Leveraging economic sanctions to reduce food waste in retail: Insights from a discrete-time simulation approach

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Abstract: Food waste is universally recognized as a critical issue: one-third of the food produced ends up lost or wasted every year according to the 2019 FAO Report. Target 12.3 of the Sustainable Development Goals (SDGs) addresses this issue, urging the UN member states to halve by 2030 the per capita quota of food waste at retail and consumption stages and reduce food loss in production and supply chain. Specifically, food waste results in all the resources used in production, transportation, and storage being consumed in vain. The product wastage in retail amounts to 7% of the total food lost and wasted in Europe. While the percentage of domestic waste is significantly higher (54%), it can be argued that it would be easier to implement measures and regulations and, more importantly, monitor the results achieved, when it comes to commercial establishments, rather than private citizens. In this context, several approaches can be adopted: one is to apply sanctions on unsold products, to deter stores from over-stocking. This measure could be particularly significant in the case of highly perishable items, with high environmental impact and specific costs, such as beef and fish. In this study, the effect of the implementation of sanctions, defined in terms of percentages of the product purchase price from 0% to 100%, is investigated by evaluating the resulting difference in the quantity of products disposed of, and the variations in the optimal replenishment policy. To this end, a discrete-time simulation approach is adopted by modelling a B2C scenario with a single product, periodic review replenishment policy, uniform demand, and deterministic lead time. The results of the study will be of great support to policy-makers, by providing them with the results of a sensitivity analysis of a possible measure aimed at limiting food waste, in line with the SDGs.

Keywords: Perishable products; food waste; inventory management; periodic review; economic penalties.

1. Introduction

According to the 2019 FAO Report (FAO, 2019), one-third of the produced food ends up lost or wasted every year. Food production, meanwhile, is suitable for feeding a third of the world's population (Herman, 2015). It is evident therefore that food waste is a complex and critical issue.

It has been years since researchers worked on this topic; just think that a query on the Scopus database having "food waste" as a keyword returns more than 19 million documents at the time of writing (i.e., the first trimester of the year 2024), with the scientific production on the topic starting in 1918 when Lucius P. Brown first wrote about some causes and remedies for food waste (Brown, 1918). Well, after more than 100 years we have not solved this issue, but rather, the situation has worsened.

In numerical terms, most of the waste is generated in the domestic environment (approximately 54%) (EUROSTAT, 2021), meaning that consumers normally pay little attention to the way they store and consume food, to the expiry date of products, or to the number of goods they buy. However, it is evident that besides activating some awareness-raising campaigns, it is practically impossible to exert direct control over the behaviour of consumers in their homes.

Going backward, before the customer another actor comes into play, which is represented by the retail function (in other words, the entity allowing a person to buy food, which could be, for instance, a super-/iper- market or a grocery shop). At the retail level, food waste could derive for instance from the tendency of the retailer to have big amounts of displayed products for marketing purposes, inefficient product display policies, or non-optimized reorder policies, among others. Evidence shows that, at the European level, the wasted amount of food in retail accounts for approximately 7% of the total food lost (EUROSTAT, 2021). This percentage is surely lower than the previously mentioned one, but the difference is that at the retail level, it could be easier to implement measures and regulations for reducing waste and to monitor the achieved results.

With reference to this attempt, several approaches have been proposed by the academic community, and recently IoT and Big Data technologies surely allowed making substantial progress with regard to this issue (Ahmadzadeh et al., 2023). However, despite their high potential in reducing and preventing food waste, it was demonstrated that these solutions still must be economically feasible to be adopted by decision-makers in the food supply chain

(Aramyan et al., 2021). Some possible technical, logistical, and marketing interventions to reduce chilled-food waste at the retail outlet have been assessed by Tromp et al. (2016) using a simulation approach with a validated model. Concerning highly perishable products, other possible strategies to prevent food waste may be dynamic shelf life and discounting strategies (Buisman et al., 2019). Besides reducing food waste, appropriately defined discounting policies can allow for increasing daily profits in retail B2C scenarios (Solari et al., 2024).

Regardless of the enormous innovations and investments, the effectiveness of the introduced measures sometimes is not sufficient to effectively reduce food waste. There is something, however, to which everyone is sensitive: money. This is the ratio behind the study presented in this paper, which tries to address the following question: what would happen if the retailers were taxed/sanctioned depending on the food they waste, namely in terms of overstock or unsold products?

