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A blockchain-based approach for food surplus management

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Abstract: Food surplus recovery is one of the priorities of modern society. Mass distribution allows one to reserve goods unsuitable for selling for organisations able to distribute them to people in need. This work contributes to this direction by considering a reward programme for donors. A methodology for supporting the cycle of the reallocation of the food surplus to people in need usingblockchain technology to support the traceability of the flows and to allow the exact evaluation of the rewards to be assigned to each retailer is described. A mathematical model is proposed for calculating the reward. An actual application of the methodology is also described.

Keywords: food recovery; rewarding; sustainable development; waste disposal tax; zero hunger

In 2015, the United Nations wrote The 2030 Agenda for Sustainable Development (United Nations 2015), establishing 17 Sustainable Development Goals (SDGs) that will be able to modify our world sustainably. The first two are focused on defeating poverty and obtaining zero hunger within those goals. Recent years have seen the spread of social-based initiatives for food surplus recovery worldwide.

In this paper, a methodology for supporting the cycle of the reallocation of food surplus to people in need is described. The proposed strategy can be useful in the context in which such kind of reallocation is planned and when local governments are willing to implement a reward system for donor companies and accelerate and make the exchange procedure more efficient. Typically, the policymaker creates incentive plans (for example, fiscal incentives) for donors, thus creating an economic return to donors in an indirect way.

In this research, the blockchain is considered a valuable technology for supporting the traceability of the flows, the food integrity and the overall process. Even though a blockchain has many advantages, research related to its adoption and implementation in food recovery is not so widely developed. The research described in this paper aims to contribute to solving the gap in the literature, providing an opportunity to understand the importance of the relationship between blockchain technology and sustainable development

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challenges. To achieve the research objectives, within the context of the blockchain, a mathematical model is proposed for calculating the reward to be assigned to donor companies. A first application of the methodology has been carried out in an Italian municipality that offers the incentive of reducing the waste disposal tax to donors.

Literature review. The new domain of social business (SB) was introduced by the Nobel Peace Prize winner, prof. Yunus (Yunus et al. 2010, 2015). Unlike traditional for-profit businesses that focus on maximising profit, an SB has dual mission objectives: solving social/environmental issues and creating revenues for entrepreneurs and shareholders (Smith and Besharov 2019). In the last years, researchers have investigated how these two dimensions, apparently incompatible, are instead complementary, highlighting the positive relationship between profit and non-profit initiatives (Devine et al. 2021). Ashraf et al. (2018) deeply studied social businesses, social enterprises, non-governmental organisations and corporate social responsibility to show how they can be aligned. An increasing amount of literature addresses food waste prevention entry points and strategies (Schneider 2013; Priefer et al. 2016) and food recovery, redistribution and donation mechanisms (Alexander and Smaje 2008; Schneider 2013; Vlaholias et al. 2015; Sert et al. 2018). Environmental, social, economic and political drivers affect how food system activities are performed, their impacts and outcomes, which, in turn, generate feedback that alter the system's functioning (Ericksen 2008; Ingram 2011). Most food waste occurs in the food chain's later stages, mainly due to behavioural issues (Parfitt et al. 2010). For this reason, many studies have focused on understanding food waste at the consumer level (Aschemann-Witzel et al. 2015; Stancu et al. 2016). Significantly fewer studies focus on the retail side (Cicatiello et al. 2017), while even fewer have studied the causes of food waste at the retail level (Teller et al. 2018). Among the studies examining supermarket waste prevention measures, Salhofer et al. (2008) and Schneider (2013) investigated charity donations. Galli et al. (2019) presented a conceptual model of the interactions between food waste reduction, food surplus recovery and food poverty alleviation.

The concept of a blockchain has been widely adopted in the food supply chain (SC) and food industries (Kamilaris et al. 2019; Wong et al. 2020). Despite the adoption of disruptive technologies, it has been introduced in the food SC to provide better solutions and replace traditional methods; these technologies aim to address specific food issues with limited interaction between the actors in the SC (Ali et al. 2021).

