijk}: The maximum purchasing price offer for product i at the beginning quality period j received from minimarket k p'^{R}_{ijl}: The maximum purchasing price offer for product i at the beginning quality period j received from restaurant l p'^{O}_{ij}: The maximum purchasing price offer for product i at the beginning quality period j received from the online store p^{M}_{ijk}: Purchasing price for product i at the beginning of quality period j by minimarket k p^{R}_{ijl}: Purchasing price for product i at the beginning of quality period j by restaurant l p^{O}_{ij}: Purchasing price for product i at the beginning of quality period j by the online store r_{dis}: Discount rate for the minimarkets, restaurants, and the online store that is considered by the supermarket TR': The total profit that the supermarket predicts for selling its products TR: The real total profit of the supermarket TR'_i: The total profit that the supermarket predicts for selling product i TR_i: The real total profit of the supermarket from selling product i TR'_{ij}: The total profit that the supermarket predicts for selling product i during the quality period j TR_{ij}: The real total profit of the supermarket from selling product i during the quality period j Q_{ij}: The amount of product i that the supermarket sells to its general customers during the quality period j **Decision Variables:** Q^{M}_{ijk}: The amount of product i that is purchased by minimarket k at the beginning of the quality period j Q^{R}_{ijl}: The amount of product i that is purchased by restaurant l at the beginning of the quality period j Q^{O}_{ij}: The amount of product i that is purchased by the online store at the beginning of the quality period j Q^{C}_{ijf}: The amount of product i that is donated to charity f at the beginning of the quality period j

Equation (4) can be revised to equation (9) and equation (10) considering a specific product (such as i) and a specific product in a specific quality period (such as j) respectively.

$$TR_i = \sum_{j=1}^{n_i} s_{ij}Q_{ij} + \left(\sum_{\forall k} \sum_{j=2}^{n_i} p^{M}_{ijk}Q^{M}_{ijk} + \sum_{\forall l} \sum_{j=2}^{n_i} p^{R}_{ijl}Q^{R}_{ijl} + \sum_{j=2}^{n_i} Q^{O}_{ij}\right) - c_i\left(D_i + \sum_{\forall f} \sum_{j=2}^{n_i} Q^{C}_{ijf}\right) \quad (9)$$

$$TR_{ij} = s_{ij}Q_{ij} + \sum_{\forall k} p^{M}_{ijk}Q^{M}_{ijk} + \sum_{\forall l} p^{R}_{ijl}Q^{R}_{ijl} + Q^{O}_{ij} - c_i\left(D_i + \sum_{\forall f} Q^{C}_{ijf}\right) \quad (10)$$

Each of the partners has a limitation in their purchasing amounts based on their inventory levels at the beginning of each quality period. Inequalities (11) to (14) indicate the limitations for the minimarkets, restaurants, the online store, and the charities.

$$Q_{ijk}^{M} \leq \left(I_{ik}^{M_{max}} - I_{ijk}^{M}\right) \quad ;\forall i,j,k\ (j \neq 1) \qquad (11)$$

$$Q_{ijl}^{R} \leq (I_{il}^{R_{max}} - I_{ijl}^{R}) \quad ;\forall i,j,l\ (j \neq 1) \qquad (12)$$

$$Q_{ij}^{O} \leq \left(I_{i}^{O_{max}} - I_{ij}^{O}\right) \quad ;\forall i,j\ (j \neq 1) \qquad (13)$$

$$Q_{ijf}^{C} \leq \left(I_{if}^{C_{max}} - I_{ij}^{C}\right) \quad ;\forall i,j,f\ (j \neq 1) \qquad (14)$$

The total waste amount of product i at the end of the evaluation period equals equation (15). The total waste is the difference between the total amount of the product which is bought by the supermarket at the beginning of the evaluation period and the total amount of product i that the supermarket sells to its general customers and other partners as well as the amount that it donates to the charities during different quality periods.

$$W_i = D_i - \sum_{j=1}^{n_i} Q_{ij} - \sum_{j=2}^{n_i} Q_{ijk}^{M} - \sum_{\forall l} \sum_{j=2}^{n_i} Q_{ijl}^{R} - \sum_{\forall f} \sum_{j=2}^{n_i} Q_{ijf}^{C} - \sum_{j=2}^{n_i} Q_{ij}^{O}$$
(15)

