Sustainable Production and Consumption 38 (2023)

Contents lists available at ScienceDirect

Sustainable Production and Consumption

journal homepage: www.elsevier.com/locate/spc

Sustainability assessment of surplus food donation: A transfer system generating environmental, economic, and social values

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ARTICLE INFO

Article history:
Received 28 December 2022
Received in revised form 19 March 2023
Accepted 23 March 2023
Available online 30 March 2023

Editor: Prof. Piera Centobelli

Keywords:
Food waste management
Life cycle assessment
Rebound effect
Food security
Food rescue
Nutrition

ABSTRACT

Retailers' food waste, often consisting of edible food, could be reduced, while simultaneously tackling food insecurity, through surplus food donations to vulnerable groups. However, sustainability assessments of food donations covering all three sustainability perspectives are scarce, hampering decision-makers in prioritizing donation as a food waste management measure. This Swedish case study assessed the environmental, economic, and social aspects of surplus food donation and examined trade-offs between the different sustainability perspectives. Methods included life cycle assessment, net economic benefit calculation, social life cycle assessment based on food security questionnaires, and nutritional assessments. The results showed that food donation was a way to reduce food waste benefitting the environment and adding economic and social value, to vulnerable people in particular. Despite substantial rebound effects offsetting some potential environmental savings, food bag donations outcompeted anaerobic digestion as a food waste management option in terms of environmental mitigation effect. Regarding trade-offs, accrued savings causing the rebound effects generated important social value for the donation recipients, by relieving their personal finances. Private and public investment was required to fund the donation units, but positive economic value was generated through valorization of surplus food. Food bag donations also showed potential to alleviate recipients' food insecurity and to contribute positively to recipients' nutrition intake. To realize the potential of surplus food donation, policy measures should be better aligned with the waste hierarchy. Despite some trade-offs and inability to solve the underlying problems of food insecurity, food donations have great short-term potential to contribute to a more sustainable society.

1. Introduction

Despite the ambition to halve global food waste set out by United Nations 2030 Agenda for Sustainable Development, unacceptable levels of food continue to be wasted worldwide, while global food insecurity is increasing due to Covid-19, climate change, conflicts, and economic shocks (UNEP, 2021; United Nations, 2022). Consumer wastage is reportedly more pervasive than previously believed, amounting to 930 million tons of food waste globally in 2019 (UNEP, 2021). The vast amounts of food wastage become even more striking, given the increasing number of people living in food insecurity. In 2021, a staggering 2.3 billion people suffered from food insecurity and 828 million people faced hunger globally, a devastating setback to the goal of zero hunger by 2030 (United Nations, 2022).

Access to adequate food is a basic human right (United Nations, 2010). A general assumption is that food insecurity does not exist in high-welfare countries such as Sweden, due to their affluent living standards and social security systems. However, in 2020, 8.6 % of people in the European Union (EU) were unable to afford a proper meal (Eurostat, 2022). In the United Kingdom (UK), 6 % of the population were living in food poverty in 2021 (Francis-Devine et al., 2022). In Sweden, a recent survey showed that 1.9 % of its population did not always have enough food to eat (Borch and Kjærnes, 2016). Increasing at-risk-of-poverty rate and a widening income gap were also reported in 2019 (SCB, 2019). In 2022, increasing food prices and inflation caused an explosive increase in demand for food donations in Sweden (Grönberg, 2022). Meanwhile, a vast amount of food waste is generated in Sweden, both as metabolic food waste, i.e. due to overeating (0.5 million tons/year) (Sundin et al., 2021), and through food discards (1.1 million tons/year) (Hultén et al., 2022). Approximately

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https://doi.org/10.1016/j.spc.2023.03.022

100,000 tons of discarded food waste are generated annually by retail alone (Hultén et al., 2022).

While retailers are responsible for a minor fraction of overall food waste (e.g. 5 % in the EU, 9 % in Sweden), they are considered a key contributor as their food waste consists of unsellable, but often edible, food (Brancoli et al., 2019; Eriksson et al., 2014; Hultén et al., 2022). One way to reduce this type of food waste, and simultaneously tackle food insecurity, is surplus food donation to people in need, which is well-aligned with the waste hierarchy advocated by the EU (European Commission, 2017). According to the waste hierarchy, surplus food redistribution to people in need is the next best option after food waste prevention (where potential surplus food is never produced, thereby saving resources and energy). However, most food waste around the globe is still treated using low-priority options such as incineration (11 %), or landfill and dumping (70 %) (Sabour et al., 2020). There is an increasing trend for retailers to follow the waste hierarchy, prioritizing food waste reduction and redistribution (Huang et al., 2021), but only a fraction of edible surplus food is redistributed. The proportion of donated surplus food within overall food waste was 4 % in the United States (US) in 2021 and 3 % in the UK in 2020 (Feeding America, 2022; WRAP, 2021). In Sweden, the fraction of donated food is even smaller, e.g. 4500 tons or only 0.4 % of overall food waste in 2021 (Lunde Dinesen, personal communication, 2022). The goal in Sweden is to increase the amount of donated surplus food to 10,000 tons/year by 2025 (IVL Svenska Miljöinstitutet, 2022).

Attempts have been made to stimulate food waste management activities, such as surplus food donation, through regulatory and policy measures. Guidelines for food donation were implemented in the EU in 2017, but their execution differs significantly between member states (Deloitte et al., 2020; European Commission, 2017). Fiscal incentives, such as VAT exemptions and tax deductions, are more popular measures. However, Sweden is lagging behind in fiscal incentives and is not aligned with the waste hierarchy, as its political ambition is to further increase anaerobic digestion of waste (Swedish Environmental Protection Agency, 2022). This is a response to the *waste as a resource* narrative in the EU, which has turned attention from waste prevention to renewable energy production technology such as anaerobic digestion (Hultman and Corvellec, 2012). The preference for biogas production over food donation has also been attributed to the framing of food loss and waste as a waste issue in environmental and economic perspectives, but neglecting the social perspective (Johansson, 2021).

Surplus food donations are mainly a focus of food waste prevention policies, and it can thus be assumed that surplus donations are of great benefit. However, only a few studies have evaluated the sustainability impacts of food donations, with the economic and social dimensions, in particular, remaining unscrutinized (Albizzati et al., 2019; Bergström et al., 2020). The aim of the present case study was to bridge this knowledge gap by assessing the environmental, economic, and social aspects of surplus food donation operations located in Uppsala, Sweden, thus providing a holistic view of the various values generated by food donation, including possible trade-offs between the three aspects of sustainability.

2. Literature review

A considerable body of scientific evidence supports a shift toward sustainable food systems for both human and planetary health (Springmann et al., 2018). In efforts to achieve this, halving global food waste is considered key (Willett et al., 2019). Food production is resource-intensive, requiring water, land, energy, labor, and capital, and thus wasting food means wasting these input resources. Food waste accounts for approximately 10 % of global greenhouse gas emissions (GHGE) (WWF-UK, 2021). For example, food that is lost and wasted occupies approximately 30 % of agricultural land area and accounts for 38 % of total energy usage in the global food system (United Nations, 2022). In addition, the most commonly used food waste management, landfill, is a major source of GHGE (Kormi et al., 2018). Food losses and waste also have negative impacts on food security, availability, and affordability, in terms of meeting sufficient caloric needs, sufficient nutrition, and meeting the need for healthy diets for the existing and growing world population (Kufuor et al., 2018). Therefore, the total environmental, economic, and social implications of global food waste come at a tremendous annual cost of 2.6 trillion USD (FAO, 2014).

Studies on the environmental implications of food waste prevention, the highest priority in the waste hierarchy, report significant emission reductions (Redlingshöfer et al., 2020; Obersteiner et al., 2021). The reduction is especially great when waste prevention is compared with lower-priority food waste management options, such as anaerobic digestion, composting, or incineration (Bernstad Saraiva Schott and Andersson, 2015; Oldfield et al., 2016; Eriksson et al., 2015). However, studies assessing the lower-priority options in the waste hierarchy are much more common (Bernstad and la Cour Jansen, 2012; Mondello et al., 2017). Previous research has thus focused on choosing the best food waste treatment method, rather than waste prevention (Redlingshöfer et al., 2020).

