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Food waste quantities, carbon footprint and nutrient loss in university students' households in Sweden

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ABSTRACT

Food waste in households poses a significant barrier to achieving sustainable food systems. This study examines food waste generated by university student households in Sweden, focusing on its weight, carbon footprint, and nutritional impacts. Using kitchen diaries, 109 students quantified their waste by weight over two weeks. On average, 115 g/person/day of food was wasted, with 46 g/person/day classified as avoidable or edible. Avoidable waste generated a carbon footprint of 1.3 kg CO_2e/kg food waste and contained key nutrients, such as dietary fiber (4.7 g/MJ) and folate (56 μg/MJ). Notably, the top 10 % of waste items accounted for 47 % of total waste and 62 % of the carbon footprint. Reducing waste from this fraction by half could achieve a 23.7 % reduction in total waste. When scaled to the national level, food waste from university students in Sweden is estimated to generate 9950 tonnes of CO_2e annually. The findings highlight the importance of targeting both high-carbon-impact and nutrient-rich waste to align with environmental and public health objectives. Educational interventions and automated waste tracking are recommended to foster sustainable consumption patterns.

1. Introduction

For several decades, the global demand and consumption of goods has reached well beyond the supply capacity of the planet. This imbalance has resulted in Earth systems being put under major stress, which will intensify if actions are not taken (Richardson et al., 2023).While some challenges, such as limited resource availability, are related to supply constraints, the majority stem from the Earth's limited assimilatory capacity for waste and pollutants. These include issues like climate change, ozone depletion, acidification, and nutrient pollution, which result from the inability of natural systems to effectively process human-generated activities and waste flows (Rockström et al., 2009).

Globally, the food system constitutes a major contributor to the environmental problems caused by humanity (Crippa et al., 2021; Foley et al., 2011). One of the three key strategies for keeping the global food system within planetary boundaries is the reduction of food waste (Springmann et al., 2018; Willett et al., 2019). Reducing food waste is also a target of the United Nations Sustainable Development Goals (SDGs), which aim to halve food waste by 2030, and it has been emphasized as a critical component in meeting the commitments of the Paris Agreement (United Nations, 2015; You et al., 2022).

An impediment to advancing the efforts required to reach the SDGs is the lack of comprehensive assessments that consider factors that impact the path of sustainable development within the food system in different ways (Fanzo et al., 2021; Wu et al., 2024). For example, not all types of food waste have the same environmental impact, with food waste from animal-based products having a higher environmental footprint compared to plant-based items like fruits and vegetables (Brancoli et al., 2017). However, since the mass of fruit and vegetable waste tends to be greater (Jansson-Boyd et al., 2024), accurate quantification in terms of mass but also in terms of waste components is crucial to assess the overall environmental impact (Amicarelli and Bux, 2021). This raises a critical question: should waste reduction strategies focus on mass, carbon footprint, or other environmental metrics? Alternatively, should considerations such as nutritional value be given higher priority given its direct implications on food security and human health? Research has shown that food waste often includes nutrient-dense foods, such as fruits, vegetables, and animal-based products, which are critical for addressing nutrient deficiencies in poor and wealthy nations alike (Global Panel, 2018; Spiker et al., 2017) However, despite this recognition, studies focusing specifically on nutrient losses associated with food waste remain limited. Thus, to answer the aforementioned questions, comprehensive assessments of food waste are required where not only quantities are considered but also the composition of food waste

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allowing the assessment of aspects such as nutrient losses and environmental footprints (Gatto and Chepeliev, 2024).

Current global estimates indicate that households generate the majority of food waste (United Nations Environment Programme, 2021). Consequently, households play a major role in driving the environmental impacts of food waste, including the generation of a substantial amount of greenhouse gas emissions (Zhu et al., 2023). When it comes to household food waste, there is a significant gap in the data needed to fully understand the underlying causes and patterns, particularly in high-income countries as highlighted by Krah et al., 2024. These gaps include insufficient insights into socioeconomic influences, consumer behaviors, and regional variations in waste management practices.

Although previous estimates have suggested that there is a discrepancy between high- and low-income countries in how much of the food waste comes from households (FAO, 2011), recent assessments contradict this, suggesting that similar amounts of food get wasted across all countries, regardless of income level (United Nations Environment Programme, 2021). However, despite there being little difference between countries, the differences within a country and between different socio-demographic groups can vary greatly. It has been found that within a country, the income level of a household can influence the amount of food wasted. However, findings diverge on whether higher or lower income leads to greater food waste. Some studies suggest that lower income households waste more (Bilska et al., 2024; Setti et al., 2016). Meanwhile, others have found an opposite correlation (Abdelradi, 2018; Van Dooren et al., 2019). There have also been studies that have found no correlation at all (Ananda et al., 2021; Williams et al., 2012). It has also been found that the number of household members can have an impact on the amount of food wasted where single-person households tend to generate more food waste per person than multiple-person households (Bilska et al., 2024; Parizeau et al., 2015). The age of household members may be yet another factor influencing the food waste where younger age groups appear to waste more than older age groups (Karunasena et al., 2021; Secondi et al., 2015; Thyberg and Tonjes, 2016).

A specific type of household where members are of a (mostly) young age, have a lower than average income, and live alone is university students. In addition to the socio-demographical indications that students would waste more food than others, students also constitute a group of people that will form future society, which makes them an important group to study. Gaining insights into their behaviour and impact could help foster sustainable habits and routines early in life. Consequently, a fair share of research has been conducted on food waste among students. However, a majority of those studies have been carried out in environments such as school cafeterias, while little seems to be known about food waste in the home environment (Zhang and Jian, 2024). A research gap therefore persists in understanding the amount and composition of food waste generated by student households, particularly in the context of a comprehensive sustainability assessment that incorporates multiple factors relevant to food system sustainability.

The aim of this study is therefore to examine the food waste generated by university students in Sweden in their homes and to assess the related carbon footprint and nutritional impact within this demographic. The study also discusses the potential for reducing food waste, identifies areas for improvements, and evaluates how these changes could influence both carbon footprint and nutritional outcomes.

2. Material and methods

2.1. Area of study and description of data collection

This study examined food waste in the households of students enrolled in the master's course “Food Waste – Current Situation and Future Opportunities” at the Swedish University of Agricultural Sciences. The course is part of the Sustainable Food Systems master's program and has been offered in the autumn semester since 2020.