To encourage other partners to buy the surplus inventory, the supermarket considers a discount rate (r_{dis}) and consequently a minimum selling price which is $(1 - r_{dis})s_{ij}$. The partners offer a price for the product to the system and the agreement between a partner and the supermarket will be executed if the price that they offer is above the minimum price. Therefore, the following constraints should be considered to make sure that this assumption is satisfied. In the other words, if a partner submits its maximum price in the system and if it is not lower than the minimum price of the supermarket, its offer would be considered as the trading price. Otherwise, the maximum price between what the supermarket offers and what the partner offers will be finalized in the agreement (the price that is offered by the supermarket).

$$p_{ijk}^{M} = max\left\{(1 - r_{dis})s_{ij}, p'^{M}_{ijk}\right\} \quad ;\forall i,j,k\ (j \neq 1) \qquad (16)$$

$$p_{ijl}^{R} = max\left\{(1 - r_{dis})s_{ij}, p'^{R}_{ijl}\right\} \quad ;\forall i,j,l\ (j \neq 1) \qquad (17)$$

$$p_{ij}^{O} = max\left\{(1 - r_{dis})s_{ij}, p'^{O}_{ij}\right\} \quad ;\forall i,j\ (j \neq 1) \qquad (18)$$

The supermarket sells and donates the surplus inventory of each quality level to other partners at the end of its equivalent quality period (at the beginning of the next quality period). The surplus inventory is the amount the supermarket cannot sell to its general customers compared to its predicted sales. So, inequality (19) indicates the maximum amount of the surplus inventory of product i that can be dedicated to other partners at beginning of quality period $j', j' \neq 1$. This inequality only is used when $\sum_{j=1}^{j'-1} (P'_{i,j} - P_{i,j}) > 0$. Otherwise, it means there is no surplus inventory.

$$Q_{ij'}^{O} + \sum_{\forall k} Q_{ij'k}^{M} + \sum_{\forall l} Q_{ij'l}^{R} + \sum_{\forall f} Q_{ij'f}^{C} \leq \sum_{j=1}^{j'-1} (P'_{i,j} - P_{i,j})$$
(19)

Note that

$$P_{ij} = Q_{ij} \quad ;j = 1 \qquad (20)$$

$$P_{ij} = Q_{ij} + \sum_{\forall k} Q_{ijk}^{M} + \sum_{\forall l} Q_{ijl}^{R} + \sum_{\forall f} Q_{ijf}^{C} + Q_{ij}^{O} \quad ; j \neq 1 \qquad (21)$$

The supermarket considers a donation rate to define the minimum and maximum amount of donations for product *i* at the beginning of the quality period *j*. This assumption can be indicated using the following inequality.

$$d_{ij}^{min} I_{ij}^{S} \leq \sum_{\forall f} Q_{ijf}^{C} \leq d_{ij}^{max} I_{ij}^{S} \quad ; j \neq 1 \qquad (22)$$

Because of the possible errors in the sales predictions, the supermarket can also define a minimum amount for a product that is considered surplus inventory. For instance, product *i* will have surplus inventory at quality period j' if $I_{ij'}^{s} = \sum_{j=1}^{j'-1} P'_{ij} - P_{ij} \geq I_{ij'}^{Minsur}$ note that $P_{ij} = Q_{ij};\ j = 1$ and $P_{ij} = Q_{ij} + \sum_{\forall k} Q_{ijk}^{M} + \sum_{\forall l} Q_{ijl}^{R} + \sum_{\forall f} Q_{ijf}^{C} + Q_{ij}^{O};\ j \neq 1$. Otherwise, it can take the risk of selling the remained products in the next period with the hope of increasing its sales to its general customers. The inventory level of product *i* at the beginning of period j' ($I_{ij'}$) equals $D_i - \sum_{j=1}^{j'-1} P_{i,j}$.
At the beginning of each quality period, the supermarket and its partners reach agreements based on the proposed assumptions using smart contracts. So, the supermarket would be able to decide about the surplus inventory in a reasonable time and avoid food waste with the goal of maximizing its profit. In other words, at the beginning of each quality period the real data of the previous periods will be updated (it is possible to use sensors and blockchain technology for controlling the inventory levels, quality periods, price, contracts, and any transaction) to indicate the surplus inventory. Then based on the inventory levels and price offers of other partners, the agreements will be executed for transferring the surplus inventory to them.

