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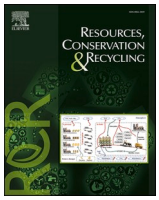

Full length article

Automated quantification tool to monitor plate waste in school canteens

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ABSTRACT

Automated tools for waste quantification hold promise in providing preciser understanding of food waste. This study evaluated a tool to quantify plate waste in primary school canteens. It encompassed data from 421,015 instances of food wastage. The evaluation revealed high accuracy, with the tool's plate waste detection falling within ±10% of manual recordings. However, the tool estimated 40% fewer individual guests compared to manual entry due to not all students wasting food. As a result, the automatically collected data indicated a 35% higher waste-to-guest ratio. The findings showed that a minority of students (20%) accounted for a majority (60%) of plate waste. Halving the waste generated by this group would reduce overall plate waste by 31%, emphasizing the importance of tailored interventions for high-profile wasters rather than applying general measures to all students. Targeting areas with the greatest potential can contribute to a more sustainable food system with reduced waste.

1. Introduction

Current population and consumption trajectories stress the importance of finding solutions that meet the increased demand for energy, fuel, clothes, and food in a fair and sustainable way (Raworth, 2012). Changing behavior is critical to sustainable development (Bergquist et al., 2023; Gosnell and Bazilian, 2021), so the idea of behavior nudging has emerged as a viable option in place of, or in addition to, legislative tools influencing behavior, such as taxes, bans, and information. Another way to get people to change their behavior is to use digital tools and gamification that measure consumption and provide information on environmental footprint, as feedback on consumer actions, to guide change (Fraternali et al., 2019; Froehlich et al., 2010; Gram-Hanssen, 2014; Guillen et al., 2021; Koivisto and Hamari, 2019).

Reduced food waste has been recognized as a key step in transition to a more sustainable food system (IPCC, 2019; Springmann et al., 2018). The majority of global food waste is generated by consumers (United Nations Environment Programme, 2021), which provides an opportunity to utilize nudging and gamification as a means of guiding consumers towards meeting the UN Sustainable Development Goal of halving food waste by 2030 (United Nations, 2015). In addition, it is essential to have tools and techniques that can effectively monitor changes and assist in collecting primary data (Xue et al., 2017).

The food service sector, which serves food to consumers in various formats, typically has two types of food waste problems; i) food waste arising within the kitchen and the serving process; and ii) plate waste left by consumers (Malefors et al., 2019). Previous food service sector studies have shown that total food waste can be around 15 g/guest or 980 g/sale (Abdelaal et al., 2019; Juvan et al., 2017). However, some studies indicate that waste levels can show considerable variation between different canteens within the same organization, e.g., Eriksson et al. (2017) found that food waste level in the best-performing canteens was only 25 % of that in canteens with the most food waste.

At present, food waste quantification is mainly performed using manual methods, such as pen and paper or software applications (Boschini et al., 2018; Eriksson et al., 2019) and emerging technologies that utilize computers or tablets connected to weighing scales, enabling users to determine mass of food waste (e.g., (Leverenz et al., 2020; WWF Germany, 2020). The latest advances in the field employ highly automated tools (provided by companies such as Leanpath and Kitro) that use image recognition software to automatically categorize food waste and its associated mass, as detected by linked weighing scales. Monitoring tools and methods are crucial to determine whether a reduction in food waste is being achieved, but few studies to date have examined the potential for utilizing automated quantification methods. While quantification is essential, it is equally important that the resulting information is promptly communicated to the relevant group for action, so that waste can be avoided (Aschemann-Witzel et al., 2023). To achieve this, gamification and nudging techniques could be useful motivating tools.

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To reduce food waste within the food service sector, it is common to have information campaigns that target food waste, based on the argument that if all guests and staff are well-informed, they will waste less food. It has been shown in a university setting that students who receive information about food waste can achieve a waste reduction of 15 % (Whitehair et al., 2013). However, only 40 % of the students approached in that study agreed to participate and let their tray waste be quantified. Information campaigns run together with some nudging schemes have also been explored. For instance, Dolnicar et al. (2020) reduced plate waste in sun-and-beach hotel restaurants with a game-based intervention. Removing trays and reducing plate size have also been shown to reduce plate waste (Kallbekken and Sælen, 2013; Thiagarajah and Getty, 2013; Obersteiner et al., 2021). Some studies suggest that the shape of a plate, specifically transitioning from round to oval, can reduce plate waste (Richardson et al., 2021). Other studies have found that manipulating plate size has no impact on waste (Qi et al., 2022). A study using communication tools in the proper context saw a reduction of 14.4 % in edible plate waste generated by hotel guests (Antonschmidt and Lund-Durlacher, 2021). A similar finding was made by Cozzio et al. (2021), who concluded that message-based appeals could nudge hotel guests towards more active engagement in avoiding food waste. Nudging has also been shown to be a successful measure in school canteens, where such strategies were found to prevent 41 % of plate waste, resulting in 27.2 g of food waste per portion according to Vidal-Mones et al. (2022). Other studies have used digital tools to interact with guests, e.g., Malefors et al. (2022) used a tablet computer connected to a kitchen scale to monitor the amount of plate waste produced by each student. The tablet provided instant feedback to guests regarding the amount of food they were wasting and the environmental impact of this waste, using a combination of gamification, nudging, and food waste quantification. This intervention yielded a reduction in plate waste, from 19 g per portion to just 12 g per portion (Malefors et al., 2022). However, most of the successful interventions described in the literature are based on the assumption that customers in a restaurant have the same lack of knowledge, or will react to the same nudges. Additionally, deploying multiple nudges simultaneously could lead to synergistic or compensatory interactions (Qi et al., 2022). Considering the large variation observed between canteens, organizations, and products in various studies (e.g., Brancoli et al., 2019; Eriksson et al., 2023, 2014), there is a strong risk of large variation also between different consumers, meaning that interventions in many cases could be wasted on consumers who are already aware or who do not waste food.

The aims of this study were to identify food waste patterns among pupils dining in Swedish school canteens, and to evaluate the accuracy of using an automated quantification and feedback tool for food waste quantification purposes. Knowledge of food waste patterns and waste amounts is important in understanding guest characteristics when designing intervention schemes to create a food system with less food waste. Evaluation of automated quantification tools is important to understand the limitations and potential of using this kind of method to move beyond time-consuming manual data collection procedures that are current practice today (if food waste data are collected at all).

2. Material and methods

2.1. Description of data collection and study material

The material analyzed in this study comprised plate waste data collected in 16 Swedish primary school canteens spread out geographically in five different municipalities. Each of the five municipalities operated on a 5–7-week menu rotation, implying a dish would reappear after 5–7 weeks. This study defines plate waste as “All waste from the plates of guests. May contain inedible part such as bones and peels” (Malefors et al., 2019; Swedish National Food Agency, 2020). All plate waste data collected originated from a “plate waste tracker”, a tool used by the kitchens to make guests more aware of their plate waste, with the ambition to lower this waste fraction. The plate waste tracker used consists of a set of weighing scales (2 g resolution) connected to a tablet computer running dedicated software which interacts with the guests. The scales are positioned under a bin into which the guests throw the food remains from their plates. Each time a weight difference occurs, the mass of this weight change is recorded, along with a time stamp. The interface displays how much food each guest is throwing away and the impact of this waste in terms that the guests can relate to. The idea is that the guests are nudged to change their behavior over time to waste less if they get feedback on how much they are wasting. Fig. 1 gives an overview over the concept for the plate waste tracker and how it interacts with guests.