Different studies have been carried out that are concerned with the advantages related to the use of blockchains in the food supply chain (Beulens et al. 2005; Doreian 2006), while there is a general lack of research on the use of blockchain in food recovery. Other works studied aspects like transparency and traceability (Galvez et al. 2018; Hew et al. 2020; Köhler and Pizzol 2020; Tan et al. 2020; Kouhizadeh et al. 2021). Müßigmann et al. (2020) conducted an in-depth literature review on blockchains in logistics and supply chain management. Many studies have been conducted concerning using blockchains in food and agricultural supply chains. The importance of blockchains for food safety and food supply information security was analysed by Kshetri (2019). Some studies on the use of crowdfunding platforms for allowing charity projects to be funded were carried out (Li et al. 2020).

MATERIAL AND METHODS

In this section, an innovative application of blockchain technology is introduced. In particular, an evolution of the Blocktrace platform developed by NTT DATA Italy, called Blocktrace EVO, was used (the authors can provide further details upon request).

Methodology architecture and actors involved. The main objective is to implement a strategy that can be used to increase the food recovered and donated, reduce the amount of food waste and alleviate food poverty.

The actors involved are policymakers, food banks and mass-market retailers. In particular, mass-market retailers can make available edible, healthy packaged products not sold in a store that can be distributed to people in need.

The promoter (i.e. the policy maker) creates incentive plans for the mass-market retailers (for example, fiscal incentives). The certifier (the food bank) is the institution that receives the donations and communicates to the promoter which companies (the donors) want to participate in the incentive campaign. In addition, it certifies the quality of the donated foods, connects the donors and beneficiaries and helps charitable organisations by handling, storing, and delivering food commodities and products. The donor company (the mass-market retailer) donates the products to the certifier and receives a reward from the promoter.blockchain technology tracks the flows and assures quality, tractility and liability.

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Figure 1 gives a graphical representation of the actors involved and their relationships.

The reward evaluation model. The procedure developed is aimed at calculating the value of the donated goods. This value determines the reward to be given to each donor. It comprises two main steps: In the first one, for each donor k and for each type of donated product i, a reduction coefficient C_i^k is calculated. In the second one, for each donor k and each type of donated product i, the donated value (VP_i^k) is calculated as Equation (1):

$$VP_i^k = P_i^k \times C_i^k \qquad (1)$$

where: P_i^k – selling price of product i; k – donor; I – donated product; C_i^k – reduction coefficient; VP_i^k – donated value.

Thus VP_i is determined as a percentage of the selling price. To evaluate the coefficient C_i^k, we defined a function which depends on a set of variables used to represent the intrinsic characteristics of the donated products and the satisfaction of the beneficiaries. In particular, continuous variables that can take a value between 0 and 1 are considered.

Mathematically, the function used to calculate C_i^k assumes Equation (2):

$$C_i^k = f(x_1, x_2, \dots, x_n) = a_1(x_1) + \dots + a_n(x_n) \qquad (2)$$

where: $x_1, x_2, \dots, x_n$ – variables (expiration date, disposal cost, the importance of the product, level of user satisfaction); $a_1, a_2, \dots, a_n$ – coefficients associated to each variable, according to its relative importance; C_i^k – reduction coefficient.

Given the definition of C_i^k, it is evident that its value should belong to the interval [0, 1]. Consequently, Equation (2) is obtained as a convex combination of the variables, that is the coefficient $a_1, a_2, \dots, a_n$ must satisfy the following conditions

$$\sum_i^n a_j = 1 \text{ and } a_j \geq 0, j = 1, \dots, n.$$

The form of Equation (2) is very general and, in some cases, it can be reduced to a single coefficient, quickly estimated by the certifier, whose value ranges between 0 (product to be discarded) and 1 (sound product). Therefore, a value which, in the best case, will be equal to the selling price will correspond to each product, in the worst case, it will be zero. In intermediate cases, the value of the given product will be a fraction of its selling price.