As part of the course, students were asked to quantify their own food waste over two weeks, using kitchen scales. The aim was to give them hands-on experience in food waste quantification and demonstrate how this data can offer insights. Each student worked individually, compiling their findings into a report. The method involved weighing their food waste and comparing it to a self-chosen reference point, such as the amount of food wasted per person per day in the household, the percentage of wasted cooked items, or similar metrics. The details of the assignment are outlined in the supplementary material (S1). It should be noted that university students in Sweden typically live off-campus, are responsible for their own meals, and do not dine in dedicated university cafeterias.

In total, 109 students completed the task across 5 course sessions. Although this might represent a relatively small sample, all students submitted reports and detailed raw data files with weights and food item information which are substantially better than using questionnaires or other survey methods (Merian et al., 2024). All student reports and raw data files submitted for the assignment were collected from the university's official archive, which is publicly accessible under the Swedish Transparency Act, and were compiled for analysis.

2.2. Student households and how they quantify food waste

To understand how students quantified their waste and what they focused on during the project, each report was analysed based on the following criteria: the chosen reference point, whether they categorized food waste as avoidable/unavoidable or edible/inedible, and whether they quantified solid waste, liquid waste, or both. Additional information was documented, including the values recorded for their main reference point (i.e., food waste g/person/day), the number of participants involved, the duration of the quantification period, the number of days waste was recorded, and the aggregation level of the study (i.e., if waste was recorded per day or per item thrown away). An overview of what the students chose to focus on during their quantification period is provided in Table 1.

Most students (87 %) submitted their raw data in the form of kitchen diaries. In total, the kitchen diaries captured 3944 observations from 95 students. Of these, 193 observations were aggregated by day, while the rest were recorded at the food item level. The data was standardized to include the following details: the date the food was discarded, the household name, whether the waste was solid or liquid, the weight of the waste (in grams) and, when available, the type of food, whether the waste was classified as avoidable/unavoidable or edible/inedible, the weight of the food before preparation or cooking, and any additional comments from the student.

If students explicitly stated whether their waste was solid or liquid in their reports, their own categorization was used. When this information was not provided, the state of the food waste was inferred based on the food item name. Additionally, a thorough cleaning, standardization, and categorization of food item names was conducted to improve data accuracy and ease of analysis. The categorization of food items was guided by their names and by previous studies (Adelodun et al., 2021; Bilska et al., 2024; Ilakovac et al., 2020; Khalid et al., 2019; Mayanti, 2024; Sigala et al., 2024; Van Dooren et al., 2019).

Following the cleaning and categorization process, a total of 236 unique food items were identified as discarded by the students, categorized into 15 distinct groups. Table 2 presents and overview of these categories, the food items within each category, and their corresponding definitions.

2.3. Amount of food waste in student households

To assess the levels of food waste in student households, the data from their written assignments was compiled into descriptive statistics. This analysis included both students who quantified only solid waste and those who quantified both solid and liquid waste. To ensure a fair

Table 1
Summary of student's focus areas for food waste quantification during the assignment, including the number of students who quantified the state of the food waste, the reference point used, avoidability/edibility classifications, aggregation levels chosen, and the number of participants per household.

	Students (n)
State of the food waste quantified	
Solid waste only	94
Solid and liquid waste	13
Liquid waste only	1
Main reference point	
g/person/day	103
g/household/day	2
g/serving/day	1
kg/person/year	1
l/person/week	1
Percentages	1
Waste classification (Avoidability/Edibility)	
Unavoidable/Avoidable	49
Edible/Inedible	16
Edible only	2
Avoidable/possibly avoidable	1
Aggregation level	
Per item	85
Aggregated per day	20
Per waste bag	2
Per meal	1

Number of household participants	Answers (n)
1	56
2	29
3	11
4	6
5	6
6	1

comparison, only students who used the reference point "food waste (g/person/day)" were included, while those who quantified only edible food or included drinking water used in cooking as food waste were excluded. After applying these criteria, nine households were excluded from the assessment. A 95 % confidence interval for the mean total food waste was calculated for households that quantified only solid waste and those that included both solids and liquids. Boxplots were used to visually compare the differences between households that quantified only solid waste and those that included both solid and liquid waste. These descriptive statistics included days where no food was wasted.

The kitchen diaries were analysed to determine the frequency and weight of food waste, as well as the proportions classified as solid or liquid. The top 10 % of food waste items by weight were examined to determine their composition, the total weight they represented, and the number of households contributing to this waste. A scenario was then developed in which this waste fraction was reduced by half, in alignment with the goal set by SDG12.3.

Additionally, the diaries provided insights into how much waste was classified as avoidable/unavoidable or edible/inedible, and how many items were not classified. When students recorded the mass of food items, this data was used to calculate the food waste percentage (%) by weight for different categories and individual items. Since some students recorded dry weights for food items and wet weights for food waste, a filter was applied to exclude cases where the food waste percentage exceeded 100 %. After this filter was applied, the dataset contained 794 records of food items and their corresponding waste weights from 28 households. To better understand the distribution of food waste across categories, the five most wasted food items were ranked by weight and frequency for each category: avoidable/edible, unavoidable/inedible, and unclassified. This analysis highlighted the food items that contributed most to waste in each category, based on both food waste in grams per person per day (g/person/day) and as a percentage of the total

Table 2
Summary of the waste categories, including the number of food items in each category and a definition of what each category includes. The table is sorted based on the number of food items.

Waste category	Number of food items	Definition
Vegetables	1213	Fresh, cooked, or processed vegetables such as leafy greens, root vegetables, potatoes and legumes
Fruits	912	Fresh, dried, or processed fruits like apples, bananas, berries, citrus, and other similar items.
Beverages	690	Refers to any liquid consumables, including coffee, tea, juice, soft drinks, alcoholic beverages, and other drinkable liquids. Solids such as coffee grounds and tea leaves are also included in this category.
Eggs	275	Mostly eggshells.
Unknown	245	Category for food items that could not be identified or were ambiguously labelled in the data (aggregated daily data).
Plate waste	109	Refers to any leftover food that was served but not consumed by the household members, regardless of the type of food.
Dairy	108	Encompasses milk, cheese, yogurt, butter, and other dairy-based products.
Bakery	104	Bread, pastries, cakes, cookies, and other baked goods made from flour.
Meat	89	Consists of all types of animal meat, including beef, pork, chicken, lamb, and processed meats like sausages or cold cuts.
Grain-based	80	Refers to foods such as pasta, rice, cereals, and grains, along with processed items like chips or tortillas.
Other	50	A catch-all category for food items that do not fit into any of the defined categories above.
Nuts	24	Includes whole nuts (shelled or unshelled)
Sauce	20	Consists of any liquid flavourings such as ketchup, mayonnaise, salad dressings, and cooking sauces.
Fish & seafood	17	Seafood such as fish, shrimp, crabs, clams, and other edible sea creatures.
Dessert/Sweets	8	Includes candies, chocolates, ice cream and sweet pastries.

waste.