To nudge guests to waste less, the interface displays different messages depending on how much each individual guest is wasting. If a guest throws away more than 70 g, the interface shows a message with a red background asking the guest to waste less next time and stating the amount of food discarded. If a guest throws away 20–70 g, the same message about throwing away less food is shown, but with an orange background. If the guest throw away less than 20 g, the feedback is that the guest created little food waste. The interface also allows the guest to provide feedback on why they wasted food, with some predefined alternatives such as “I did not like it/It was not to my taste”, “I took too much food”, “I did not have time to finish my meal”, “I ate it all, thanks for the food”. Guests can provide multiple answers, but it’s preferable that they offer just one.

In addition to visually representing the individual contribution of plate waste from each guest, the visualization also presents guests with the total plate waste generated during the current meal. This information is then compared to the waste generated on the previous day within the same week, as well as to the average waste from previous week. Information for the previous day and the average for the previous week are based on manually recorded values entered by kitchen staff each time the plate waste bin is emptied. The reason for this procedure is that staff can record the actual amount of plate waste if the scales are tampered with by the pupils. The staff can also record the number of guests served each day, to get the relative indicator ‘plate waste/guest’. Fig. 2 shows the different parts of the interface and how it interacts with the guests.

Some of the kitchens included in this study had a plate waste tracker permanently at their location, whereas others used the device during shorter, but more focused, periods. A total of 421,015 plate waste events were recorded by the plate waste trackers in the 16 primary school kitchens between 8 October 2020 and 20 February 2023.

2.2. Plate waste quantification framework and evaluation

To restrict measurements to only the lunch meal and to remove plate waste events triggered by items other than plate waste (e.g., replacing paper/plastic bag in the bin and placing it back on the scales), a filter was used. The filter only looked at events between 10:00 and 14:00 h, and only considered weights greater than 3 g and less than 500 g. Applying this filter to all collected plate waste data reduced the number of plate waste events to 398,991 (records of weight differences). Table 1. shows the period in which plate waste trackers were active in the different kitchens and the number of days, along with the number of plate waste events (after the filter was applied) for which the plate waste tracker recorded information. Descriptive statistics for plate waste is also provided.

To analyze the distribution of plate waste, the plate waste data were arranged in ascending order from the smallest to the largest amount. This list was then divided into 10 groups based on deciles and the median value was computed for each group. This procedure was conducted for the complete dataset, and separately for each canteen.

In a further analysis, the two decile groups within the complete dataset that demonstrated the most significant levels of waste were

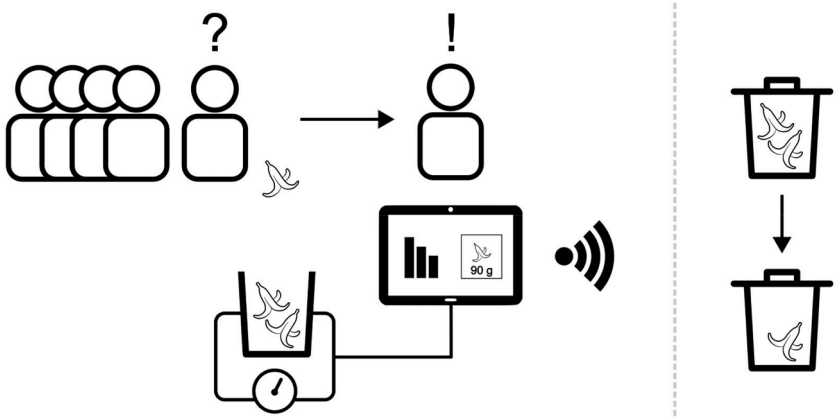

Fig. 1. Overview of how the guests interact with the plate waste tracker. The guests throw their plate waste into a bin which sits on weighing scales. The banana peel icon symbolizes all types of plate waste, regardless of their edibility. The scales are connected to a tablet computer that displays the weight of the items thrown away, among other information. All the information collected is also sent to a central database.

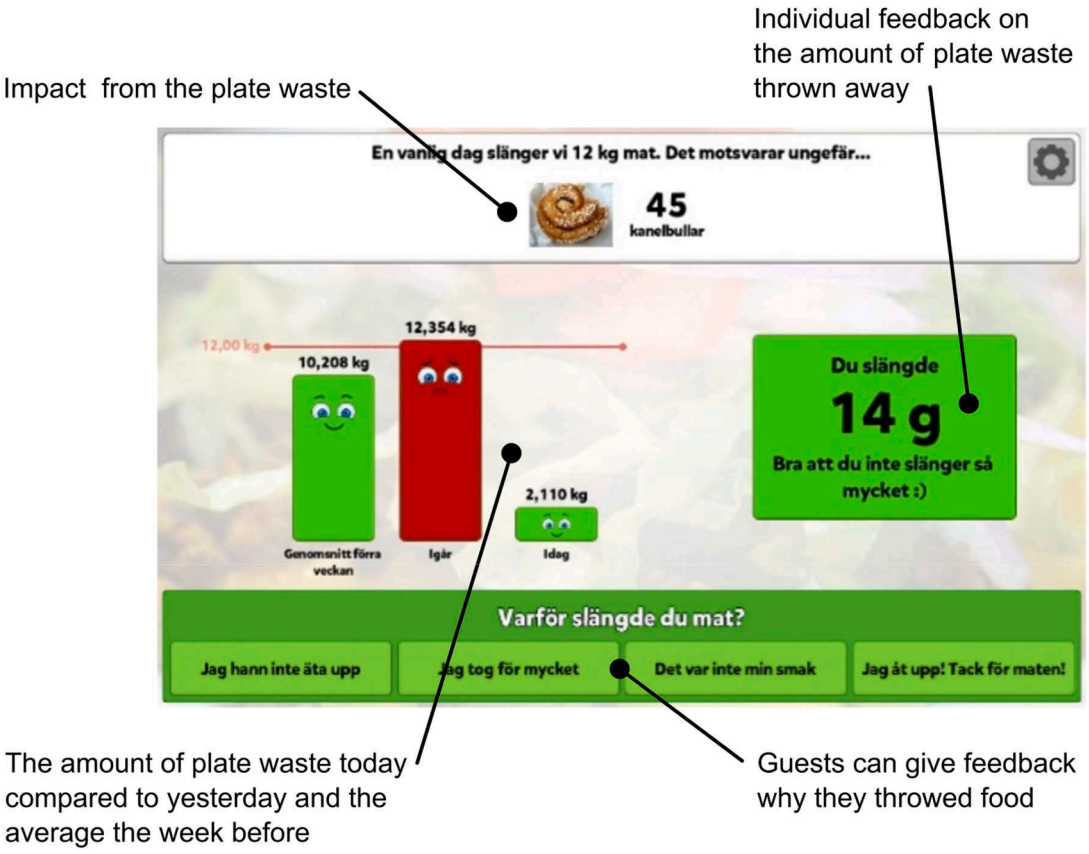

Fig. 2. Overview of the interface of the plate waste tracker software and the different elements. The top part of the interface gives information about the impact of the plate waste generated (approximately) in the canteen in terms that the students can relate to, for instance the number of cinnamon buns that 12 kg of plate waste represents. The middle part of the interface displays how today's accumulated levels of plate waste relates to the previous day's and the previous week's average. This information is also relative to a goal that the canteen has set, in this case 12 kg. Individual feedback is displayed to the right of this information and changes depending on how much food is wasted. The bottom part of the interface lets the guests give feedback on why they are wasting food.

