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Surplus food donation: Effectiveness, carbon footprint, and rebound effect

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ABSTRACT

Surplus food redistribution can be a way to relieve co-existing food insecurity and food waste. The food waste hierarchy ranks surplus food donations for human consumption as the next best strategy, when food waste cannot be prevented. However, the effectiveness of food donation in terms of the amount consumed, or food donation as a food waste management measure have rarely been assessed. The few studies conducted to date report substantial environmental savings, but the results may be sensitive to assumptions regarding substituted food. Rebound effects are also not included, but are likely to offset environmental savings from food donation. Therefore, this study investigated the effectiveness, carbon footprint, and rebound effect of a food donation system run by a charity in Sweden, and compared the results with those of anaerobic digestion. Multiple analytical methods were used, including material flow analysis, life cycle assessment, questionnaire, and 24-hour dietary recall. In the life cycle assessment, carbon footprint of substituted products were credited to the overall results using a system expansion. In addition, direct and indirect rebound effects associated with re-spending of substitution-related monetary savings were included. The results revealed a complex but effective network aimed at salvaging as much of the redistributed food as possible, with 78% of redistributed food eaten, but there was also a substantial rebound effect, offsetting 51% of potential carbon emissions savings from food donation. Nonetheless, the net result of food donation was almost twice the climate benefit of anaerobic digestion (-0.40 vs. -0.22 kg CO2e/FU), supporting the food waste hierarchy.

1. Introduction

Food waste has been characterized as a wicked problem, with complex root causes (Minor et al., 2019; Närvänen et al., 2020; Weber and Khademian, 2008). Food waste has now reached unprecedented levels, with roughly one-third of global food produced becoming food loss and waste (FLW), representing a missed opportunity for improved food security and an annual environmental, economic, and social cost of 2.6 trillion USD (FAO, 2014; Gustavsson et al., 2011). In the European Union (EU), food waste represents 20% of food produced, costing 143 billion EUR annually (Stenmarck et al., 2016). Prevention of food waste at source must be the highest priority, but the food waste hierarchy, also adopted in the EU, ranks redistribution of surplus food for human consumption as the next best strategy when food waste cannot be prevented (European Commission, 2020). In reality, however, most food waste is treated by far lower-priority options, such as composting, incineration, or landfill (European Commission, 2020; Eurostat, 2020; Obersteiner et al., 2021).

Surplus food redistribution, i.e., food donation to people in need, can be beneficial for various reasons. Apart from environmental, economic, and social gains, using the food for its intended purpose salvages its energy and nutrient content. In fact, a previous study highlighted the high nutritional value of retail and consumer food waste and pointed to a corresponding nutrient deficit in the average American diet (Spiker et al., 2017). Moreover, surplus food redistribution is increasingly being recognized as a way to relieve food insecurity and food waste issue simultaneously (Schneider, 2013).

Although sufficient food is produced worldwide to meet the needs of the global population, 2 billion people still lack regular access to sufficient food and more than 690 million are hungry (FAO, 2021a). The vast majority of global hunger occurs in low-income countries and the largest share of FLW occurs in middle- and high-income countries, but food insecurity and food waste can coexist within countries and regions (FAO, 2021a; Lawrence and Friel, 2019). In high-income regions such as North America and the European Union, where annual FLW amounts to 168 Mt and 129 Mt, respectively (Caldeira et al., 2019a; CEC, 2017;

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FAO, 2019), up to 12% of the population still experiences food insecurity. Even in a welfare state like Sweden, food insecurity is a concern for the 6% of the population with low income, and the income gap and at-risk-of-poverty rate are increasing (Karlsson, 2019; SCB, 2019). Meanwhile, 1.3 Mt of food waste is generated in Sweden annually (Swedish Environmental Protection Agency, 2020).

Hunger and FLW are both issues of global concern and both are included in the United Nation's Sustainable Development Goals (SDG). SDG target 12.3, concerning global FLW, includes a specific target on halving per capita food waste at retail and consumer level by 2030 (United Nations, 2015). The retail level generates the least food waste throughout the food supply chain (UNEP, 2021), but a reduction at that level is still deemed necessary since the farther downstream food waste is generated, the more emissions are generated and the more resources are used, and these are recoverable only to a minor degree (Brancoli et al., 2020; Eriksson et al., 2015; Eriksson and Spångberg, 2017; Reynolds et al., 2020; Schneider et al., 2020). Additionally, the retail sector plays a key role in the food supply chain (Brancoli et al., 2019). According to SDG target 2.1, global hunger must also be eradicated by 2030. While food donation does not have the capacity for solving the issues behind hunger or retail food waste, it could work as a short-term solution to relieve both issues. In fact, less than one-quarter of current global food waste would feed the global hungry (FAO, 2021b).

Food donation has been criticized for shifting responsibility from public to private (Riches, 2018) or for not matching clients' needs (Mourad, 2016). Simultaneously, the inevitability of a certain amount of surplus food and a need for feasible solutions for its redistribution has been acknowledged (Facchini et al., 2018; Priefer et al., 2016). Countries such as the United States and France have already implemented legislation to ensure food redistribution (Condamine, 2020; Schneider, 2013). In the EU, food donation guidelines were adopted in 2017, but the level of implementation differs greatly between member states, with countries such as Italy, France, and Spain in the lead (Deloitte et al., 2020). In Sweden, national guidelines are lacking and food redistribution is still loosely managed and represents only a small fraction of national food waste, although great potential for increased food redistribution has been identified (Deloitte et al., 2020; Hanssen, 2014).

While food donation is widely advocated, ineffectiveness of redistribution may arise due to various barriers, such as short shelf-life of perishable foods or lack of organization (De Boeck et al., 2017; Patel et al., 2021). Some food redistribution initiatives have been evaluated for their effectiveness in terms of mass of food rescued (Hecht and Neff, 2019; Goossens et al., 2019). However, in such evaluations ambiguity may exist as to whether the food was redistributed from retail to charity or from charity to people in need, and whether food waste generated in the redistribution process was included. In fact, the amount eaten is seldom reported, although it essentially indicates the effectiveness of surplus food redistribution (Alexander and Smaje, 2008; Hecht and Neff, 2019).

Life cycle assessment (LCA) is a systematic method enabling environmental assessments of food supply chains related to food production and consumption including food waste generation (Caldeira et al., 2019; Moberg et al., 2020; Sinkko et al., 2019; Sundin et al., 2021). Some previous studies have assessed the environmental value of donated food (Cicatiello et al., 2016; Moggi et al., 2018; Reynolds et al., 2015), but more studies are needed on assessing food donation as food waste management. The majority of such studies have focused on evaluating food waste prevention or less prioritized food waste management options such as incineration, composting, and anaerobic digestion (Bernstad and la Cour Jansen, 2012; Bernstad Saraiva Schott and Andersson, 2015; Salemdeeb et al., 2018, 2017a, 2017b). Some previous studies investigating food donation include a system expansion where emissions related to avoided food production by food donation are credited (Albizzati et al., 2019; Bergström et al., 2020; Damiani et al., 2021; Eriksson et al., 2015, 2014). The substitution method has allowed pinpointing the environmental benefit of food donation contributing to reports with substantial environmental savings. These results, however, may have been sensitive to assumptions made on substituted food due to a lack of data on the type and quantity of food that is actually substituted. Further, rebound effects, i.e. emissions arising from re-spending of accrued savings when receiving donated food have not been included in previous analyses although such effects are likely to arise, offsetting some of the environmental savings from food donation, with possible implications for food waste hierarchy (Hagedorn and Wilts, 2019; Martinez-Sanchez et al., 2016; Redlingshöfer et al., 2020).

Therefore, the aim of the present study was to investigate the effectiveness, i.e. the actual eaten amount, and environmental impact of food donation, including the rebound effect, utilizing dietary survey data to investigate food substitution, and to compare food donation to an alternative food waste management approach, anaerobic digestion.

2. Materials and Methods

In a case study commencing in August 2020 to investigate the effectiveness and environmental impact of food donation, a Swedish non-profit organization, Uppsala City Mission (UCM), was chosen as the case. UCM aims to support people in need living in social and financial vulnerability in Uppsala City, and one of its activities is redistribution of surplus food obtained from local retailers. Food redistribution is operated by two sub-units, a food bag center (since 2018) and a soup kitchen (within the current framework since 2016), that are open from Monday to Friday for approximately 45 weeks of the year. On average, the food bag center had 250 active food bag subscribers in 2020, while 34 new subscribers were welcomed in September 2020 and an additional 55 in March 2021. Subscription for a weekly grocery bag in that year was subject to an income limit of 9290 SEK (~910 EUR) per month, set as the threshold for financial vulnerability by UCM. The membership fee is currently 250 SEK (~25 EUR), entitling subscribers to a weekly food bag for six months. Although UCM is unable to predict the exact type and quantity of foods received, it seeks to ensure that food bags always contain certain foods, such as bread, fruit, vegetables, and dairy products. In 2020, the food bag center redistributed 13,756 food bags, representing approximately 170 metric tonnes (t) of food. The soup kitchen had 12,175 visitors in 2020 and served 12 t of surplus food as breakfast and coffee breaks, 3.2 t as lunches (400 g portions), and 19 t as take-away meals to people living in social vulnerability and homelessness.

