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# Sustainability assessment of educational approaches as food waste prevention measures in school catering

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ABSTRACT

A large proportion of school meals are wasted, leading to missed opportunities to nourish pupils, environmental impacts, and economic losses. This intervention study evaluated the long-term efficacy of three educational approaches (giving feedback to guests via plate waste tracker, pedagogic meals, and kitchen workshops) in reducing plate waste in school canteens across Europe (Austria, Germany, and Sweden). Following the intervention, a sustainability assessment was conducted, including environmental, economic, and social perspectives. The results showed that the plate waste tracker significantly reduced plate waste, by 17% (4 g/guest) from an already lower baseline level of 23 g/guest, while demonstrating long-term efficacy with sustained waste reduction up to 15 months post-implementation. This reduction lowered the environmental impacts (by 212 kg carbon dioxide equivalents per school & year) and nutrient losses (1018 MJ, 12 kg protein, and 4 kg fiber per school & year), while proving cost-effective with a payback period of only 1–2 years. Therefore, despite upfront costs and implementation barriers, food waste reduction measures in school canteens provide substantial long-term benefits across environmental, economic, and social dimensions, making them a valuable investment for sustainable school meal programs.

## 1. Introduction

School meal programs reach broad audiences and can be promising avenues to improve the sustainability of food systems as they serve large volumes of food regularly over long periods from an individual's perspective, facilitating normative behavior among pupils (Höijer et al., 2020). They positively impact pupils' diets across countries (Andersen et al., 2014; Eustachio Colombo et al., 2020; Hayes et al., 2018). However, approximately 20% of food served in public catering, up to 178 g/guest in schools, is wasted (Boschini et al., 2020; Lonska et al., 2022; Malefors et al., 2022a; Pancino et al., 2021; Silvennoinen et al., 2015). This waste has significant environmental impacts, causes economic losses, and exacerbates social injustice (UNEP, 2021). In school meals, most waste comprises serving waste and plate waste, both of which involve resource-intensive preparation processes (Malefors et al., 2022; Read et al., 2020).

School meal programs differ globally in regulations, goals, target groups, menu composition, and nutritional content (Lucas et al., 2017). In low-income countries, such programs enhance food security and reduce undernutrition, while in high-income countries they promote healthy eating and seek to combat obesity (Alderman and Bundy, 2012; Aliyar et al., 2015). However, meeting children's nutritional needs is a universal objective (GCNF, 2022). Some countries, like Sweden, legally mandate that school meals must be nutritious, with published guidelines

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recommending that these meals cover 30% of pupils' daily nutritional needs (Swedish Food Agency, 2022). In Finland, meal provision is also mandated by law, and legally binding guidelines ensure these meals are nutritionally balanced, steered by the national nutrition and food recommendations (National Nutrition Council, 2017). Others, like Austria and Germany, offer official guidelines for voluntary use (Ages, 2021; DGE, 2022). There is also a trend toward promoting organic and plant-based foods for increased sustainability (GCNF, 2022; Swedish Food Agency, 2022; DGE, 2022). However, if school meals are wasted due to low acceptance, the core objectives of these programs are undermined, representing a missed opportunity (Sundin et al., 2023).

Previous studies have identified several causes of food waste in school catering. Planning and preparation issues include lack of ordering and planning systems, overproduction, and whether food is prepared from scratch or heated on-site (Boschini et al., 2020; Cordingley et al., 2011; Falasconi et al., 2015). Guest-related factors include large portions, dish unpopularity, meal sensory characteristics, stressful eating environment, short lunch duration, and scheduled recess immediately after lunch (Byker et al., 2014; Cohen et al., 2013; Martins et al., 2016a; Painter et al., 2016; Sundin et al., 2023). Age of pupils has mixed effects, with some studies observing more waste with older students and others the opposite (Cordingley et al., 2011; Niaki et al., 2017; Steen et al., 2018). Lack of awareness about the sustainability impact of food waste is also a factor, although pupils may be well aware of this issue (Blondin et al., 2015; Painter et al., 2016; Wilkie et al., 2015).

Potential solutions to prevent food waste in school catering include staff training, saving food for later, serving smaller portions, measuring food waste, fostering a less stressful environment, and enhancing staff support during mealtimes (Blondin et al., 2015; Persson Osowski et al., 2022). Teacher presence during lunches can reduce plate waste (Liz Martins et al., 2020), while accurate forecasting can reduce serving waste (Malefors et al., 2021). Regular monitoring and tools like waste trackers and table talkers can significantly reduce food waste (Malefors et al., 2022b; Pancino et al., 2021). Visual, participatory, and educational nudges also show promise, although some nudging interventions may increase food waste despite higher meal participation (Metcalfe et al., 2020; Vidal-Mones et al., 2022). To strengthen the current evidence, more longitudinal studies backed up with control groups are required (Byker Shanks et al., 2017; Reynolds et al., 2019).

Current sustainability efforts in school canteens focus more on recycling or composting food waste than on prevention (dos Santos et al., 2022). Ethnographic research in Japan has identified some effective practices, such as measuring food waste, teacher involvement during meals, and integrating waste and nutrition education into the curriculum (Izumi et al., 2020). However, these practices often lack quantified evidence of success (Reynolds et al., 2019). Behavioral factors are crucial in food waste prevention, suggesting interventions should raise awareness and educate on food waste and nutrition (Derqui et al., 2018). Nutrition education mainly achieves short-term success in reducing plate waste, emphasizing the importance of the teacher role for sustained results (Martins et al., 2016a). Cross-curricular approaches, while limited in evidence, show great promise in promoting healthy eating habits in elementary pupils (Karpouzis et al., 2024; Metcalfe et al., 2020; Peralta et al., 2016). In such approaches, the pedagogic meal (PM) is a key strategy supported by Nordic policymakers (Persson Osowski and Fjellström, 2019; Sarlio-Lähteenkorva and Manninen, 2010).

There is growing interest in mitigating the environmental footprint of school meal programs, aligning with the drive for sustainable food systems under Agenda 2030 (GCNF, 2022). Food waste reduction is a crucial target, alongside dietary changes, to ensure sustainability within the planetary boundaries (Springmann et al., 2018; Willett et al., 2019). Educational approaches, similar to those promoting healthy eating, are increasingly proposed to raise awareness about food waste (Balzaretti et al., 2020; Derqui et al., 2018; Persson Osowski et al., 2022). However, robust evidence of their long-term efficacy is scarce (Reynolds et al., 2019; Sundin, 2024). This study aimed to bridge this knowledge gap by examining the short- and long-term efficacy of educational approaches, here plate waste trackers (PWT), kitchen workshops (KWS) and PM, in reducing plate waste in school canteens. The sustainability impacts (environmental, social, and economic) of these measures were then examined, where applicable, to evaluate their contribution to more sustainable school meal programs.