To analyse the amount of food waste that could have been avoided, the quantification data from the students who included information on the state of the food (avoidable/unavoidable etc.) was assessed. Anything, liquid or solid, that was categorized as either avoidable, possibly avoidable, edible or unclear was included, although one item specified as "paper towel" was removed. In total, 42 households (74 participants) provided data with at least one item categorized according to the inclusion criteria. To assess the average amount of avoidable/edible food that was wasted per person/day, the total number of participants who contributed to this data was multiplied by the total number of quantification days from those households ($n_{days} = 611$), which also included days when no avoidable/edible food was wasted. In this way, the number of total participant days could be derived, which could then be divided by the total amount of avoidable/edible food waste.

2.4. Carbon footprint of food waste in student households

Data on the carbon footprint of the wasted food was obtained using the SAFAD tool (Swedish University of Agricultural Sciences, 2024), with the Swedish market being a consideration. Since landfilling is prohibited in Sweden and food waste is instead treated through anaerobic digestion or composting, the downstream emissions of the waste management were considered negligible and therefore excluded from the scope of the study. Only food waste that was categorized as avoidable/edible by the students was assessed ($n_{items} = 672$). If a food waste item could not be found in the SAFAD tool, the carbon footprint of the food determined as being most similar to the item was used. When the food waste item had been categorized with a lower level of detail, such as fish, cheese, or pizza, where a specific carbon footprint could not be found, an average was derived from other sub-categorized food items.

When an item had a different carbon footprint when cooked than as a raw commodity, student's comments were used to select the most appropriate alternative. For instance, when a comment stated that it was leftovers, it was assumed that the item was cooked. Similarly, when it was unclear what the food item referred to (for example, when it only was labelled *meat*), students' comments were also used to select an appropriate carbon footprint alternative in the SAFAD tool. Food items categorized as mixed, and kitchen sink strainer were assumed to be composed of the other food waste categorized and were therefore assigned the average carbon footprint of the other food items. The items classified as vegetables were assigned the average carbon footprint of the other specified vegetable items. The food waste that had been classified as plate waste by the students was assigned a carbon footprint of 1 kg CO_2e per kg food, based on Sundin et al. (2024). For items classified as leftovers, the comments sometimes specified what they were comprised of, so they were therefore assigned the corresponding carbon footprint suggested in the SAFAD tool. The items without specification were assigned the same carbon footprint as the plate waste items, from which an average for the leftover items could be drawn to apply to the whole category.

To illustrate how each food category contributed to the carbon footprint, their relative contribution (percentage) was compared against their relative contribution in terms of weight. Moreover, similar to the analysis of the amount of food waste, the top 10 % of food waste items in terms of carbon footprint (n = 68) were examined to determine their composition and contribution to the total carbon footprint. From this 10 %, the top 10 single items were also analysed separately to examine this top tier more in-depth.

To set the results of the carbon footprint in a larger context, the results were scaled up to national level. According to official Swedish statistics, around 450,000 students are enrolled at Swedish universities (Statistics Sweden, 2023). This number of students was therefore multiplied with the average carbon footprint per student per day as well as with 365 to get the annual carbon footprint from university students in Sweden. To obtain the average carbon footprint per student per day, the total value of carbon footprint was divided with the total number of person-days (1068).

2.5. Nutrient loss calculations

Nutrient calculations were performed using Nutrition Data, 2024) software to estimate the nutrient losses within the avoidable/edible fraction of food waste. The analysis included energy content, macronutrients, micronutrients, and dietary fiber. These values were calculated for the entire data collection period and then expressed as mean values per kilogram of avoidable/edible food waste and per person per day. This was done by dividing the total nutrient values by the total amount of avoidable/edible waste (48.4 kg) and by the total person-days (1068), respectively.

Additionally, the macronutrient content was expressed as energy percentage (E%) values, while the micronutrient content was presented as nutrient density (per MJ). To calculate this, the mean nutrient values per kilogram of avoidable/edible food waste were divided by the mean energy content per kilogram of edible food waste (223 MJ). The number of wasted nutrient days (WND), representing the days during which the avoidable/edible waste could meet the daily recommended intake (RI) for adults on a group level, was also calculated. This was done by dividing the total micronutrient values by the RI values for males and females aged between 25 and 50 with average physical activity levels, using the larger value when differences occurred, based on the Nordic Nutrition Recommendations, 2023 (Blomhoff et al., 2023).

3. Results

The results show that, on average, the students in this study generated 115 g of food waste per person per day (95 % CI: 103–128 g) when combining households that quantified both solid waste and solid with liquid waste. Of this food waste, 46 g/person/day was considered to be avoidable/edible. This fraction was found to generate a carbon footprint of 1.3 kg CO_2e per kg. The analysis also revealed substantial micronutrient losses, as the avoidable/edible waste fraction was notably rich in dietary fiber (4.7 g/MJ), vitamin A (134 RE/MJ), vitamin C (26 mg/MJ), and folate (56 μg/MJ), exceeding the recommended nutrient density for dietary planning (Blomhoff et al., 2023).

3.1. Household food waste in terms of weight

Households that included liquids in their quantification reported a median of 145 g/person/day, while those that measured only solid waste reported a lower median of 101 g/person/day. On average, households that measured both solid and liquid waste reported 158 g/person/day, compared to 110 g/person/day for those quantifying only solid waste. Fig. 1A illustrates this comparison between households that included liquids and those that focused solely on solid food waste.

The average weight of individual wasted items was 53 g (95 % CI: 50–56 g), with a median weight of 26 g. Fig. 1B shows the distribution of wasted item weights. Solid items made up 97 % of all the recorded items. Among the solid items (n = 3528) that were classified as either avoidable/edible or unavoidable/inedible, 39 % (by weight) were considered avoidable/edible, while 61 % (by weight) were considered unavoidable/inedible by the students. This breakdown is shown in Fig. 1C, which also indicates the number of items that were not classified by the students. Fig. 1D presents the same information for liquid waste (n = 114), where, notably, none of the liquids were classified as unavoidable/inedible by the students.

Fig. 1B shows a long tail in the distribution, indicating that a small number of items account for a significant portion of the total food waste by weight. Analyzing the top 10 % of the wasted items (by weight) revealed that they account for nearly half (47 %) of the total food waste and that 58 households contributed to this waste. Reducing this waste by half would lead to an overall reduction of food waste by weight of 23.7 %. Table 3 lists the key food items that dominate the top 10 % across the categories of avoidable/edible, unavoidable/inedible, and unclassified.