targeted, with the aim of reducing the waste in these groups by 50 % (in line with the objective specified in SDG12.3). To evaluate the effectiveness of this approach, detected plate waste across all canteens was aggregated and compared against the total waste amount calculated in the scenario of 50 % waste reduction.

The median plate waste values for the highest 1 % and the lowest 1 % quantiles were also examined for all the plate waste observations. Furthermore, the median plate waste was calculated across all canteens in the entire dataset, allowing the findings to be compared with those in previous studies. The median value was chosen as a measure of central tendency due to its robustness in handling outliers, as described in Quinn and Keough (2002).

To connect each amount of plate waste to the reason given by the guest as to why they threw away food, the weight difference in plate waste was associated with the next occurring feedback event on the tablet computer within a 15-s time frame. Fig. 3 gives an overview of

Table 1
Summary of where and when the plate waste trackers were active in the 16 participating primary school kitchens, and number of plate waste events captured by each tracker and associated descriptive statistics.

School	Municipality	No. of plate waste events	Start date	End date	No. of quantification days	Median plate waste (g)	Average plate waste (g)	Standard deviation plate waste (g)
1	1	15,639	2020–12–15	2022–04–20	149	16	33	44
2	1	96,980	2020–12–15	2023–02–20	427	14	31	43
3	1	44,191	2020–12–11	2023–01–27	185	12	37	59
4	1	64,058	2020–12–14	2023–02–20	453	24	39	45
5	1	22,824	2020–12–14	2022–02–17	220	8	19	31
6	1	39,573	2021–09–07	2023–02–01	287	28	48	54
7	2	61,657	2022–04–28	2023–02–20	149	56	81	81
8	3	7356	2020–10–08	2020–11–27	35	28	48	60
9	3	12,028	2020–10–08	2021–06–14	58	24	42	51
10	3	17,835	2020–10–08	2021–09–01	73	12	30	44
11	4	7912	2020–10–12	2020–11–24	32	14	32	44
12	5	7546	2022–11–17	2023–02–17	46	26	44	52
13	5	160	2023–02–20	2023–02–20	1	24	34	36
14	5	383	2022–10–17	2022–10–24	5	20	30	30
15	5	599	2022–05–03	2022–05–06	4	24	37	41
16	5	250	2023–01–23	2023–01–27	5	20	37	46

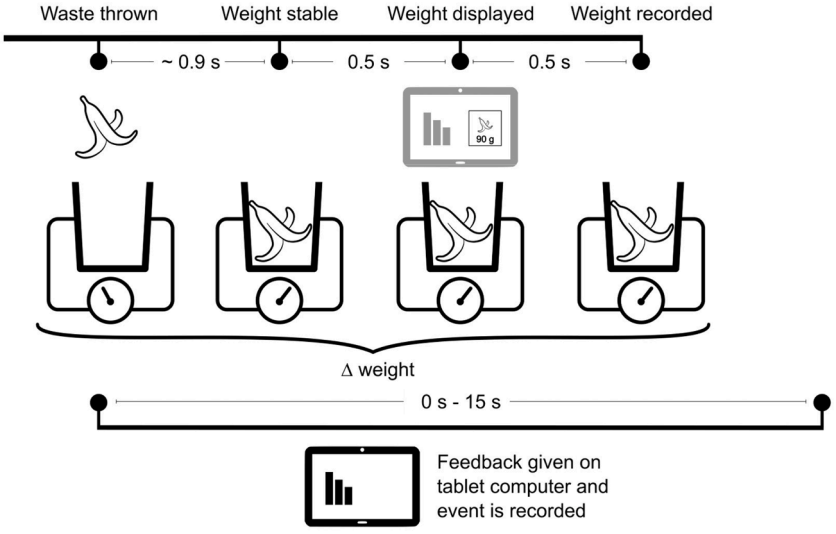

Fig. 3. Flowchart describing how plate waste weight differences were recorded and how feedback events were linked to these weight differences.

how a weight difference was recorded in the database and its relationship to guest feedback on the tablet computer: Waste was first thrown in the bin and when the new weight was stable (after roughly 0.9 s), it took 0.5 s before the difference was recorded in the database. This weight was then displayed to the guest via the interface of the tablet computer. If the guest indicated a reason for their food waste or their perception of the food on the tablet computer, this feedback event was associated with the weight difference. Reasons for wasting food were then evaluated by looking at lowest 80 % of plate waste compared with the highest 20 % of plate waste where feedback events could be tied to the plate waste events. 95 % confidence intervals for each feedback category highlight potential significant differences between the feedback categories within the lowest 80 % of plate waste versus the highest 20 % of plate waste events (Wasserstein et al., 2019).

In the best-case scenario, a weight change was directly followed by feedback provided by the guest (Scale -> Feedback). These two events could then be connected and analyzed as reasons for wasting food. However, it was also possible for other combinations of events to occur, such as two (or more) feedback events without a detected scale change in between (Feedback -> Feedback), due to a guest not throwing away any food but providing feedback to the canteen anyway, or at least two scale changes without any feedback given on the tablet computer (Scale -> Scale), if a guest chose not to provide feedback or waited more than 15 s before doing so. A descriptive summary of all the combinations of these feedback events was made, as aggregated values for all participating canteens.

To evaluate the accuracy of the automated plate waste detection procedure, which measures waste by recording weight differences, compared with the manual data entered by the kitchen staff at the end of each day or bin emptying, the median waste in kilograms per day was compared for each method. Similarly, to determine the number of guests discarding food, the median number of weight differences (plate waste events) was compared against the median number of guests recorded manually by the kitchen staff per day. The number of guests recorded manually by the kitchen staff was based on the number of plates, as described by Malefors et al. (2021). To ensure reliable results, only canteens with over 20 observations were considered in evaluating the plate waste tracker's ability to detect waste and guests accurately in comparison with manual recording by kitchen staff. Waste-to-guest ratio was calculated based on the average waste per day for each procedure and the average number of guests served per day, and used to assess the efficiency of both the automated and manual procedures.