At first, the minimum donations that are defined by the supermarket will be dedicated to the charities. Then, the remained surplus inventory based on the rules and the priorities will be sold to other parties. Finally, if there is still some surplus inventory, a part of it can again be dedicated to the charities considering the maximum donation rate. The charities can be ranked based on their needs and the number of previous donations to them.

Other partners, including the minimarkets, restaurants, and the online store are ranked based on their price offers (the partner with the highest priced offer is prior to the others). Then in the case of having identical situations, they can be ranked based on other factors such as their previous cooperation in buying the surplus inventories, payments, and even their food waste levels that are being controlled at the end of each evaluation period. The surplus inventory will be sold to them according to the automatic ranking that the system provides considering the proposed factors.

5. Algorithm for Implementing Smart Contracts

Smart contracts are programs that automatically enforce the agreement if certain conditions are met, without the need for an intermediary. The code contains a set of rules under which the parties of that smart contract agree to interact with each other. In this section, a sample code is provided to control agreement conditions between the supermarket and other parties. This algorithm works based on the assumptions, parameters, and constraints that were described in the previous section.

Using the proposed algorithm, the surplus inventory will be dedicated to different parties at the beginning of each quality period considering the priority or their ranks. They are ranked based on the highest price that they offer and in the case of offering similar prices, the priority of them is indicated according to their needs, their cooperation during the previous periods, or even the preference of the supermarket (for instance the supermarket may consider a high priority for the minimarkets comparing to other parties). The agreements will be automatically executed when the conditions are met using smart contracts.

Algorithm: Executing Smart Contracts Between Different Parties

Input:
Inventory levels, expiration dates (quality levels), price, discount, donation rate, and ranks of the parties
Output:
Making decisions about selling the surplus inventory to different parties (Q^M_{ijk}, Q^R_{ijl}, and Q^O_{ij}) or donating them (Q^C_{ijf})
Algorithm:
Do the following steps for all the product types ($i = 1,2,\dots,g$) at the beginning of quality period j ($j = 2,3,\dots,n$):
For quality period j
For product i

Step 1. Calculate the surplus inventory (I^{sur}_{ij}) considering the prediction and real sales of the previous periods and the minimum level that is considered as the surplus inventory (I^{Minsur}_{ij}) by the supermarket.
Step 2. If there is a surplus inventory for product i continue the following steps. Otherwise, stop the algorithm for product i at quality period j.
Step 3. Calculate the amount that the charities need based on their current inventory levels (I^C_{ijf}) and their maximum inventory levels ($I^{C_{max}}_{if}$).
Step 4. Dedicate the minimum level of donation (d^{min}_{ij} percent) of the surplus inventory to the charities considering their priorities.
Step 5. Calculate the amount that the other parties including the minimarkets, the restaurants, and the online store need based on their current inventory levels (I^M_{ijk}, I^R_{ijf}, I^O_{ij}) and their maximum inventory levels ($I^{M_{max}}_{ik}$, $I^{R_{max}}_{if}$, $I^{O_{max}}_{i}$).
Step 6. Remove the parties from the list if they do not need the surplus inventory or they have offered a price lower than the minimum selling price that the supermarket considers ($(1 - r_{dis})s_{ij}$) for selling the surplus inventory.
Step 7. Sort the remaining parties considering the maximum price offers. The party with the highest offered price is located at the top of the list which means it has the highest priority.
Step 8. Dedicate the remaining surplus inventory to the parties according to the sorted list from the previous step.
Step 9. If there is no more surplus inventory remaining for product i stop the algorithm for product i at quality period j, and go to Step 11. Otherwise, go to the next step.
Step 10. Dedicate the maximum level of donation (d^{max}_{ij} percent) of the surplus inventory to the charities considering their priorities. If this is the last quality period ($j = n$), consider $d^{max}_{ij} = 1$.
Step 11. Execute the agreements that meet the conditions based on the previous steps.

6. Numerical Example

Consider a supermarket that purchases 200 kg of apples from its supplier at the wholesale price of 1.5 euros per kg. The shelf life of the fruit is four weeks and the supermarket divides it into four quality periods with the length of one week (there are four quality levels). It is predicted it can sell 100 kg during the first week at the price of 4 euros per kg, 60 kg during the second week at the price of 3.5 euros per kg, and 40 kg during the third week at the price of 2.5 euros per kg. The supermarket anticipates selling all of them during the first three weeks and the revenue that it predicts equals 410 euros. It usually does not sell apples with the quality level 4 and if something remains at the end of the third week, it will be left at the corner of the supermarket so people who need can use it as a donation otherwise it would be wasted. Based on the previous data, about 60% of their surplus inventories usually will be wasted. This does not seem an efficient way and a large portion of the surplus inventories are going to be wasted when they cannot sell their goods at the level that they have predicted before.