The majority of food waste classified as avoidable/edible by the students came from plate waste, with 11 observations contributing 2.9 % of the total recorded weight. In some cases, a single observation had a significant impact on the overall waste, such as noodles and a single instance of soft drink waste. The second most wasted item in this category was bread, which made up 1.7 % of the total weight.

In the unavoidable/inedible category, coffee waste and corn were the largest contributors to the total waste. Coffee waste primarily consisted of leftover coffee grounds from filter coffee, and in many cases, it was recorded as wet weight. A few individual observations also had a significant impact on the total waste, such as one instance of elderberry waste, which accounted for 2 % of the total, along with notable contributions from tomato and dhal waste.

In the unclassified category, pineapple was the largest contributor, accounting for 4.2 % of the total weight, followed by coffee at 3.9 %. Coffee also appeared in the unavoidable/inedible category. Other items, such as watermelon, chicken, and banana, also overlapped with the unavoidable/inedible category.

An analysis of the food waste, in which the initial mass of the food item had also been recorded, showed that 19 % of total food (95 % CI: 18–20 %) was wasted. When categorizing the wasted items based on both indicators, food waste (g/person/day) and food waste (%), plate waste emerged as the largest contributor, with a median of 36 g/person/day or 28 %, as illustrated in Fig. 2. Most observations were based on the reference point of food waste (g/person/day), where different types of

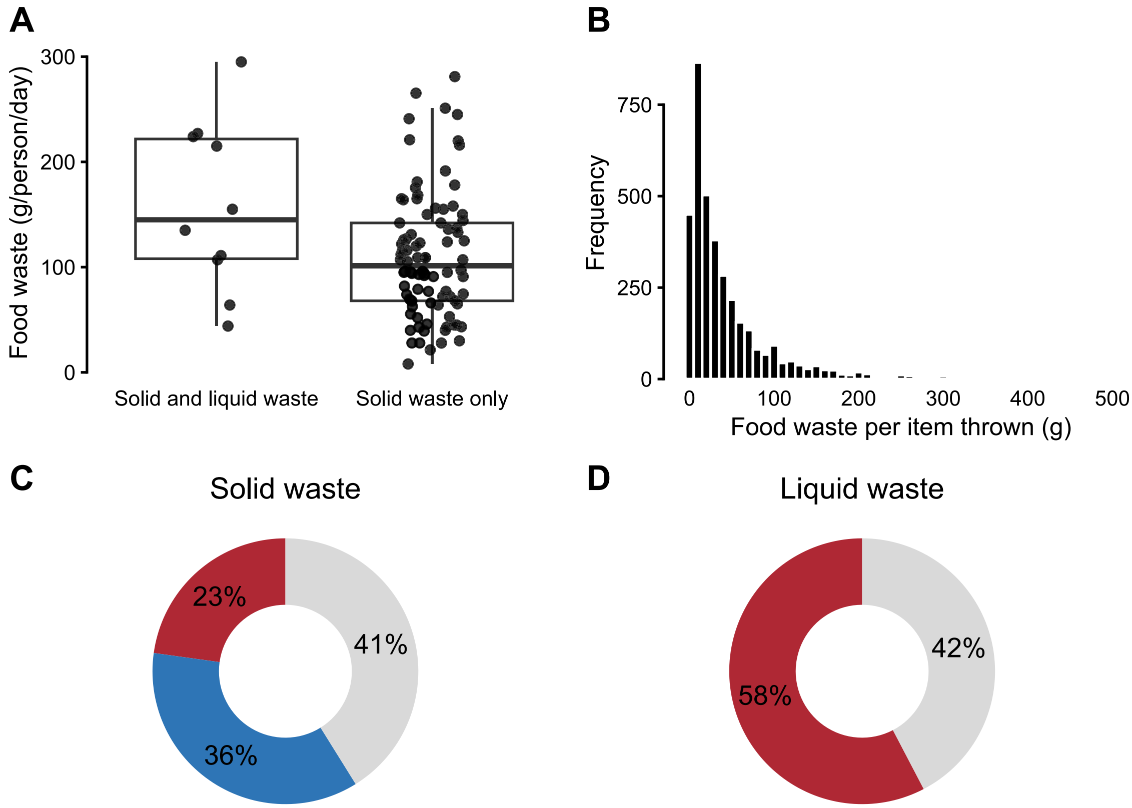

Fig. 1. Summary of the distribution and classification of reported food waste. (A) shows the distribution of food waste (g/person/day) for households that quantified both solid and liquid waste, compared to those that recorded solid waste only. (B) displays a histogram of the distribution of individual food waste items (g) recorded by the students in their kitchen diaries, capped at 500 g. (C–D) shows the proportions of food waste categorized as ■ Avoidable/Edible, ■ Unavoidable/Inedible, or ■ Unclassified for solid waste (C) and liquid waste (D).

animal-based foods ranked second and third, with median values of 26 g/person/day for meat waste and 32 g/person/day for fish waste. Vegetables, fruits and beverages were the most commonly discarded food items, with 1197, 909, and 672 observations, respectively, showing widespread reported waste values. The distribution of waste across the different is illustrated in Fig. 2.

Examining the food items within each waste category for different reference points reveals that the most commonly wasted item classified as avoidable/edible by the students was bread, based on the food waste (g/person/day) reference point, and apples, based on the food waste (%) reference point. Bread is also the second most wasted item in the food waste (%) reference point, with 17 % of its total weight being wasted across 4 observations. Apples rank as the third most wasted item by food waste (g/person/day), while plate waste ranks fourth in the same category and third in the food waste (%) reference point. Table 4 provides descriptive statistics on the five most commonly wasted items across different reference points and categories of avoidability/edibility. It also shows that coffee and tea are frequently discarded and considered by students to be unavoidable/inedible, followed by eggs, onions, and bananas (peels and shells). In the unclassified category, several items overlap with the unavoidable/inedible category, including tea, onions, coffee, bananas, and eggs.

3.2. Food waste in terms of carbon footprint

The assessment of the carbon footprint of the 48.4 kg food waste that was categorized as avoidable/edible revealed a total emission of 64.7 kg CO_2e. This means that for each kg of wasted avoidable/edible food, there is an associated carbon footprint of approximately 1.3 kg CO_2e. The average carbon footprint per student per day was 0.06 kg CO_2e. When scaling this up to national level, including all students enrolled in Swedish universities, this equals 9950 tonnes CO_2e per year.