A biogas plant located in Uppsala, Sweden, was used in this study to represent the alternative food waste management scenario (anaerobic digestion). In 2020, the plant treated approximately 48,000 t of food waste, of which almost half originated from households and the other half from the retail and food service sector (Uppsala Vatten, 2021a). The end-products, biogas and biofertilizer, were mainly used as fuel for city buses and in crop cultivation, respectively, in that year (Uppsala Vatten, 2021a).

Although the facilities described above are specific to Uppsala City, central Sweden, they are common in a Swedish and European context, making the results generalizable outside the specific case study.

2.1. Material flow analysis

Material flow analysis (MFA) was conducted for the food donation scenario, comprising the surplus food flow from retail gate via charity organization to people in need, based on process mapping of surplus food redistribution activities (Fig. 1). Apart from following surplus food flows from one stakeholder to another, transport of food and occasions when food waste occurred were included in process mapping.

2.1.1. Surplus food flows including pre-consumer waste

The input of surplus food to the system was calculated based on data obtained from UCM. In the study period (2020), the soup kitchen reported having received 28.6 t of surplus food from retail and 16 t from the food bag center, while the food bag center reported that 170 t

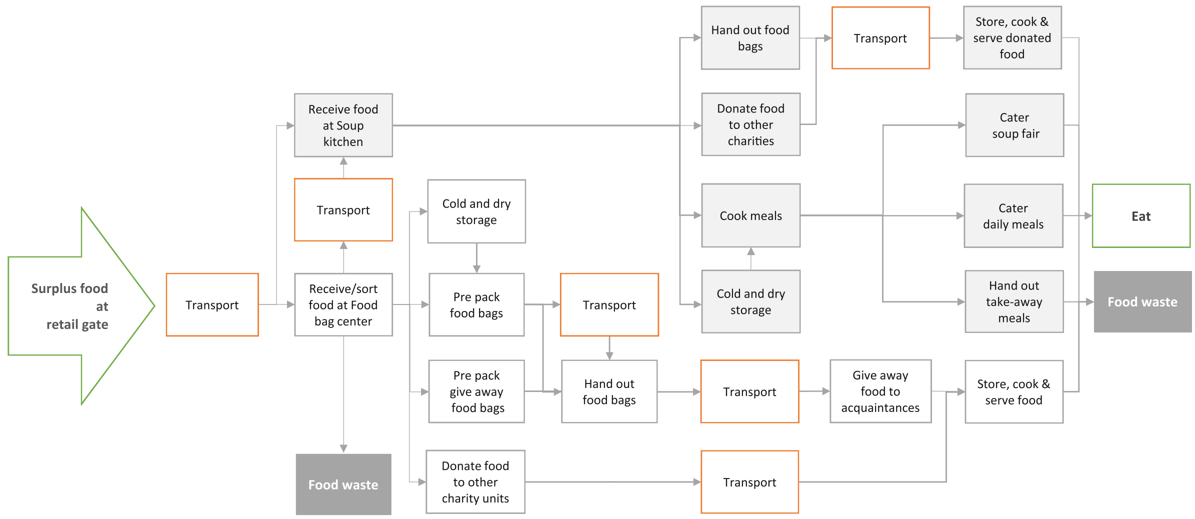

Fig. 1. Process map of the main activities in surplus food flow from retail gate to charity organization units (food bag center and soup kitchen), and then on to people in need.

surplus food were allocated to food bags and 7.8 t to other charity units. The food bag center used a scale and a barcode scanner to record the net weight of food handled, while the soup kitchen logged the weight manually into its computer system. The recorded weights included inedible components. Moreover, 4 t of give-away food bags was assumed for 2020, based on an estimated 85 kg of food per week with such short shelf-life that it was not good enough for any other purpose and not logged onto any system.

As part of the present study, daily food waste measurements (kg) were conducted at the food bag center between August 17, 2020 and April 9, 2021. The average daily amount of food waste was 48.6 kg (± 28.1), consisting of approximately 2.7% dairy, 1.6% meat, and 95.7% plant-based foods. Based on these statistics, food waste in 2020 was calculated to be 11 t, by multiplying the daily average by 223 days, and added to the total surplus food input.

At the soup kitchen, based on its records, approximately 39 t of surplus food were allocated to catering, 3 t to food bags given to visitors, and 2.9 t to other charities in 2020. Of the catering allocation, the records showed that 19 t were allocated further to daily catering, such as serving breakfast, coffee breaks, and lunch, 19 t to take-away meals, and 1.2 t to an annual soup fair. No measuring of pre-consumer food waste took place at the soup kitchen during 2020, but daily catering was estimated to produce 2 t of food waste annually, a figure that was also assumed for the take-away meals.

2.1.2. *Post-consumer waste*

To assess the amount of food bag waste, food bag subscribers were asked to complete a self-administered questionnaire. Specifically, the subscribers were asked whether they wasted any food from the food bags. If they answered in the affirmative, they were asked to self-estimate the average fraction (%) of their food bag food waste, and the reason for the waste. The results showed that 52% of the respondents did not admit to wasting any food. The most common reason for wasting food was short expiry date or not having time to eat the food before its expiry date (42% of responses), while 35% responded that the wasted food was inedible or of bad quality. Food preferences (not accustomed, not liking, unhealthy, too much of the same) were given as the reason in 23% of the responses. The reported food waste fraction was 9% (± 13%), but with very high variation (2%-60%). A similar figure was assumed for the food bags donated from the soup kitchen. Further, 34% of the respondents reported donating some items from the food bags to their close circle, and 7% reported returning unwanted food items to the food bag center. To assess the inedible fraction of the food bags, composition analysis was conducted. The fraction was found to be 12%, which was then assumed for the total amount of surplus food redistributed except for the cooked meals made by the soup kitchen. The methods used, including the questionnaire and composition analysis, are described in further detail below.

2.1.3. *Self-administered questionnaire*

A self-administered questionnaire investigating various aspects of food donation was distributed to people receiving food donations. Study participants were recruited by staff from among visitors to the food bag center and the soup kitchen in the period August 2020-April 2021. Data were collected from three specific recipient groups: 1) existing food bag subscribers; 2) new food bag subscribers; and 3) vulnerable people visiting the soup kitchen. The inclusion criteria were: i) understanding of Swedish, Arabic, or English, ii) existing food bag subscribers had to be subscribers for the last 30 days and new subscribers must not have received any food bags during the previous 30 days; and iii) soup kitchen participants had to free from the influence of alcohol or drugs, and from physical or mental discomfort, during the interview. In total, 67 existing food bag subscribers, 42 new food bag subscribers, and nine soup kitchen visitor participants were recruited (for demographic details of the participants, see Appendix A). The questionnaire was coded to protect the anonymity of the participants. The participants were informed about the present study both verbally and in writing (Swedish, Arabic, or English). Signed informed consent forms were obtained from all the participants.

2.1.4. *Composition analysis of food bags*

Twelve randomly selected food bags were analyzed in terms of their total net weight, percentages of perishable food items and inedible, spoiled, and edible parts, and estimated retail value (Table 1). Since approximately 66% of the food bag subscriptions were *pork-free*, 15% *omnivorous* (mixed diet), 13% *vegetarian,* and the remaining 6% were *special* (e.g., *gluten-* or *lactose-free*), eight of the 12 bags analyzed bags were *pork-free,* two *omnivorous,* and two *vegetarian.* The food bags were analyzed based on photographs of the contents supplied by staff at the food bag center. Food item weights were recorded based on the net weights stated on the packaging or standard weights found in the literature (KF och ICA provkök, 2000) multiplied by the number of items included in the food bag (Appendix B). The edible and inedible fractions were estimated based on literature values (De Laurentiis et al., 2018; KF och ICA provkök, 2000). The proportion of spoilage was visually assessed in the photographs when possible, and no spoilage was detected.

Table 1
Results of composition analysis on 12 randomly chosen food bags (FB1-FB12).