To reply, a discrete-time simulation approach is adopted by modelling a B2C scenario with a single product, periodic review replenishment policy, uniform demand, and deterministic lead time. The effect of sanctions, defined in terms of percentages of the product selling price from 0% to 100%, is then investigated by evaluating the resulting difference in the quantity of products disposed of, and the variations in the optimal replenishment policy.

This strategy could be particularly suitable for those categories of food having three specific peculiarities: (*i*) great economic value, (*ii*) high perishability, and (*iii*) great environmental impact. For example, this is the case of beef or fish (the readers are invited to refer to (Qalase and Harding, 2022) or (Geß et al., 2022) for the outcomes of Life Cycle Assessments and Life Cycle Costing of pork and lamb meat production, by way of example, supporting the strong impact).

The results of this study can be of great support to policy-makers, by providing them with the results of a sensitivity analysis of a possible measure aimed at limiting food waste. Moreover, this contribution could support Target 12.3 of the Sustainable Development Goals (SDGs), whose aim is to halve by 2030 the pro capita quota of food waste at retail and consumption stages and to reduce food loss in the production and supply chain.

2. Methodology

In the present study, the analysis focused on the inventory and reorder management of a perishable product in a retail store. Perishable products, e.g., food and beverages, differ from standard items in the fact that they are characterized by a period when they're adequate for consumption, called "shelf life". Usually, when given the chance, the consumers tend to buy fresher products, i.e., those with the highest residual shelf life; this is due to higher perceived and actual food quality, as well as a longer period available for food consumption. Some products present higher perishability than others, with shelf life periods only a few days long: this makes the management of the inventory more complex and increases the risk of wasting food.

2.1 Simulation model

The inventory management of a retail store was modelled with a discrete-time approach using MS Excel, focusing on the reorder policy of a single product. The simulated product was beef, as it is characterized by short shelf life and high environmental impact. Due to the rapid decay of the products, periodic review reorder management was deemed appropriate to satisfy the customers' demand while maintaining an efficient and easily manageable order-issuing schedule. With this replenishment policy, orders are issued at fixed time intervals (*DT*) to restore a fixed order-up-to-level (*OUTL*).

During the modelling of the inventory system, the following assumptions were made:

- B2C context (retail store);
- Periodic review inventory management;
- Single product scenario (beef);
- Orders are fulfilled according to Last-Expired-First-Out (*LEFO*) policy that, in this case, coincides with Last-In-First-Out (*LIFO*);
- Intended consumer demand follows a uniform distribution by default; it is however age-sensitive, so the actual demand depends on the age of the products on hand;
- In the case of shortages, the sale of the missing products is considered lost (*LS*);
- The last day available to sell an item is when its residual shelf life (*SL*) is equal to 1;
- The items that remain unsold at the end of their shelf life must be disposed of;
- The cost sustained for order emission and transport of the goods from the supplier is fixed and independent of the ordered quantity;
- The ordered items (*O*) are delivered after a number of days equal to the lead time (*LT*); being the product highly perishable, a short supply chain with limited delivery time is assumed, with the products assumed to be delivered to the retail store on the next day following the order issuing;
- The products' *SL* starts to decrease when they are shipped from the supplier, i.e., *LT* days before arriving at the store;
- All the products in a single delivery are assumed to have the same *SL*;
- The whole available inventory is displayed to the customers, i.e., the newly delivered products are put on sale right away without waiting for the older ones to be sold first.

The simulated inventory system is age-dependent, and classifies the products based on their date of delivery, i.e., residual *SL*; in particular, there is the category of "New" products, that arrived within the last delivery, and up to 7 levels of "Old". In particular, when one batch is delivered to the store, the items are classified as "New" until the following order is delivered; then, the former "New" products are classified as "Old 1" and the just delivered, fresher ones, as "New". If there are still "Old 1" products when the next bath is delivered, they will become "Old 2" and so on, potentially increasing the order of "Old" items with every delivery. The sum of all inventory age levels constitutes the stock-on-hand (*OH*).