In the waste hierarchy, food re-use for human consumption, and re-use for animal feed, lie between prevention and lower hierarchy options such as anaerobic digestion. Salemdeeb et al. (2017b) assessed animal feed in comparison with composting and anaerobic digestion, and confirmed its higher ranking in the waste hierarchy. On assessing the environmental benefits of re-using potato protein side-streams, Bartek et al. (2022) found that producing food instead of feed reduced the environmental impact and caused less damage to ecosystems. Albizzati et al. (2021) found that food waste prevention followed by redistribution was the best valorization pathway to manage food waste. However, similarly to Martinez-Sanchez et al. (2016), they pointed out that the expected environmental benefits may not be realized if economic savings from food waste prevention and redistribution lead to additional consumption that is high in emissions. The trade-offs mediated by rebound effects have been extensively investigated in terms of energy efficiency improvements (Sorrell and Dimitropoulos, 2007). However, only a few studies have considered rebound effects in assessing food waste management options (Albizzati et al., 2022; Sundin et al., 2022), although rebound effects can arise if measures lead to reduced costs for actors in the food chain (Reynolds et al., 2019). Studies investigating household food waste prevention have found substantial rebound effects, ranging between 57 % and 78 % (Hagedorn and Wilts, 2019; Lekve Bjelle et al., 2018; Salemdeeb et al., 2017a).

As in household food waste prevention, rebound effects may arise when redistributing surplus food if recipients of donated food (hereafter simply 'recipients') accrue monetary savings. Rebound effects associated with food donation have been reported to offset 51 % of the potential GHGE savings, although the climate benefit of food donation still outweighs the climate benefit of anaerobic digestion (Sundin et al., 2022). Several studies investigating surplus food donation compared with redistribution initiatives have found that surplus food donations achieve higher GHGE reductions than initiatives such as reprocessing or waste management (Bergström et al., 2020; Eriksson and Spångberg, 2017; Moult et al., 2018). However, those studies did not include rebound effects, which would likely reduce the reported benefits.

The majority of studies to date have focused on GHGE in their environmental assessments, essentially confirming emission savings in the order of the waste hierarchy, but fewer studies have included several environmental impact categories. Brancoli et al. (2020) included 18 impact categories in their investigation of surplus bread donation and concluded that anaerobic digestion and incineration offered the lowest environmental savings, particularly in a low-impact energy system. Similarly, a study comparing food donation to lower hierarchy options concluded that donation generated significant environmental benefits as long as food rescue processes were run efficiently (Damiani et al., 2021). Further, Albizzati et al. (2019) found that anaerobic digestion and incineration were outcompeted in an environmental and economic perspective by surplus food redistribution and use-as-feed.

Sustainability comprises the three-pillar concept of environmental, social, and economic sustainability, also integrated into life cycle assessment (LCA) methodology (Purvis et al., 2019). Complete sustainability assessments, including all three perspectives, on surplus food donation are scarce, as most studies have focused on the environmental or economic aspects (Hecht and Neff, 2019). Further, a standardized approach to sustainability assessment has been lacking (Caldeira et al., 2019). Nevertheless, existing studies suggest promising effects, such as positive return on investment, decreased environmental burden, large quantities of food rescued, and high stakeholder satisfaction (Caldeira et al., 2019; Hecht and Neff, 2019; Reynolds et al., 2015). Among the few complete sustainability assessments conducted on redistribution, Albizzati et al. (2021) found that food waste prevention followed by redistribution was the best pathway to manage food waste across all three pillars of sustainability, whereas Bergström et al. (2020), who compared different redistribution initiatives such as food bag donation and soup kitchens, concluded that these initiatives had different areas of strength in terms of sustainability.

In the literature, social sustainability has received the least attention, although the social benefits of food donation are likely to be of high relevance to recipients in particular. Social impact indicators suggested in the evaluation framework for surplus food redistribution include number of meals donated, jobs created, people learning new skills, and food-insecure people supported (Caldeira et al., 2019). Effects such as community engagement, staff working hours, and volunteer altruism have also been reported (Goossens et al., 2019; Mirosa et al., 2016; Mousa and Freeland-Graves, 2017). However, using social indicators such as these places the focus on society or workers/volunteers, rather than on recipients. Several social impacts of high relevance have been identified for recipients of donated food, such as improved purchasing power, food security, and nutrition (Mousa and Freeland-Graves, 2019a, 2019b; Vittuari et al., 2017; Wolfson and Greeno, 2020), but to date, these type of indicators have rarely been included in social or sustainability assessments of food donation. In addition, recipients as a stakeholder group have rarely been included in economic assessments of food donation activities (Cicatiello et al., 2016; SVA, 2013).

Empirical evidence on the environmental impacts of food waste management options indicate superiority of surplus food donation over lower hierarchy options. However, studies evaluating the sustainability of food donation from all aspects of sustainability and including recipients as a stakeholder group are scarce, hampering decision-makers in prioritizing different measures (Goossens et al., 2019; Vieira et al., 2022). Complete sustainability assessment of surplus food donation would provide a more comprehensive view of its overall impacts, as trade-offs between the three aspects of sustainability are common (UNEP, 2011).

3. Materials and methods

This sustainability assessment on surplus food donation was a case study on the Swedish non-profit organization, Uppsala City Mission (UCM). The operating model of UCM is to redistribute surplus food from retailers to people in need. In addition to supporting vulnerable people while preventing food waste, UCM provides job-training opportunities to people having difficulties entering the labor market. The redistribution operations are funded by donations from private donors, companies, foundations, the local municipality, and the state. The operations are run by a mixture of employed and voluntary labor working in two sub-units, a food bag center and a soup kitchen. The soup kitchen serves cooked meals free of charge to people who are exposed to social vulnerability. The food bag center redistributes weekly food bags for a biannual 250 SEK (~25 EUR) membership fee to recipients whose income must not exceed UCM's threshold for financial vulnerability, 9290 SEK/month (~910 EUR).

To represent an alternative prevalent food waste management in Sweden when investigating the environmental impacts of surplus food donation, a biogas plant located in Uppsala was chosen. This plant treats approximately 48,000 tons of food waste annually to produce biogas and bio fertilizer (Uppsala Vatten, 2021).

Although the facilities included in this case study are located in central Sweden, they are common both in Sweden and in Europe making the case study generalizable to similar, fully operational units beyond the specific location of the case study.

3.1. Life cycle assessment

To assess the environmental impact of food donation, an attributional LCA, where ISO standards 14,040–14,044 were used as guidelines was performed (ISO, 2006a, 2006b). The environmental impacts of three food waste management scenarios, involving food bag donations, soup kitchen donations, and anaerobic digestion, were compared (Fig. 1). In the scenarios, the functional unit (FU) of *1 kg surplus food ready for dispatch at the retail gate* was applied. Further, similarly to Sundin et al. (2022), the environmental impacts associated with substituted products and rebound effects were credited or added to the overall results, respectively.

The system was modelled in SimaPro 9.2 software, using the ReCiPe2016 (H) method for midpoint and endpoint impact assessment (Database & Support team PRé Sustainability, 2021). Datasets from Ecoinvent 3.8 and Agri-footprint 5.0 (mass allocation) representing European conditions were used to describe the system. At the midpoint level, 18 impact categories were assessed. At the endpoint level, 16 of the midpoint impact categories were aggregated to two endpoint categories: 1) Ecosystems, expressed as the loss of species over a certain area and time (species.years) and 2) human health, expressed as disability-adjusted life years (DALYs).

3.1.1. Food waste management scenarios

The three scenarios were modelled as parallel processes with retail gate (surplus food ready for transport) as the starting point. Site location for all scenarios was Uppsala, Sweden, and site-specific input data and inputs were used when possible (see Appendix A). For the food bag and soup kitchen scenarios, the following processes were included: transport to charity, packaging, transport home, food waste treatment, and energy for storage. For anaerobic digestion, the processes included pre-treatment (including transport), and anaerobic digestion.

3.1.2. Substitution

In each of the scenarios, emissions from substituted products were subtracted from the environmental impacts generated by the food waste management scenarios. In the anaerobic digestion scenario, the biogas produced was used to run the bus traffic in Uppsala, thereby substituting for natural gas, and the biofertilizer was used for cultivation, substituting for mineral fertilizer. For more details concerning the input datasets, see Appendix B.

In the food donation scenarios, the substitution involved avoided food purchases and therefore presumed avoided food production, due to receipt of donated food. The substituted food was investigated with the help of a single 24-h dietary recall survey, using FAO's dietary diversity questionnaire (Kennedy et al., 2013), as described in detail in Section 3.3.3, and composition analysis of 30 randomly selected food bags collected in different seasons in 2020–22. The composition analyses were conducted based on photographs of all food items included in the bags. The net weights from packaged food items were used when possible. Further, the number of fruit and vegetables found in the food bags were multiplied by their standard gross weights (KF och ICA provkök, 2000). For a complete list of food groups and items per food bag in grams, see Table C.1 in Appendix C.