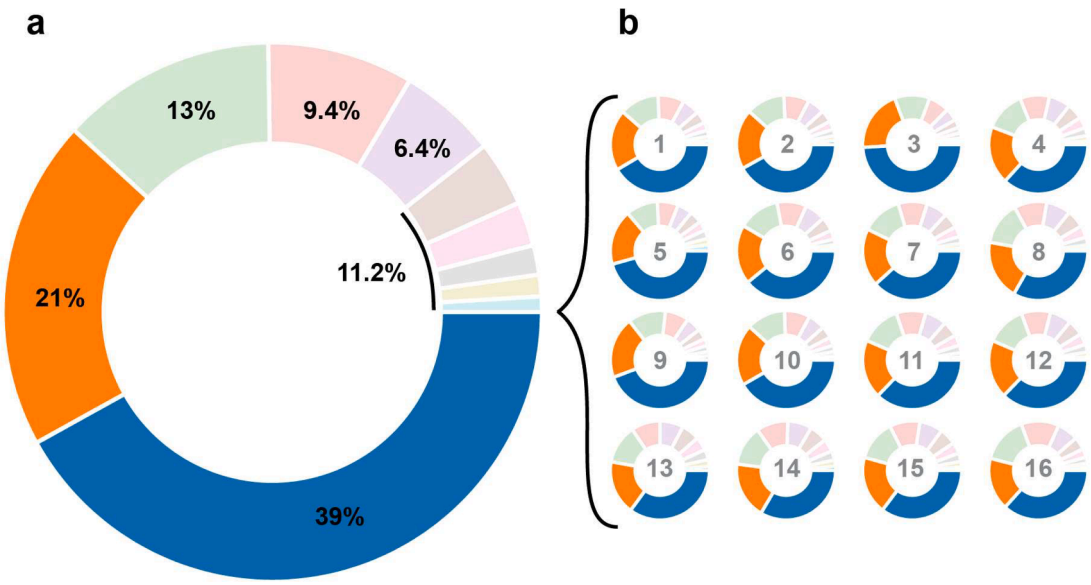

Fig. 4. Plate waste rate per decile in (a) all 16 participating school canteens and (b) in the individual school canteens. The segments of each ring represents one decile and the number printed in each segment in (a) indicates the proportion of plate waste occurring in that segment.

3. Results

It was found that 20 % of plate waste events across all participating kitchens accounted for 60 % of all plate waste. All kitchens reported similar findings, with canteen number 3 having the highest proportion of waste (69 %) coming from 20 % of all the plate waste events and kitchen 14 have the lowest proportion (52 %). Half of all plate waste events in all canteens accounted for 11.2 % of all plate waste. Fig. 4 shows the waste rate per decile for all 16 school canteens, and the pattern for the individual canteens.

Analysis of the top 1 % of all plate waste events across all school canteens showed that these events accounted for 8 % of all plate waste, whereas the bottom 1 % accounted for 0.09 % of all plate waste. The reported median plate waste for all canteens was 20 g. Fig. 5 illustrates a scenario where the top 20 % of plate wasters successfully reduced their waste by 50 %, leading to an overall 31 % decrease in plate waste across the studied canteens. The combined plate waste recorded in all canteens during the period amounted to approximately 17 tonnes. If the top 20 % of plate wasters were to halve their plate waste, the projected mass of plate waste would be around 11.7 tonnes.

Of the 398,991 recorded weight differences, it was possible to link 55,505 feedback events to guests giving feedback on why they wasted food. Among reasons given by the bottom 80 % (plate waste range 4–66 g/plate) for why they wasted food, a majority (56 %) responded that they were happy with the food and ate it up, while the remaining 44 % responded that the food was either not to their taste, or they took too much or did not have enough time to finish their plates. Of the guests that represented the top 20 % of all plate waste (range 66–500 g/plate), 56.8 % gave the reason that the food was not to their taste or that they took too much or did not have enough time to finish it. Fig. 6 summarizes the answers from the guests that could be matched to a plate waste event and also divides the answers into the bottom 80 % and top 20 % of plate waste events. The difference in plate waste events between the bottom 80 % and the top 20 % is significant for each category. There are no overlapping confidence intervals, except for the “not enough time to eat” category.

A total of 164,890 feedback events were recorded by the guests across all the canteens. Examining the order revealed that most were Scale -> Scale events (350,022), where there was no feedback event in between. There were also 93,900 Feedback -> Feedback events, where there was no scale recording in between.

To understand how well the plate waste tracker detected waste amount and number of guests, canteens that could provide more than 20 days of observations of each type was evaluated. Table 2 displays the waste and guest differences for the individual school canteens, along with information about how many days on which both guests and plate waste events were recorded. In the school canteens that could provide such data, the number of tracker-detected guests (plate waste events) was lower than the number of manually recorded portions. The average number of detected guests/day was around 40 % lower than the average number of recorded guests/day. Across all kitchens that fulfilled the filtering criteria, the difference between manually recorded plate waste and the amount of tracker-detected plate waste per day was around 7 %. The largest difference in the plate waste tracker’s ability to detect waste was observed in canteen 11, where the amount of detected plate waste was 31 % lower than the amount of manually recorded plate waste. The remaining canteens had plate waste that was within ±10 % of the manually recorded value.

As derived from Table 2, the manual recordings showed a value of 31 g waste/guest,[1] while the automatic procedure resulted in 48 g/guest[2] (13 kg/268 guests). The manual recording procedure therefore resulted in a waste-to-guest-ratio that was 35 %[3] lower than the automatically detected value for the eight canteens that could provide more than 20 days of observations.

4. Discussion

In this study of primary school canteens, it was found that most plate waste (60 %) came from a relatively small proportion of guests (20 %), while the majority of pupils wasted only a small amount or did not waste any food at all. This confirms findings in other areas that a small proportion of events account for a majority of the impact, e.g., it has been shown that all humans contribute to climate change, but not equally (Chancel, 2022). In the present study, the results were based on automated tracker-recorded plate waste events, which means that additional guests present who did not throw away any plate waste were not reflected in the results. For instance, the detected number of guests per day

[1] Calculated as 14 kg/ 449 guest *1000)
[2] Calculated as 13 kg/ 268 guests * 1000)
[3] Calculated as (1-31/48)