Although the category with the most wasted food in terms of weight was vegetables (38 %), the category with the highest carbon footprint was dairy waste (21 %), which only accounted for 7 % of the weight. The category with the relatively largest contribution discrepancy between weight and carbon footprint was meat, which contributed almost 7 times more to carbon footprint than to weight. This was followed by the fish and dairy categories, which contributed approximately 5 and 3 times more to carbon footprint than to weight, respectively. Beverage waste, however, was shown to contribute more than three times less to carbon footprint compared to weight. The relative contribution of each food waste category to the total weight and carbon footprint is illustrated in Fig. 3.

Moreover, it was found that the top 10 % of items that contributed most to the carbon footprint accounted for 62 % of the total carbon footprint. Of this 62 %, the categories that contributed most were dairy (32 %), plate waste (20 %), and meat (15 %). Vegetable waste, despite being the second most frequently occurring category, only accounted for 11 % of the carbon footprint. The 10 individual food items contributing most to the overall carbon footprint accounted for 24 % in total and are listed in Table 5.

3.3. Nutrient losses

The assessment of nutrient losses in avoidable/edible food waste revealed an energy content of 5 MJ per kg of waste, or 0.2 MJ per person per day. Per kg of waste, the protein, carbohydrate, and fat content were 38 g, 145 g, and 35 g, respectively (Table S2). Additionally, the avoidable/edible waste fraction contained 14 % of energy (E%) from protein, 57 E% from carbohydrates, and 29 E% from fat, indicating a balanced macronutrient composition in line with dietary recommendations

Table 3
Top 10 most wasted food items divided into Avoidable/Edible, Unavoidable/Inedible and Unclassified by the students. For each item, the category, percentage of total food waste by weight, and the number of observations (n) are provided.

Food item	Category	% of total weight	Observations (n)
Avoidable/Edible			
Plate waste	Plate waste	2.9	11
Beans	Vegetable waste	1.7	5
Bread	Bakery waste	1.7	8
Cucumber	Vegetable waste	1.7	4
Noodles	Grain-based waste	1.6	1
Potato	Vegetable waste	1.5	6
Soup	Plate waste	1.5	2
Aubergine	Vegetable waste	1.4	2
Rice	Grain-based waste	1.2	4
Soft drink	Beverage waste	1.1	1
Unavoidable/Inedible			
Coffee	Beverage waste	6	35
Corn	Vegetable waste	3.6	12
Melon	Fruit waste	2.1	7
Elderberries	Fruit waste	2.0	1
Watermelon	Fruit waste	1.1	3
Chicken	Meat waste	1	5
Tomato	Vegetable waste	0.8	1
Banana	Fruit waste	0.7	5
Pumpkin	Vegetable waste	0.7	2
Dhal	Plate waste	0.6	1
Unclassified			
Pineapple	Fruit waste	4.2	3
Coffee	Beverage waste	3.9	20
Watermelon	Fruit waste	3.8	13
Potato	Vegetable waste	3.1	12
Cauliflower	Vegetable waste	1.9	5
Chicken	Meat waste	1.8	7
Banana	Fruit waste	1.7	10
Mixed	Other	1.6	6
Lamb	Meat waste	1.5	1
Mushroom	Vegetable waste	1.3	2

(Table S2). Furthermore, the analysis showed significant nutrient losses, as the avoidable/edible waste was particularly rich in micronutrients. Notably, the waste exceeded the recommended nutrient density for dietary planning (Blomhoff et al., 2023) in terms of dietary fiber (4.7 g/MJ), vitamin A (134 RE/MJ), vitamin C (26 mg/MJ), and folate (56 μg/MJ). The evaluation of the WND indicated that the total avoidable/edible waste could have met the daily micronutrient needs of 9 to 76 adults, depending on the specific micronutrient (Table S2). Specifically, the WND values were 30 for dietary fiber, 37 for vitamin A, 52 for vitamin C, and 38 for folate.

4. Discussion

The results show that the students wasted 158 g/person/day, which is lower than the Swedish national average of 203 g/person/day (Swedish Environmental Protection Agency, 2024). Both figures include the quantification of both solid and liquid waste. When focusing solely on solid waste, students report an average of 110 g/person/day, compared to 153 g/person/day reported by the Swedish Environmental Protection Agency. It is important to note that the method students used to capture their food waste differs from that used by the Swedish Environmental Protection Agency for solid waste. The agency relies on data from the organic fraction collected by garbage trucks, which is then scaled to a national level. However, for liquid food waste, the agency also used a kitchen diary approach (Åkerblom, 2021) similar to the method employed by the students. Despite these differences in methodology, there was considerable variation in the waste reported by the students. Some households in the study reported waste amounts well above both the 153 g/person/day for solid waste and the 203 g/person/day national average. However, the proportion of solid food waste classified as avoidable/edible by the students aligns closely with official Swedish figs. (23 % compared to 27 %) and is consistent with findings from other studies. For example, Hanssen et al. (2016) reported that roughly 37 % of food waste in Norway is classified as edible and 30 % is avoidable in Greece (Abeliotis et al., 2015). It is possible that the students' reported avoidable/edible waste is actually higher, as a significant portion of the items they recorded were unclassified. Also, the amount of liquid food waste generated across all households is unknown as only 14 students included this fraction in their quantification. Although there are indications that liquid food waste may reach high levels, it is a fraction that is commonly overlooked, highlighting a need to include liquids in food waste quantification (Malefors et al., 2024a; Van Dooren et al., 2019).

Major limitations in most food waste studies that try to quantify food waste are bound to occur when there is no set standard of how food waste should be quantified, resulting in difficulties to, for example, compare different studies against each other (Baquero et al., 2023; Withanage et al., 2021; Xue et al., 2017). Diaries where households self-report on their food waste have been found to be more reliable than, for example, questionnaires where food waste is estimated retrospectively based on participants memory (Van Herpen et al., 2019). However, considering that the use of diaries means that participants are constantly reminded of their food waste (assuming that they are reporting their waste levels accurately), there is a risk of behavioural changes leading to less food waste being generated during the course of the study (Merian et al., 2024). In this case, because the participants were students in a course on food waste, some of them may have already been more conscious of their food waste, reducing the likelihood of such behavioural changes.

While this study relies on a relatively small sample of student-reported data, this flexibility allowed students to explore aspects of food waste they found personally relevant. Despite the limited sample size, the data exhibits substantial variation between households. This variation, even among households that focused on similar aspects of food waste using the same reference points, highlights the potential value of studying food waste using a longitudinal approach. This type of variation between households was also found by Aitken et al. (2024), who also concluded that even larger variations can be found within households. Thus, even though the amount of food waste generated by the sample in this study was lower than the general population and may therefore not be considered representative, the patterns of the distribution and variation were similar to those found in previous studies. Tracking the waste patterns of households or individuals over an extended period, potentially even over a lifetime or in different age groups, could therefore provide deeper insights into long-term waste behaviour patterns and trends.