	Total net weight (g)	Perishable food* fraction (%)	Inedible fraction (%)**	Spoilage fraction (%)	Edible fraction (%)	Retail value*** (SEK)	Sample date
Average (SD)	9834 (1033)	70 (7.4)	12 (2.5)	1 (1.7)	87 (2.1)	197 (34.3)	
Pork-free food bags							
FB2	8 164	86	8	0	92	249	7-Sep-20
FB3	9 310	68	11	0	89	150	7-Apr-21
FB4	11 160	59	13	0	87	204	7-Apr-21
FB7	10 920	65	11	0	89	176	12-Apr-21
FB8	10 660	63	11	0	89	222	12-Apr-21
FB10	9 270	64	13	0	87	194	13-Apr-21
FB11	9 040	70	14	0	86	149	14-Apr-21
FB12	9 205	71	14	0	86	178	14-Apr-21
Omnivorous food bags							
FB1	11 469	76	8	6	86	242	23-Mar-21
FB5	10 335	69	12	0	88	239	9-Apr-21
Vegetarian food bags							
FB6	9 053	68	15	0	85	177	9-Apr-21
FB9	9 420	78	14	0	86	191	13-Apr-21

* Perishable food included fresh fruit, vegetables, dairy, fats, meat and fish.
** FB1 based on self-measured data, otherwise fractions retrieved from De Laurentiis et al. (2018) or KF och ICA provkök (2010).
*** Retail value retrieved from www.willys.se including a 50% discount.

To test the quantification method described above, the composition of food bag *FB1* (Table 1), was quantified by weighing all unpackaged food items (Appendix B). Perishable food items were checked for spoilage by looking, feeling, and/or sniffing them. Fruit and vegetables were separated into parts deemed unfit for consumption, such as peels, skins, and stalks, and parts that were spoiled, which were then weighed and recorded. For bananas, strawberries, and lettuce, the separation of spoiled parts was straightforward, but mushrooms had to be considered 100% inedible due to a foul odor from the package. Although this quality check was subjective, it was considered strict and the identified spoilage was deemed justified. The difference in total net weight between weighted FB1 (11469 g) and the estimation thereof based on photographs (11580 g) was 111g (1%). According to the results, 86% of the net weight of *FB1* consisted of edible foods, 8% consisted of inedible parts, and 6% was inedible due to spoilage.

The composition data were averaged, giving a food bag weighing approximately 9830 g and including 70% perishable food items, such as fruit, vegetables, dairy, meat, fish, or fats, and 30% dry goods. The average inedible food waste fraction was 12% (Table 1).

2.2. Carbon footprint analysis

To assess the environmental impact of food donation in terms of global warming potential (GWP), an attributional life cycle assessment including a system expansion for substituted products according to ISO standards 14040–14044 was conducted. Two scenarios were compared in the LCA, food donation and anaerobic digestion (Fig. 2). Carbon footprint (CF) associated with substituted products was credited to the overall results in each scenario. Direct and indirect rebound effects associated with re-spending of substitution-related monetary savings were included. The functional unit (FU) selected was 1 kg surplus food prepared for transportation at the retail gate.

2.2.1. Carbon footprint of food donation

In the assessment of the food donation scenario, emissions relating to transport, packaging, electricity, and food waste treatment were calculated, including the food bag center and the soup kitchen.

2.2.1.1. Transport. Transport data were obtained from UCM, based on its annual statistics. The food bag center collected roughly 70% of the donated surplus food in a van during daily rounds that also included forwarding food to other UCM units. For these deliveries, covering 12,023 km in 2020, 794 L biodiesel were used. The biodiesel used was assumed to be produced in Sweden, with an environmental impact of 0.454 kg CO_2e/L (Swedish Energy Agency, 2020). The remaining 30% of surplus food was delivered by various donors. Their CF was modeled based on the distance between the donors and the food bag center, delivery frequency, delivery tonnage, type of vehicle, and assuming no dead freight, using the NTMCalc 4.0 Environmental Performance Calculator (NTM, 2021). The soup kitchen's vehicle was driven 11,418

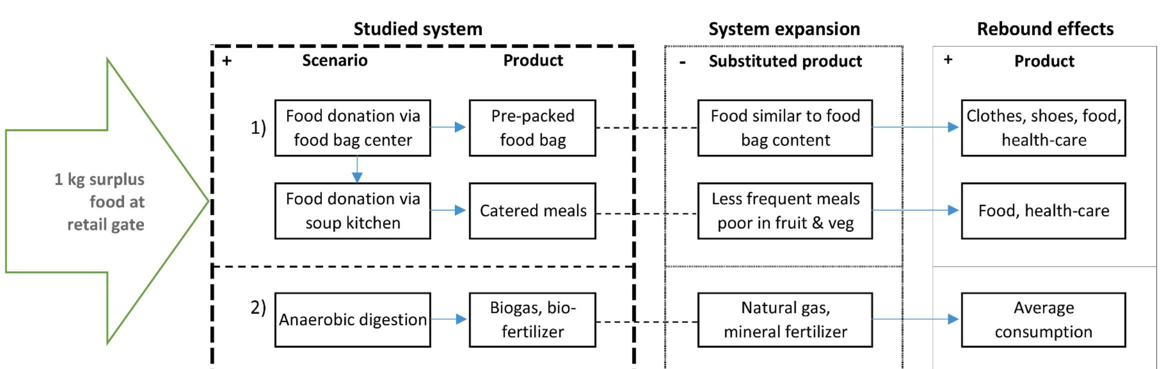

Fig. 2. System diagram illustrating the two scenarios compared, food donation and anaerobic digestion, and their respective products, and a system expansion including substituted products for each scenario and rebound effects associated with product substitutions. For each system, a positive (+) or negative (-) sign indicates the contribution to the net environmental impact of the system.

km in 2020, using 925 L petrol, of which 70% was estimated to be food donation-related driving. The petrol used was assumed to be produced in Sweden, with an environmental impact of 2.92 kg CO_2e/L (Swedish Energy Agency, 2020). The CF of daily food deliveries of 37 kg over 2 km distance by van was modeled assuming no dead freight (NTM, 2021).

The following transport-related data from the questionnaire, which were assumed to be representative of all receivers of food donation were also utilized: 1) place of residence and 2) usual transport method to UCM. According to the results, approximately 50% of the food bag center respondents took the bus, 35% bicycled or walked, and 15% drove a car when picking up their food bags, while 60% of the soup kitchen visitors bicycled or walked, 39% took the bus, and only 1% drove a car. The average return trip by bus amounted to 29.6 km and by car to 14.2 km. The CF for the bus trips was modeled assuming 45% biogas and 55% biodiesel, and 50% passenger occupancy, and that for the car trips assuming petrol and one passenger (NTM, 2021; Wisell et al., 2020).

2.2.1.2. Packaging. In 2020, the food bag center reported using approximately 150 new non-woven polypropylene bags, 100 LDPE plastic bags, and 100 paper bags, the CF of which was estimated based on 0.65, 0.11, and 0.031 kg CO_2e/bag, respectively, including end-of-life management through incineration, (Bisinella et al., 2018). The CF for 2.5 reusable plastic crates (3.279 kg CO_2e/crate) was also included for the food bag center (Tua et al., 2019). For the soup kitchen, the CF of 9500 LPDE freezer bags, 50 LPDE plastic bags, and 25 paper bags per annum was accounted for (Bisinella et al., 2018).

2.2.1.3. Electricity. The food bag center had seven upright freezers, one chest freezer, one small freezer, two fridge-freezers, and two refrigerators. All of these used 100 W/h except for the two fridge-freezers, which used 150 W/h. The compressor run-time was calculated as 12 h/day for all devices except the two refrigerators (8 h/day). The soup kitchen had four upright freezers, three chest freezers, three fridge-freezers, and one refrigerator, for which the values above were assumed. Electricity for one hour of cooking per day was also accounted for, as 1500 W/h. For the electricity, the Nordic electricity mix with an emission factor of 90.4 g CO2e/kWh was assumed (SMED, 2021).

2.2.1.4. Food waste treatment. Since donated surplus food was wasted both at UCM and in recipients' homes, the associated CF of both was included. At home, 47% of food waste was assumed to be sorted correctly and therefore treated by anaerobic digestion, with the remaining part incinerated (Swedish Waste Management, 2016). For UCM, a higher waste sorting rate of 80% was assumed. The CF associated with anaerobic digestion was -0.227 CO_2e/kg (present study). For incineration, the figure was -0.11 kg CO_2e/kg food waste, assuming that food waste consisted of one-third each of banana, lettuce, and bread (Eriksson et al., 2015).