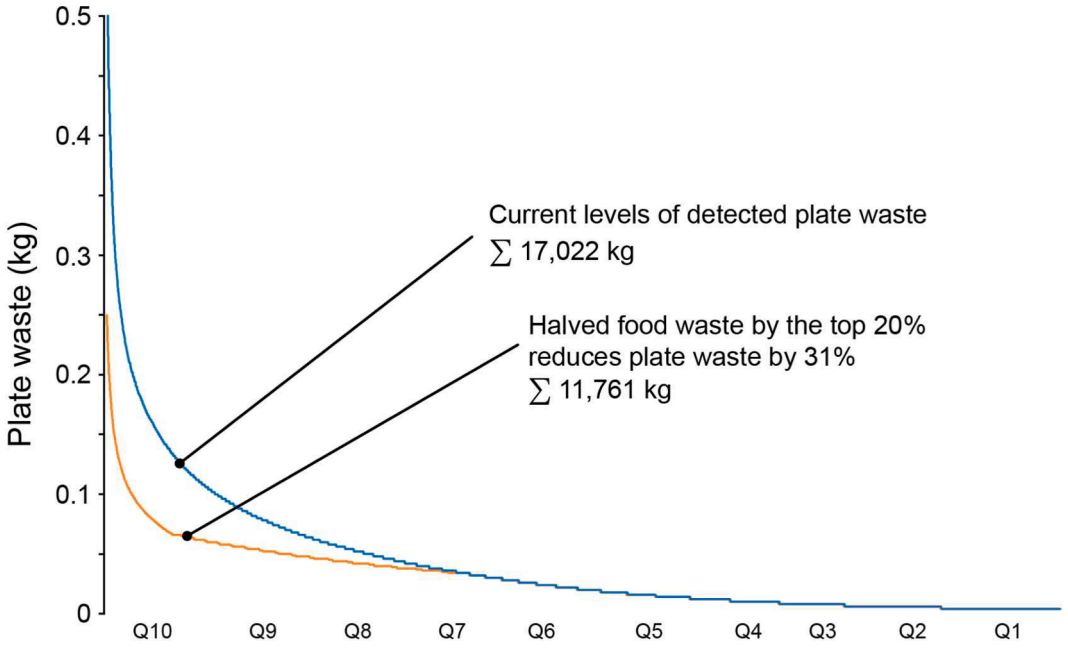

Fig. 5. Scenario in which the top 20 % of plate wasters manage to reduce their waste by half, resulting in a 31 % reduction in overall plate waste in the canteens studied.

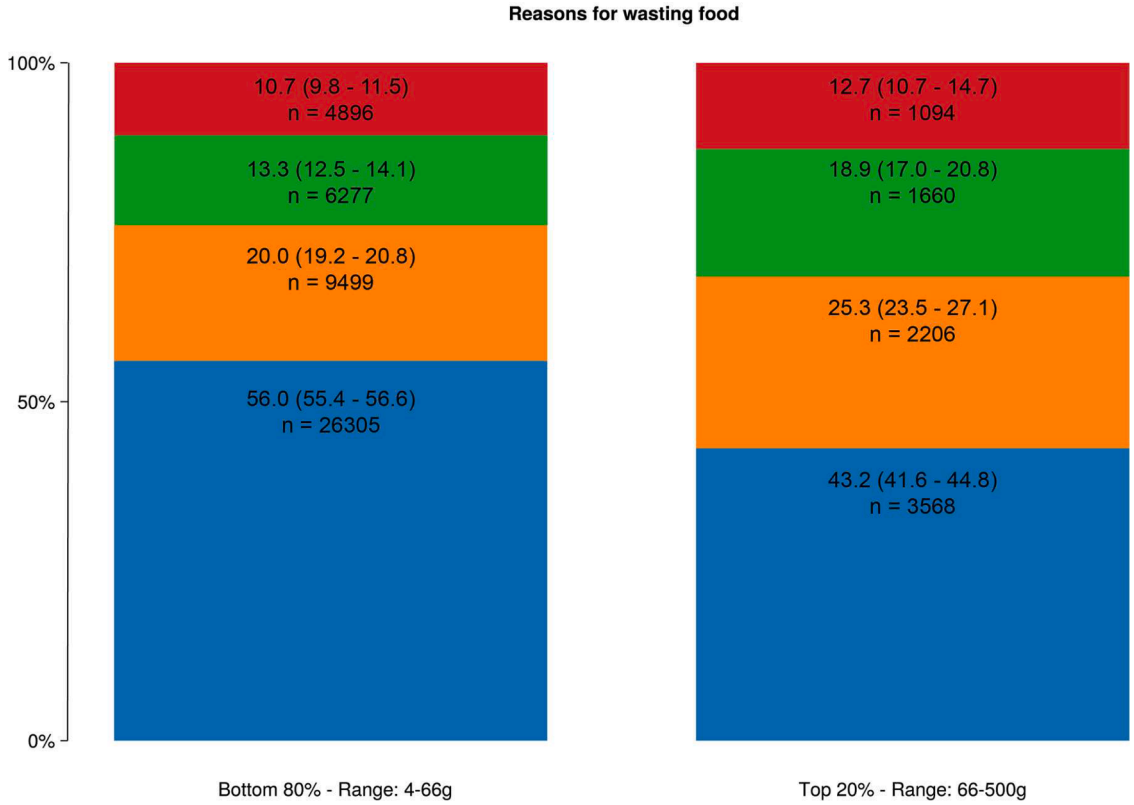

Fig. 6. Reasons given for wasting food by the bottom and top fractions of plate wasters: ■ Not enough time to eat; ■ Took too much; ■ It was not my taste; ■ I ate up my food. The numbers in parentheses represent the 95 % confidence interval range (rounded), and the vote count for each category is also provided.

(or of plate waste events) was 10–51 % lower than the number manually recorded by the kitchen staff at the different canteens. A similar pattern was observed on examining the order of the events, where there was a substantial number of feedback events in a row with no recorded weight change in between that could be associated with a feedback event. This probably means that guests gave feedback to the tablet computer, but did not deposit any plate waste in the bin. If this were the case, then the approach used underestimated the degree of food waste inequality between the guests.

It is clear that not every canteen or every guest had the same

Table 2
Waste and guest differences for the individual school canteens, and number of observations for the different cases. Only canteens that could provide more than 20 observations of each type were considered in the evaluation. Plate waste (kg) is rounded with two digits precision.

School	Plate waste Observations	Automatically detected waste/day (kg)	Manually recorded waste/day (kg)	Δ%	Portions Observations	Automatically detected guests/day	Manually recorded guests/day	Δ%
2	235	8.1	7.5	**8**	182	217	344	**−37**
3	107	10	11	**−9**	229	343	554	**−38**
6	225	9	8.6	**5**	232	168	319	**−47**
7	141	35	37	**−5**	140	439	800	**−45**
8	28	12	12	**0**	29	225	362	**−38**
9	47	10	11	**−9**	47	233	475	**−51**
10	66	8	8.8	**−9**	68	260	288	**−10**
11	28	9.7	14	**−31**	26	258	450	**−43**
Average:	110	13	14	**−7**	119	268	449	**−40**

problem, and that it was not evenly distributed. For instance, if the high-profile wasters (in the top 20 %) could manage to reduce their food waste by half, this would lead to an overall reduction in plate waste of 31 % in the canteens studied. If the highest-profile wasters (top 1 %) could manage to halve their waste, this would lead to a decrease in overall food waste of 4 %. Targeting these groups of wasters could potentially have a huge impact and, since half of their current food waste is still a large amount in comparison with many other pupils, this is probably a moderate estimate of their reduction potential.