If there is enough *OH*, consumer *D* will be satisfied with "New" products first, according to the LEFO policy, proceeding to decrease the number of "Old 1" products if the "New" ones are not sufficient and use higher orders of "Old" products to follow. The stock-out is tracked in the highest order of "Old" products, as it is the last age level to be checked for product availability. If *OH* is not sufficient to fulfill *D*, the sale of the missing items is lost as stated.

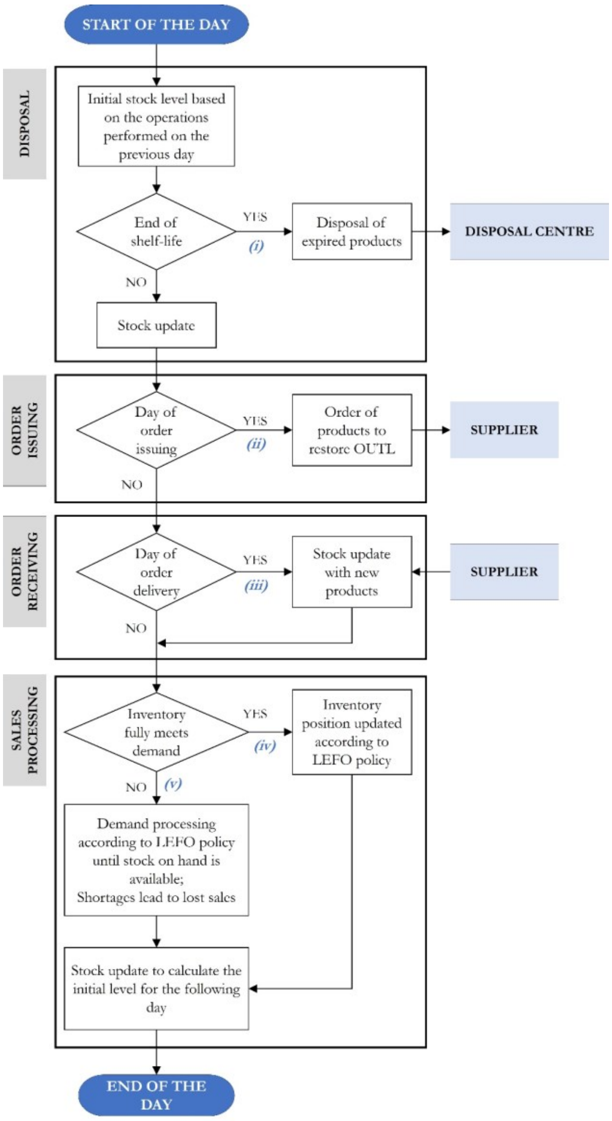

Figure 1. Flowchart of the operations performed each day.

Each row of the simulation model represents a day; in total, 10'000 days (*N*) were modelled. On each day *i*, characterized by a given customer demand D_i, the operations presented in Figure 1 are performed and computed as follows:

(i) $OH_{i-1|SL_{i-1}=1} - D_{i-1} = Q_{exp,i}$

(ii) $O_i = OUTL - OH_i$

(iii) $OH_i = OH_{i-1} - Q_{exp,i} + O_{i-LT}$

(iv) *if* $OH_i > D_i$, $OH_{i+1} = OH_i - D_i$

(v) *else* $LS_i = D_i - OH_i$;

$OH_{i+1} = 0$ *if* $O_{i-LT+1} = 0$

The modelled demand is age-sensitive demand, accounting for customers potentially interested in buying a product, but who may desist if it is not perceived as fresh enough.

2.2 Economic aspects

The management of the inventory obviously generates costs, which can be due to product purchase, order issuing and delivery, inventory holding, disposal of expired items, and costs associated with shortages. On the other hand, revenues are generated with the sale of each product unit.