2.2.2. Carbon footprint of anaerobic digestion

Anaerobic digestion was modeled as an alternative waste management scenario where food originating from Uppsala donated to the food bag center (140 t) was instead treated at the biogas plant in Uppsala. In the regional energy plan to cut the CF of domestic transport, increasing local biogas production and its utilization is prioritized (Troeng et al., 2019). Consequently, biogas production has increased continuously in recent years (+38% since 2017), using food waste as substrate and producing biofertilizer as a by-product (Uppsala Vatten, 2021b, 2021a). In this study, transport- and electricity-related CF were accounted for in the anaerobic digestion scenario.

2.2.2.1. Transport. To model transport of food waste to the biogas plant, retailers were first grouped per location, enabling measurement of the pick-up distances as rounds. The pick-ups were assumed to be conducted twice a week, resulting in a total of 6013 km. The plant's trucks consume 0.00012 L/tkm and run on 40% biogas and 60% diesel (I. Vita, personal communication, 23 June 2021). The biodiesel and diesel used were assumed to be produced in Sweden, with an environmental impact of 0.763 and 2.69 kg CO_2e/L, respectively (Swedish Energy Agency, 2020). Transport of biofertilizer was modeled as 30 km distance on rural roads performed by a diesel-run heavy truck with Euro 5 engine assuming 50% load (Eriksson et al., 2015; NTM, 2021).

2.2.2.2. Electricity. The electricity requirement for production of biogas was assumed to be 10 kWh/t of substrate (Eriksson et al., 2015). For CF, the Nordic electricity mix with an emission factor of 90.4 g CO_2e/kWh was assumed (SMED, 2021).

2.2.3. Substitution of food donation

In the food donation scenario, the substitution comprised emissions from foods substituted by food donation (food that was avoided from being purchased and therefore presumed avoided from being produced), excluding food waste. To investigate the food substitution by the food bags, the results of the 24-h dietary recall were analyzed as differences in intake frequencies of food groups between new and existing food bag subscribers. The results indicated similar consumption frequency (70-100% of respondents) for cereals, vegetables, fruit, meat, dairy, spices, beverages, and oils & fats for new and existing subscribers. For potatoes, carrots, red peppers, green leafy vegetables, and fish with lower consumption frequencies (20-50% of respondents), slightly higher frequencies (10-20%) were observed for existing subscribers in comparison with new subscribers. For sweet items, intake frequency was slightly lower for existing compared with new subscribers (50% vs. 60%). Based on the above, it was concluded that the food bags were likely to substitute for food items from the most frequently consumed food groups according to the typical content of the food bags, such as bread, pasta, vegetables, fruit, dairy, and coffee. The CF for the substituted foods was calculated based on the weight fractions of donated foods using cradle to gate CF, including packaging (Röös, 2014) (Appendix B).

To investigate the substituted food by soup kitchen donations, a different type of assessment was conducted because the food donations mainly comprised cooked meals instead of food items. Therefore, for the soup kitchen visitors, the dietary recall results were first analyzed as number of daily meals (including breakfast, lunch, dinner, and snacks). The results suggested that visitors ate 4.5 meals/day when visiting the soup kitchen and 2.3 meals/day when not visiting. Since the soup kitchen served breakfast, lunch, and snacks and provided visitors with take-away meals, i.e., not necessarily covering all the reported 4.5 meals/day, the substitution was based on two meals, amounting to 850 g of food/visitor and day. Based on the dietary data collected, the substituted meals consisted of coffee, bread, dairy, pasta/rice/potato, meat, and some vegetables (Appendix C). The CF of the meals was calculated using cradle to gate CF per food item, including packaging and excluding transport within Sweden, cooking, and waste treatment (Röös, 2014).

2.2.3.1. 24-h dietary recall. To investigate the food intake of receivers of food donation, a single 24-h dietary recall survey was conducted among the study participants using the dietary diversity questionnaire created by FAO (Kennedy, 2011). In total, 55 existing and 36 new food bag subscribers were telephone-interviewed by trained nutritionists. Furthermore, nine soup kitchen visitors were interviewed face-to-face by soup kitchen staff. During the interviews, the participants were asked to recall all food and drink consumed the previous day, including the amounts, and ingredients in the case of composite meals.

2.2.4. Substitution of anaerobic digestion

In the anaerobic digestion scenario, the substituted products were assumed to be natural gas and mineral fertilizer. The biogas produced in

Uppsala is mainly used for running the city's buses, but also some regional buses (Uppsala Vatten, 2021a). However, due to the Covid-19 pandemic, the use of public transportation decreased in 2020, leading to an increase in use of the biogas to produce electricity (Uppsala Vatten, 2021a). Even under normal circumstances, biogas supply and demand may not always match and biogas has to be used for other purposes, or natural gas is required as a buffer to run the buses (Uppsala Vatten, 2021a). While acknowledging the complexity of the energy system, in the scenario it was assumed that the biogas produced was used to run the bus traffic in Uppsala, substituting for natural gas. The yield of the Uppsala biogas plant in 2020 was 0.1 Nm^3 upgraded biogas/kg food waste with an energy content of 9.7 kWh/Nm^3 (L. Nordin, personal communication 24 June 2021). The natural gas emissions replaced were 69.3 g CO_2/MJ, corresponding to the average natural gas consumed in Sweden (Swedish Energy Agency, 2020).

Further, the biofertilizer was used for cultivation, substituting for mineral fertilizer. The substituted production of fertilizer was assumed to use natural gas as an energy source, emitting 2.41 kg CO_2e/kg N (Ahlgren et al., 2010). The amount of fertilizer substituted was based on the average nitrogen content of the average food bag, obtained by dividing the average protein content by a conversion factor of 6.25 (SNFA, 2021). The CF from substituted phosphorus (P) was also calculated, based on an average content of 12.9 g P/kg food (Uppsala Vatten, 2019) and an emission factor of 3.6 kg CO_2e/kg P (Linderholm et al., 2012).

2.2.5. *Rebound effect*

Rebound effects can arise either from changes in consumption patterns lowering the costs or from efficiency improvements making a service cheaper (Lekve Bjelle et al., 2018). In the context of the present study, rebound effects arise from re-spending of accrued savings due to receiving donated food substituting food that would have otherwise been purchased. The re-spending leads to environmental emissions that are quantified and added to the net carbon footprint results in contrast to emissions corresponding to the substitution that are credited to the net results. The rebound effect is defined as the relationship between potential CF savings (ΔH) and the CF savings not realized (ΔG) (Chitnis et al., 2014; Druckman et al., 2011):(Eqn 1)

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

To calculate ΔG, monetary savings associated with substitution, and their re-spending, were investigated for each scenario. The monetary savings were then multiplied by consumption-related GHG intensity (Grabs, 2015) (Appendix D) and added to the CF results of the scenarios.

2.2.5.1. Rebound effect of food donation. For the food donation scenario, the survey results were used to calculate ΔG. The average self-estimated savings of the food bag subscribers were 176 (± 131) SEK/week (17 EUR/week), amounting to 165 SEK/week (16 EUR/week) with the subscription fee deducted. For the soup kitchen visitors, the daily median saving amounted to 25 SEK (± 36) (2 EUR). The savings were mostly spent on clothes or shoes, complementary food, and healthcare (Appendix D).

2.2.5.2. Rebound effect of anaerobic digestion. For the anaerobic digestion scenario, a potential increase in biogas sales profits was assumed. Although aiming at zero financial results, due to being a tax-funded company, surpluses and deficits incur and are settled against prepaid fees of subscribers in the balance sheet. In 2020, the waste operations of the biogas plant as a whole made a deficit of 21 MSEK (2 MEUR), which increased the cost to subscribers to 29.3 MSEK (2.9 MEUR) (Uppsala Vatten, 2021b). Simultaneously, biogas sales resulted in 6.4 MSEK (0.6 MEUR) profit while treating 48,000 t of food waste (Uppsala Vatten, 2021b). Based on these values, treating an extra 237 t of food waste could have increased the biogas sales profits by approximately 30 000 SEK (2900 EUR), which was far too little to settle the existing subscriber debt. However, with no debt, the additional sales profits could have been used to reduce the subscriber fees, resulting in monetary savings for households that were assumed to be spent according to the average Swedish consumption pattern (Grabs, 2015).