A common strategy for canteens that have recognized their food waste issue is to deploy various information or awareness campaigns aiming to lower food waste. Previous studies have shown that this can in some cases be quite successful (Manomaivibool et al., 2016; Pinto et al., 2018), whereas other studies have not observed the same potential (Whitehair et al., 2013). This indicates that information or awareness campaigns are quite blunt and can only lower food waste to a certain extent, if at all, which is likely to relate to how large the problem was to start with. For instance, Eriksson et al. (2019) found that hotels and restaurants reduced their food waste by 61 % on quantifying food waste and displaying the result, although the variation between establishments was large and an important factor in achieving a large reduction was to start with a high level of food waste (the larger the initial problem, the greater the potential for improvement). Food waste reduction is likely subject to the law of diminishing returns (Meier et al., 2021), so further actions are needed beyond information and awareness campaigns to target the guests that account for most plate waste.

Nudging guests to throw away less food can be an option and some studies have found it to be successful in lowering plate waste. For instance, Roe et al. (2022) found that individually tailored food waste reduction interventions in a household setting reduced plate waste by 79 %, although the sample of participants in their study was small. The plate waste trackers used in this study have previously been demonstrated to lower the amount of plate waste by 37 % (not statistically significant) and serving waste by 62 %, but the amount of plate waste in that study was already low, with initial plate waste of 19 g/guest (Malefors et al., 2022). In the present study the median level of plate waste was 20 g/guest, quantified in 16 canteens using the plate waste trackers, compared with two canteens in Malefors et al. (2022). The median level in this study is similar to that reported in other studies covering the Swedish public catering sector in general and primary schools in particular (Malefors, 2022; Swedish National Food Agency, 2021).

To date, policy makers and practitioners in the public catering sector seeking to achieve food waste reductions have targeted all pupils with the same information, campaigns, and nudges. The results in the present study suggest that this is a waste of effort, as the majority of the pupils targeted do not have any practical possibility to reduce their food waste. Instead, greater potential to achieve food waste reductions lies in targeting a much smaller group of high-profile wasters that have real potential to reduce their waste. Efforts should therefore be made to devise interventions that reach this minority of pupils and change their behavior in a desired direction. It is possible that information and nudging can still be useful methods, but the messages provided need to be adapted for the minority rather than the majority and ideally should be tailored to different consumer groups.

A secondary aim in this study was to assess the accuracy of an automatic quantification procedure compared with manually recording the amount of waste and the number of guests. The average amount of plate waste at most participating canteens was within ±10 %, but one canteen exceeded this range of variation and had 31 % lower amount of tracker-detected plate waste compared with manually recorded plate waste. The tracker-detected number of guests also deviated from the manually entered number. An important question thus arises regarding the comparability of waste and guest data captured by different methods when converted into a relative indicator (waste-to-guest ratio). Use of an automated system may result in a lower number of detected guests, as it will only record guests who actually waste food, leading to a higher waste-to-guest ratio compared with the manual recording procedure. This is exemplified by the 35 % lower waste-to-guest ratio observed for the manual recording procedure compared with the automated procedure in this study. This difference should be considered when reporting food waste values to management or to national statistics. However, it is unlikely that automated systems will replace manual recordings any time soon and both methods are likely to co-exist for some time. A potential compromise worth considering is to employ both manual and system-detected methods for data entry. In this study, canteen staff did not have access to information on the automatically calculated waste-to-guest ratio and instead the statistics displayed on the interface were based on the manually entered information, which allowed staff to maintain a sense of control and make the key figure comparable to the manual records.

Another factor to consider is that it is difficult to automatically determine the reasons for food waste. In the present study, we were able to link 55,505 feedback events to a corresponding plate waste event, out of a total of 164,890 feedback events. However, it should be noted that in most cases only scale events were recorded, without any corresponding feedback events, partly due to the pandemic situation where some canteens made the tablet computer inaccessible to guests due to hygiene concerns. Despite this limitation, using an automated system to capture guest feedback is still beneficial, as it is a cost-effective way to gather opinions compared with conducting surveys. Although it may be challenging to link the feedback to a waste event automatically, canteens can still act based on the feedback they receive. The idea is for canteens to understand how guests perceive certain menus through their feedback. By identifying which dishes might lead to more food waste, canteens can introduce customized interventions, possibly decreasing serving waste. This concept has been previously demonstrated in a study where plate waste trackers were found to lower serving waste by 38 g/

guest, although other circumstances may also have had an effect (Malefors et al., 2022).

Although the results of this study are promising, there are some limitations that should be considered. First, the sample size of participating canteens was relatively small, with only 16 canteens contributing data. While these canteens were geographically dispersed and participated voluntarily, there may be some selection bias inherent in this approach. It is not uncommon for technological solutions to be voluntary, but this may limit the generalizability of the findings. Future studies assessing the reliability of automated food waste quantification tools would benefit from a larger sample size and inclusion of canteens from other parts of the food service sector. It is worth noting that while we refer to a group of 'high-profile wasters', we were unable to determine whether the same individuals exhibited this behavior consistently over time or whether the group consisted of different individuals over time. To gain a better understanding, surveys or on-site observations would need to be conducted in conjunction with the plate waste trackers. Additionally, the data collected by the plate waste trackers could be cross-referenced with student schedules to identify specific classes or groups of students with high levels of waste, allowing for targeted interventions. Food waste levels are recognized to vary over time, influenced by various factors, including the composition and quality of the menu. In this study, the system solely records plate waste by weight. To gain a more comprehensive understanding of what enters the waste bin, the system could potentially be enhanced to include the content of the bin through technologies like cameras and innovative image recognition. This expansion could shed light on the correlation between specific menus and varying levels of plate waste. Furthermore, this could enable feedback to guests on the plate waste on particular menu generated compared to its previous serving, offering a more direct comparison than the current practice of comparing daily waste levels without considering the menu variations. Additionally, modifying the interface to display feedback as averages instead of total accumulated plate waste would ensure that each individual's contribution affects the average. This change would prevent the last few students each day from being the sole reason the plate waste exceeds the target.

Another potential improvement to the plate waste trackers used in this study would be to expand the quantification of food waste to include its true cost, as proposed by Martin-Rios et al. (2023). Such an approach may be particularly relevant for establishments outside the public catering sector where customers pay for their meals directly. By incorporating this additional information, plate waste trackers could provide an even more comprehensive assessment of the economic and environmental impact of food waste, and potentially motivate customers to reduce food waste by highlighting its financial cost.

By further personalizing the messages targeted at the high-wasting minority of pupils, it is possible to achieve a greater impact and significantly reduce food waste, thereby contributing to a more sustainable food system with less waste.

5. Conclusions

Automated tools for quantifying food waste are an emerging technology with some promise. This study demonstrated the effectiveness of one such tool, the plate waste tracker, in accurately detecting plate waste with a high level of precision (within ±10 % of values manually recorded by staff). By detecting waste directly from plates, this tool also provided insights into the number of guests discarding food, which was approximately 40 % lower on average than the number obtained when staff manually counted plates and entered the information. Consequently, the automatically collected data indicated a 35 % higher waste-per guest ratio than that derived from manual information.