## 2. Material and methods

### 2.1. Study design

A quasi-experimental design with non-randomized intervention and control groups was employed (Cook and Campbell, 1979). Schools participated voluntarily in the interventions and control group data were collected from similar schools based on data availability, allowing for comparison between intervention and control groups to assess the efficacy of the plate waste reduction measures.

The study involved four main phases (Fig. 1). First, baseline food waste was quantified in a pre-intervention phase. Second, interventions involving PWT, PM, and KWS were implemented and tested, with food waste quantified to capture reduction potential. Third, food waste was quantified in a post-intervention phase to analyze long-term efficacy. Finally, an evaluation phase analyzed food waste composition, carbon footprint, nutritional, and economic data in a sustainability assessment.

### 2.2. Intervention groups

The educational approaches were tested in 10 Swedish primary schools (2020–23), three German secondary schools (2021–24), and 11 Austrian secondary schools (2022–23) (Table 1). The PWT approach was tested in 12 canteens (n = 12), PM in five (n = 5), and KWS in 11 (n = 11) (Fig. 1). The types of schools varied to accommodate the specific requirements of each intervention under local circumstances, such as literacy skills or the ability to handle kitchen equipment. The schools participating in Sweden were public schools with a buffet serving style, with half of the kitchens being satellite and the other half production kitchens. In Austria, 10 out of the 11 participating schools provided in-house meal services, while one relied on a private catering organization. In Germany, all three participating schools used a cook-and-serve system, with two kitchens operated by the local community and one by an external catering company. Outreach rates (calculated as (participants/enrolled pupils in school) * 100%) differed across interventions due to varying intervention design requirements, such as need for space or kitchen equipment availability for KWS.

### 2.3. Interventions - educational approaches

The educational approaches involved three interventions aimed at reducing plate waste: 1) testing a PWT in school canteens to raise awareness among guests (i.e. mostly pupils and in some cases also teachers eating school lunch), 2) implementing PM to raise awareness among pupils, staff, and teachers, and 3) conducting KWS to educate kitchen staff and pupils.

#### 2.3.1. Plate waste tracker

The PWT is an interactive system with a tablet computer connected to a scale beneath the food waste bin. When guests discard leftovers, the tablet displays the wasted amount and its impact. Kitchen staff can set a daily waste goal and the tablet provides feedback on meeting this goal, illustrating the waste in terms of portions, such as number of cinnamon buns. In addition, visual cues like happy or sad faces and color schemes (red or green) amplify the message, and user feedback can be given to the kitchen on why food was wasted. These latter features are optional and were used only in Swedish schools in this study (Fig. 2). The system also allows kitchen staff to record the food waste generated in the school

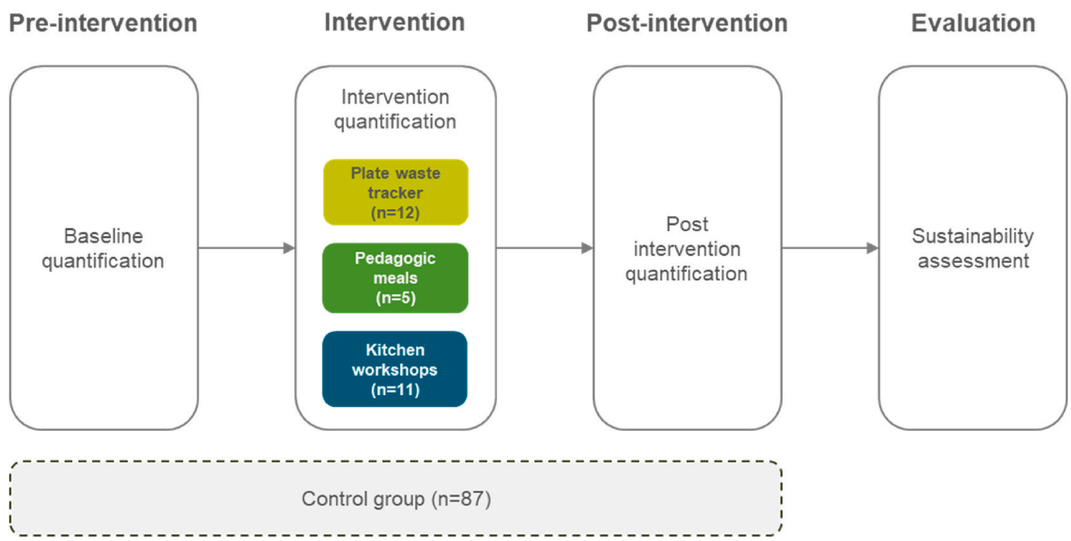


**Fig. 1.** Design of the present study and its four main phases: pre-intervention, intervention, post-intervention, and evaluation. Number of schools participating in each intervention and in the control group is indicated in brackets.

**Table 1**
Overview of participating schools and interventions tested. Outreach rate of guests indicates proportion of canteen guests reached by the intervention.

| Country | Location | School | Age of pupils [years] | Enrolled pupils [n] | Intervention type[a] | Outreach rate of guests |
|---|---|---|---|---|---|---|
| Sweden | Falköping | S1 | 7–15 | 424 | PWT | 100% |
| | Sala | S2 | 7–12 | 200 | PWT | 100% |
| | Sala | S3 | 7–12 | 200 | PWT | 100% |
| | Sala | S4 | 7–12 | 260 | PWT | 100% |
| | Sala | S5 | 7–15 | 430 | PWT | 100% |
| | Uppsala | S6 | 6–9 | 300 | PWT | 100% |
| | | | | | PM | 100% |
| | Uppsala | S7 | 6–9 | 400 | PWT | 100% |
| | | | | | PM | 35% |
| | Uppsala | S8 | 6–12 | 320 | PWT | 100% |
| | | | | | PM | 100% |
| | Uppsala | S9 | 13–15 | 480 | PWT | 100% |
| | | | | | PM | 19% |
| | Uppsala | S10 | 8–12 | 615 | PM | 45% |
| Germany | Münsterland | G1 | 10–19 | 660/178[b] | PWT | 100% |
| | Münsterland | G2 | 10–19 | 780/249[b] | PWT | 100% |
| | Münsterland | G3 | 10–16 | 435/165[b] | PWT | 100% |
| Austria | Vienna | A1 | 14–16 | 492 | KWS | 1% |
| | Graz | A2 | 14–16 | 115 | KWS | 7% |
| | Graz | A3 | 14–16 | 115 | KWS | 7% |
| | Bad Ischl | A4 | 15–17 | 324 | KWS | 2% |
| | Vienna | A5 | 14–16 | 280 | KWS | 3% |
| | Krems | A6 | 14–16 | 116 | KWS | 11% |
| | Vienna | A7 | 14–16 | 337 | KWS | 3% |
| | Vienna | A8 | 14–16 | 600 | KWS | 2% |
| | Hollabrunn | A9 | 14–16 | 670 | KWS | 1% |
| | Vienna | A10 | 14–16 | 533 | KWS | 2% |
| | Vienna | A11 | 14–16 | 157 | KWS | 9% |

[a] Plate waste tracker (PWT); pedagogic meals (PM); kitchen workshops (KWS).
[b] Number of pupils participating in school meal scheme.

canteen. The main intention with the plate waste tracker is for guests to act upon the feedback and throw away less food over time.