The donation smart value of a given set of goods donated by k is calculated as the sum of their values determined by using Equation (1), that is Equation (3):

$$VCP^k = \sum_i VP_i^k \qquad (3)$$

where: VCP^k – donation smart value; P_i^k – selling price of product i.

Now we describe the procedure that can be used to calculate, for each product, the value of the variables of Equation (2). In particular, we consider a specific scenario where the following five variables are used to represent the main characteristics of the donated products: *i*) x_1 is related to the expiration date of the product; *ii*) x_2 is evaluated considering the cost of disposal; *iii*) x_3 provides an assessment of the importance of the product for the store; *iv*) x_4 and x_5 allow one to represent the level of user satisfaction, in particular, x_4 is calculated considering the variety of the product while x_5 is determined based on its brand; *v*) x_6 is related to the quantity of CO_2 saved.

The value of the variables mentioned above can be determined as follows:

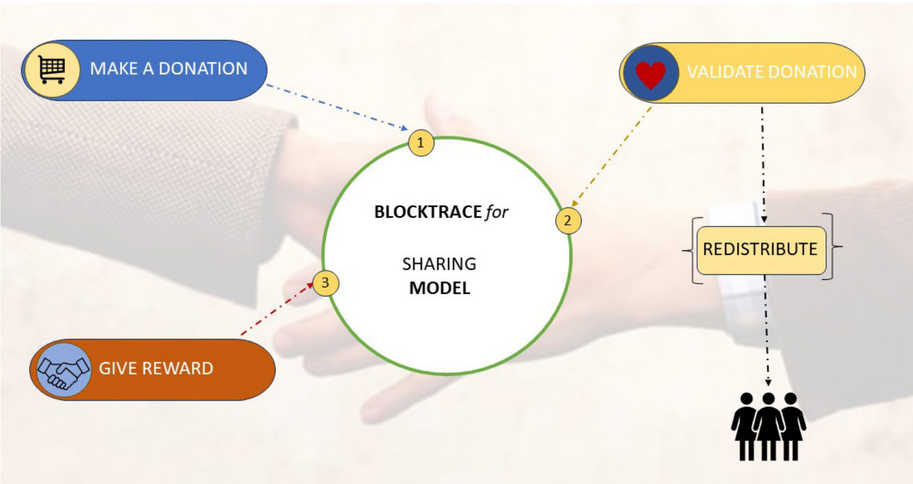

Figure 1. Graphical representation of the relationship among the three types of actors

Source: NTT DATA Italia

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– x_1 expiration date; $x_1 = (tsc–tc)/(tsc–tcs)$, where: *tsc* – expiration date; *tc* – delivery date; *tcs* – shelf placing time. The variable describes the time before the expiration date the store gives the good in a percentage of the period on the shelf.

– x_2 disposal cost; x_2 = 1 (*disposal cost/selling price*), x_2 increases with the disposal cost reduction. The idea is to reward the donors who give low-disposal cost products.

– x_3 product store importance; the value of this variable increases with the importance of the product for the donor. In other words, the idea is to highly reward popular goods with a high demand value (wine, ham). A possible strategy to set this variable is to consider three levels: high (1), medium (0.6), and low (0.2).

– x_4 variety of the product; this variable is related to the feeling of the unicity of the donated product, and it is used to evaluate how much the good is different with respect to the product usually available. In particular, high values for x_4 can be considered for children's and niche products, whereas low values are associated with x_4 for standard products, such as canned goods.

– x_5 product brand; this variable is related to customer satisfaction, which is supposed to be high, for example, when the final user finds a product labelled by a very famous brand. The brand of the box leads to an increasing variable. Also, in this case, it is possible, for example, to set the variable on three levels: high (1): market leaders; medium (0.6): less known/famous brands; low (0.4): brandless goods.

– x_6 CO_2 saved; this variable is related to the reduction in the pollution from CO_2. A high value of x_6 is associated with products with high CO_2 emissions (Moberg et al. 2019).

It is important to note that it is also possible to evaluate, for each donation, the amount of CO_2 saved as the sum of the quantities saved for each donated product.