The tool provided guests with the opportunity to provide feedback on the reasons behind their food waste. However, automatically determining the specific reasons for wasting food and linking them to the actual waste proved to be a challenging task, so the ability to identify certain behaviors associated with food waste based on this feedback remains elusive. As automated tools for quantifying food waste become more prevalent, it is crucial to understand the results produced by these methods in comparison with manual approaches. The automated tools have an advantage over manual recordings in that they can track food waste with greater granularity. Because the waste was not measured as an aggregate value in the present study, the automated approach was able to reveal that a minority of students (20 %) were responsible for a significant proportion (60 %) of all plate waste. If this waste alone could be halved, this would reduce overall food waste by 31 %. Therefore, identifying measures that target high-profile wasters would have a substantial impact in reducing plate waste overall. To date, policy makers and practitioners in the public catering sector seeking to achieve food waste reduction have targeted all pupils with the same information, campaigns, and nudges. The results in the present study suggest that this is a waste of effort, as most of the pupils do not have any practical possibility to reduce their food waste. Greater potential lies in targeting a much smaller group of high food wasters that have real potential to reduce their waste. Efforts should therefore be made to devise interventions that reach this minority of pupils and change their behaviors in a desired direction. This, together with other actions, is necessary to achieve a more sustainable food system.

CRediT authorship contribution statement

Christopher Malefors: Conceptualization, Methodology, Visualization, Data curation, Formal analysis, Writing – original draft, Writing – review & editing. **Erik Svensson:** Software, Data curation, Formal analysis, Writing – review & editing. **Mattias Eriksson:** Conceptualization, Methodology, Funding acquisition, Writing – review & editing.

Declaration of Competing Interest

The authors declare the following financial interest/personal relationships which may be considered as potential competing interests: The authors Christopher Malefors, Erik Svensson, and Mattias Eriksson developed the plate waste tracker used. Christopher Malefors and Mattias Eriksson are shareholders in the company Matomatic AB, which owns the rights to the plate waste tracker.

Data availability

The authors do not have permission to share data.

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References

Abdelaal, A.H., McKay, G., Mackey, H.R., 2019. Food waste from a university campus in the Middle East: drivers, composition, and resource recovery potential. Waste Manag. 98, 14–20. https://doi.org/10.1016/j.wasman.2019.08.007.

Antonschmidt, H., Lund-Durlacher, D., 2021. Stimulating food waste reduction behaviour among hotel guests through context manipulation. J. Clean. Prod. 329, 129709 https://doi.org/10.1016/j.jclepro.2021.129709.

Aschemann-Witzel, J., Asioli, D., Banovic, M., Perito, M.A., Peschel, A.O., Stancu, V., 2023. Defining upcycled food: the dual role of upcycling in reducing food loss and waste. Trends Food Sci. Technol. 132, 132–137. https://doi.org/10.1016/j.tifs.2023.01.001.