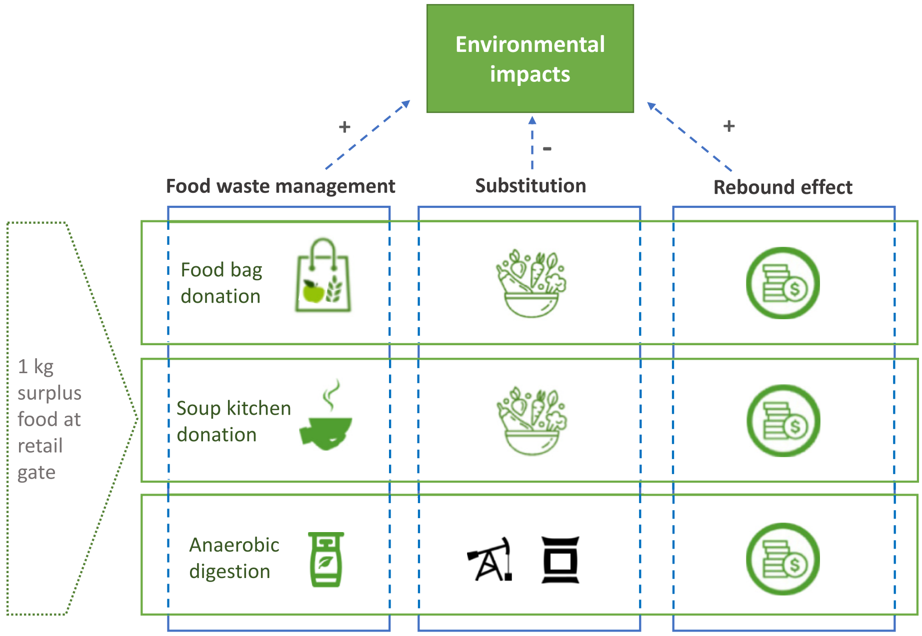

Fig. 1. System boundary diagram illustrating the three scenarios compared, and their respective products. The scenarios included system expansions for substituted products and rebound effects stemming from the substitution. The positive (+) or negative (−) signs demonstrate the nature of the contribution of each sub-system to the overall environmental impacts.

According to the interview results, it was plausible that the food bags substituted for foods from the most frequently consumed food groups according to the average content of the food bags (Fig. 2), as previously observed by Sundin et al. (2022). Expensive *luxury* food items, such as mango, chocolate, and ready-made meals, were excluded, and in total 90 % of food bag weight was assumed to be substituted and 10 % wasted. Substitution of the soup kitchen donations was based on two meals amounting to 850 g food/visitor/day consisting of coffee, bread, dairy, meat, staple foods such as pasta, and some vegetables (Sundin et al., 2022). For more details on the input datasets, see Appendix B.

3.1.3. Rebound effect

The rebound effect refers to reductions in expected benefits from energy efficiency improvements by households because of related behavioral responses in the form of greater energy use (Chitnis et al., 2013). In the present study, a rebound effect was expected to arise from emissions generated by re-spending of accrued savings due to receiving donated food (Sundin et al., 2022) defined as the relationship between potential emission savings (ΔH) and emission savings not realized (ΔG) (Chitnis et al., 2014; Druckman et al., 2011):

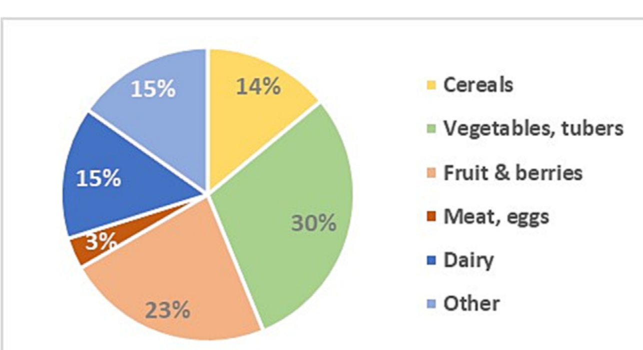

Fig. 2. Average net weight composition (%) of the food bags by food group.

$$Rebound\ effect = \frac{\Delta G}{\Delta H} \tag{1}$$

To model ΔG for the food donation scenarios, the monetary savings accrued per food bag received (165 SEK) and per daily soup kitchen visit (25 SEK) were used, together with their associated consumption patterns (Sundin et al., 2022). For the anaerobic digestion scenario, the potential increase in profits from biogas sales (30,000 SEK) was assumed to reduce subscriber fees, resulting in monetary savings for households (Sundin et al., 2022) that were used for the average Swedish consumption pattern (Grabs, 2015). For each consumption category, the rebound-related emissions were modelled per product using the equation:

$$\frac{Accrued\ savings\ (SEK)}{Product\ price\left(\frac{SEK}{kg}\right)} \times Product\ per\ category\ (\%) \times Spendings\ per\ category(\%) \tag{2}$$

For a complete list of the consumption categories, datasets, and prices used for the modelling, see Appendix D.

3.2. Economic impact assessment

To assess the economic impact of the food donation scenarios, their net economic benefits were calculated based on the difference in economic benefits created for society through the redistribution activities and the overall cost of these activities (Caldeira et al., 2019). The benefits and costs were investigated from a stakeholder perspective, where the key stakeholders were either accountable for the cost or received the benefit (Fig. 3).

3.2.1. Net economic benefits

The following elements were included in the net benefit calculation: a) the economic value of avoided purchase of food; b) the avoided cost of food waste disposal; and c) the cost of the action (Caldeira et al., 2019). Avoided purchase of food was applied to recipients but not to UCM, as their food donation activities depended on a free supply of surplus food and therefore no purchasing of food was avoided. Due to high

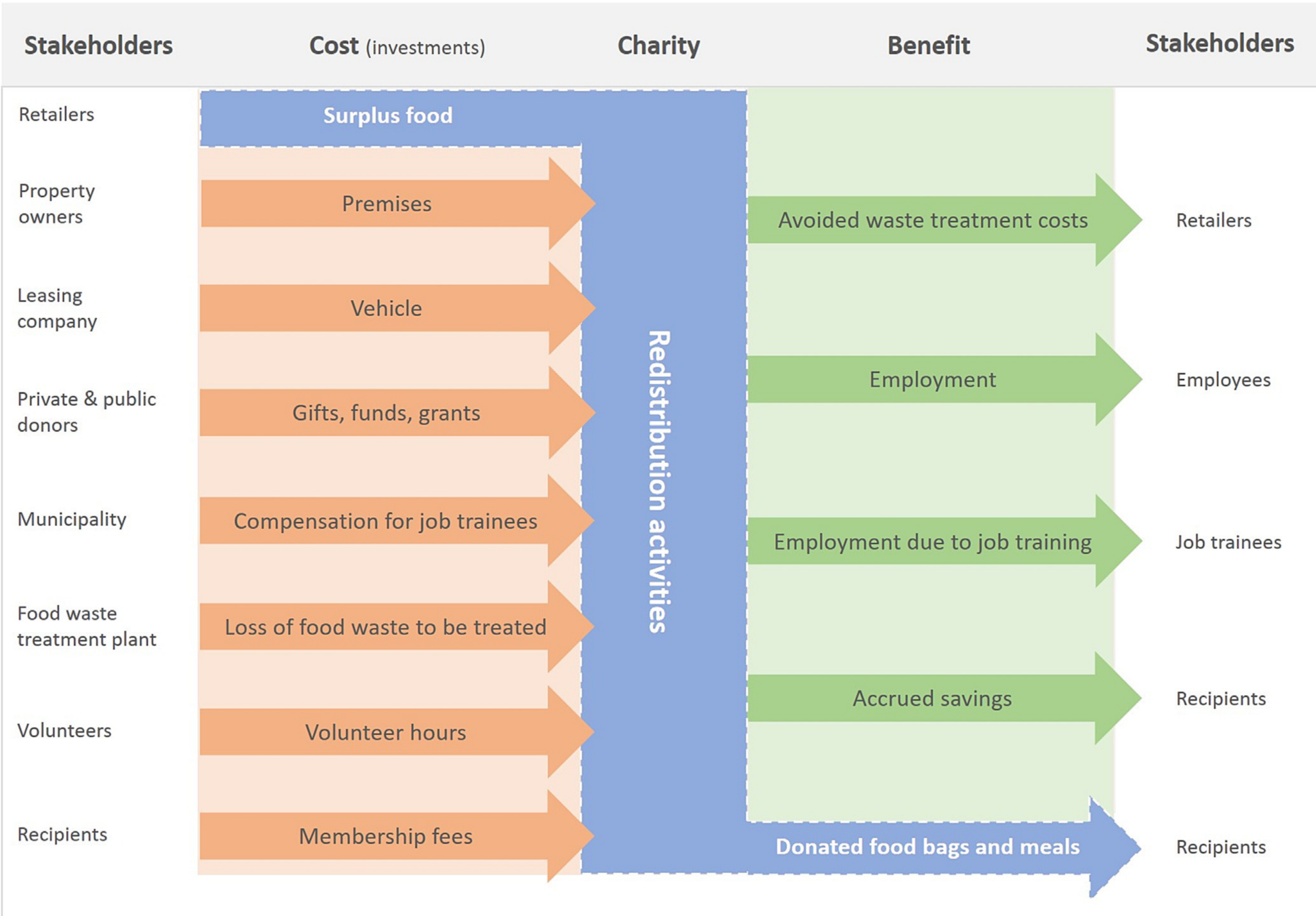

Fig. 3. Illustration of the costs (investments) and benefits associated with surplus food redistribution activities by Uppsala City Mission. The surplus food donated from retail was considered food waste and therefore bore no economic value on entering the system. Through the redistribution activities, enabled by external investments, surplus food was transformed into food bags and cooked meals, creating economic benefits for stakeholders.