In particular, let $Q^k_{iCO_2}$ be the reduction in the CO_2 emissions for product *i* donated by retailer *k*, the total quantity of CO_2 saved as a result of the donation by *k* is calculated as:

$$Q^k_{CO_2} = \sum_i Q^k_{iCO_2}.$$

The amount of CO_2 saved can be used as an additional parameter in order to calculate the incentive to be paid to the donor. The values of the donated products are used to calculate the benefit (in terms of a disposal tax) for each donor. Given the overall budget of the campaign (*BC*), determined by the promoter, several strategies can be used to distribute the *BC* among the donors.

The first strategy is based on a fraction of the total donations. In particular, the *BC* will be divided among all the donors as a function of the single donor contribution (also, CO_2 savings are considered). More specifically, for each donor *k*, the value of the wallet W^k, representing the tax reduction is determined as Equation (4):

$$W^k = \left(\frac{VCP^k}{\sum_k VCP^k} \right) \times BC \quad (4)$$

where: W^k – value of the wallet; *BC* – budget of the campaign; VCP^k – donation smart value.

The main drawback of this strategy is that the donor's wallet value will be available only at the end of the incentive campaign.

An alternative procedure is based on the preliminary definition of a proportional coefficient that links the donated value and the reward (*CR* – coefficient of reward). For instance, with a *CR* = 0.01, 1 EUR will be earned by the donor according to 100 units of the donated value of the products. In this specific scenario, for each donor *k*, at each period *t* in which a donation from *k* occurs, the value of wallet $W^k(t)$ is calculated as Equation (5):

$$W^k(t) = CR \times VCP^k \quad (5)$$

where: $W^k(t)$ – value of wallet; VCP^k – donation smart value; *CR* – Coefficient of Reward

It is worth observing that, at each period *t*, it is necessary to check that the sum of all the rewards is less than the available budget, that is, $\sum_k W^k(t) < BC(t)$.

This strategy allows that the wallet for each donor can be shown after any donation. In this case, to define the value of the *BC*, the promoter can take into account the expected amount of given goods in a certain time horizon.

RESULTS AND DISCUSSION

A preliminary application of the proposed methodology has been carried out in the municipality of an Italian town. The main players are the donor stores belonging to the town, the Banco Alimentare that collects the goods that are to be delivered to people in need afterwards, and the municipality that allocates the budg-

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et to promote activities that will be rewarded to the donor companies. The budget rewarded to the donors is implemented in terms of the savings obtained by the donors on the waste disposal tax.

Banco Alimentare is an Italian organisation that supports the poorest. From a technical point of view, the system has been implemented on a properly designed NTT Data platform based onblockchain technology, able to certify the goods exchanged with Banco Alimentare.

The model described in the previous sections has been applied to a case study by considering a simplified version of the reward evaluation model. In particular, Equation (2) has been evaluated by considering only two variables: x_1 representing the time to the expiration date; x_2 related to the quantity of saved CO_2. As the variables considered are only two, x_6, the variable related to CO_2, is renamed as x_2. In addition, two different settings have been considered for the parameters a_1 and a_2, as described in the following paragraph.

In order to analyse the behaviour of the developed system, different simulation scenarios for calculating the reward have been considered. The case study is built on real donations made by two donor companies in the town, in the year 2019, to Banco Alimentare. Two types of goods are considered, according to the categorisation made by Banco Alimentare: *i*) mixed-dry food and *ii)* mixed-fresh food. A specific price is assigned to the two products, and the unitary CO_2 saved per kg is estimated. The delivery date and the expiration date of the donated foods are considered to set the variables of the evaluation function. The authors can provide the donated products' detailed (quantitative) characteristics upon request.

Regarding the evaluation of Equation (2), the following assumptions were made: The variable x_1 is calculated on the basis of the time interval (in days) between the delivery date and the expiration date. A value of 1 is assigned to a time interval greater or equal to one year, values less than 1 are assigned for a period below one year.