Consider the supermarket sells 80, 70, and 15 kg of the apples during the first, second, and the third period respectively. So, it sells 20 kg lower than the amount that is predicted for the first period. In the second period, it sells 10 kg more than what was anticipated and for the third period, it cannot sell more than 15 kg which is 25 kg less than the predicted quantity. Considering the indicator of apples in the supermarket 1 (*i=1*) and $I^{sur}_{1j} = 5\ kg$ (*j=2,3,4*), there is 20 *kg* surplus inventory at the beginning of the second quality period and 35 *kg* surplus inventory at the beginning of the last quality period. As mentioned before, the supermarket does not sell the apples with quality level 4 and they will be left at a corner of the supermarket to be picked up by people who need them. Finally based on the previous data, 60% of them will be wasted which equals 21 kg. Although the supermarket is predicted to gain 410 euros in revenue by selling the apples during different periods, the real revenue equals 302.5 euros and 21 kg of the apples will be wasted.

The owner of the supermarket decides to use smart contracts with a blockchain platform to cooperate with other parties to avoid food waste and find a quick way to decide about the surplus inventories when they have better quality. This may help her to minimize food waste, maximize its profit and also have better plans for donations by dedicating them to charities when they have a higher quality.

The other parties that are connected to the new platform with the ability to execute smart contracts include four minimarkets, three restaurants, one online store, and two charities. For analyzing the agreement conditions, the inventory level of different products is being controlled by the sensors and besides that, the system considers the maximum purchasing price for different quality levels of the products that are defined by all parties (except the charities that receive the goods at no cost) as well as the selling priority (the rank of different parties based on previous data) when two parties offer identical purchasing price. Table (2) indicates the various purchasing price and the maximum inventory levels of different parties based on the quality level of apples.

Table 2. Purchasing prices and maximum inventories of different parties.

Parties	Price for Quality levels (euros)				Maximum Inventory (kg)			
	Level 1	Level 2	Level 3	Level 4	Level 1	Level 2	Level 3	Level 4
Minimarket 1	3.5	3.2	2.2	1.5	10	10	5	5
Minimarket 2	3.8	3.3	2.4	1.4	12	10	8	5
Minimarket 3	3.3	3.1	2.3	--	15	15	10	--
Minimarket 4	3.6	3.15	2.2	1	15	10	8	5
Restaurant 1	3.7	3.3	2.1	--	8	8	4	--
Restaurant 2	3.5	3.2	2	--	15	5	5	--
Restaurant 3	3.8	3.5	2.2	1	10	5	5	5
Online store	3.6	3.2	2.3	0.9	20	20	20	20
Charity 1	--	--	--	--	10	10	10	10
Charity 2	--	--	--	--	15	15	15	15

At the beginning of the second quality period, there is a 20 kg surplus inventory that needs to reach some agreements with other parties regarding it to possibly reduce the final waste and increase the revenue of the supermarket. Table (3) shows the inventory level of different parties at the beginning of the second period and their priority which are indicated based on the rank numbers (the lower the rank is, the higher priority it has). In this example, the supermarket does not consider a priority for the charities and the donation will be divided equally between them. For the first three periods, the minimum and the maximum donation rates are considered 2% and 4% respectively. The supermarket considers a 10% discount for other parties. For the last quality period the maximum donation rate will be 100%, which means if there is no customer for them, all of them can be donated.

Table 3. Inventory and the rank of different parties at the beginning of the second and the last periods.

Parties	Inventory (kg)		Priority (to use when they offer identical purchasing price)	
	Quality Level 2	Quality Level 4	Quality Level 2	Quality Level 4
Minimarket 1	8	0	1	5
Minimarket 2	5	1	8	3
Minimarket 3	10	--	7	--
Minimarket 4	8	2	5	1
Restaurant 1	2	--	3	--
Restaurant 2	1	--	4	--
Restaurant 3	3	2	2	4
Online store	10	4	6	2
Charity 1	2	4	--	--
Charity 2	5	3	--	--

Using the algorithm that is provided in the previous section, agreements will be executed at the beginning of the second and last quality periods respectively. The outputs are brought in Table (4).