Bergquist, M., Thiel, M., Goldberg, M.H., van der Linden, S., 2023. Field interventions for climate change mitigation behaviors: a second-order meta-analysis. Proc. Natl. Acad. Sci. 120, e2214851120 https://doi.org/10.1073/pnas.2214851120.
Boschini, M., Falasconi, L., Giordano, C., Alboni, F., 2018. Food waste in school canteens: a reference methodology for large-scale studies. J. Clean. Prod. 182, 1024–1032. https://doi.org/10.1016/j.jclepro.2018.02.040.
Brancoli, P., Lundin, M., Bolton, K., Eriksson, M., 2019. Bread loss rates at the supplier-retailer interface – Analysis of risk factors to support waste prevention measures. Resour. Conserv. Recycl. 147, 128–136. https://doi.org/10.1016/j.resconrec.2019.04.027.
Chancel, L., 2022. Global carbon inequality over 1990–2019. Nat. Sustain. 5, 931–938. https://doi.org/10.1038/s41893-022-00955-z.
Cozzio, C., Tokarchuk, O., Maurer, O., 2021. Minimising plate waste at hotel breakfast buffets: an experimental approach through persuasive messages. Br. Food J. 123, 3208–3227. https://doi.org/10.1108/BFJ-02-2021-0114.
Dolnicar, S., Juvan, E., Grün, B., 2020. Reducing the plate waste of families at hotel buffets – A quasi-experimental field study. Tour. Manag. 80, 104103 https://doi.org/10.1016/j.tourman.2020.104103.
Eriksson, M., Christensen, J., Malefors, C., 2023. Making food waste illegal in Sweden – Potential gains from enforcing best practice in the public catering sector. Sustain. Prod. Consum. 35, 229–237. https://doi.org/10.1016/j.spc.2022.11.003.
Eriksson, M., Malefors, C., Callewaert, P., Hartikainen, H., Pietiläinen, O., Strid, I., 2019. What gets measured gets managed – Or does it? Connection between food waste quantification and food waste reduction in the hospitality sector. Resour. Conserv. Recycl. X 4, 100021. https://doi.org/10.1016/j.rcrx.2019.100021.
Eriksson, M., Osowski, C.P., Malefors, C., Björkman, J., Eriksson, E., 2017. Quantification of food waste in public catering services – A case study from a Swedish municipality. Waste Manag. 61, 415–422. https://doi.org/10.1016/j.wasman.2017.01.035.
Eriksson, M., Strid, I., Hansson, P.-A., 2014. Waste of organic and conventional meat and dairy products—A case study from Swedish retail. Resour. Conserv. Recycl. 83, 44–52. https://doi.org/10.1016/j.resconrec.2013.11.011.
Fraternali, P., Cellina, F., Herrera Gonzales, S.L., Melenhorst, M., Novak, J., Pasini, C., Rottondi, C., Rizzoli, A.E., 2019. Visualizing and gamifying consumption data for resource saving: challenges, lessons learnt and a research agenda for the future. Energy Inform. 2, 22. https://doi.org/10.1186/s42162-019-0093-z.
Froehlich, J., Findlater, L., Landay, J., 2010. The design of eco-feedback technology. In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. Presented at the CHI '10: CHI Conference on Human Factors in Computing Systems. ACM, Atlanta Georgia USA, pp. 1999–2008. https://doi.org/10.1145/1753326.1753629.
Gosnell, G.K., Bazilian, M.D., 2021. Changing behaviour is the key to solving the climate challenge. Nat. Hum. Behav. 5, 294. https://doi.org/10.1038/s41562-020-01047-8. –294.
Gram-Hanssen, K., 2014. New needs for better understanding of household's energy consumption – behaviour, lifestyle or practices? Archit. Eng. Des. Manag. 10, 91–107. https://doi.org/10.1080/17452007.2013.837251.
Guillen, G., Hamari, J., Quist, J., 2021. Gamification of Sustainable Consumption: a systematic literature review. In: Presented at the Hawaii International Conference on System Sciences. https://doi.org/10.24251/HICSS.2021.163.
IPCC, 2019. Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems.
Juvan, E., Grün, B., Dolnicar, S., 2017. Biting off more than they can chew: food waste at hotel breakfast buffets. J. Travel Res. 57, 232–242. https://doi.org/10.1177/0047287516688321.
Kallbekken, S., Sælen, H., 2013. `Nudging' hotel guests to reduce food waste as a win–win environmental measure. Econ. Lett. 119, 325–327. https://doi.org/10.1016/j.econlet.2013.03.019.
Koivisto, J., Hamari, J., 2019. The rise of motivational information systems: a review of gamification research. Int. J. Inf. Manag. 45, 191–210. https://doi.org/10.1016/j.ijinfomgt.2018.10.013.
Leverenz, D., Moussawel, S., Hafner, G., Kranert, M., 2020. What influences buffet leftovers at event caterings? A German case study. Waste Manag. 116, 100–111. https://doi.org/10.1016/j.wasman.2020.07.029.
Malefors, C., 2022. Food Waste Reduction in the Public Catering Sector. Swedish University of Agricultural Sciences, Uppsala, Sweden.
Malefors, C., Callewaert, P., Hansson, P.-A., Hartikainen, H., Pietiläinen, O., Strid, I., Strotmann, C., Eriksson, M., 2019. Towards a baseline for food-waste quantification in the hospitality sector—quantities and data processing criteria. Sustainability 11, 3541. https://doi.org/10.3390/su11133541.
Malefors, C., Strid, I., Hansson, P.-A., Eriksson, M., 2021. Potential for using guest attendance forecasting in Swedish public catering to reduce overcatering. Sustain. Prod. Consum. 25, 162–172. https://doi.org/10.1016/j.spc.2020.08.008.
Malefors, C., Sundin, N., Tromp, M., Eriksson, M., 2022. Testing interventions to reduce food waste in school catering. Resour. Conserv. Recycl. 177, 105997 https://doi.org/10.1016/j.resconrec.2021.105997.
Manomaivibool, P., Chart-asa, C., Unroj, P., 2016. Measuring the impacts of a save food campaign to reduce food waste on campus in Thailand. Appl. Environ. Res. 13–22. https://doi.org/10.35762/AER.2016.38.2.2.
Martin-Rios, C., Rogenhofer, J., Sandoval Alvarado, M., 2023. The true cost of food waste: tackling the managerial challenges of the food supply chain. Trends Food Sci. Technol. 131, 190–195. https://doi.org/10.1016/j.tifs.2022.12.005.
Meier, T., Von Borstel, T., Welte, B., Hogan, B., Finn, S.M., Bonaventura, M., Friedrich, S., Weber, K., Dräger De Teran, T., 2021. Food waste in healthcare, business and hospitality catering: composition, environmental impacts and reduction potential on company and national levels. Sustainability 13, 3288. https://doi.org/10.3390/su13063288.
Obersteiner, G., Gollnow, S., Eriksson, M., 2021. Carbon footprint reduction potential of waste management strategies in tourism. Environ. Dev. 39, 100617 https://doi.org/10.1016/j.envdev.2021.100617.
Pinto, R.S., Pinto, R.M., dos, S., Melo, F.F.S., Campos, S.S., Cordovil, C.M.-S., 2018. A simple awareness campaign to promote food waste reduction in a University canteen. Waste Manag. 76, 28–38. https://doi.org/10.1016/j.wasman.2018.02.044.
Qi, D., Li, R., Penn, J., Houghtaling, B., Prinyawiwatkul, W., Roe, B.E., 2022. Nudging greater vegetable intake and less food waste: a field experiment. Food Policy 112, 102369. https://doi.org/10.1016/j.foodpol.2022.102369.
Quinn, G.P., Keough, M.J., 2002. Experimental Design and Data Analysis For Biologists. Cambridge University Press, Cambridge, UK ; New York.
Raworth, K., 2012. A safe and just space for humanity: can we live within the doughnut?
Richardson, R., Prescott, M.P., Ellison, B., 2021. Impact of plate shape and size on individual food waste in a university dining hall. Resour. Conserv. Recycl. 168, 105293 https://doi.org/10.1016/j.resconrec.2020.105293.
Roe, B.E., Qi, D., Beyl, R.A., Neubig, K.E., Apolzan, J.W., Martin, C.K., 2022. A Randomized Controlled Trial to Address Consumer Food Waste with a Technology-aided Tailored Sustainability Intervention. Resour. Conserv. Recycl. 179, 106121 https://doi.org/10.1016/j.resconrec.2021.106121.
Springmann, M., Clark, M., Mason-D'Croz, D., Wiebe, K., Bodirsky, B.L., Lassaletta, L., Vries, W.de, Vermeulen, S.J., Herrero, M., Carlson, K.M., Jonell, M., Troell, M., DeClerck, F., Gordon, L.J., Zurayk, R., Scarborough, P., Rayner, M., Loken, B., Fanzo, J., Godfray, H.C.J., Tilman, D., Rockström, J., Willett, W., 2018. Options for keeping the food system within environmental limits. Nature 562, 519–525. https://doi.org/10.1038/s41586-018-0594-0.
Swedish National Food Agency, 2021. Matsvinn i Kommunala förskolor, Skolor Och äldreboenden - Kartläggning Av Matsvinnet 2020 (No. L 2921 Nr 22). Livsmedelsverket, Uppsala.
Swedish National Food Agency, 2020. Handbok För Minskat Matsvinn - för verksamheter Inom Vård. skola och omsorg.
Thiagarajah, K., Getty, V.M., 2013. Impact on plate waste of switching from a tray to a trayless delivery system in a university dining hall and employee response to the switch. J. Acad. Nutr. Diet. 113, 141–145. https://doi.org/10.1016/j.jand.2012.07.004.
United Nations, 2015. Transforming Our World: The 2030 Agenda for Sustainable Development. New York.
United Nations Environment Programme, 2021. Food Waste Index Report 2021. Nairobi.
Vidal-Mones, B., Diaz-Ruiz, R., Gil, M., J, 2022. From evaluation to action: testing nudging strategies to prevent food waste in school canteens. Waste Manag. 140, 90–99. https://doi.org/10.1016/j.wasman.2022.01.006.
Wasserstein, R.L., Schirm, A.L., Lazar, N.A., 2019. Moving to a World Beyond "$p < 0.05$. Am. Stat. 73, 1–19. https://doi.org/10.1080/00031305.2019.1583913.
Whitehair, K.J., Shanklin, C.W., Brannon, L.A., 2013. Written Messages Improve Edible Food Waste Behaviors in a University Dining Facility. J. Acad. Nutr. Diet. 113, 63–69. https://doi.org/10.1016/j.jand.2012.09.015.
W.W.F. Germany, 2020. Collection and recording of food waste from out-of-home-catering - Overview of policy frameworks and existing recording tools.
Xue, L., Liu, G., Parfitt, J., Liu, X., Van Herpen, E., Stenmarck, Å., O'Connor, C., Östergren, K., Cheng, S., 2017. Missing food, missing data? A critical review of global food losses and food waste data. Environ. Sci. Technol. 51, 6618–6633. https://doi.org/10.1021/acs.est.7b00401.