### *2.3.2. Pedagogic meals*

In the PM concept applied in this study, a fixed framework in terms of duration of the intervention (10 consecutive weeks) and a minimum number of teaching occasions (10) was provided to participating teachers. Within this framework, the teachers were asked to integrate themes, such as food waste prevention, nutrition and health, and food production into their existing curriculum, and keep a journal listing their chosen topics and activities. The teachers were also encouraged to use school lunches as learning occasions for the pupils, to eat school meals together with pupils, and to integrate lunches to classes before and/or after meal times. The teachers were provided with tips on age-appropriate teaching materials available online, free of charge, suitable for natural and social sciences, arts, and language classes. They were given the freedom to use these materials or their own materials for the teaching occasions. Moreover, at the beginning of the intervention phase, the catering staff received a lecture on how to reduce food waste in the school kitchen and canteen. During the intervention, food waste-

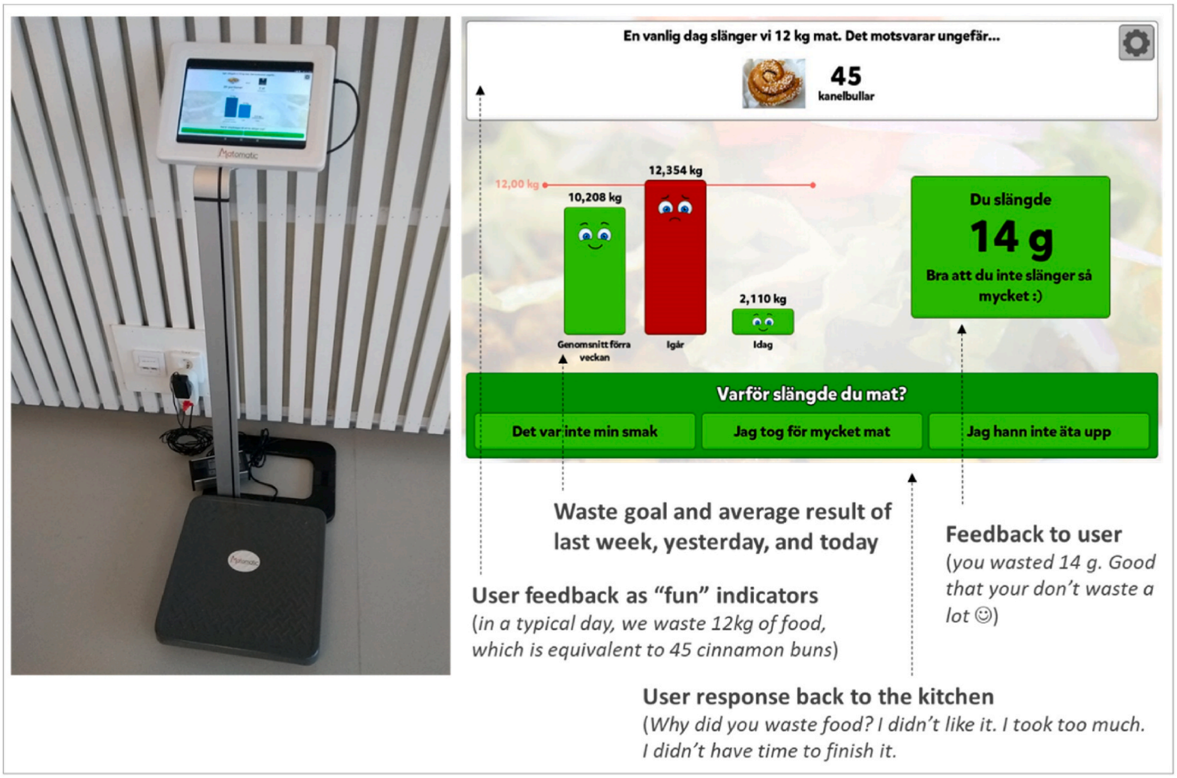


**Fig. 2.** Plate waste tracker (PWT) in operation and (right) screen shot of its display screen showing various communications to waste generators at individual and group level in terms of meeting the waste goal set by kitchen staff.

related posters and table talkers were placed in the canteens. In addition, school kitchen staff supported the teachers by supplying them with plate waste quantification data and food items such as fresh fruit and vegetables that could be used during teaching activities.

#### 2.3.3. Kitchen workshops

The KWS comprised a combination of a lecture or knowledge transfer and a cooking workshop. As an introduction, a lecture was given with general information about food waste. Pupils were informed about the different types of food waste and loss, and the huge quantities generated each year. Initial tips and tricks for avoiding waste in a commercial kitchen and at home were also provided. The second part was a practical workshop where, under the guidance of a renowned chef, the students prepared some delicious dishes (Fig. 3). The aim was to teach them in a playful way why and how to avoid food waste, using unusual ingredients or parts of foods that are edible, but rarely used in cooking.

### 2.4. Control groups

Control-group data were collected from 55 public primary schools in Sweden and 32 primary and secondary schools in Austria that are in the same geographical areas as the intervention groups and serve similar ages of pupils. These control schools did not actively aim to reduce food waste during the intervention. The Swedish data served as the control for the PWT and PM, while Austrian data served as the control for the KWS. No control group data was available from Germany. The control

**Fig. 3.** Kitchen workshop (KWS) in a school in Austria, where pupils learned to cook delicious meals with zero waste.

groups were used to check whether food waste reductions were due to interventions or other factors. The Swedish data were divided into similar periods as the data from the intervention groups (i.e., baseline, intervention, and post-intervention), while the Austrian data were divided into two periods, with the first of these representing baseline and the second the intervention and post-intervention.

### 2.5. Data collection

Swedish canteens used pre-existing food waste data from 2012 onwards, averaging five years of baseline data. These data were collected by kitchen staff during their daily routines, typically in spring and autumn semester to capture seasonal variations. Food waste was weighed using kitchen scales and recorded in kilograms, while the number of guests was noted to calculate plate waste per guest (Malefors et al., 2022). German and Austrian canteens started collecting baseline data in a similar manner for one month before starting interventions. Data collection was conducted by kitchen staff after a thorough briefing by the researchers, with the exception of one school in Germany where waste measurement was carried out by the researchers. Another exception was that the PWT was used to quantify baseline data in four out five school canteens where the PM intervention was implemented.

Variations in Covid-19 management affected the starting point, duration, and frequency of data collection (Appendix B). In one German canteen, baseline data collection started in late 2021, whereas in the other two canteens it started in late 2022, lasting approximately one month. In Austria, baseline data collection began in late 2022 and was concluded in late 2023, with quantification for at least one month before interventions.