Table 4. Agreements at the beginning of the second and the last quality periods.

Parties	**Agreements (kg)**	
	Quality Level 2	**Quality Level 4**
Minimarket 1	2	5
Minimarket 2	5	4
Minimarket 3	--	--
Minimarket 4	--	3
Restaurant 1	6	--
Restaurant 2	4	--
Restaurant 3	2	2.7
Online store	0.6	--
Charity 1	0.2	0.15
Charity 2	0.2	0.15

Based on the selling agreements which are shown in table (3), the supermarket revenue increases from 302.5 euros (when it does not use the new platform) to 383.02 euros. Moreover, the wasted apples from 35 kg reduce to zero kg. It should be mentioned that the example that is provided in this section is related to only one product and the new platform can be used for all the products that exist in the supermarket. In that case, the amount of products that are being sold or donated using smart contracts will be noticeable. Therefore, using the new technologies including blockchain and smart contracts can help the supermarkets to have more cooperation with other parties in an agile way which leads to mitigating the food waste and increasing the revenue for all of the parties.

6. Conclusion

In this paper, the application of smart contracts for making decisions regarding the surplus inventories at the supermarkets is studied. A sample algorithm is developed to check the proper conditions for executing agreements between the supermarket and other parties including minimarkets, restaurants, online stores, and charities at the beginning of each quality period to avoid food waste and increase the revenue of the supermarket at the end of the evaluation period. The quality periods are categorized based on the expiration dates of the products and the selling price will reduce when the quality level decreases. To automatically execute agreements, the system considers various factors such as the prices that are offered by different parties, the inventory levels, discount rate, donation rate, and the rank or priority of the parties when they offer identical prices for the products. This platform can help all of the parties to provide for their needs at a reasonable price and avoid food waste. Making decisions about the surplus inventories when they have a higher quality would be more efficient rather than trying to sell them when they have poor quality.

In future research, different scenarios and algorithms can be examined to find proper strategies for executing the terms of agreements between the supermarket and other parties considering specified conditions. Moreover, a cost-benefit analysis can be done for implementing a smart contract platform as well as the possibility of outsourcing its implementation, maintenance, and monitoring to a third-party company.

References

Ahmad, R. W., Salah, K., Jayaraman, R., Yaqoob, I., & Omar, M., Blockchain for waste management in smart cities: A survey, *IEEE Access*, vol. 9, pp. 131520-131541, 2011.

Alharby, M., Aldweesh, A., & Van Moorsel, A., Blockchain-based smart contracts: A systematic mapping study of academic research, *International Conference on Cloud Computing, Big Data and Blockchain (ICCBB)*, pp. 1-6. IEEE, 2018.

Alladi, T., Chamola, V., Sahu, N., & Guizani, M., Applications of blockchain in unmanned aerial vehicles: A review, *Vehicular Communications*, vol. 23, pp. 1-24, 2020.

Almeida Oroski, F. D., Exploring food waste reducing apps—a business model lens, In *Food Waste Management*, Palgrave Macmillan, Cham, pp. 367-387, 2020.

Bai, X., Cheng, Z., Duan, Z., & Hu, K., Formal modeling and verification of smart contracts, In *Proceedings of the 7th international conference on software and computer applications*, pp. 322-326, 2018.

Brancoli, P., Rousta, K., & Bolton, K. Life cycle assessment of supermarket food waste, Resources, *Conservation and Recycling*, vol. 118, pp. 39-46, 2017.

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

De Giovanni, P., Digital supply chain through dynamic inventory and smart contracts. *Mathematics*, vol. 7(12), pp. 1-25, 2019.

De Giovanni, P., Blockchain and smart contracts in supply chain management: A game theoretic model, *International Journal of Production Economics*, vol. 228, pp. 1-18, 2020a.

De Giovanni, P., *Dynamic quality models and games in digital supply chains*. Springer Nature: Cham, Switzerland, 2020b.

Eriksson, M., *Supermarket food waste*, SLU Service/Repro, Uppsala, 2015.

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

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

FAO, F., *Agriculture organization of the United Nations*, Food wastage footprint, impacts on natural resources, 2013.

FAO, I. WFP., The State of Food Insecurity in the World, *Meeting the international hunger targets*: taking stock of uneven progress, Rome, 2015.

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

Horoś, I. K., & Ruppenthal, T, Avoidance of food waste from a grocery retail store owner's perspective, *Sustainability*, vol. 13(2), pp. 1-22, 2021.