Building on this variation, most students focused on quantifying solid food waste using g/person/day as their reference point. This enabled them to classify food items into categories and facilitated comparisons between them. Additionally, 28 students recorded the weight of food items, allowing the calculation of food waste as a percentage of the total weight. Both reference points indicated that vegetables, fruits, and beverages (such as coffee grounds and tea leaves) were the most commonly discarded food items, consistent with findings from other studies (Eičaitė and Baležentis, 2024; Herzberg et al., 2020; Torode et al., 2023). However, plate waste, animal-based food items, grains, and bakery products had more waste per item and were more often classified as avoidable. Bread and plate waste, regardless of the reference point used, were frequently discarded and categorized by students as avoidable/edible.

While this study involved students quantifying their food waste over two-week periods on five separate occasions, it is important to acknowledge that short-term measurements may not capture all high-impact waste events. Longer-term quantification is needed to better

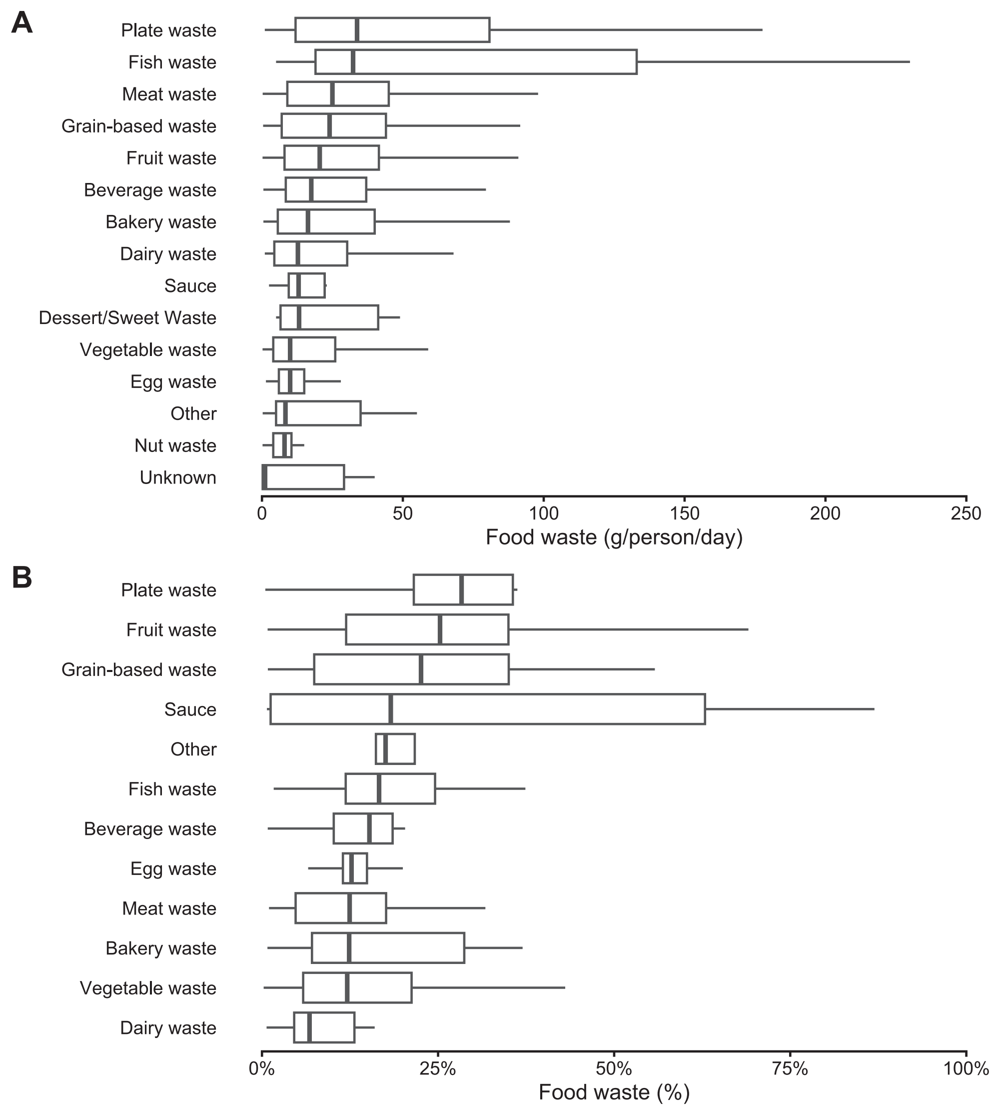

Fig. 2. Boxplots illustrating two food waste indicators across different waste categories. (A) shows food waste in grams per person per day, and (B) shows food waste as a percentage (%). Each boxplot represents the distribution of waste values within each category.

understand waste patterns across different seasons and to fully capture these extreme occurrences. The fact that this top 10 % of waste comes from 58 different households, rather than being concentrated in a small group, shows that the problem is widespread. Many households occasionally waste large amounts of food, reinforcing the need for longer measurement periods to accurately capture these patterns. Reducing waste from this top 10 % by half could lead to a 23 % overall reduction in food waste. If these extreme waste events were eliminated altogether, halving total food waste could be within reach. This highlights key leverage points where efforts should be focused to achieve significant reductions. These findings suggest that targeting these high-waste events may be a practical strategy, and similar approaches should be explored in broader population groups, including different demographic segments. Additionally, strategies should be developed to address both extreme waste events and daily food waste. Similar patterns have been observed in other areas, such as studies showing that a small number of individuals are responsible for the majority of global greenhouse gas emissions (Khalfan et al., 2023). In the food service sector, 20 % of waste events account for 60 % of total waste, highlighting important intervention points (Malefors et al., 2024b). Automating the process of quantifying household food waste, rather than relying on kitchen diaries, could be a promising method for obtaining more reliable data (Sjölund et al., 2025). This approach would also enable long-term quantification and better capture seasonal variations in food waste, particularly for animal-based products, which may be discarded more frequently at certain times of the year. Indication to the potential of applying technology for long-term monitoring can be drawn from the food service sector where similar solutions are already being implemented (Goossens et al., 2022; Malefors et al., 2024b; Mui et al., 2022).