3. Results

3.1. *Effectiveness of food donation*

The proportion of donated food eaten was 78% (185 t), and the proportion wasted was thus 22% (53 t), of the total input of 237 t in 2020 (Fig. 3). The food bag center received 208 t of surplus food, of which 16 t was forwarded to the soup kitchen. Moreover, the soup kitchen received 29 t directly from various retailers, redistributing 45 t of surplus food in total. Upon receipt at the food bag center, surplus food was sorted according to its estimated remaining shelf-life, or disposed of if deemed spoiled (5%). To optimize the system, food with the longest shelf-life was designated for weekly food bags or stored for later use, whereas food close to its expiry was allocated to other charities that could utilize the food shortly or given away as extra to food bag subscribers. Further, 34% of the questionnaire respondents indicated donating part of their food bag content to friends, revealing an additional existing measure to minimize food waste. Similarly, food waste was minimized at the soup kitchen through an allocation to daily catering at the premises, take-away meals, food bags, or other charities. Approximately 12% of the total input via the soup kitchen was estimated to become food waste, while the food waste rate was 25% for the food bag center. Of the total food waste, approximately 28 t (54%) was edible and 24 t (46%) was inedible.

3.2. *Carbon footprint*

The anaerobic digestion scenario resulted in a carbon-negative net result of -0.22 kg CO_2e/FU. In comparison, the CF of food donation was almost twice that value (-0.40 kg CO_2e/FU) (Fig. 4). These carbon-negative results were largely due to the substitution effects, -0.26 and -0.95 kg CO_2e/FU, respectively. Further, the food donation scenario received minor benefits through credited emissions from the food waste treatment (-0.026 kg CO_2e/FU).

The carbon savings from the food donation scenario were substantially reduced due to the rebound effect of 51%, offsetting 0.50 kg CO_2e/FU. For the anaerobic digestion scenario, the rebound effect was only 2% (0.006 kg CO_2e/FU). Other contributors to the CF were transport-related, including end-user transport for food donation (0.061 kg CO_2e/FU) and transport of bio-fertilizer from the anaerobic digestion plant (0.032 kg CO_2e/FU). Emissions from transport from retail (0.012 kg CO_2e/FU), packaging (0.001 kg CO_2e/FU), and electricity (0.004 kg CO_2e/FU) were only minor contributors to the food donation results. For the anaerobic digestion system, transport from retail (0.001 kg CO_2e/FU) and electricity (0.0009 kg CO_2e/FU) also played only a minor role in the results.

When the soup kitchen and food bag center results were separated, some differences were observed (Fig. 4). While the net result of the soup kitchen was -0.27 kg CO_2e/FU, the food bag center was 55% more carbon-negative, at -0.42 kg CO_2e/FU. The difference was mainly due to a smaller substitution effect of the soup kitchen compared with the food bag center (-0.82 vs. -0.98 kg CO_2e/FU), although transport-related emissions also contributed. Transport emissions from retail, amounting to 0.065 kg CO_2e/FU for the soup kitchen, were higher than transport emissions from the food bag center (0.003 kg CO_2e/FU). End-user transport emissions were also higher for the soup kitchen (0.092 kg CO_2e/FU) than for the food bag center (0.054 CO_2e/FU). Further, due to the higher food waste rate of the food bag center, the amount of emissions credited due to food waste treatment, amounting to -0.03 kg CO_2e/FU, was three-fold the amount (-0.01 CO_2e/FU) from the soup kitchen.

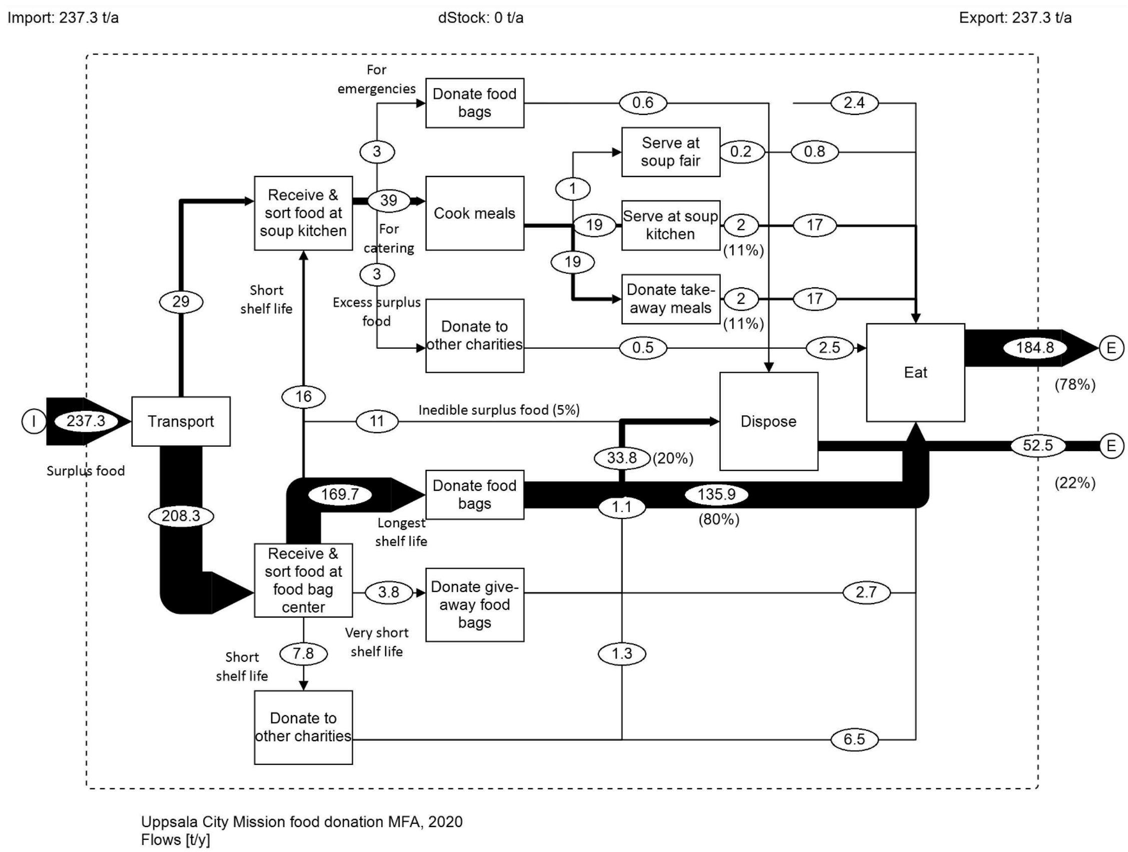

Fig. 3. Material flow diagram of surplus food throughput (237 t in total) via the soup kitchen and food bag center of Uppsala City Mission in 2020. The main flows and various side-flows created in an attempt to minimize food waste within the system are depicted. Approximately 78% (185 t) of the total surplus food flow was eaten, i.e., 22% (53 t) was wasted.

Lastly, the rebound effect was 47% of the potential carbon savings (0.39 kg CO_2e/FU) for the soup kitchen and 52% (0.53 kg CO_2e/FU) for the food bag center.

3.3. *Sensitivity analyses*

Although transport from retail did not have the greatest influence on the net results, due to an uncertainty related to possible dead freight, in a sensitivity analysis this parameter was tested with 100% return dead freight and max dead freight inbound and outbound (Fig. 5). Moreover, due to the high variation in the survey results utilized for calculating the substitution and rebound effects of food donation, the sensitivity of the most important parameters was tested, including the proportion of substituted meat for the food bags (min 0%; present study 4%; max 10%) and the number of substituted meals (min 1; present study 2; max 4) for the soup kitchen visitors. The following parameters related to the rebound effect were also tested: 1) amount of savings due to receiving donated food (min 0 SEK; present study 165 SEK; max 600 SEK/food bag, and min 0 SEK; present study 25 SEK; max 100 SEK/soup kitchen visit); and 2) spending the savings on the most GHG-intensive consumption category, complementary food (min 0%; present study 20% (food bags) and 43% (soup kitchen); max 100% complementary food). Finally, the effect of changes in the food waste fraction of the food bags was tested (min 2%; present study 9%; max 60%). The results showed low sensitivity to dead freight and food bag food waste fraction, but high sensitivity to the rebound effect-related parameters, potentially resulting in backfire effects, i.e. the rebound effect exceeding 100% (Fig. 5).

4. Discussion

This study investigated the effectiveness, CF, and rebound effect of food donation conducted by a charity organization in Sweden. The results revealed a complex but effective network of processes aimed at salvaging as much of the redistributed food as possible, with a 22% food waste fraction, including household food waste, of the 237 t of surplus food redistributed in 2020. However, there was a substantial rebound effect, offsetting 51% of the potential carbon savings from food donation. Nonetheless, the net effect of food donation was almost twice the climate benefit of anaerobic digestion (-0.40 vs. -0.22 kg CO2e/FU), supporting the food waste hierarchy.