- The *purchase cost* ($C_{p,i}$) [€] is calculated based on the unitary purchase cost c_p [€/kg] and the order dimension O_i [kg]: $C_{p,i} = c_p \cdot O_i$.
- The *order issuing cost* ($C_{oi,i}$) [€], includes order invoicing, administrative, transportation, and receiving costs; it is fixed and independent of the ordered quantity O_i.
- The *inventory holding cost* ($C_{inv,i}$) [€] includes the costs sustained by the retail management to keep the products in stock under the appropriate storing conditions; it is calculated by considering the cost of keeping one kg of product for a day (c_{inv}) [€/kg] and the level of stock-on-hand [kg]: $C_{inv,i} = c_{inv} \cdot OH_i$.
- The *disposal cost* ($C_{disp,i}$) [€] typically includes collection and transport fees, treatment expenses, disposal taxes and administrative costs (c_{disp}, [€/kg]); in this study, it is calculated based on the volume of produce disposed of [kg]: $C_{disp,i} = c_{disp} \cdot Q_{exp,i}$.
- The *stock-out cost* $C_{so,i}$) [€], associated with shortages, is generally difficult to estimate and it accounts for, among others, the lost sale revenues and the potential loss of customer trust; it is calculated as the unitary stock-out cost c_{so} [€/kg] multiplied by the volume of shortages [kg]: $C_{so,i} = c_{so} \cdot LS_i$.
- The *packaging cost* (C_{pk}) [€], associated with the packaging of trays with beef meat prepared by food operators at the retail store facilities when a new meet delivery arrives: $C_{pk} = c_{pk} \cdot O_{i-LT}$.

- The *total daily management cost* ($C_{tot,i}$) [€] is calculated as the sum of all the cost items detailed above: $C_{tot,i} = C_{p,i} + C_{oi,i} + C_{inv,i} + C_{disp,i} + C_{so,i} + C_{pk}$.
- The *daily revenues* (R_i) [€] are calculated by multiplying the unitary sale price p [€/kg] by the volume of produce sold [kg]: $R_i = p \cdot min(D_i, OH_i)$.
- The *daily profits* (PR_i) [€], therefore, can be calculated as: $PR_i = R_i - C_{tot,i}$.

For optimization purposes, the average management costs (C_{tot}), revenues (R), and profits (PR), calculated over the simulated period, will be considered:

$$C_{tot} = \frac{\sum_{i=1}^{10000} C_{tot,i}}{N}; R = \frac{\sum_{i=1}^{10000} R_i}{N}, PR = R - C_{tot}.$$

2.3 Scenario setup

After setting up the general simulation model, it was necessary to define the specifics of the investigated scenario, i.e., the sale of beef in retail stores. In particular, it was necessary to determine the costs and selling prices, as well as to make appropriate assumptions about the daily customer demand.

For this purpose, the data was derived from the ISMEA (Istituto di Servizi per il Mercato Agricolo Alimentare) "Value chain of the organic beef supply chain" report (ISMEA, 2022). In particular, the authors considered data relating to the "non-integrated value chain", intended as an organizational model where farms operate independently from the subsequent processing and commercialization stages, i.e., slaughterhouses and wholesalers. This model is characterized by the separation between various stages of the supply chain and the lack of vertical integration. The value chain is summarized in Table 1.

With regard to the demand, the following considerations were made. The average beef consumption per capita amounts to 16.8 kg/year approximately (ISMEA, 2023). Given the Italian population of 58'940'000 people, it can be estimated that 990'192'000 kg of beef are consumed in Italy every year, resulting in 2'712'855 kg/day.

In the same report, it is estimated that approximately 70% of beef is sold in retail stores other than butcher shops (1'898'998 kg/day); considering 25'082 retail outlets in Italy, it can be estimated that an average of 76 kg is sold in each store every day (D_m). It was assumed that, as often happens in retailing, the stores acquire cut meat from the processing company and package it into trays in dedicated store facilities.

The daily demand was assumed to be reasonably stable, following a uniform distribution ranging from $D_m \cdot (1 - 0.25)$ to $D_m \cdot (1 + 0.25)$. In particular, this demand can be defined as "intended", representing the intention of the customers to buy when they walk into the store. The demand for a highly perishable product like the one discussed in this study may decrease based on the product's age, in this study, therefore, it is modelled as age-sensitive.

The product *SL* was assumed to have an average value of 5 days at the moment of shipping from the processing company to the retail store; with an average *LT* = 1, the products are characterized by a maximum *SL* of 4 days when they arrive on the store shelves.

When a customer who intends to buy beef finds a tray with the highest possible *SL* (4 days), he always proceeds with the purchase; when *SL* = 3 days, 75% of the intended demand ends up in a sale, 50% when *SL* = 2 days, and only 25% on the last day before expiration. In this scenario, coupled with the *LEFO* policy, several product units risk remaining unsold and being disposed of.