Hu, K., Zhu, J., Ding, Y., Bai, X., & Huang, J., Smart contract engineering. *Electronics*, vol. 9(12), pp. 1-26, 2020.

Maleki Vishkaei, B., Pasandideh, S. H. R., & Farhangi, M., The %100 screening Economic Order Quantity model under shortage and delay in payment, *Scientia Iranica*, vol. 21(6), pp. 2429-2435, 2014.

Maleki Vishkaei, B., Niaki, S. T. A., Farhangi, M., & Mahdavi, I., A single-retailer multi-supplier multi-product inventory model with destructive testing acceptance sampling and inflation, *Journal of Industrial and Production Engineering*, vol. 36(6), pp. 351-361, 2019.

Marrucci, L., Marchi, M., & Daddi, T., Improving the carbon footprint of food and packaging waste management in a supermarket of the Italian retail sector. *Waste Management*, vol. 105, pp. 594-603, 2020.

Mattsson, L., Williams, H., & Berghel, J., Waste of fresh fruit and vegetables at retailers in Sweden–Measuring and calculation of mass, economic cost and climate impact, *Resources, Conservation and Recycling*, vol. 130, pp.118-126, 2018.

Moser, C., Managerial practices of reducing food waste in supermarkets, *In Food waste management*, Palgrave Macmillan, Cham, pp. 89-112, 2020.

Özbük, R. M. Y., & Coşkun, A., Factors affecting food waste at the downstream entities of the supply chain: A critical review, *Journal of Cleaner Production*, vol. 244, pp. 1-26, 2020.

Pasandideh, S. H. R., Niaki, S. T. A., & Vishkaei, B. M., A multiproduct EOQ model with inflation, discount, and permissible delay in payments under shortage and limited warehouse space, *Production & Manufacturing Research*, vol. 2(1), pp. 641-657, 2014.

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

Tonini, D., Albizzati, P. F., & Astrup, T. F., Environmental impacts of food waste: Learnings and challenges from a case study on UK, *Waste Management*, vol. 76, pp. 744-766, 2018.

Vishkaei, B. M., Niaki, S. T. A., Farhangi, M., & Rashti, M. E. M., Optimal lot sizing in screening processes with returnable defective items, *Journal of Industrial Engineering International*, vol. 10(3), pp. 1-9, 2014.

Zheng, Z., Xie, S., Dai, H. N., Chen, W., Chen, X., Weng, J., & Imran, M., An overview on smart contracts: Challenges, advances and platforms, *Future Generation Computer Systems*, vol. 105, pp. 475-491, 2020.

Acknowledgements

This contribution is a part of a project that has received funding from the Lazio region ESF operational programme 2014-2020, Axis III- Education and Training, Investment Priority 10.ii) - Specifific Objective 10.5, Pivotal Action 21 – Call for proposals "Contributi per la permanenza nel mondo accademico delle eccellenze" – Project Title: "Implementazione di progetti di digitalizzazione responsabile nelle supply chain" - CUP (Unified Project Code): F86J20002710009.

Biographies

Behzad Maleki Vishkaei is an Assistant Professor at the Department of Business and Management. Prior to joining Luiss, he was an Assistant Professor at the University of Eyvanekey (Iran), and before that he used to teach as an instructor at several universities in Iran. He cooperated also with different companies as a Strategic Planning and Project Management expert. He holds a Ph.D. in Industrial Engineering from Mazandaran University of Science and Technology (Iran). His research topics focus on Supply Chain Management, Operations Research, Transportation, Digital Transformation, and Smart Cities. He is interested in developing practical models and solutions that can be useful for companies and cities.

Pietro De Giovanni is a Full Professor of Circular Economy, Operations and Supply Chain at the Department of Business and Management at Luiss University. He holds a PhD from ESSEC Business School, and was visiting PhD candidate at GERAD, HEC Montréal. Before joining Luiss, he has held positions at ESSEC Business School, Vrije Universiteit Amsterdam, and NOVA School of Business and Economics. His research interests are supply chain, operations management, sustainability, and digital transformation. He is Associate Editor of International Transactions of Operations Research. He has published in Journal of Operations Management, European Journal of Operational Research, Transportation Research. Part D Transport and Environment, Annals of Operations Research, International Journal of Production Economics, Journal of Business Research, 4OR, Omega, Research Policy.