Beyond the importance of reducing food waste as a whole, reducing waste with a high carbon footprint is especially important for environmental sustainability (Wu et al., 2024). This study found that each kg of wasted food had an associated carbon footprint of 1.3 kg CO_2e. This is lower than what was found by Adelodun et al. (2021) and Silvennoinen et al., 2022 where each kg of food waste was found to generate approximately 2.5 and 2.3 kg CO_2e respectively. This difference can be explained by the higher quantity of meat wasted in the other two studies, as well as in the methods applied to calculate the carbon footprint. Moreover, how high the carbon footprint of the food waste per capita gets also depends on the amount of food wasted. Since the average amount of food waste among the sample of this study was found to be low compared to other studies (e.g. Antonelli et al., 2024) and Liu et al. (2023)), the associated carbon footprint of the wasted food may not stand out as substantial as compared to studies where higher

Table 4
Descriptive statistics for the five most wasted food items, classified as avoidable/edible, unavoidable/inedible or unclassified, based on two reference points: Food waste (g/person/day) and Food waste (%).

Reference point	*Food item*	*Observations (n)*	*Min*	*Mean*	*SD*	*Median*	*Max*
Avoidable/Edible							
Food waste (g/person/day)	Bread	48	0	31	51	10	221
	Carrot	33	0	12	12	8	48
	Apple	32	2	15	18	10	97
	Plate waste	29	2	51	41	46	141
	Cucumber	26	1	32	77	6	386
Food waste (%)	Apple	7	4	22	16	23	50
	Bread	4	1	17	16	17	33
	Plate waste	4	26	57	30	59	84
	Potato	4	3	16	10	17	25
	Broccoli	3	6	14	14	7	30
Unavoidable/Inedible							
Food waste (g/person/day)	Coffee	207	5	37	23	33	120
	Tea	201	0	12	10	9	71
	Egg	190	1	11	14	8	181
	Banana	141	6	39	23	32	131
	Onion	129	1	12	21	8	195
Food waste (%)	Egg	54	4	13	4	12	20
	Onion	29	3	13	7	12	27
	Apple	27	3	13	5	12	25
	Banana	25	20	36	8	36	50
	Carrot	18	1	10	9	6	28
Unclassified							
Food waste (g/person/day)	Tea	123	1	11	9	9	46
	Onion	114	0	16	23	8	139
	Coffee	112	7	53	45	38	324
	Banana	101	5	43	27	35	130
	Egg	84	2	18	15	14	114
Food waste (%)	Banana	50	20	36	11	35	91
	Onion	48	2	15	15	11	76
	Carrot	34	1	15	7	15	34
	Apple	31	4	18	11	15	55
	Egg	29	9	15	6	13	39

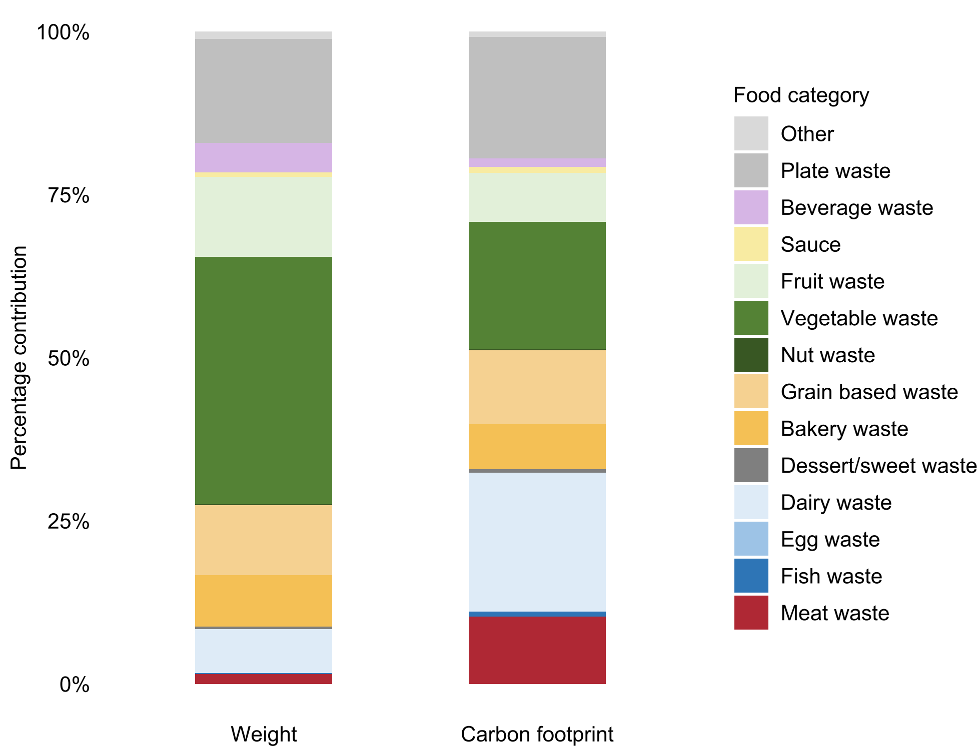

Fig. 3. The relative contribution of each food category in terms of weight (left panel) and carbon footprint (right panel), based on the food waste categorized as avoidable/edible.

Table 5
Summary of the 10 individual items with the highest carbon footprint. For each item, the corresponding food category, weight, carbon footprint, and contribution to the total carbon footprint (%) are provided. The food items cheese in the table refers to semi-hard cheese made from whole milk.

Food item	Category	Weight (g)	Carbon footprint (kg CO_2e)	% Of total carbon footprint
Cheese	Dairy waste	278	2.61	4.0
Meat	Meat waste	74	2.33	3.6
Cream	Dairy waste	450	1.69	2.6
Cheese	Dairy waste	170	1.60	2.5
Gyros plate	Plate waste	132	1.38	2.1
Hamburger	Plate waste	54	1.23	1.9
Noodles	Grain based waste	1469	1.22	1.9
Cottage cheese	Dairy waste	324	1.19	1.8
Creme fraiche	Dairy waste	300	1.14	1.8
Cheese	Dairy waste	118	1.11	1.7

quantities of food waste are recorded. However, addressing the carbon footprint is still of importance since this provides information necessary to guide policy so that actions can be prioritized. Therefore, if results of the carbon footprint are found to be trivial when compared to other issues and aspects, informed decisions can be made to direct the effort to where the gain shows highest potential.

However, when scaling up to national level, the results showed that food waste from university students in Sweden contribute with a carbon footprint of 9950 tonnes of CO_2e. This is comparable to the yearly amount of food waste and its associated carbon footprint generated in Swedish elementary schools if assuming that 1 kg of food waste in schools generates 1 kg of CO_2e (Sundin et al., 2024; Swedish Environmental Protection Agency, 2024). Another parallel can also be drawn to consumption-based emissions from the average Swedish person, which amounts to approximately 8 tonnes per year (Swedish Environmental Protection Agency, 2023). This means that the carbon footprint from students' food waste amounts to the emissions of about 1250 persons (0.01 % of total population). However, this assumes that all students would have equal amounts of food waste and waste similar types of foods, which is unlikely to be true, especially considering that the study sample consists of students showing interest in the food waste issue by taking part in the course. It is therefore likely that the carbon footprint of all students in Sweden is higher.