labor costs, volunteers are a necessary part of UCM's operating model. UCM also receives compensation from the municipality to employ job trainees in exchange for helping them to overcome employment barriers. Therefore, the societal benefits created through *employment* and *job-training leading to employment* were included as an additional element (d) in the net benefit calculation. For covering the costs, different types of investments were included, such as monetary gifts and grants that enabled UCM to pay for their running costs (staff salaries, etc.), but also investments that enabled UCM to avoid paying for costs, such as receiving a leasing car free of charge (Fig. 3). The economic loss associated with food waste that was not treated by anaerobic digestion but donated was also included. However, the cost of donated surplus food was omitted because the food had become unsellable, i.e. food waste from the retail perspective. The net economic benefit was calculated as a + b + d − c. For more details on each element, see Table E.1 in Appendix E.

3.2.2. Efficiency

The efficiency of the food donation scenarios was evaluated by setting the costs against their economic benefits, amount of food waste prevented, ecological savings, and social benefits (Goossens et al., 2019). For assessment of economic efficiency, the benefit-cost ratio was calculated by dividing the benefits by the costs (Investopedia, 2020). The food waste prevention and ecological efficiencies were calculated as the cost for reducing 1 ton of food waste and for abating 1 ton of carbon emissions (CO_2 eq.), through the ratio of cost to food waste reduction potential or emission savings, respectively (Goossens et al., 2019). Social efficiency was calculated as the cost of donating one food bag or meal, by dividing the costs by the number of food bags or meals donated.

3.3. Social impact assessment

To assess the social impacts of food donation, social life cycle assessment (S-LCA) methodology was applied for the goal, scope, and stakeholder definitions (UNEP, 2020). The goal of the assessment was to examine the *actual* social impacts of food donation for the key stakeholder categories, based on primary data. The scope was redistribution by UCM of surplus food from the retail gate to the recipients, including product end-use. The stakeholder categories chosen were consumers, workers, and the local community, based on the operating model of UCM. Based on categories, the key stakeholders were identified as recipients, employees, job trainees, volunteers, and the local community (Table 1).

3.3.1. Impact categories and impact subcategories

While inspiration was drawn from the S-LCA handbook issued by UNEP (2020), decisions on impact categories and subcategories assessed were largely based on their deemed relevance concerning the actual social and socio-economic impacts of the system studied, although data availability also played a role. An overview of the chosen stakeholder categories, stakeholders, impact categories, impact subcategories, and their corresponding indicators is presented in Table 1. The primary data used as indicators were collected from the

Table 1
An overview of the chosen stakeholder categories, stakeholders, impact categories, impact subcategories and their corresponding indicators used in the social impact assessment of food donation scenarios.

Stakeholder categories	Stakeholders	Impact categories	Impact subcategories	Indicators
Consumers	Recipients	Health and safety	Food security	High or marginal (0–1); Low (2–4); Very low (5–6)
			Individual dietary diversity	WDD score; min: 0; max: 9
			Nutrient rich foods score (food bags)	NRF11.3
		Equal opportunities	Gender ratio	Male/female (%)
		Economic security	Accrued savings due to receiving donated food	SEK/food bag or visit to soup kitchen
		Customer satisfaction	Service satisfaction	% happy (4 or 5) (scale 1–5)
			Increased life quality	% positive (4 or 5) (scale 1–5)
			Influence on health	% improved (4 or 5) (scale 1–5)
			Influence on personal economy	% improved (4 or 5) (scale 1–5)
Workers	Employees	Working conditions	Working time (full-time)	Working hours/week
	Job trainees		Working time (part-time)	Working hours/week
	Volunteers		Overtime	Hours/week
			Overtime payment	Yes/no
			Job positions	Full-time positions
			Fair salary	SEK/month
			Rehabilitation effectiveness	Job trainees entering labor market (%)
		Health and safety	Sickness absence	Long-term absences; >90 days
			Employee turnover	Turnover rate (%)
			Workplace violence; external threats	Number of incidents
		Equal opportunities	Gender ratio in work positions	Female workforce (%)
			Gender ratio in work positions	Female managers (%)
			Gender ratio in salary	Ratio of basic salary of men to women
Local community	Local community	Social responsibility	Surplus food redistributed	t/year
			Food bags or meals donated	No/year
			Poverty alleviation	Food bag recipients or soup kitchen visits/year
		Environment	Food waste prevented	t/year

stakeholders through a food security questionnaire (Appendix F), a dietary diversity interview (Appendix G), UCM staff interviews, UCM annual reports, and previous scientific studies, and by conducting nutritional calculations on the edible content of the food bags.

3.3.2. Food security questionnaire

Study participants were recruited by UCM staff during August 2020–April 2021 as previously described by Sundin et al. (2022). Data were collected from: 1) existing food bag recipients; 2) new food bag recipients; and 3) soup kitchen visitors. During the previous 30 days, the existing recipients had to be food bag recipients, while new recipients were not allowed to have received any of them. The questionnaire was available in Swedish, Arabic, and English. The following participants were recruited: 67 existing food bag recipients; 42 new food bag recipients; and nine soup kitchen visitors. For the demographics of the study participants, see Table H.1 in Appendix H. The participants were informed verbally and in writing about the study and informed consent was obtained from all participants, signed by them. No sensitive personal data was collected.

To investigate the food security status of the recipients, a self-administered six-item food security questionnaire was used (USDA, 2012) (see Appendix F). The mean scores for new and existing food bag recipients were compared, to evaluate whether food bags could potentially contribute to improved food security status among the recipients.

3.3.3. Dietary diversity questionnaire

The dietary diversity of the recipients was investigated by a 24-h dietary recall survey using the FAO dietary diversity questionnaire (Kennedy et al., 2013) (see Appendix G8). To conduct the questionnaire, 55 existing and 36 new food bag recipients were interviewed by nutritionists over the telephone. In addition, the staff of the soup kitchen conducted nine face-to-face interviews among their visitors. The participants recalled their food and drink intakes from the previous day during the interviews. The type of food and drink, their amounts, and the ingredients of composite meals were noted down. Based on the recalled dietary data, nine food groups were recorded as either consumed or non-consumed, to calculate an individual dietary diversity score (WDDS) (Kennedy et al., 2013). The mean dietary diversity scores of new and existing food bag recipients were compared to evaluate whether food bags improved the individual dietary diversity of the recipients.

3.3.4. Nutritional assessment of food bags

To assess the nutritional quality of the food bags, nutritional calculations were conducted based on the composition data obtained for the edible content of the 30 sampled food bags, using Nutrition Data (2022) software. The edible fractions of fruit and vegetables were calculated using literature values (De Laurentiis et al., 2018). The energy, nutrient, and dietary fiber contents of the food bags were expressed as mean values. To assess the number of days on which the food bags met daily reference intake values (DRI), the mean energy and macronutrient values were divided by the DRI values for women and men aged 31–60 years with an average physical activity level according to the Nordic nutrition reference values (NNR (2012)) (Nordic Council of Ministers, 2014). The macronutrient contents were also expressed as energy percent (E%) values and compared against the NNR (2012) reference E% values. Lastly, micronutrients were expressed as standardized for energy, i.e. nutrient density (per MJ). The nutrient densities of dietary fiber and all vitamins and minerals were calculated by dividing the mean nutrient values by the mean energy content of food bags (43.4 MJ). The nutrient densities were compared against NNR (2012) reference values for recommended nutrient density (per MJ) used for diet planning purposes for groups aged 6–65 years with a heterogeneous sex and age distribution.

3.3.5. Nutrient-rich foods index

To assess the nutritional quality of the food bags using a single indicator, the *nutrient-rich food* (NRF) index, more specifically the Sweden-tailored NRF11.3 index, was used (Bianchi et al., 2020). The NRF index assigns a *nutrient density* score based both on nutrients to be encouraged (qualitative nutrients, x in Eq. (3)) and nutrients to be limited (disqualitative nutrients, y in Eq. (3)) (Fulgoni et al., 2009). Eleven qualitative nutrients (protein, fiber, calcium, iron, folate, magnesium, potassium, and vitamins A, C, D and E) and three disqualitative nutrients (saturated fat, sodium, and total sugar) were considered in this study.