The PWT intervention was implemented in three canteens in 2020, six in 2021, and three in 2023 (Appendix B). The device was tested over 1–6 months (average five months) with post-intervention data collected from two canteens on average 12 months later, averaging eight months with a data gap (Appendix B). Five of the 12 canteens continued using the PWT during the post-intervention quantification period, whereas seven canteens returned to their regular procedure as described above.

The PM intervention commenced in 2022, lasted for 10 consecutive weeks and included an additional one-month intervention quantification at a minimum before commencing with post-intervention quantification (Appendix B). Four canteens continued measuring their plate waste using the PWT, while the fifth canteen measured waste manually as described above. At the time of commencement of the post-intervention quantification, which lasted seven months on average, three canteens were continuing to use the PWT to measure their plate waste, whereas the other two canteens measured waste manually.

The KWS intervention occurred over one day during 2023, followed by one month of intervention quantification, after which any data collected were considered in post-intervention quantification (Appendix B).

In addition to plate waste, serving waste was quantified and analyzed to examine possible unintended spillover effects. Serving waste includes food served but not consumed, while plate waste includes leftovers and inedible items such as napkins (Malefors, 2022). In Austrian canteens, data collection combined kitchen and serving waste (food preparation scraps, excess food, and buffet leftovers) into a single measurement, alongside plate waste.

### 2.6. Analysis

To compare the different interventions during their different phases, two metrics were calculated: “plate waste per guest per day” and “serving waste per guest per day”. Guest refers to those eating school lunch in school canteens, typically pupils and occasionally their teachers. Only days where schools reported serving waste, plate waste, and number of guests were considered in the analysis. Additionally, any instances of obvious reporting errors were corrected, such as reporting food waste quantities in grams instead of kilograms.

The material used for analysis of plate waste, including the baseline, intervention, and post-intervention for all the interventions and control groups, comprised 41,386 observations (in total from 115 school canteens), as summarized in Table 2.

To increase the reliability of plate waste analysis (g/guest), the median value was used to mitigate the influence of outliers. Results for both the intervention and control groups are presented as grouped scatter plots, with 95% confidence intervals calculated using the normal approximation method to assess the precision and potential significance of observed differences. By examining the overlap or separation of confidence intervals, the potential significance of results was inferred.

Intervention results were compared across the baseline, intervention, and post-intervention periods, with control group results presented similarly to identify changes in plate waste outside the intervention. Serving waste was also analyzed and compared with that reported for the control group. When reductions were observed in both groups, the control group’s reduction was subtracted from the intervention group’s reduction (g/guest).

### 2.7. Sustainability assessment

For educational approaches resulting in significant reductions in food waste, a sustainability assessment covering environmental, social and economic impacts was conducted. The economic impact of all educational approaches was also assessed.

#### 2.7.1. Environmental impact assessment

To assess the average annual environmental impact mitigation of an intervention per school, the climate mitigation impact of the food waste reduction was calculated using a carbon footprint of 1.0 kg $CO_2$e/kg plate waste (Sundin et al., 2024). The calculation was based on the average food waste reduction minus any reduction observed in the control group, average number of daily guests (298), and annual number of school days (178). The following assumptions were made: 1) plate waste reduction took place in similar proportions to the composition reported by Sundin et al. (2024); and 2) the reduction substituted for similar foods. Environmental impacts related to conducting the interventions, such as the use of electronic devices or electricity, were excluded from the assessment, despite their potential significance (European Parliament, 2020). To make the results more tangible, the $CO_2$e savings were converted into an equivalent number of school meals based on a carbon footprint of 0.83 kg $CO_2$e per meal (Eustachio Colombo et al., 2020).

#### 2.7.2. Social impact assessment

To assess the social impact of an intervention, average annual reductions in energy and nutrient losses per school were calculated based on the composition of plate waste and corresponding nutrient loss reported by Sundin et al. (2024). As indicators, energy, protein, and dietary fiber per kg plate waste were used, due to their high value for both human and planetary health. In addition, the calculations were based on the average amount of food waste reduced, average number of daily

**Table 2**
Number of observations related to plate waste, specified for each intervention[a], including the baseline, intervention, post-intervention, and control group quantifications. In total, the study material comprised 41,386 observations.

| | Baseline | Intervention | Post-intervention | Control group |
|---|---|---|---|---|
| PWT | 1235 | 634 | 411 | 18,659 |
| PM | 726 | 149 | 454 | 18,649 |
| KWS | 238 | 132 | 63 | 36 |
| **Total** | 2199 | 915 | 928 | 37,344 |

[a] Plate waste tracker (PWT); pedagogic meals (PM); kitchen workshops (KWS).

guests (298), and annual number of school days (178). The results were made more tangible by comparing the energy and nutrient savings to an equivalent amount of school meals covering 30% of the daily requirements of pupils according to the Nordic nutrition recommendations (Nordic Council of Ministers, 2023).

#### 2.7.3. Economic impact assessment

To assess the economic impact of the interventions tested, cost-benefit analysis was conducted based on the difference between the cost of implementation of the interventions and the economic benefits accrued through the reduction in plate and/or serving waste per school during one year (Caldeira et al., 2019). In addition, the payback period of the investment was calculated where applicable.

For the PWT, the cost of purchasing a tracker (18,000 SEK, or 1600 EUR) was included as the only cost factor. To demonstrate differences in the cost-benefit structures between Sweden and Germany, an assessment of the PWT implemented in Germany was also conducted. Compared with Sweden, where staff were employed on a monthly salary and expected to integrate use of the PWT into their ordinary working hours, in Germany staff expenses were included based on an hourly rate of 24.82 EUR and working time of 5 h/year and 5 min/day to operate the PWT. Another difference was that all children enrolled in schools in Sweden participated in school meals, while this was not the case in Germany (see Table 1). The German calculation was based on the average reduction in plate and serving waste (assuming no changes took place in control group), average number of daily guests (144), and annual number of school days (178).

For the PM, the costs included paid lunches for an average of 13 teachers per school at 46 SEK (4 EUR) per meal over a 10-week period. Since PM are intended for continuous implementation, a yearly cost estimate was also calculated, assuming that 50% of the teaching staff (19 teachers) participate in school lunches throughout the entire school year. For the KWS, the costs for the food waste reduction experts and the professional chef were calculated as 300 EUR and 660 EUR per workshop, respectively.

The benefit calculation was based on the average amount of food waste reduced, from which any reduction in the control group was deducted when applicable, average number of daily guests, annual number of school days (178), and the purchasing price of school meal ingredients. In Sweden, the latter was assessed with 33 SEK/kg (3 EUR) (Sundin et al., 2024) (Appendix A). In Germany, a value of 2.44 EUR/meal was used, which was adjusted for inflation effects (DGE, 2022). In Austria, a purchasing price of 5.86 EUR per school meal was used.