Due to the strong economic variability in retailing, the unitary costs were estimated as fractions of the gross margin (11.29 €): 10% for the stock-out costs, 0.5% for the daily inventory holding cost, 0.5% for the baseline disposal cost; furthermore, three order issuing costs were evaluated, equal to 50, 75, and 150 € per order. The characteristics of the demand and costs are reported in Table 2.

The disposal cost was investigated by applying progressively higher sanctions to the baseline c_{disp}. The aim of the study was to investigate how the introduction of penalties could mitigate the waste of food; to this end, it was decided to perform a sensitivity analysis by gradually incrementing the value of the sanctions from 0% to 100% of the retail purchase price.

Table 1: Unitary prices of beef at different stages of the value chain (2022)

Prices at different production stages	€/kg
Selling price from farmer	6.53
Selling price from slaughterhouse	8.63
Selling price from the meat processing company	10.14
Selling price from packaging company	14.61
Retail selling price to the final consumer	21.43

Table 2: Summary of the demand and economic features

Item	Value	Unit	Description
$D_{i,mean}$	76	kg	Average daily demand
r	19	kg	Half range of daily demand
C_{oi}	50/75/150	€	Order issuing cost
c_{inv}	0.0565	€/kg	Unitary daily inventory holding cost
c_{disp}	0.0565	€/kg	Unitary baseline disposal cost
c_{so}	1.129	€/kg	Unitary stock-out cost
c_{pk}	1.129	€/kg	Unitary packaging cost
c_p	10.14	€	Unitary purchase cost
p	21.43	€	Selling price

For each evaluated case the simulation model was used to determine the optimal operating leverages (*DT*, *OUTL*) of the reorder policy, aiming to maximize the system profits. The variation in the disposed of produce was the key performance indicator (*KPI*) related to food waste considered in this study; during the simulation campaign, it was registered to observe whether, and to what extent, the introduction of the penalty decreased the occurrence of food wastage under optimal operating conditions.

This evaluation was carried out considering both an age-sensitive demand and a case without age-sensitivity, to evaluate the impact of this important modelling assumption.

3. Results and discussion

The first results that can be observed summarize the trend in the operating leverages as the disposal cost increases due to penalties for the case with age-sensitivity of the demand (Figure 2) and without (Figure 3).

Overall, *OUTL* levels in the second case appear higher, and both operating leverages appear more insensitive to the disposal cost compared to the case with age-sensitive demand, with the ratio *OUTL/DT* being fairly constant.

This is related to the fact that, in the first case, i.e., with the age-sensitive demand, the customers tend to buy fresher products and leave the older ones unsold with the risk of them being disposed of. In the second case, on the other hand, the customers are assumed to not make distinctions between products of different ages, and buy the product they came for regardless of their residual *SL*.

In the case of food products, especially those highly perishable like fresh meat, this is a very strong and unrealistic assumption: the results, indeed, highlight the importance of including the sensitivity of the demand to the product age in the simulation models.

As the disposal cost increases, the ratio of *OUTL* to *DT* decreases, exposing the retail store to stock-out risks in case of high demand variability. This highlights how it is essential to accurately model the demand distribution in order to obtain reliable data and minimize the risk of shortages and wastages due to wrong estimates during the definition of the management policy.

To this end, it would be necessary to further develop the simulation model to include additional demand features, such as trends and seasonality.

In Figure 4, the trend in the monitored food waste *KPI*, i.e., the disposed of products, is presented as the unitary disposal cost increases due to penalties.

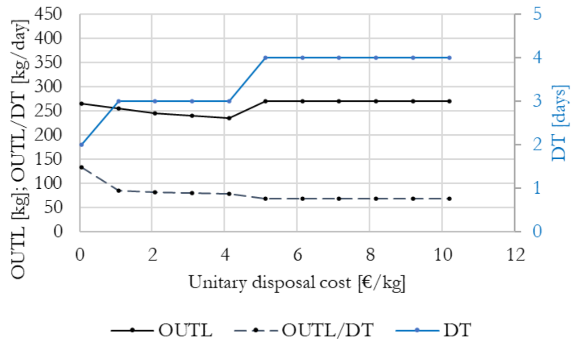

Figure 2: Trend in the optimal operating leverages, and their ratio, at increasing disposal cost values; case with age-sensitive demand.