Since the food bags were donated weekly, the mean nutrient values of the food bags were first divided by seven (days) and then calculated as percentage of daily values. The Codex Alimentarius reference values (Lewis, 2019) were used as DRIs and maximum recommended intakes (MRIs) for all nutrients except dietary fiber, for which the NNR (2012) reference value was used. The percentages of daily values of qualitative nutrients were capped at 100 % where applicable, to avoid overstating their impact. The NRF11.3 score was calculated as:

$$\boldsymbol{NRFx.y} = \left(\sum \mathbf{1} - \boldsymbol{x}\left(\frac{\boldsymbol{Qualitative\ nutrient}}{\boldsymbol{DRI}}\right)\right) - \left(\sum \mathbf{1} - \boldsymbol{y}\left(\frac{\boldsymbol{Disqualitative\ nutrient}}{\boldsymbol{MRI}}\right)\right) \quad (3)$$

4. Results

The results showed that food donation to reduce food waste was of benefit to the environment and also brought added economic and social values, for the recipients in particular. Despite substantial rebound effects offsetting some of the potential environmental impact savings, the overall environmental performance of food donation was superior to that of anaerobic digestion. It is important to note, however, that the environmental trade-offs caused by the rebound effects gave other significant benefits, e.g. the accrued savings relieved the personal finances of the recipients and allowed purchases of necessities such as clothing and healthcare. While contributions from several stakeholders were necessary to fund the food donation scenarios, positive economic value was generated in the food bag scenario and was mainly transferred to the recipients. The results suggested that food bags also had potential to alleviate the food insecurity of the recipients, although they did not fully solve the issue. Further, due to their high nutrient density, food bags had the potential to improve nutrition intake by the recipients.

4.1. Environmental impacts

With respect to environmental impact, the results indicated that the food bag scenario generated the lowest impact for 17 out of 18 midpoint indicators, including global warming, acidification, and land use. For these 17 categories, the values obtained were negative, indicating mitigation of the environmental impacts (Table 2). The anaerobic digestion scenario generated the highest environmental impacts in 11 out of 18 midpoint impact categories. However, the impacts were still negative in 10 of the categories, indicating impact mitigation. The soup kitchen scenario had the highest environmental impacts in seven categories, while 11 categories had negative values indicating impact mitigation.

When the midpoint indicators were aggregated to endpoint level impacts, the food bag center continued to perform best in the ecosystem damage and human health impact categories, while anaerobic digestion had the highest impacts in both these categories (Table 2). The ecosystem damage results were largely due to the GWP, land use, and terrestrial acidification midpoint results, whereas GWP and fine particulate matter results contributed the most to the human health results across all scenarios (see Figs. I.1 and I.2 in Appendix I). In both categories, the food bag scenario resulted in the lowest environmental impacts and the anaerobic digestion scenario resulted in the highest.

Overall, the substitution effect was the largest contributor to the net results obtained, while food waste management operations, such as transport, played a minor role (Fig. 4 presents an example for GWP). Some of the potential emission savings, largely due to the substitution

Table 2
Environmental impacts per 1 kg food waste at retail gate comparing three different food waste management scenarios, anaerobic digestion, redistribution via food bag center and redistribution via soup kitchen. Both the midpoint and endpoint levels are presented. The best environmental outcome for each impact category is indicated by light green and for the worst by light pink.

Environmental impact method	Impact category	Units	Anaerobic digestion scenario	Food bag scenario	Soup kitchen scenario
Midpoint level	Global warming	kg CO_2 eq	-2.3×10^{-1}	-7.7×10^{-1}	-2.6×10^{-1}
	Stratospheric ozone depletion	kg CFC11 eq	-4.7×10^{-8}	-6.8×10^{-6}	-3.5×10^{-6}
	Ionizing radiation	kBq Co-60 eq	2.1×10^{-2}	-6.7×10^{-3}	4.5×10^{-2}
	Ozone formation. Human health	kg NOx eq	-1.3×10^{-4}	-1.6×10^{-3}	-2.0×10^{-4}
	Fine particulate matter formation	kg PM2.5 eq	-5.9×10^{-5}	-1.3×10^{-3}	-3.4×10^{-4}
	Ozone formation. Terrestrial ecosystems	kg NOx eq	-1.4×10^{-4}	-1.7×10^{-3}	-2.0×10^{-4}
	Terrestrial acidification	kg SO_2 eq	-2.0×10^{-4}	-7.8×10^{-3}	-3.6×10^{-3}
	Freshwater eutrophication	kg P eq	-4.2×10^{-7}	-1.8×10^{-3}	-3.7×10^{-4}
	Marine eutrophication	kg N eq	3.9×10^{-6}	-2.2×10^{-3}	-1.5×10^{-3}
	Terrestrial ecotoxicity	kg 1.4-DCB	1.3 × 10−1	−1.3	3.2 × 10−1
	Freshwater ecotoxicity	kg 1.4-DCB	4.6×10^{-5}	-1.0×10^{-2}	9.1×10^{-3}
	Marine ecotoxicity	kg 1.4-DCB	9.5×10^{-5}	2.1×10^{-3}	1.6×10^{-2}
	Human carcinogenic toxicity	kg 1.4-DCB	-1.8×10^{-4}	-1.1×10^{-2}	9.6×10^{-3}
	Human non-carcinogenic toxicity	kg 1.4-DCB	3.8×10^{-3}	−1.3	−2.6 × 10−1
	Land use	m^2a crop eq	8.4×10^{-3}	−1.8	−5.5 × 10−1
	Mineral resource scarcity	kg Cu eq	-2.3×10^{-4}	-3.4×10^{-4}	2.3×10^{-3}
	Fossil resource scarcity	kg oil eq	-8.7×10^{-2}	-9.5×10^{-2}	1.0×10^{-2}
	Water consumption	m^3	6.9×10^{-4}	-5.8×10^{-2}	-7.7×10^{-3}
Endpoint level	Ecosystem damage	species.years	$-6.2 \times 10–1^{0}$	-2.1×10^{-8}	-6.7×10^{-9}
	Human health	DALYs	-2.5×10^{-7}	-1.9×10^{-6}	-4.9×10^{-7}

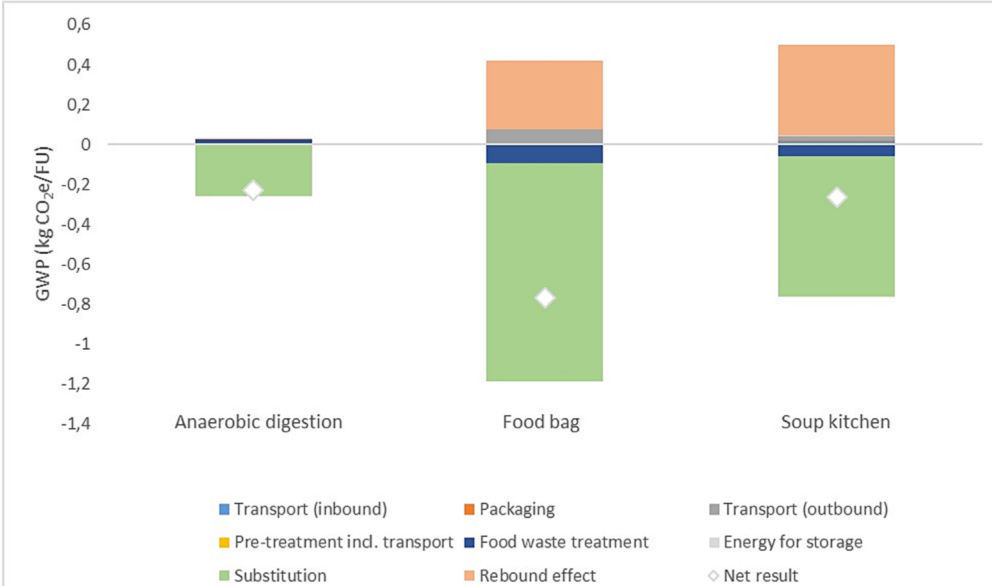

Fig. 4. Net global warming potential (GWP) impact, broken down into contributing food waste management operations, substitution effect, and rebound effect for the three scenarios (anaerobic digestion, redistribution via food bag center, and redistribution via soup kitchen).

effect, were offset by the rebound effect. With respect to GWP, the rebound effect was 31 % (food bags), 64 % (soup kitchen), and 2 % (anaerobic digestion).