## 3. Results

### 3.1. Food waste reduction potential of educational approaches

#### 3.1.1. Plate waste tracker

Among the three educational approaches tested, the PWT designed to raise awareness of waste among lunch guests resulted in a significant reduction in plate waste, of 17% from the baseline (23 g/guest) to intervention quantification (19 g/guest), while no change in plate waste

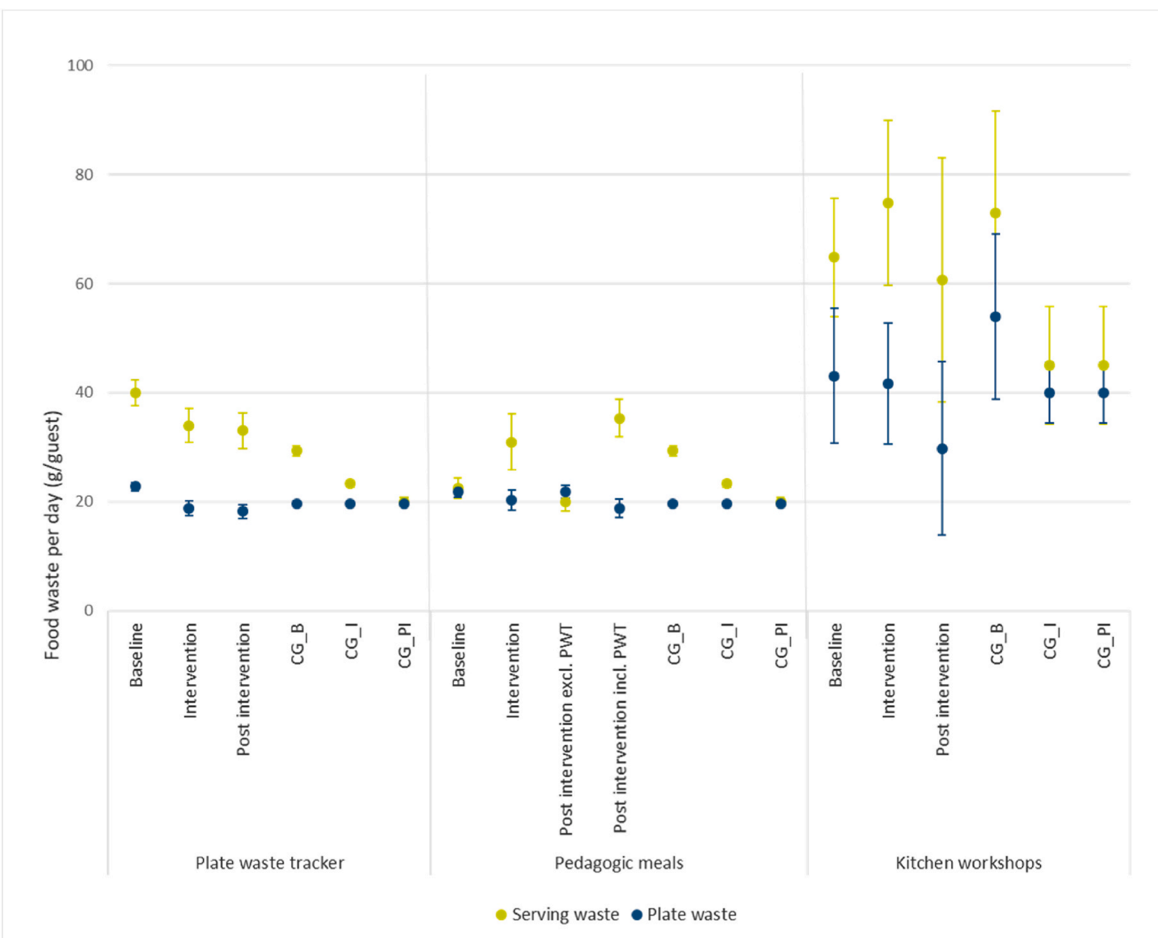


**Fig. 4.** Median food waste per guest in grams, divided into serving and plate waste, with uncertainty indicated as 95% confidence interval. Baseline (B), intervention (I), and post-intervention (PI) quantification values are presented for interventions involving the plate waste tracker, pedagogic meals, and kitchen workshop interventions in comparison with a control group (CG).

level was observed in the control group (Fig. 4). The PWT-induced reduction persisted in the long-term, with post-intervention quantification indicating a significant reduction of 22% from the baseline and no significant difference between intervention and post-intervention quantifications (18 g/guest).

On ruling out any unintended spillover effect from plate waste to serving waste, a significant reduction in serving waste was also observed. In comparison with the baseline of 40 g/guest, a reduction of 6 g/guest (16%) was observed in the intervention quantification (34 g/guest) and a reduction of 7 g/guest (18%) in the post-intervention quantification (33 g/guest). However, significant reductions of 6 g/guest (21%) in the intervention period and 9 g/guest (32%) at post-intervention were also observed in the control group, in comparison with the baseline of 29 g/guest.

### 3.1.2. Pedagogic meals

The PM intervention resulted in a 7% reduction in plate waste from baseline (22 g/guest) to intervention (20 g/guest), but this reduction was not statistically significant (Fig. 4). However, a significant reduction in plate waste of 14% was observed at post-intervention quantification (19 g/guest) in comparison with the baseline (22 g/guest) in the canteens using PWT. In canteens manually measuring their plate waste, plate waste rebounded to the baseline level (22 g/guest) at post-intervention. No change was seen in the control group. However, there was a significant increase of 38% in serving waste at intervention (31 g/guest) in comparison with the baseline (23 g/guest) (Fig. 4). At post-intervention, canteens using the PWT continued to show an increased amount of serving waste (35 g/guest), whereas canteens not using the PWT had serving waste of 20 g/guest, with no significant difference to the baseline. Meanwhile, the control group significantly reduced serving waste from the baseline of 29 g/guest to intervention (23 g/guest) and post-intervention (20 g/guest).

Based on teachers' journals, three of the schools participating in PM had on average 16 teaching occasions, one had 10, and one had fewer than 10. Two schools spent over 70% of their sessions on food waste topics, one spent 50%, and two spent 20%. On average, 50% of the time was focused on food waste, 30% on nutrition and health, and 20% on food production topics. Examples of materials and topics used for the PM included short films and news articles about retail and consumer food waste, and food waste prevention and management, leading to classroom discussions. Furthermore, calculations were conducted based on food waste statistics from the school kitchens.

### 3.1.3. Kitchen workshops

The KWS resulted in a 3% reduction of plate waste from baseline (43 g/guest) to intervention (42 g/guest), and a 31% reduction from baseline to post-intervention (30 g/guest), although the observed differences were considered non-significant. A reduction of 26% (from 54 to 40 g/guest) was observed in the control group, also considered non-significant. Further, an increase of 15% in serving waste from baseline (65 g/guest) to intervention (75 g/guest) was observed, although this returned to the baseline levels at post-intervention (61 g/guest). Meanwhile, a reduction of 38% was observed in the control group.