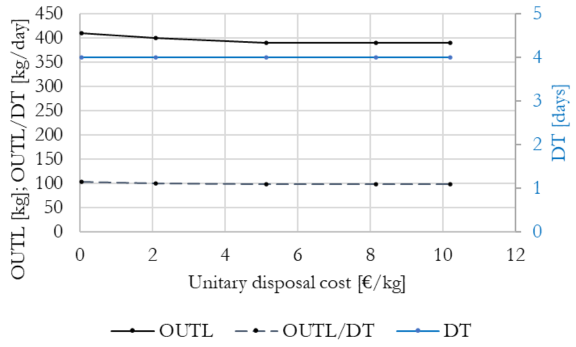

Figure 3: Trend in the optimal operating leverages, and their ratio, at increasing disposal cost values; case without age-sensitivity of the demand.

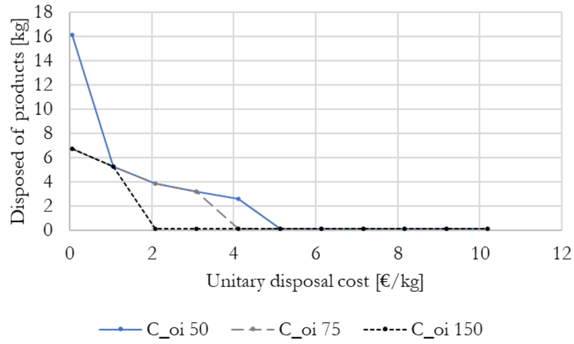

Figure 4: Trend in the quantity of disposed of products as the unitary disposal cost increases (with age-sensitivity of the demand).

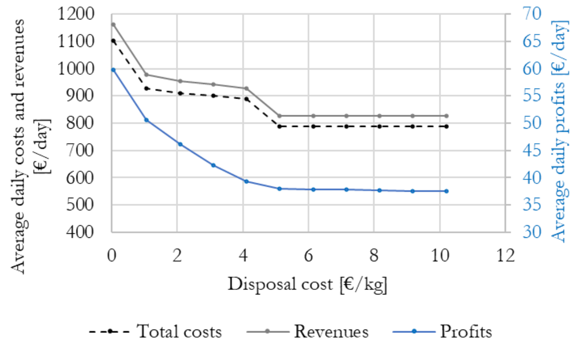

Figure 5: Trend in the average daily costs, revenues, and resulting profits, as the disposal cost increases due to penalties (with age-sensitivity of the demand).

It can be seen that, as expected, for higher penalty values, the disposals decrease. It can be noted, however, that the trends tend to differ when varying other costs, such as order issuing.

While all three cases tend to stabilize over a zero-waste configuration at a certain point, when the overall cost levels are lower, the disposals tend to decrease more gradually with the penalty. On the other hand, with high operating costs, the system tends to reach the optimal situation more rapidly, to limit the occurrence of operating costs.

Also, the initial disposal level with the lowest disposal cost resulted in being higher than the cases with higher operating costs. Since the optimal operating leverages were determined based on the maximization of the profit, it is possible that other costs, e.g., stock-out cost, were more significant and more in need of minimization to achieve the best operating conditions.

As the disposal cost increases, the optimization of the model tends to minimize the wastage of products to reduce the occurrence of economic penalties. This is achieved by reducing the quantity of products ordered, as observed also in Figure 2, resulting in lower costs, but also lower revenues and profits for the retail store (Figure 5).

4. Conclusions

In this study, a discrete-time simulation model of a retail store selling beef was generated. The model featured age-dependent inventory classification of the stored highly perishable products and *LEFO* fulfilment policy of an age-sensitive demand. The stock-on-hand was replenished according to a periodic review policy as it was deemed particularly efficient for highly perishable items that need to be re-ordered often.

The effect of the disposal cost and the introduction of economic sanctions on unsold products were investigated. It emerged that both the optimal operating leverages, intended as those that allow to maximize the profits in given operating conditions, and the disposed of products strongly depend on the disposal cost. This effect appears to be much more significant when the age sensitivity of the demand is included in the model, highlighting the importance of correctly defining the assumptions. Moreover, the impact of the increase in the disposal cost appears to depend on the levels of the other operating costs.