4.1.1. Sensitivity analysis

In sensitivity analysis, several parameters were altered to test their impact on GWP. Changes tested included different allocation for Agrifootprint datasets, alternative substitution products, and substitution rates, along with adjustments in prices and savings (Fig. 5). Switching the mass allocation method to economic allocation did not change the results for anaerobic digestion, but changed the result for the food bag and soup kitchen scenarios by 18 % and 86 %, respectively. However, the overall order of the scenarios was not affected. Similarly, the substitution of diesel instead of natural gas did not affect the overall results markedly with a 20 % change for anaerobic digestion, although anaerobic digestion results became slightly more climate negative than the results for soup kitchen. The rebound effects of food donation scenarios were not sensitive to price changes ($\pm$15 %). However, the rebound effects showed high sensitivity to amount of accrued savings ($\pm$SD = $\pm$131 SEK for food bags; $\pm$36 SEK for soup kitchen), and the proportion of savings spent on food (0 %; 100 %), both of which led to backfire effects in the soup kitchen scenario. The substitution effects were sensitive to changes in the amount of food substituted (50 %; 70 %). The sensitivity of the above mentioned parameters were also tested on land use with similar results as for GWP as shown in Fig. J.1 in Appendix J.

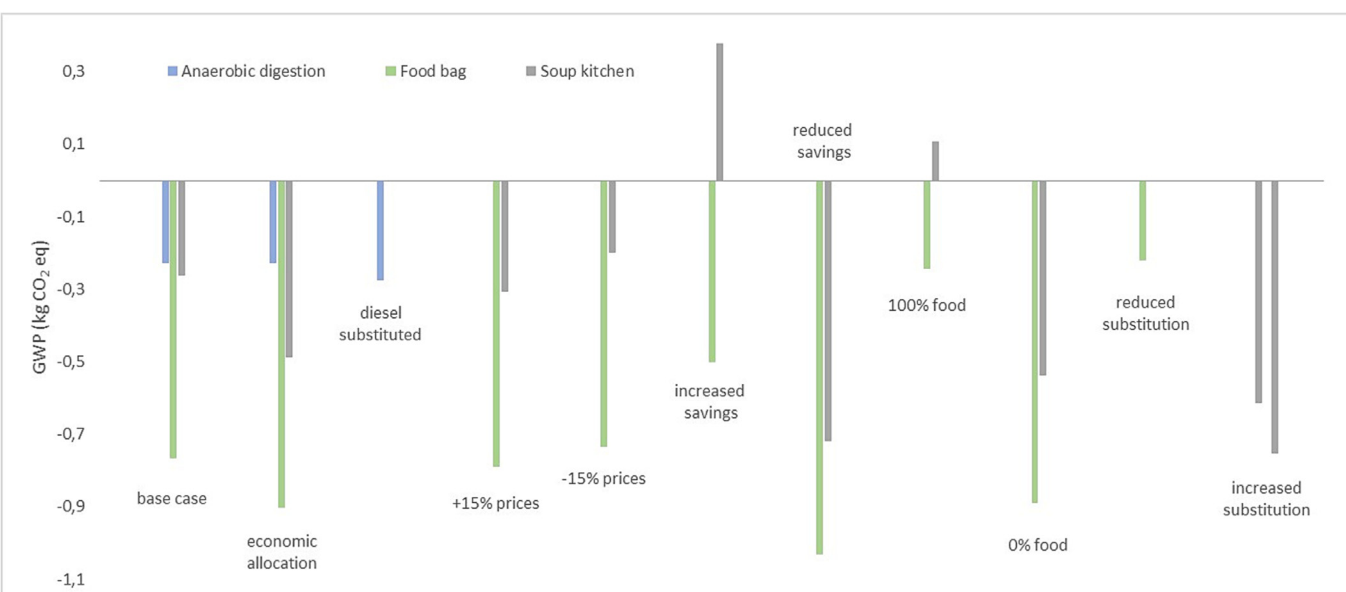

Fig. 5. Global warming potential (GWP) results in sensitivity analyses in comparison with the base case for the three scenarios (anaerobic digestion, redistribution via food bag center, and redistribution via soup kitchen), expressed per kg donated food. The results were sensitive to changes in accrued savings, proportion of savings spent on food, and proportion of food substituted.

4.2. The economic value of surplus food donation

4.2.1. Net economic benefits

The net economic result for the food bag scenario was positive (1502 kSEK) indicating that positive economic value was generated (Table 3). In contrast, the net result for the soup kitchen was negative (−622 kSEK) indicating that the costs of this redistribution activity exceeded the benefits generated. Overall, the net benefit calculations highlighted the high level of investment required from different stakeholders to run the redistribution activities.

4.2.2. Efficiency

The benefit-cost ratio of the food bag center was 1.37 and that of the soup kitchen was 0.75, where a value >1.0 indicates a positive net value outcome (Table 4). As regards economic efficiency in food waste prevention, the cost of preventing 1 ton of food waste was 28 kSEK for the food bag center, but more than twice as much (64 kSEK) for the soup kitchen. As regards ecological efficiency, the cost of 1 ton CO_2e abated was 27 kSEK for the food bag center and eight-fold higher (216 kSEK) for the soup kitchen. As regards social efficiency, the cost of donating one food bag was 292 SEK for the food bag center and the cost of donating one meal was 25 SEK for the soup kitchen.

4.3. The social value of surplus food donation

Three key stakeholder groups, i.e. consumers (recipients), workers (employees, job trainees, volunteers) and the local community were included in the social assessment of surplus food donation. An overview of the results with the chosen indicators per stakeholder and scenario is presented in Table 5. Below, the most important results are described separately for the recipient and worker stakeholder groups.

4.3.1. Recipients

When assessing the social values generated through surplus food redistribution for the *recipients* stakeholder group, the main values considered related to nutritional aspects such as food security and dietary diversity status of the recipients, as well as the nutritional value of the food bags. The results revealed that the mean food security score of the new food bag recipients was 3.3, whereas the score of the existing food bag recipients was 2.4. Although the score of the existing recipients indicated better food security in comparison with new recipients, their food security status was still low. For the soup kitchen visitors, the food security status (score 4.3) was lower than for both categories of food bag recipients.

Overall, there was no difference in the dietary diversity of the recipients (5.5 for new food bag recipients; 5.3 for existing food bag recipients), although higher intake frequencies in some food groups frequently provided by the food bags, such as white roots and tubers (+70 %), vitamin A-rich tubers (+10 %) and green leafy vegetables (+18 %), were observed for existing recipients. However, consumption frequency of legumes, nuts, and seeds (−51 %), eggs (−15 %), and sweets (−15 %) was lower for existing recipients than for new recipients. The dietary diversity score of the soup kitchen visitors was 3.4, which was considerably lower than the score of the existing food bag recipients (5.3).

The nutrient quality data for the food bags indicated overall good quality. The bags contained macronutrients such as protein, carbohydrates, and fat, in proportions that were largely within the reference values (Table 6). In addition, the bags were low in sugar and the fat they contained was of good quality. The bags were also nutrient-dense and in line with reference values for most vitamins and minerals, with a high content of vitamins A, C, and E and niacin (Table 7). Further, the bags were high in dietary fiber, and the salt content was below the maximum reference value. Consequently, the nutrient-rich foods score (NRF11.3) of the food bags was 729, indicating high nutrient density (min −300; max 1100). The energy content of the food bags covered the energy needs of an adult person aged 31–60 years, with an average level of physical activity, for approximately four days.

4.3.2. Workers (employees, job trainees, and volunteers)

To assess the social values generated through surplus food redistribution for the *workers* stakeholder (*employees, job trainees, volunteers*), the main values investigated were related to their working conditions, health and safety, and equal opportunities. The employees had normal working hours, and fair salaries (above minimum wage), and there had been no long-term sick leaves (Table 5). The turnover rate of employees was low (0), but that for food bag center volunteers was higher (8). Approximately half of the job trainees received employment following their training period. The female managers at both units indicated equal opportunities.

5. Discussion

This study investigated all three aspects of sustainability in relation to surplus food donation in order to gain a holistic view. The results

Table 3
A cost-benefit analysis of Uppsala City Mission food bag center and soup kitchen for 2020.

Stakeholders	Benefit/cost variable	Food bag scenario kSEK/year	Soup kitchen scenario kSEK/year
	Benefits[a]		
Recipients	Accrued savings due to receiving donated food	2587 (47 %)	304 (16 %)
Retailers	Avoided food waste treatment	34 (1 %)	8 (1 %)
Employees	Employment (salaries, benefits)	1956 (35 %)	1326 (69 %)
Job trainees	Employment due to job training	947 (17 %)	271 (14 %)
	Total	5524 (100 %)	1909 (100 %)
	Costs[b]		
Property owners	Premises	180	180
Car leaser	Vehicle	60	25
Private and public donors	Gifts, grants, raised funds	2811	1872
Municipality	Compensation paid for job trainees	656	241
Food waste treatment plant	Loss of food waste[c]	*0*	*0*
Volunteers	Volunteer hours	226	213
Recipients	Membership fees	89	0
	Total	4022	2531
	Net benefits [benefits-costs]	1502	−622

[a] Values of outcomes created through food redistribution activities.
[b] Funding covering for the cost linked to redistribution process.
[c] Due to being a tax-funded company aiming at zero financial result, where deficits and surpluses are settled against subscriber fees, and due to the amount of lost food waste corresponding to <0.5 % of the total volume of food waste treated, the value was considered negligible.