## 3.2. Sustainability impacts of educational approaches

Estimated reductions in sustainability impacts (environmental, social, and economic) for the intervention (PWT) observed to bring about a significant reduction in waste are presented in Table 3.

### 3.2.1. Environmental impact

The climate mitigation impact of PWT through plate waste reduction amounted to 212 kg $CO_2e$ per school and year, based on the average daily reduction in plate waste of 4 g/guest. In other words, the abated environmental impact from reduced plate waste corresponded to the $CO_2e$ of 255 school meals. No environmental mitigation was included for PM and KWS due to the lack of significant waste reduction observed in the findings.

**Table 3**
Annual reduction in environmental, social, and economic impacts resulting from prevented plate waste due to implementation of the plate waste tracker (PWT).

| Prevented plate waste (kg/school and year) | 212 |
|---|---|
| **Environmental impact reduction** | |
| Carbon footprint (kg $CO_2e$/school and year) | 212 |
| *Corresponding number of school meals*[a] | *255* |
| **Social impact reduction** | |
| Energy (MJ/school and year) | 1018 |
| *Corresponding number of school meals*[b] | *339* |
| Dietary fiber (g/school and year) | 4031 |
| *Corresponding number of school meals*[b] | *538* |
| Protein (g/school and year) | 12,094 |
| *Corresponding number of school meals*[b] | *920* |
| **Economic impact reduction** | |
| **Benefits** (abated plate waste, SEK (EUR)/school and year)[c] | 7002 (620) |
| **Costs** (plate waste tracker, SEK (EUR)/school) | 18,000 (1600) |
| **Net benefits SEK (EUR)** | −10,998 (−980) |

[a] Based on carbon footprint of 0.83 kg CO2e/meal (Eustachio Colombo et al., 2020).
[b] Number of school meals fulfilling 30% of the daily energy (10 MJ), fiber (25 g), and protein (44 g) requirement of schoolchildren (averaged for 7–16 years of age).
[c] Based on 4 g/guest plate waste reduction, 298 guests/day, 178 school days/year, and cost of 33 SEK/kg plate waste.

### 3.2.2. Social impact

The abated nutrient losses due to reduced plate waste using the PWT amounted to 1018 MJ (243,000 kcal) of energy, 12 kg protein, and 4 kg dietary fiber per school and year. These nutrient savings corresponded to 339, 920, and 538 school meals, respectively, based on fulfilling 30% of the respective daily nutrition needs of pupils. No social impact mitigation was included for PM and KWS due to the lack of significant waste reduction observed in the findings.

### 3.2.3. Economic impact

The net economic benefits of all three interventions were negative when calculated on a first-year basis. The net benefit of the PWT over all participating schools was −10,998 SEK (−980 EUR) per school (Table 3), so the investment costs were recouped and positive net benefits generated during the third year of use. In the case of German school catering establishments, the net benefit of the PWT amounted to −121 EUR per school and year based on a food waste reduction of 15 g per meal (5 g plate waste and 10 g serving waste reduction) and 144 daily meals served (Table 4). The break-even point for the PWT investment in that case was reached when serving a minimum of 153 meals per school, or the investment costs were recouped during the second year of use.

The net economic benefit of the PM and KWS interventions was negative, as there was no significant reduction in waste and therefore no benefit was gained, while the cost of the interventions amounted to 29,900 SEK (2600 EUR) and 960 EUR per school and year, respectively.

**Table 4**
A breakdown of the factors contributing to the net economic benefit results calculated for the first year of implementing and using the plate waste tracker in German school catering establishments.

| Plate waste tracker (Germany) | |
|---|---|
| Prevented plate waste (kg/year) | 128 |
| Prevented serving waste (kg/year) | 256 |
| Prevented total waste (kg/year) | 384 |
| **Economic benefits** (EUR/school and year) | 1971 |
| **Costs** (staff resources EUR) | 492 |
| (plate waste tracker EUR) | 1600 |
| **Net benefits** (EUR/school and year) | **−121** |

Additionally, the annual cost of continuous implementation of PM was estimated at 154,000 SEK (13,000 EUR) per school.

## 4. Discussion

This study investigated the sustainability outcomes of educational approaches as a plate waste reduction measure in school canteens in three European countries, Austria, Germany, and Sweden. The results showed significant waste reduction potential for a PWT device designed to raise awareness of food waste among lunch guests. The PWT reduced plate waste by 17% (4 g/guest) from the baseline of 23 g/guest. This reduction was also sustained in the long-term (up to 15 months after the intervention implementation). In addition to mitigating environmental impacts by 212 kg $CO_2$e per school and year, the PWT also saved valuable nutrients, such as protein (12 kg per school and year) and fiber (4 kg per school and year). On the other hand, no significant waste reduction was observed for the interventions of PM and KWS in this study. Educational methods, such as PM and workshops, are often seen as entailing potential for raising awareness and reducing food waste (Balzaretti et al., 2020; Derqui et al., 2018; Engström and Carlsson-Kanyama, 2004; Martins et al., 2016b; Painter et al., 2016). However, our results did not support this expectation. Reasons for this failure are identified with the low outreach rate of pupils as well as the diffuse flow of information (compared to a more targeted information flow from the PWT).

The small sample size of schools testing the PM (n = 5) and the low outreach rates of pupils, especially with KWS (4%) compared with PWT (100%) and PM (60%) are shortcomings for testing the efficacy of interventions in practice. The COVID-19 pandemic was also challenging for implementation of the interventions and conducting quantifications, due to lockdown and/or restrained staff resources contributing to reduced sample sizes and datasets. Moreover, interventions such as PM may be hindered by teachers' high stress levels and lack of time (Berggren et al., 2021), which can limit their ability to participate in additional activities, such as implementing new food waste reduction programs (Agyapong et al., 2023). Adding PM as a distinct topic could allow more time for teachers, but would come at the expense of existing subjects, given the fixed hours allocated for each topic in the curriculum. Furthermore, PWT may be easier to standardize as a food waste prevention method, whereas PM could be more subjective and influenced by the personal enthusiasm level of individual teachers (Persson Osowski et al., 2013), which may have impacted the results in this study. While the framework given to the participating teachers for the PM specified the duration and frequency of the PM, it offered them great freedom in designing the content of the intervention and thus lacked standardization, which may have been a drawback. Thus, further studies addressing these limitations are warranted.