Effectiveness refers to the food waste reduction potential or the degree to which a food waste prevention measure reaches its objective (Caldeira et al., 2019b; Goossens et al., 2019). The indicator total amount of food redistributed, applied for effectiveness in the literature, could cause ambiguity as to whether food waste generated throughout the redistribution process is included (Caldeira et al., 2019b; Hecht and Neff, 2019). Redistribution extending to households, such as food bag donation, also generates additional food waste that is seldom reported. Therefore, rather than just reporting the total amount of food redistributed, the present study investigated its food waste fraction (22%). One previous study estimated that 40% of food donated by retailers in the UK is wasted (Alexander and Smaje, 2008). However, in contrast to the present study, the only outlets for donated food in that study were soup kitchens, explaining some of the difference in the results. The present study revealed a network of outlets utilized by the food bag center and the soup kitchen to salvage surplus food, such as other charity organizations or take-away meals. Further, 34% of the food bag subscribers surveyed in this study reported passing some of the donated

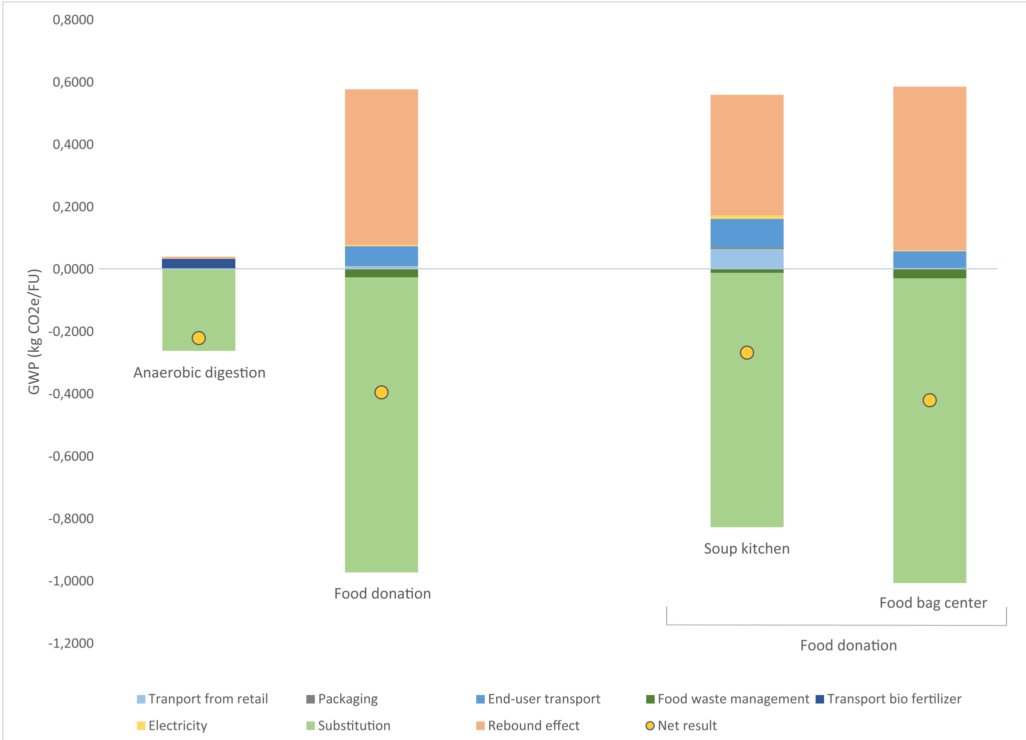

Fig. 4. Carbon footprint of surplus food converted to biogas or donated to charity. The rebound effect for food donation was 51%, offsetting its carbon savings substantially. The two columns to the right give a breakdown of the food donation results for the soup kitchen and food bag center, including a rebound effect of 47% and 52%, respectively.

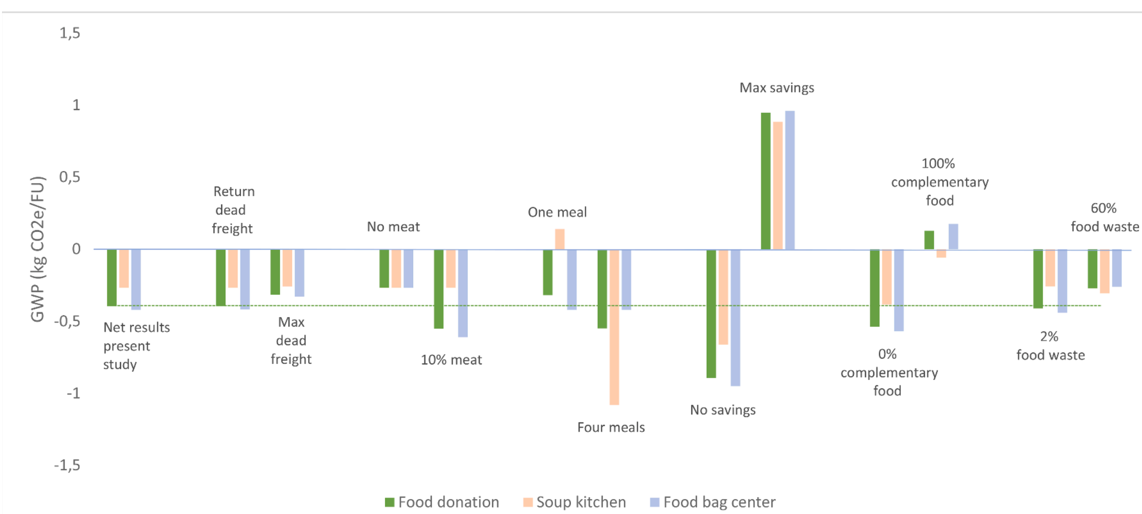

Fig. 5. Results of sensitivity analysis on net carbon footprint of the food donation scenario, with a breakdown of the results to the soup kitchen and food bag center. The parameters tested relative to the net results of the present study were: no dead freight; 4% meat substitution by food bags; two-meal substitution by soup kitchen; savings of 165 SEK/food bag and 25 SEK/soup kitchen visit; 20% (food bag subscriber) and 43% (soup kitchen visitor) of savings used on complementary food; and 9% food waste fraction of food bags.

food on to their friends to minimize waste. This ‘extended network’, in combination with the quick food sorting process, ensured high daily turnover of the surplus food, which is essential to minimize waste due to the short shelf-life of surplus food. Despite these efforts, approximately 20% of the food in food bags was wasted (9% edible and 12% inedible food waste). Although this could be seen as shifting food waste along the food supply chain, it could also be a necessary step in order to salvage the rest. While retail has the perspective of disposing/donating food that cannot be sold, charities have the interest of salvaging as much as possible of food that is still edible. Further, while the level of wastage was in line with household food waste fractions reported in the literature (Gustavsson et al., 2011), the main reason differed. The most common reason reported for household food waste, not being used in time, was not the issue for food bag waste, but rather the fact that there was no time to use the food before its expiry, a well-acknowledged barrier to food donation (Caldeira et al., 2019b; Quested and Johnson, 2009). Food wastage in the soup kitchen (11%) was less than previously indicated for the catering sector (20%) (Malefors et al., 2019), which could be due to people in need consuming more of the food served than the average population visiting restaurants and school canteens.

As seen in previous studies, the CF of food donation was strongly influenced by the substitution, resulting in substantial carbon savings (Albizzati et al., 2019; Bergström et al., 2020; Eriksson et al., 2015; Eriksson and Spångberg, 2017). However, in contrast to previous studies, the present assessment included the rebound effects, with the results suggesting that the carbon savings from food donation are less than previously reported. The CF-related rebound effect is a well-studied phenomenon related to energy efficiency improvements (Brockway et al., 2021; Chitnis et al., 2013; Druckman et al., 2011), but has been less well studied in the context of food waste management. Some studies investigating the highest level of the food waste hierarchy, food waste prevention, have reported rebound effects of similar magnitude to those seen in the present study, i.e., 50-106% at consumer level (Albizzati, 2021; Chitnis et al., 2014; Druckman et al., 2011; Hagedorn and Wilts, 2019; Salemdeeb et al., 2017a). As with household food waste prevention, food donation leads to accrued household monetary savings. However, there were some methodological differences influencing the results. First, as shown in the present study, food waste is generated throughout food donation, which should be accounted for, lowering the rebound effect. Further, food substitution may differ between prevention and donation and, as demonstrated by the present study, even between different types of donation. Moreover, in the present study the savings accrued by donated food bags were equivalent to a discounted retail price, instead of the full price, suggesting that food waste prevention can generate larger monetary savings. That in turn could lead to a higher rebound effect, although depending on how the savings are spent. In fact, the rebound effect has been shown to increase with decreasing income, due to the consumption pattern increasing in GHG intensity (Chitnis et al., 2014; Grabs, 2015; Hagedorn and Wilts, 2019), suggesting that food donation can be particularly affected.