Table 4
Efficiency indicators of Uppsala City Mission food bag center and soup kitchen for 2020.

Efficiency dimension	Indicator	Food bag scenario	Soup kitchen scenario
Economic benefits	Benefit-cost ratio	1.37	0.75
Food waste prevention	Cost of 1 ton food waste prevented[a] (kSEK)	28	64
Ecological savings	Cost of 1 ton CO_2e abated (kSEK)	27	216
Social benefits	Cost of donating one food bag or meal[b] (SEK)	292	25

[a] Effectiveness (amount of redistributed food eaten) derived from Sundin et al. (2022).
[b] Corresponds to food bags donated by the food bag center or meals (400 g/portion) donated by the soup kitchen.

showed that food donation was a way to reduce food waste providing benefits for the environment while adding social value but requiring economic investments from several stakeholders. Food bag donation generated the largest environmental impact savings in all but one of the 18 midpoint categories considered in comparison with anaerobic digestion, but also in both endpoint categories, *ecosystem damage,* and *human health*, a novel contribution of the study. However, considerable rebound effects (31 % for food bags; 64 % for soup kitchen) were found to offset some of the potential GHGE savings but despite them, the overall results were still aligned with the waste hierarchy and with previous findings in studies where rebound effects were not considered (Eriksson and Spångberg, 2017; Moult et al., 2018). Further, the midpoint-level results showed that redistribution offers higher overall environmental savings in comparison with anaerobic digestion of food waste, also suggested by some previous studies (Albizzati et al., 2019; Brancoli et al., 2020; Damiani et al., 2021).

The net environmental gains generated by the two food donation scenarios were greatly influenced by the substitution and rebound effects (Fig. 4), rather than the actual process-related impacts. Meanwhile, sensitivity analyses revealed high sensitivity of the net environmental results to the amount of food substituted, but also to the amount of savings accrued and the degree to which these savings were spent on food (Fig. 5), thus, these results are best interpreted on their magnitude level. Nevertheless, the aforementioned factors also explained some of the differences in net environmental outcome between the two donation scenarios, due to the units serving different socio-economic recipient groups. Food bags were substituted to a higher degree than soup kitchen meals, but food bag recipients spent their savings proportionally less on food, leading to a lower environmental impact and thus lower rebound effect. This difference between the recipient groups was also reflected in the better food security and dietary diversity status of food bag recipients compared with soup kitchen visitors.

Table 5
An overview of the actual social impacts of the food bag center and soup kitchen of Uppsala City Mission based on 2020 data. The food security and dietary diversity scores of food bag recipients concerned those participants who had received food donation during a minimum of 30 previous days.

Impact categories	Impact subcategories	Indicators	Food bag scenario	Soup kitchen scenario
			Recipients	Recipients
Health and safety	Food security	High or marginal (0–1); Low (2–4); Very low (5–6)	2.4	4.3
	Individual dietary diversity	WDD score; min: 0; max: 9	5.3	3.4
	Nutrient-rich foods score (food bags)	NRF11.3	729	
Equal opportunities	Gender ratio	Male/female (%)	47/53	75/25
Economic security	Accrued savings due to receiving donated food	SEK/food bag or visit to soup kitchen	165	25
Customer satisfaction[a]	Service satisfaction	% happy (4 or 5) (scale 1–5)	87	
	Increased life quality	% positive (4 or 5) (scale 1–5)	74	
	Influence on health	% improved (4 or 5) (scale 1–5)	51	
	Influence on personal finances	% improved (4 or 5) (scale 1–5)8	84	

Impact categories	Impact subcategories	Indicators	Food bag scenario			Soup kitchen scenario		
			Employees	Job trainees	Volunteers	Employees	Job trainees	Volunteers
Working conditions	Working time (full-time)	Working hours/week	40			40		
	Working time (part-time)	Working hours/week	30			30		
	Overtime	Hours/week	0			0		
	Overtime payment	Yes/no	Yes			Yes		
	Job positions	Full-time positions	4.25	7	15	1.75	1	24
	Fair salary	SEK/month	29,000	Compensation	0	27,000	Compensation	0
	Rehabilitation effectiveness	Job trainees entering labor market (%)		50			100	
Health and safety	Sickness absence	Long-term absences >90 days	0	0	0	0	0	0
	Employee turnover	Turnover rate (%)	0	50	8	0	100	0
	Workplace violence; external threats	Number of incidents	0	0	0	0	0	0
Equal opportunities	Gender ratio in work positions	Female workforce (%)	70			50		
	Gender ratio in work positions	Female managers (%)	100			100		
	Gender ratio in salary	Ratio of basic salary of men to women	1			1		

Impact categories	Impact subcategories	Indicators	Food bag scenario	Soup kitchen scenario
			Local community	Local community
Social responsibility	Surplus food redistributed	t/year	193	45
	Food bags or meals donated	#/year	13,756	9543
	Poverty alleviation	Food bag recipients or visits/year	250	12,175
Environment	Food waste prevented	t/year	144	40

[a] Results based on Topor (2021).

Table 6
Energy and macronutrient content of weekly food bags in comparison to reference values.

Energy and macronutrients		Mean	Reference value[a]	Days meeting RDI[b]	E%[c]	Reference value E%[d]
Energy	kJ	43,439	8800/11000	4.9/3.9		
Protein	g	310	70/82	4.4/3.8	12	10–20
Carbohydrates	g	1535	271/340	5.7/4.5	60	45–60
Sucrose	g	185			7	<10
Total fat	g	292	77/97	3.8/3	24[e]	25–40
SFA	g	103			9	<10
MUFA	g	113			10	10–20
PUFA	g	47			4[e]	5–10

[a] Reference daily intake (RDI) values for energy of women/men of 31–60 years of age corresponding to an average physical activity level, which have been used as a basis for the reference values of protein, carbohydrates and total fats (NNR, 2012).
[b] Number of days the energy and macronutrient content of food bags meets the RDI of women/men.
[c] Percentage of macronutrient of the total energy content of food bags.
[d] Reference values according to NNR (2012). For sucrose, the reference value refers to added sugars, but the presented mean and E% include both added sugars and natural sources of sucrose.
[e] Value not meeting the reference value.

Private and public investments were required to run the food donation units, but positive economic value was generated only in the case of the food bag scenario. In contrast, previous assessments resulted in considerably higher economic value due to differences in assumptions and scope (Cicatiello et al., 2016; SVA, 2013), underscoring the importance of interpreting such results within their context. Cicatiello et al. (2016) allocated donated food full retail value, but excluded the costs of volunteer labor and salaries from the scope of their assessment, resulting in a benefit-cost ratio of 4.6. Another study counted volunteer time as an investment, but excluded the value of food, as it was considered waste, giving a benefit-cost ratio of 2.75 (SVA, 2013). In contrast to both previous assessments, the present study included accrued savings and salaries in the benefit-cost calculation, resulting in a ratio of 1.37 for the food bag scenario but only 0.75 for the soup kitchen scenario, due to a lower amount of accrued savings. This was also the main factor contributing to the negative net benefit result for the soup kitchen (−622), as the lower benefits generated did not cover the relatively high labor costs in that scenario.

Table 7
Vitamin, mineral and fiber content of food bags in comparison to reference values.