A main difference between PWT and other educational approaches, such as PM and KWS, is furthermore the direct access to those guests who generate waste, rather than addressing all pupils, including those who do not waste any food. A previous study found that the majority of plate waste (60%) is generated by a small minority of canteen guests (20%), while 40% of guests do not waste any food (Malefors et al., 2024), highlighting untapped food waste prevention potential in school canteens. This raises the challenge of identifying waste generators and effectively reaching out to them. Since the PWT communicates directly to those wasting food, it has the advantage of reaching out to these individuals without personally singling them out. Future studies are warranted to identify the type of message that best influences the behavior of waste generators.

The findings obtained in this study are noteworthy for several reasons. The novelty of the work lay in investigating the long-term efficacy of interventions while also using control groups to verify the results. Control group data revealed that there were changes even in schools without interventions, highlighting the necessity of control data for accurate interpretation of results. Importantly, data confirming the long-term efficacy of PWT indicated sustained plate waste *prevention*, a top priority in food waste action (European Commission, 2020). Once successfully implemented, the tracker appears to become an integral and permanent part of operations, impacting new pupils and staff as they join (Malefors, 2022), possibly explaining the enduring results.

Previous research has highlighted the importance of controlling for possible unwanted spillover effects between different types of food waste in canteens when implementing reduction measures. For example, Malefors et al. (2022b) found that tasting spoons reduced plate waste, but increased serving waste. However, spillover effects can also be beneficial. The PWT implemented in Germany, although targeting plate waste, appeared to have an even larger waste-reducing effect on serving waste (although non-significant). Serving waste is often a greater problem in primary school canteens than plate waste, while the opposite is true in secondary schools (Eustachio Colombo et al., 2020; Malefors, 2022). In the present study, the baseline for plate waste when testing the PWT was 23 g/guest, while the baseline for serving waste was 40 g/guest. The participating schools thus had a lower range of plate waste (21–38 g/guest), but a higher range of serving waste (23–28 g/guest), than recorded in previous studies (Malefors, 2022). This indicates that while plate waste was at a relatively low level, there was still significant plate waste prevention potential and associated cost, nutrient, and environmental savings. Therefore, PWT could become best practice, especially in sufficiently large canteens with high initial amounts of plate and possibly even serving waste. Further studies are needed to confirm the potential of the PWT in such contexts.

The economic assessment of PWT implementation in Germany highlighted several interesting factors influencing the net results. Not all enrolled pupils participated in the school meals program (144), which negatively impacted the net results in comparison with the overall PWT results with a higher number of participants (298). However, the addition of just nine more participants in German schools would have achieved break-even already in the first year. The results indicated a dual benefit, in reducing both plate and serving waste, as also found by Malefors et al. (2022b), addressing two issues with one measure. This generated sufficient economic benefits to cover the investment by the second year, despite including staff costs. Additionally, preventing serving waste likely leads to production cost savings, while plate waste prevention avoids resource wastage by ensuring food is eaten instead of wasted, although this is yet to be confirmed and requires future study.

Demonstrating the long-term efficacy of interventions is crucial for transitioning from merely testing reduction measures to real-life implementation. Overcoming barriers such as high stress levels, lack of time, comfort with old habits, and implementation costs is essential for the implementation process (Laitinen et al., 2023; Persson Osowski et al., 2022). Management decisions are pivotal, as the initial investment often has to be justified by long-term savings (Kaur et al., 2021). The PWT proved to be cost-effective, paying for itself by the second or third year after installation. This short payback period makes it a highly effective investment (Kagan, 2024).

The findings in the present study should be interpreted in light of strengths and limitations of the work. While we utilized an average carbon footprint for assessing plate waste based on Swedish school meal composition (Sundin et al., 2024), it is important to acknowledge that not all food waste necessarily carries the same carbon footprint. Meat, for example, has a significantly higher carbon footprint compared to vegetables. Therefore, variations in the proportions of meat and plant-based foods in other countries' meal compositions may influence the generalizability of our findings. While the challenges posed by each country's unique food culture and organizational structures can be seen as a limitation, the diversity can also be viewed as a strength. The contextual differences may affect comparability, however, the core principles of each intervention have universal relevance, highlighting the need for contextual adaptation in generalizing the findings in future studies.

European school meal programs are generally more mature in global terms, with comprehensive policies, widespread coverage, and high nutritional standards (GCNF, 2022). However, the structures of these programs vary across Europe due to cultural, economic, and policy differences (European Commission, 2023). A key limitation in this study was the low sample size, which reduced the overall certainty of some results due to increased variability and wider confidence intervals. A strength was the ability to test different educational approaches across various European countries, capturing key differences in the school meal landscape. Sweden provides universal free meals, while Germany offers targeted free meals and Austria provides free meals in parts of the country, reflecting the overall variation in Europe (Guio, 2023). However, governance and operational differences exist not only between countries, but also within countries and municipalities, and a small sample size may not represent this variety, leading to potential biases and limiting generalizability. Despite these differences, all school meal programs share the goals of nourishing children and reducing their food waste. European school meal programs often benefit from decades-long implementation, with purpose-built facilities, well-established food service systems, and adequate funding models supporting sustainable operations (Manson et al., 2024). However, due to the high variability, no single design fits all contexts, highlighting the need to consider specific local contexts when developing food waste reduction measures.

This study showed significant potential of a PWT device in reducing food waste, whereas PM and KWS struggled to reach all pupils. Technical solutions like PWT offer cost benefits over staff-intensive measures like PM. However, the results were also influenced by the limitation that the focus was on quantifiable aspects only. The success of PWT, especially in Swedish canteens, likely also stems from staff's prior knowledge and level of engagement, and municipalities' decade-long efforts to reduce food waste, thus creating a mature environment for the PWT. Staff discussions about food waste with pupils were likely to enhance the PWT's efficacy, indicating the importance of the social context in technical innovations. Thus, while technical solutions like the PWT can be highly effective and cost-efficient, their success is deeply intertwined with the social environment and staff engagement and it is important not to overlook the social context of any technical innovation. Policymakers should therefore implement tools like PWT along with social interventions such as KWS or PM as standard solutions in school canteens. A reasonable approach would be to start with schools where other simpler waste-reducing activities like reusing leftovers, setting goals, and communicating with guests are already in place (Eriksson et al., 2023). Starting with the basic measures and progressively adding more can be the most cost-efficient way to reduce food waste, save money, and lower environmental emissions, which are necessary in transition to a sustainable food system.

## 5. Conclusions

The PWT significantly reduced plate waste (by 17%), mitigating environmental impacts (by 212 kg $CO_2$e per school and year) and losses of nutrients such as protein (12 kg per school and year) and fiber (4 kg per school and year). These reductions were maintained in the long term, indicating substantial food waste prevention potential over time rather than an initial reduction. In addition, PWT proved highly cost-efficient, with a payback period of only 1–2 years. The PM and KWS approaches achieved non-significant reductions in food waste reduction (7% and 3%, respectively), and require further research. In conclusion, the upfront costs of implementing food waste reduction measures in school canteens can be significant and barriers such as lack of time among kitchen staff need to be overcome. However, the long-term benefits in terms of all three sustainability perspectives (environmental, economic, and social) make these initiatives worthwhile investments for more sustainable school meal schemes.