The variable x_2 is determined on the basis of the unitary saved CO_2 for each of the two types of products. A value of 1 is assigned to the product (mixed-fresh food) that allows the greatest quantity of CO_2 to be saved. For the weights a_1 and a_2, two different settings have been considered: *i*) $a_1 = a_2 = 0.5$ and *ii*) $a_1 = 0.7$ and $a_2 = 0.3$. The value donated for each type of product is calculated on the basis of these choices (The authors can provide a detailed accounting of the obtained results upon request.).

Three different strategies were considered for calculating the reward for the donors. The first one can be used to represent an *ex-ante* scenario in which, starting from historical data, the overall quantity (kg) expected in all the years from the donations is estimated. In this case, the reward is calculated, for each donation, in terms of the percentage of the quantity the total quantity expected. The function is not used in this case, but only the donated kilograms are considered.

Also, a second strategy can be used to model the *ex-ante* policy. In this case, a reward rate, i.e. a unitary reward coefficient, is supposed to be defined. For instance, a unitary reward of 0.2 EUR means that the donor company earns 0.2 EUR for each EUR of donated value. In this specific scenario, the overall reward is calculated on the basis of the donated value.

The third one represents an *ex-post* scenario. The reward is calculated *ex-post* on the basis of all the received donations. For each donor company, the reward is calculated based on the quota of the monetary value donated by the donor on the overall value donated by all the donors. The overall budget al.ocated by the municipality is supposed to be 100 000 EUR. In Table S1 in the Electronic Supplementary Material (ESM), the detailed calculation of the reward, under each scenario, for Donor Company 1, is shown (The detailed calculation of the reward, under each scenario, for Donor Company 2 can be provided by the authors upon request).

The following two tables (Tables 1 and 2) summarise the value donated and the reward calculated for the two donors for the different scenarios considered. The two tables are related to the two different assumptions for the weights of the evaluation model.

The first and the second scenarios (*ex-ante*) are constructed on a strategy in which the reward for each donor is known at any time and, in particular, after any donation. In this way, the donor has the actual measure of the benefit obtained. Furthermore, it is possible to calibrate the donation strategy according to the results reached day by day. The different values between scenario 1 and scenario 2 are due to the different criteria upon which the two scenarios are based.

The municipality can select the criterion depending on the monetary values originated. From this viewpoint, it is evident that scenario 2 is safer than scenario 1, due to the lower value of the reward assigned to the donors. It is worth underlining that, under the two considered scenarios, all the budget is used before the end of the time horizon and, thus, the reward campaign has to be stopped in advance.

The third scenario is based (*ex-post*) on the quota of the monetary value donated by the single donors with respect to the overall value donated by all the donors.

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Table 1. Rewarding evaluation ($a_1 = a_2 = 0.5$)

Rewarding values	Initial overall value (EUR)	Overall CO_2 saved (kg)	Donated value (EUR)	Scenario 1 (*ex-ante*): rewarding based on estimated overall kg donated (EUR)	Scenario 2 (*ex-ante*): rewarding based on estimated unitary rewarding (EUR)	Scenario 3 (*ex-post*): rewarding based on quota-value donated (EUR)
Donor company 1	11 866.00	3 490	4 687.34	2 326.67	937.47	78 974.91
Donor company 2	5 574.67	2 429	1 247.89	1 032.68	249.58	21 025.09
Total	17 440.67	5 919	5 935.23	3 359.34	1 187.05	100 000.00

Source: Authors' elaboration

Table 2. Rewarding evaluation ($a_1 = 0.7; a_2 = 0.3$)

Rewarding values	Initial overall value (EUR)	Overall CO_2 saved (kg)	Donated value (e) (EUR)	Scenario 1 (*ex-ante*): rewarding based on estimated overall kg donated (EUR)	Scenario 2 (*ex-ante*): rewarding based on estimated unitary rewarding (EUR)	Scenario 3 (*ex-post*): rewarding based on quota-value donated (EUR)
Donor company 1	11 866.00	3 490	5 613.00	2 326.67	1 122.60	85 354.02
Donor company 2	5 574.67	2 429	963.14	1 032.68	192.63	14 645.98
Total	17 440.67	5 919	6 576.14	3 359.34	1 315.23	100 000.00

Source: Authors' elaboration

In this case, it is assumed that only the two donor companies, 1 and 2, are included in the campaign for the year, and then only those two donors divide the entire budget among themselves. So this scenario is just theoretical, given that there are more than two expected donors.