The present study also included the rebound effect for the alternative food waste management scenario, anaerobic digestion, which has previously been less well studied. In that scenario, the monetary savings were not accrued due to food waste prevention, but by increasing the amount of food waste treated by anaerobic digestion, based on the assumption that additional biogas sales profits would lead to monetary savings for households in Uppsala City through reduced service fees. The results showed that the rebound effect was significantly lower for anaerobic digestion in comparison with food donation (2% vs. 51%), and dividing the modest savings between thousands of households in Uppsala City made the rebound effect negligible.

A strength of the present study was in investigating both the effectiveness and rebound effect of food donation. The method for assessing the rebound was applied in a similar manner to the substitution, through a system expansion in the LCA, making the assessment holistic, and easy to apply in future studies. Other strengths were the use of primary data related to sensitive parameters (the substitution, monetary savings, and what the savings were spent on) and the use of primary data regarding the food waste fraction and an inedible fraction of the food bags, which reduced data uncertainty. However, there were also some limitations, in particular the fact that the primary data quantifying food waste from the soup kitchen and food bags were non-measured and susceptible to bias. However, based on sensitivity analysis of the food waste parameters, any such bias would not have greatly affected the overall results. Further, the Covid-19 pandemic limited the data collection to some degree resulting in a small sample size of the food bags. Another limitation caused by the pandemic was the low participation rate in the survey and interviews via the soup kitchen, resulting in uncertainty in the data. In sensitivity analysis, parameters related to substitution and rebound effect were found to affect the soup kitchen results, but due to the smaller volume of food redistributed by the soup kitchen, the impact on the overall results was minor.

A further limitation was exclusion of possible climate savings related to land-use change in food substitution by food donation (Albizzati et al., 2019), suggesting that the results could be somewhat underestimated. Moreover, the soup kitchen reported occasionally purchasing food in the past to feed its visitors, when donated food was not available. This substitution effect was also excluded from the present analysis, because prior to the current redistribution set-up the food served was very simple, uncooked, in low amounts, and served to fewer visitors. Since 2016, the food served has been cooked, served regularly, and in larger amounts, extended to take-away meals, and in cases of surpluses even forwarded to other charities, thus serving a larger population of people in need. In addition, the substitution effect of the food bags was investigated based on intake frequencies of food groups instead of intake amounts, which could have led to some misinterpretation of differences in food intake between new and existing food bag subscribers. Further, the CFs of the Food-Climate list (Röös, 2014) are average values for food groups consumed in Sweden, and thus not necessarily representative of the food groups included in donated food. Similarly, the GHG intensities were based on average Swedish consumption (Grabs et al., 2015). Therefore, the substitution and rebound effect results should be interpreted as approximate. Lastly, the anaerobic digestion scenario was modeled with simplified reality, as some retail food waste is incinerated due to being packaged, and should therefore be regarded as the best-case scenario, rather than a reflection of reality.

Despite some wastage, food donation was found to be effective, with 78% of the redistributed food eaten. To achieve this, strategic planning for swift handling of the variable surplus food input with short expiry date was required. The extended network of dedicated donation outlets, including the informal spillover effect into other low-income households, was another key success factor. However, human resources were also required, which could be a vulnerability for an organization relying on volunteers and a barrier in terms of scalability (Berti et al., 2021). To scale up such organizations is likely to require policy support such as the ban to waste food from retail implemented in France (Condamine, 2020). In Sweden, food donation is expected to grow according to the recent dialogue between different stakeholders, but is currently supported by the EU guidelines only while national guidelines are lacking (Swedish Food Agency, 2021). Moreover, to support future policy decisions, a complete sustainability assessment, including the economic and social performance of food donation should also be investigated (Goossens et al., 2019).

Further, mitigating rebound has previously been recommended through policy actions for example by guiding people towards greener or reduced consumption patterns (Druckman et al., 2011; Lekve Bjelle et al., 2018). Considering that low-income groups are associated with a consumption pattern with the highest carbon intensity, strictly from the environmental perspective, such policy work could be of importance when promoting food donation. However, from an equity and ethical point of view, the rebound effect could play an important role as a way to mitigate social issues such as at-risk-of-poverty (Font Vivanco et al., 2016; SCB, 2019). Therefore, such policy work could be focused on limiting the rebound effect from becoming a backfire effect to promote the overall sustainability of food donation. Moreover, food donation aimed at meeting the dietary needs of receivers could reduce their need to purchase complementary food, allowing less carbon-intensive consumption, a strategy worth considering. Interestingly, the results also pointed to the possibility of rebound effects increasing towards the top of the food waste hierarchy, warranting further studies. Overall, while surplus food redistribution cannot address the root causes of food waste or food insecurity, it has a relieving effect and short-term potential for significant contributions to sustainability.

5. Conclusions

Despite some wastage, food donation in the study case was found to be effective, with 78% of 237 t redistributed surplus food eaten, benefiting hundreds of people in need. However, food donation had a substantial rebound effect of 51% (0.50 kg CO_2e/FU), albeit outweighed by the substitution effect (-0.95 kg CO_2e/FU). Despite this rebound effect, food donation resulted in almost twice the climate benefit of anaerobic digestion, supporting the food waste hierarchy. However, strategies for mitigating rebound effects limiting them from becoming backfire effects should be considered when promoting food donation.

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Author Contributions

Niina Sundin: Conceptualization, Data curation, Formal analysis, Methodology, Writing – original draft, Writing – review & editing. Christine Persson Osowski: Conceptualization, Methodology, Supervision, Writing – review & editing. Ingrid Strid: Conceptualization, Methodology, Supervision, Writing – review & editing. Mattias Eriksson: Conceptualization, Funding acquisition, Methodology, Supervision, Writing – review & editing. All authors have read and agreed to the published version of the manuscript.

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.

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Appendix A: Demographics of the study participants

	Existing food bag subscribers	New food bag subscribers	Soup kitchen visitors
Number of study participants	67	21	9
Gender, n (%)			
Male:	30 (45)	7 (33)	5 (56)
Female:	37 (55)	14 (67)	4 (44)
Age, mean (SD)	45 (14)	32 (11)	60 (7)
Educational level, n (%)			
Primary School:	13 (19)	6 (43)	5 (56)
Realschule:	9 (13)	1 (7)	0
Lower secondary education:	9 (13)	0	0
Upper secondary education:	4 (6)	4 (29)	0
College or University:	22 (33)	2 (14)	4 (44)
Don't know:	10 (15)	1 (7)	0
Permanent place of living*, n (%)			
Yes:	44 (73)	9 (60)	7 (78)
No:	16 (27)	6 (40)	2 (22)
Number of adults in household, mean (SD)	1.8 (1)	1.4 (0.5)	1 (0)
Number of children in household, mean (SD)	1.7 (2)	1.4 (1.6)	0.1 (0)

Appendix B: Average food bag (FB) content per food group and food item (g/FB), and food bag content per food bag per food item (g)

Food group	Net weight fraction	Food item	Average net weight (g/FB)	kg CO2e/kg food*	Net weight fraction	FB1	FB2	FB3	FB4	FB5	FB6	FB7	FB8	FB9	FB10	FB11	FB12
Cereals	17%	Bread	942	0.80	10%	1 275	560	0	1 000	850	1 048	1 325	1 350	300	1 300	1 300	1 000
		Hard bread	41		0%	0	245	0	0	0	0	0	0	0	245	0	0
		Pasta	292	0.80	3%	500	0	500	500	500	500	500	500	0	0	0	0
		Grains	419	0.60	4%	0	0	2 000	2 000	0	0	0	0	325	700	0	0
White tubers and roots	5%	Potatoes	404	0.10	4%	1 000	750	0	0	0	0	0	0	900	400	900	900
		Crisps	25		0%	0	0	0	0	0	0	0	0	0	0	150	150
		Parsnip	42		0%	0	0	0	0	0	0	500	0	0	0	0	0
Vitamin A rich vegetables and tubers	3%	Sweet peppers (red)	134	1.40	1%	508	125	0	0	0	150	150	150	125	100	150	150
		Carrots	122	0.20	1%	0	264	0	0	0	0	500	0	0	400	150	150
		Sweet potato	13	0.20	0%	0	0	0	150	0	0	0	0	0	0	0	0
Dark green leafy vegetables	9%	Lettuce	365	1.40	4%	528	500	0	0	500	500	500	650	500	500	200	0
		Fennel	21	1.40	0%	0	0	0	0	0	250	0	0	0	0	0	0
		Broccoli	75	0.20	1%	296	0	300	300	0	0	0	0	0	0	0	0
		Kale	17		0%	0	0	0	0	0	0	0	0	200	0	0	0
		Cabbage	278	0.20	3%	0	0	900	930	0	0	0	0	1 500	0	0	0
		Parsley leaves	42		0%	0	0	0	0	0	0	0	0	0	0	250	250
		Eggplant	67	1.40	1%	0	0	0	0	0	0	0	0	0	0	400	400