While economic penalties might be leveraged to reduce food waste, great attention and consideration are needed from the policy makers to accurately and clearly define the strategies and policies to apply. To this end, simulation can be a valuable tool, allowing them to test what-if scenarios on a digital and tunable tool.

Obviously, economic penalties are not the only possible tool to leverage to minimize food waste: it is also possible to implement incentives, discounting policies, regulations, and other sustainable strategies that could also be integrated to enhance their efficiency. The effect of these measures should be evaluated with appropriate *KPIs*, assessing both economic and sustainable aspects.

Future research activities will aim to investigate these topics, as well as to further develop the simulation model to account for its present limitations.

To make the model more realistic, it would be particularly important to accurately assess and model the customer demand, which undoubtedly is one of the main aspects to take into account when defining the appropriate reorder policy for highly perishable products that are particularly prone to being wasted.

Other aspects worth including in the investigation are the introduction of discounting policies and the evaluation of the service levels in the case of highly perishable items. Moreover, with regard to the items, other perishable products, as well as multi-product inventories, can be analyzed to derive further insights. Finally, in future research activities, the results of the generated model will be evaluated against other approaches available in the literature, to compare and validate the obtained outcomes.

References

Ahmadzadeh, S., Ajmal, T., Ramanathan, R., and Duan, Y. (2023). A comprehensive review on food waste reduction based on IoT and Big data technologies. *Sustainability*, 15(4), 3482.

Aramyan, L., Grainger, M., Logatcheva, K., Piras, S., Setti, M., Stewart, G., and Vittuari, M. (2020). Food waste reduction in supply chains through innovations: a review. *Measuring Business Excellence*, 25(4), 457-492.

Brown, L.P. (1918). Food wastes – some causes and remedies. *Journal of the Franklin Institute*, 185(5), 585-610.

Buisman, M. E., Haijema, R., & Bloemhof-Ruwaard, J. M. (2019). Discounting and dynamic shelf life to reduce fresh food waste at retailers. International Journal of Production Economics, 209, 274–284. https://doi.org/10.1016/j.ijpe.2017.07.016

EUROSTAT (2021). Food waste and food waste prevention - estimates. Available at: https://ec.europa.eu/eurostat/statistics-Explained/index.php?title=Food_waste_and_food_waste_prevention_estimates#Amounts_of_food_waste_at_EU_level

FAO (2019). The State of Food and Agriculture. Moving forward on food loss and waste reduction. Rome. License: CC BY-NC-SA 3.0 IGO.

Geß, A., Tolsdorf, A., and Ko, N. (2022). A life cycle perspective of lamb meat production systems from Turkey and the EU. Small Ruminant Research, 208, 106637.

Herman. A. (2015). Enchanting resilience: relations of care and people-place connections in agriculture. *Journal of Rural Studies*, 42, 102–111.

ISMEA (2023). Tendenze Bovino da carne - dicembre 2023. Coordinated by Michele Di Domenico. Edited by Paola Parmigiani.

ISMEA (2022). Catena del valore della filiera carne bovina biologica. Coordinated by Antonella Giuliano. Contrib. by Riccardo Meo, Alessandro Trotta, Giuseppe Fornaciari, Gianluigi Sagarriga Visconti, and Franco Torelli.

Qalase, C., and Harding, K.G. (2023). Eco-efficiency assessment of pork production through life-cycle assessment and production system value in South Africa. E3S Web of Conference, 349, 13002.

Solari, F., Lysova, N., Bocelli, M., Volpi, A., & Montanari, R. (2024). Perishable Product Inventory Management In The Case Of Discount Policies And Price-Sensitive Demand: Discrete Time Simulation And Sensitivity Analysis. *Procedia Computer Science*, 232, 1233–1241. https://doi.org/10.1016/j.procs.2024.01.121

Tromp, S.-O., Haijema, R., Rijgersberg, H., & van der Vorst, J. G. A. J. (2016). A systematic approach to preventing chilled-food waste at the retail outlet. *International Journal of Production Economics*, 182, 508–518. https://doi.org/10.1016/j.ijpe.2016.10.003