Vitamins, minerals and fiber		Mean	Reference value[a]	Number of days meeting reference value[b]	Nutrient density per MJ	Reference value[c]
Vitamin A (RE)	RE	5205	800	6.5	120	80
Vitamin D	μg	19	10	1.9	0.4[d]	1.4
Vitamin E	α-TE	69	9	**7.7**	1.6	0.9
Vitamin B1 (Thiamin)	mg	9	1.2	**7.5**	0.2	0.12
Vitamin B2 (Riboflavin)	mg	8	1.2	6.3	0.17	0.14
Niacin	NE	170	15	11.3	3.9	1.6
Vitamin C	mg	1394	100	13.9	32.1	8
Vitamin B6 Pyridoxine	mg	11	1.3	8.8	0.3	0.13
Vitamin B12	μg	9	2.4	3.9	0.2	0.2
Folate	μg	2467	400	6.2	56.8	45
Phosphorus	mg	6703	700	9.6	154.3	80
Iron	mg	53	14	3.8	1.2[d]	1.6
Calcium	mg	3954	1000	4.0	91.0[d]	100
Potassium	g	24	3.5	6.9	0.6	0.35
Magnesium	mg	2347	310	7.6	54.0	32
Sodium	mg	9110	2000	4.6	209.7	245
Selenium	μg	139	60	2.3	3.2[d]	5.7
Iodine	μg	478	150	3.2	11.0[d]	17
Zinc	mg	47	11	4.2	1.1[d]	1.2
Dietary fiber	g	190	25–35	7.6	4	3

[a] Codex Alimentarius nutrient reference values for vitamins and minerals (where nutrient reference values are based on the daily intake value that is estimated to meet the nutrient requirement of 98 % of an apparently healthy individual, thus the RDI or RDA) for the general population, identified as individuals older than 36 months (FAO and WHO, 2019). Sodium not to be exceeded. Fiber according to NNR (2012).
[b] Number of days the nutrient content of one food bag meets the reference value of nutrient.
[c] NNR (2012) reference values for recommended nutrient density (per MJ) used for diet planning purposes for groups of 6–65 years of age with a heterogeneous sex and age distribution. Sodium not to be exceeded.
[d] Value not meeting the reference value.

The economic value received by the recipients generated social value by improving their personal finances, playing potentially an important role as a factor for increased choice among recipients (Wolfson and Greeno, 2020). Furthermore, our results showed that the donated food was well-balanced and nutrient-dense, due to a large proportion of perishable foods, such as fruit, vegetables, and dairy products similar to the findings by Mousa and Freeland-Graves (2019a) and Vittuari et al. (2017). Some studies, however, identified a nutrient imbalance in food donations but concluded that larger proportions of perishable foods would resolve that issue (Brennan and Browne, 2021; Simmet et al., 2017; Tse and Tarasuk, 2008). Moreover, previous studies have identified a positive effect of food donations rich in perishable foods on recipients' diets (Mousa and Freeland-Graves, 2019b; Nogueira et al., 2021b, 2021a). Thus, high nutrient density of surplus food provides potential to contribute positively to recipients' diets, further supported by the previous finding of high recipient acceptance of the donated food (Sundin et al., 2022).

The food donations also showed potential for alleviating recipients' food insecurity, as found in previous studies (Mousa and Freeland-Graves, 2019b; Wolfson and Greeno, 2020), although the recipients were not food-secure according to the survey results. The average energy content of the food bags met the energy requirements of an average adult for four days. Considering that, on average, the recipients were families of four (two adults and two children) receiving one food bag/week, it is reasonable that the donations only had a relieving effect, especially since the parents could be expected to prioritize their children's food intakes. The school meal scheme provided to all children free of charge in Sweden aims to cover one-third of children's nutritional requirements (Osowski et al., 2015), and food donations can be an important supplement to provision by the welfare state.

A strength of the present study lay in including all three aspects of sustainability, to gain an understanding of trade-offs between these and also a more comprehensive view of food donation. In addition to discovering that the rebound effects contributed to other important values, such as economic and social benefits for the recipients, the results showed that the soup kitchen did not generate as high environmental gains or positive economic value as food bags did. However, the economic assessment did not capture the value of donated food that did not substitute for any food, which still likely played an important role in helping the most vulnerable in society. It should also be acknowledged that the soup kitchen contributed to the effectiveness of the food bag center, annually salvaging 16 tons of its surplus food with a very short shelf-life (Sundin et al., 2022), suggesting that a *hybrid model* of redistribution combining *direct* and *indirect donations* could be a key success factor. Further studies are, however, needed to understand the interdynamics of such models and how to optimize these.

Another strength of the present study was the use of primary input data in the assessments, due to access to UCM data. However, using the ReCiPe method, representing European conditions, might not have been able to fully capture the local conditions in the LCA. While no randomized method was used for recruiting study participants, a strength of the study was to recruit recipients instead of relying on charity personnel's perceptions on issues concerning recipients, a method commonly applied in previous studies (Mirosa et al., 2016; Vittuari et al., 2017). However, the low participant rate at the soup kitchen (due to the Covid-19 pandemic) was a weakness and challenging to overcome, whereas telephone interviews were used to overcome this issue with the food bag recipients. Further, it should be noted that the economic and social assessments were not exhaustive and other valuable factors could have been included, such as the monetary value of abating environmental impacts or feeling shame as a recipient. Limitations of the method itself should also be kept in mind when using the results for decision-making. For example, the assessment did not consider any initial investment costs and the results are therefore only generalizable to a donation scheme that is already operational, and not to establishment of new food donation organizations. However, the potential of surplus food donation can be generalized to other countries, as retail surplus food even outside Sweden often consists of perishable foods (bread, fruit, and vegetables) with high nutritional value (Schneider and Eriksson, 2020).

UCM's swift food handling process has previously been identified as a key to its success (Sundin et al., 2022) and also a prerequisite for realizing environmental gains of food donation (Damiani et al., 2021). High recipient acceptance of redistributed food is another key factor, as food acceptance can be complex (Leng et al., 2017; Sundin et al., 2023). In fact, most of the values would not have been generated if the donated food had been discarded instead of eaten by recipients, regardless of the efficiency of the redistribution process. To maximize the benefits of food donations, policymakers should seek to enable charities to meet the dietary needs and preferences of recipients to the highest degree possible. The more surplus food eaten, the higher the substitution effect leading to accrued savings, while the lower the need to spend accrued savings on complementary foods, the lower the rebound effect. In a way, UCM is already addressing this by adapting food bags to the dietary preferences of recipients (e.g. lactose-free and vegetarian) (Sundin et al., 2022). Another option could be to adjust the contents of food bags according to the recipient's family size, in order to distribute the food in a potentially fairer way.

The results showed multiple environmental benefits of food donation as a food waste management option compared with anaerobic digestion. Food donation also imparted social values to vulnerable groups while food and nutrients were salvaged for their intended purpose, i.e. human consumption. However, while retailers are showing increasing interest in surplus food redistribution, at present only a fraction is donated (Huang et al., 2021; Johansson, 2021). Lack of financial incentive has been identified as a major barrier to surplus food donation (Deloitte et al., 2020). This could be due to retailers' decision-making being steered mainly by economic considerations, while environmental and social factors play a minor role (Rosenlund et al., 2020). Under recent Swedish legislation, retailers are exempted from paying VAT on their food donations (Swedish Food Agency, 2022). However, as this study showed, the economic value transferred to retailers due to surplus food redistribution is negligible (1 % of total benefits). To provide economic gains to retailers, an appropriate fiscal framework making surplus food redistribution more cost-effective for retailers than disposal must be implemented. A waste tax deduction could be one option, as it could activate food redistribution while generating multi-stakeholder benefits (Franco and Cicatiello, 2021). Alternatively, legislation must be used to enforce the use of higher-priority waste handling options to save natural resources, as suggested by Eriksson et al. (2023). These measures could be used in parallel, as edible food waste could be redistributed and inedible food waste sent to anaerobic digestion when prevention is not achievable (Johansson, 2021).

6. Conclusions

This study showed that surplus food donation was a way to reduce food waste benefitting the environment, with added economic and social value to vulnerable groups, in particular, in Sweden. While there were some trade-offs, such as rebound effects, these were outweighed by the benefits generated. However, the system for handling surplus food donations required economic investments from various stakeholders, as well as surplus food free of charge from retailers. Food donation can be seen as a transfer system, where economic values and retailers' food waste are transferred and converted by food centers into environmental, economic, and social benefits. However, there is no incentive for retailers to donate their surpluses resulting in a lack of *win-win*. To realize the potential of surplus food donation, policy measures should be better aligned with the waste hierarchy so as to stimulate prevention and reuse for human consumption. Although surplus food donations organized by charities cannot be considered a long-term solution, due to their inability to solve the root causes of food insecurity and food wastage, their activities can alleviate both these issues simultaneously and therefore have short-term potential to contribute to a more sustainable society.

Funding

This work was financially supported by the Swedish Research Council for Sustainable Development (Formas), grant number FR-2020/0008.

CRediT authorship contribution statement

Niina Sundin: Conceptualization, Methodology, Investigation, Data curation, Software, Validation, Formal analysis, Visualization, Writing – Original draft. **Louise Bartek:** Methodology, Data curation, Software, Validation, Writing – review & editing. **Christine Persson Osowski:** Conceptualization, Methodology, Formal analysis, Writing – Review & Editing. **Ingrid Strid:** Conceptualization, Methodology, Writing – Review & Editing. **Mattias Eriksson:** Conceptualization, Methodology, Formal analysis, Writing – Review & Editing, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The authors gratefully acknowledge the staff at Uppsala City Mission for their continuous support and contribution to the data collection.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.spc.2023.03.022.

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