The main strength of this strategy is that the amount of money delivered is the same as initially allocated by the municipality. The main drawback is that the donors will know their reward only at the end of the time horizon. Another weak point is that if the donors participating in the campaign are few, in any case, the entire budget has to be divided among the participants. Hence, generating rewards is too high for a single donor (this is the case in the third scenario). The analysis of the results obtained in this application can be useful for the municipality to refine the model parameters and, furthermore, to decide the budget to allocate. It is important that the tax benefit obtained by the single donors would be relevant: this aim can be reached by comparing the simulation results with the overall amount of the tax generally paid by the donors. In this context, blockchain technology can provide transparency, real-time information and traceability of the flows.

It has to be underlined that blockchain technology, despite all the advantages previously described, has two major barriers that could make the adoption difficult: economic and technological barriers. Since the blockchain is a relatively new disruptive technology with a short interest in its adoption in recent years, Jabbar and Dani (2020) found that a great amount of financial resources is required for developing the infrastructure surrounding the blockchain in terms of the capital expenditures (capex) due to technological implementation, and the costs related to the energy usage. Another important uncertainty can be linked to the potential skill gaps with the utilisation of the technology. This situation may require investing resources in training the internal resources, acquiring market competencies through a hiring campaign, or asking for advisory services from third parties. These aspects could make its adoption not economically feasible. Hastig and Sodhi (2020) found that technological barriers to blockchain adoption are the most critical barriers. Barriers that could represent a threat are: *i*) the immutability challenge of blockchain technology and *ii*) the immaturity of the technology. The first relates to the fact that records cannot be deleted from ledgers, which could represent a problem. Regarding the immaturity of the technology, the problem could be that blockchain technology would have issues handling a large number of transactions.

CONCLUSION

This paper illustrates a methodology developed to reward mass distributors that reallocate surplus food

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to needy people. A proper model has been developed: it evaluates the reward assigned to donor companies based on different variables related to the characteristics and the value of the donated food. In the developed system, blockchain technology has been used to support the traceability of the flows, transparency and auditability of the process, quality of the food and thus allowing the exact evaluation of the reward to be assigned to each participating donor. A first application of the methodology has been carried out by considering the specific case of the municipality of an Italian town. The aim was to assign a reward to the donors, to be implemented in terms of savings on the waste disposal tax. A simplified version of the model has been defined and used for this goal. In order to analyse the implications and impacts of the policy, different simulation scenarios for calculating the reward were considered. The main strength and weak points of the reward strategies were analysed. The simulation results can be useful for the municipality to allocate the budget to the donors.

As regards the use of blockchain technology in food recovery, there is a general lack of studies that have been conducted. The research presented in the paper aims to contribute to reducing this research gap. The research findings indicate that blockchain technology can provide transparency and real-time information on any product and allow the traceability of the flows, thus allowing one to develop a theoretical exercise and a practical methodology that can be used in real life to reduce food waste. Within the context of the blockchain, the methodology for calculating the exact reward to be assigned to each retailer can be usefully used.

The research introduces a methodology and provides preliminary empirical evidence that is not exempt from limitations which, however, may identify future research directions. The paper has not investigated the potential disadvantages and difficulties associated with adopting and implementing blockchain technology in a real-life context. As discussed in the previous section, the adopting chain can have two main barriers: economic and technological. For this reason, this paper suggests further research and studies related to the economic and technological feasibility factors that might encourage its adoption. Furthermore, concerning the methodology developed in this paper, future research may be considered by expanding the scale-up of the model to larger geographic areas. The idea is to refine the model and assess its robustness according to a growing number of stakeholders.

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