(*continued on next page*)

(*continued*)

Food group	Net weight fraction	Food item	Average net weight (g/FB)	kg CO2e/kg food*	Net weight fraction	FB1	FB2	FB3	FB4	FB5	FB6	FB7	FB8	FB9	FB10	FB11	FB12
		Pak choi	25		0%	0	0	0	0	0	0	0	0	0	0	0	300
Other vegetables	11%	Onion	100	0.20	1%	355	0	200	200	125	0	80	240	0	0	0	0
		Zucchini	120	1.40	1%	242	300	0	0	300	0	0	0	300	300	0	0
		Champignon	66	1.40	1%	376	0	0	0	180	0	0	240	0	0	0	0
		Cucumber	109	1.40	1%	0	350	0	0	0	320	320	320	0	0	0	0
		Tomatoes	308	1.40	3%	0	890	480	400	0	0	960	960	0	0	0	0
		Green & yellow pepper	177	1.40	2%	0	500	375	175	200	100	125	250	400	0	0	0
		Beetroot	95	0.20	1%	0	0	425	325	0	0	0	0	0	0	390	0
		Radish	8	0.20	0%	0	0	0	0	100	0	0	0	0	0	0	0
		Corn (conserve)	48		0%	0	0	0	0	285	285	0	0	0	0	0	0
		Chives	3		0%	0	0	0	0	0	0	0	40	0	0	0	0
Vitamin A rich fruit	0%		0		0%	0	0	0	0	0	0	0	0	0	0	0	0
Other fruit and berries	21%	Banana	535	0.60	5%	568	450	750	600	450	600	600	600	300	300	600	600
		Kiwi	31	0.60	0%	123	0	0	0	0	0	0	0	0	0	0	250
		Apple	423	0.60	4%	425	300	600	600	625	575	300	450	300	300	300	300
		Citrus fruits	644	0.60	7%	275	125	575	550	850	1 275	400	575	1 150	875	500	575
		Grapes	75	0.60	1%	0	400	0	500	0	0	0	0	0	0	0	0
		Strawberries	91	11.00	1%	368	0	125	200	200	200	0	0	0	0	0	0
		Avocado	96	0.60	1%	0	0	0	0	200	200	0	0	300	450	0	0
		Dates	33	0.60	0%	0	0	0	0	400	0	0	0	0	0	0	0
		Pear	125	0.60	1%	0	0	0	0	0	0	300	150	0	0	450	600
		Graded coconut	17	0.60	0%	0	0	0	0	0	0	0	0	0	0	200	0
		Blueberries	8	11.00	0%	0	0	0	0	0	0	0	0	0	0	0	100
Organ meat	0%		0		0%	0	0	0	0	0	0	0	0	0	0	0	0
Flesh meats	4%	Charcuterie; mettwurst	173	7.00	2%	1000	0	0	0	1 070	0	0	0	0	0	0	0
		Chicken nuggets	200	3.00	2%	0	0	0	0	0	0	800	800	0	800	0	0
Eggs	0%		0		0%	0	0	0	0	0	0	0	0	0	0	0	0
Fish	0%		13		0%	0	0	0	0	0	0	0	0	160	0	0	0
Legumes, nuts, seeds	1%	Chick peas	19	0.70	0%	230	0	0	0	0	0	0	0	0	0	0	0
		Kidney beans	96	0.70	1%	0	0	230	230	0	0	0	0	230	0	230	230
Dairy	14%	Milk (0.5%)	500	1.00	5%	1000	0	0	0	1 000	0	0	0	0	0	2 000	2 000
		Yoghurt (3%)	433	1.00	4%	1000	0	1 000	1 000	0	0	1 000	1 000	0	200	0	0
		Other	465	2.00	5%	0	250	600	600	1 000	2 000	0	125	1 000	0	0	0
Oils and fats	1%		133	1.50	1%	0	0	0	0	0	0	1 000	600	0	0	0	0
Sweets	4%	Pastries	100	2.00	1%	180	270	0	150	450	0	0	0	150	0	0	0
		Juice	125	0.80	1%	500	0	0	0	0	0	0	0	0	1 000	0	0
		Chocolate	77	2.00	1%	0	100	200	200	100	100	0	0	100	100	20	0
		Candy	128	2.00	1%	0	0	0	0	120	120	400	500	200	200	0	0
		Chewing gum	3	2.00	0%	0	0	0	0	0	0	0	0	0	0	20	20
Spices, condiments and beverages	7%	Tea	38	3.00	0%	50	0	50	50	50	50	50	50	0	0	50	50
		Coffee	346	3.00	4%	0	0	0	500	450	450	450	450	450	500	450	450
		Mineral water	275	0.30	3%	0	0	0	0	330	330	660	660	330	330	330	330
		Cacao	33		0%	0	0	0	0	0	0	0	0	0	0	0	400
Ready-made meals	2%	Sandwiches & wraps (cheese/chicken/shrimp)	117	2.00	1%	190	945	0	0	0	0	0	0	0	270	0	0
		Pastasalad (cheese/ham/chicken)	106	2.00	1%	480	790	0	0	0	0	0	0	0	0	0	0
Other	0%	Yeast	4		0%	0	50	0	0	0	0	0	0	0	0	0	0
		Oatbased cream	17		0%	0	0	0	0	0	0	0	0	200	0	0	0
			9 834			11 469	8 164	9 310	11 160	10 335	9 053	10 920	10 660	9 420	9 270	9 040	9 205

*Carbon footprint used for the calculation of substituted food (Röös, 2014).

Appendix C: Food substitution effect of food donations from the soup kitchen including carbon footprint (CF)

	kg substituted food/person/day	kg CO2e/kg*
Bread	0.06	0.8
Cereals	0.02	0.6
Pasta	0.01	0.8
Rice	0.03	2
Potato	0.04	0.1
Vegetables	0.04	1
Pea Soup	0.07	1
Dairy	0.14	1
Beef	0.06	26
Ham	0.01	7
Sausage	0.02	7
Chicken	0.03	3
Caviar	0.01	3
Margarine	0.00	1.5
Coffee	0.20	3
Buns	0.05	2
Nuts	0.06	1.5
Total	0.85	

*Röös, 2014

Appendix D: Alternative spending of substitution-related monetary savings and greenhouse gas (GHG) intensities

	Expenditure pattern	Expenditure (%)	Expenditure SEK/wk/subscriber	GHG intensity* (kg CO2e/SEK)
Food donation scenario - food bag center	Clothes and shoes	29	48	0.027
	Food	20	33	0.082
	Consumables	17	28	0.03
	Healthcare	16	26	0.018
	Services	7	12	0.008
	Transportation	4	7	0.078
	Housing (rent, energy)	4	7	0.044
	Leisure	1	2	0.027
	Furniture	1	2	0.023
	Restaurant visits	1	2	0.011
	Expenditure pattern	Expenditure (%)	Expenditure SEK/day/visitor	GHG intensity* (kg CO2e/SEK)
Food donation scenario - soup kitchen	Food	43	11	0.082
	Transportation	14	4	0.078
	Healthcare	14	4	0.018
	Housing (rent, energy)	14	4	0.044
	Restaurant visits	14	4	0.011
	Expenditure pattern**	Expenditure** (%)	Expenditure SEK/year***	GHG intensity* (kg CO2e/SEK)
Anaerobic digestion scenario	Housing (rent, energy)	24	7200	0.044
	Transportation	19	5700	0.078
	Leisure	19	5700	0.027
	Food	12	3600	0.082
	Other****	11	3300	0.024
	Clothes and shoes	5	1500	0.027
	Furniture	5	1500	0.023
	Services	5	1500	0.008

*Grabs (2015)
**Expenditure pattern of the average Swedish consumer (Grabs, 2015).
***Collective annual expenditure of the subscribers of the household food waste collection services by Uppsala Vatten.
****Average GHG intensity of expenditures related to beverages, tobacco, consumables and healthcare.

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