Furthermore, the results revealed a discrepancy between the relative contribution to weight and to carbon footprint among the food waste categories. The highest contributor to the carbon footprint of avoidable/edible food waste (23.7 % of all waste) came from dairy waste, despite having lower relative weight compared to, for example, vegetable, fruit, and grain-based waste. The category that showed the largest contribution to the carbon footprint relative to its contribution to weight was meat. Similar findings have been presented by Cakar et al. (2020), Qian et al. (2022), and Silvennoinen et al., 2022), indicating that even though more fruit and vegetables are wasted by weight, addressing waste of animal origin could have a larger positive effect on reducing carbon emissions, even if this fraction is comparably small if weight is used as a metric. Additionally, as with the distribution of the food waste weight, it may be that a minority of the wasted items contributed to a majority of the carbon footprint. Considering that 10 % of the wasted items contributed 62 % of the carbon footprint and, moreover, that only 10 single items accounted for 24 % of the total carbon footprint, the leverage point of targeting the top tier of the food waste is further emphasized.

However, the findings also highlighted significant nutrient losses in the avoidable/edible food waste generated by university student households, particularly in terms of dietary fiber (4.7 g/MJ) and folate (56 μg/MJ). These nutrients are already under-consumed by the Swedish population, with the average daily intake of dietary fiber falling short of the updated Nordic Nutrition Recommendations (NNR 2023), which now recommend 30–35 g per day for adults (females-males). The current intake levels in Sweden average around 20–24 g per day, leaving a gap of 6–15 g per person per day. The recently increased recommendations for both dietary fiber and folate in the NNR 2023 emphasize their crucial role in reducing the risk of chronic diseases such as cardiovascular disease, type 2 diabetes, and certain cancers (Blomhoff et al., 2023).

A trade-off is, thus, evident in our study; although approximately half of the avoidable/edible waste consisted of vegetables and fruit—foods that are typically rich in fiber and folate—these foods did not represent the highest contributors to carbon footprint. However, their reduction is essential for minimizing nutrient losses and addressing dietary gaps in food intake. The Wasted Nutrient Days (WND) analysis further underscores this missed opportunity, revealing that the total waste could have met the daily folate needs of 38 adults or the fiber needs of 35–30 adults (females-males). This suggests that nutrient-dense foods like fruits and vegetables, which are relatively low in environmental impact, should still be a priority for waste-reduction efforts to simultaneously improve public health outcomes. Future food waste prevention strategies should therefore balance the dual objectives of reducing environmental impacts and closing nutrient intake gaps, particularly for populations at risk of nutrient deficiencies. Educational interventions aimed at improving food planning, storage, and consumption behaviors could be effective in reducing waste, while enhancing nutrient intake among university students and the general population.

Moving forward, a key focus could be on reducing extreme waste events or accidents. Considering that nearly half (47 %) of the avoidable/edible food waste came from only 10 % of the observations, it suggests that a few isolated instances—likely accidents or unusual events—are responsible for a significant portion of the waste. However, it is also crucial to look beyond waste weight and consider factors like carbon footprint and nutrient losses. The findings of the study suggest that targeting fruit and vegetable waste has the greatest potential to reduce weight and nutrient losses, while targeting animal-based waste would be most effective from a carbon footprint viewpoint. Nevertheless, regardless of which fraction is targeted, it is imperative that action is taken to reduce food waste. Considering the participants of this study constitute a group of consumers that will play a key role in future society, focusing on them and the top 10 % fraction simultaneously has the potential to provide long-term benefits and contribute to a food system with less waste.

5. Conclusions

This study assessed food waste in student households using kitchen diaries and reports, revealing an average of 115 g/person/day, with considerable variation between households. Solid food waste was the most frequently quantified, and there is potential to improve methodologies for reporting liquid waste, which remains an underreported fraction. Avoidable/edible food accounted for 23 % of the total waste, representing a key opportunity for targeted interventions.

Nearly half (47 %) of the total waste came from 10 % of the wasted items, suggesting an opportunity to target these events to reduce overall food waste. Halving this fraction could result in a 23.7 % reduction, and eliminating the top 10 % would bring us close to achieving the goal of halving food waste, in line with Sustainable Development Goal 12.3. A policy recommendation is therefore to develop methods to determine which items these are likely to be and to develop interventions to target this fraction. The relatively even distribution of these high-waste items across households indicates that this approach could be effective across a broader, more socio-economically diverse sample.

From an environmental perspective the top 10 % of wasted food items accounted for 62 % of the total carbon footprint, underscoring the importance of focusing on this fraction of waste. Animal-based food waste, particularly dairy, was the largest contributor to carbon footprint, followed by plate waste and meat waste. Although vegetable waste was the most frequently discarded, it only accounted for 20 % of the total carbon footprint, and only 11 % of the top 10 % of wasted items. This reveals an interesting trade-off: although reducing animal-based waste is crucial for lowering environmental impacts, the nutrient-rich nature of vegetable and fruit waste—especially in terms of dietary fiber and folate—underscores the importance of minimizing these losses. Future food waste reduction strategies should therefore adopt a dual focus, targeting both the environmental impact of animal-based waste and the nutrient loss associated with plant-based waste.

To address these issues there are potential for various policy recommendations on different levels. Educational or awareness campaigns regarding food waste should focus on both the environmental and nutritional consequences of food waste which are also framed towards high-impact items. Leverage digitalization and automation to develop more accurate and efficient waste tracking systems that provide direct feedback and personalized suggestions. These tools can encourage behaviour change, enable longer quantification periods, and support the inclusion of a more diverse sample of households. Develop and support methods specifically designed to quantify liquid waste, addressing this underreported fraction of food waste. By focusing on these areas, it is possible to make meaningful progress in reducing food waste in households. Such efforts will contribute to achieving environmental sustainability, improving nutritional outcomes, and supporting global food waste reduction goals.

CRediT authorship contribution statement

Christopher Malefors: Writing – review & editing, Writing – original draft, Visualization, Methodology, Formal analysis, Data curation, Conceptualization. **Amanda Sjölund:** Writing – review & editing, Writing – original draft, Visualization, Formal analysis. **Niina Sundin:** Writing – review & editing, Writing – original draft, Formal analysis.

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. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.spc.2025.01.017.

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