## CRediT authorship contribution statement

**Niina Sundin:** Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Christopher Malefors:** Writing – review & editing, Visualization, Methodology, Investigation, Formal analysis, Data curation. **Christina Strotmann:** Writing – review & editing, Methodology, Investigation, Formal analysis, Data curation. **Daniel Orth:** Writing – review & editing, Methodology, Investigation, Formal analysis, Data curation. **Kevin Kaltenbrunner:** Writing – review & editing, Methodology, Investigation, Formal analysis, Data curation. **Gudrun Obersteiner:** Writing – review & editing, Data curation. **Silvia Scherhaufer:** Writing – review & editing. **Amanda Sjölund:** Writing – review & editing. **Christine Persson Osowski:** Writing – review & editing. **Ingrid Strid:** Writing – review & editing. **Mattias Eriksson:** Writing – review & editing, Methodology, Funding acquisition.

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## Declaration of competing interest

The authors declare the following financial interests/personal relationships, which may be considered as potential competing interests: The authors Christopher Malefors and Mattias Eriksson developed the PWT device and own the rights to the innovation, through the company Matomatic AB. There is a potential conflict of interest as these authors have a financial interest in the innovation.

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## Appendix A

**Table A1**
Purchasing price of food ingredients for school meals in Uppsala Municipality, Sweden, in 2023

| Food item | Purchasing price (SEK/kg) |
|---|---|
| Pasta | 17 |
| Potato | 18.4 |
| Rice | 27 |
| Chicken | 76.5 |
| Pork | |
| Pork | 79 |
| Ham | 86 |
| Beef | |
| Beef | 101 |
| Meatballs | 94.5 |
| Minced meat | 108.5 |
| Fish | 95.5 |
| Cheese | 77 |
| Eggs | 42 |
| Pancakes | 40 |
| Vegetarian meal options (lasagna, quorn, vegetarian patties) | |
| Quorn | 79 |
| Vegan burger | 60 |
| Falafel | 47 |
| Vegan mince | 60 |
| | |
| Salad buffet: | |
| Broccoli | 32 |
| Tomato | 43 |
| Lettuce | 20 |
| Olives | 40 |
| Carrots | 25 |
| Bell peppers | 70 |
| Beans | 40 |
| Chickpeas | 39 |
| Bread | |
| Hard bread | 60 |
| Soft bread | 33 |
| Hamburger bread | 37 |

## Appendix B

**Table B1**
Quantification periods, including start and stop dates, and number of observations for each school canteen participating in the interventions

| Intervention group | | Baseline quantification | | | Intervention implemented | Intervention quantification | | | Post intervention quantificaton | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | School | Start | Stop | # observations | | Start | Stop | # observations | Start | Stop | # observations |
| **PWT** | S1 | 2014-03-31 | 2019-10-25 | 94 | 2021-04-06 | 2021-04-06 | 2021-04-16 | 9 | 2021-10-11 | 2023-02-20 | 11 |
| | S2 | 2014-11-24 | 2019-04-05 | 113 | 2020-04-02 | 2020-04-02 | 2021-04-30 | 36 | 2021-09-27 | 2022-04-29 | 10 |
| | S3 | 2015-03-02 | 2020-10-09 | 130 | 2021-04-26 | 2021-04-26 | 2021-06-10 | 32 | 2021-09-27 | 2022-04-29 | 10 |
| | S4 | 2014-11-24 | 2019-04-05 | 121 | 2020-04-01 | 2020-04-01 | 2020-10-09 | 26 | 2021-04-26 | 2021-10-08 | 15 |
| | S5 | 2014-11-24 | 2019-04-05 | 115 | 2020-04-01 | 2020-04-01 | 2020-10-09 | 34 | 2021-04-26 | 2022-04-29 | 10 |
| | S6 | 2012-10-08 | 2021-06-15 | 99 | 2021-08-19 | 2021-08-19 | 2022-02-25 | 114 | 2022-06-07 | 2022-12-27 | 64 |
| | S7 | 2012-10-08 | 2021-03-26 | 129 | 2021-04-06 | 2021-04-06 | 2022-01-14 | 108 | 2022-05-01 | 2023-02-06 | 88 |
| | S8 | 2015-10-16 | 2020-12-18 | 90 | 2021-01-12 | 2021-01-12 | 2021-09-15 | 143 | 2022-06-07 | 2022-12-23 | 108 |
| | S9 | 2012-10-08 | 2021-08-31 | 286 | 2021-09-24 | 2021-09-24 | 2022-02-25 | 78 | 2022-10-03 | 2023-01-31 | 72 |
| | G1 | 2021-12-06 | 2022-01-17 | 20 | 2023-04-17 | 2023-04-17 | 2023-05-26 | 26 | – | – | 0 |

(continued on next page)

**Table B1** (*continued*)

| Intervention group | School | Baseline quantification Start | Stop | # observations | Intervention implemented | Intervention quantification Start | Stop | # observations | Post intervention quantificaton Start | Stop | # observations |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | G2 | 2022-08-29 | 2022-09-30 | 25 | 2023-03-01 | 2023-03-01 | 2023-03-29 | 17 | – | – | 0 |
| | G3 | 2022-10-17 | 2022-11-11 | 13 | 2023-05-03 | 2023-05-03 | 2023-06-05 | 11 | 2024-02-05 | 2024-03-22 | 23 |
| **PM** | S6 | 2021-08-19 | 2022-02-25 | 114 | 2022-02-28 | 2022-02-28 | 2022-04-29 | 32 | 2022-06-07 | 2022-12-27 | 64 |
| | S7 | 2021-04-06 | 2022-01-14 | 108 | 2022-01-17 | 2022-01-17 | 2022-03-24 | 37 | 2022-05-01 | 2023-02-06 | 88 |
| | S8 | 2021-01-12 | 2022-02-25 | 143 | 2022-01-24 | 2022-02-28 | 2022-04-29 | 36 | 2022-06-07 | 2022-12-23 | 108 |
| | S9 | 2021-09-24 | 2022-02-25 | 78 | 2022-02-28 | 2022-02-28 | 2022-04-01 | 22 | 2022-10-03 | 2023-01-31 | 72 |
| | S10 | 2012-10-08 | 2021-09-28 | 283 | 2022-01-24 | 2022-02-28 | 2022-04-01 | 22 | 2022-06-07 | 2023-01-31 | 122 |
| **KWS** | A1 | 2022-11-07 | 2022-12-15 | 16 | 2023-01-23 | – | – | 0 | 2023-03-21 | 2023-12-14 | 28 |
| | A2 | 2023-02-13 | 2023-03-16 | 17 | 2023-03-22 | 2023-03-24 | 2023-04-21 | 13 | 2023-04-24 | 2023-04-28 | 5 |
| | A3 | 2023-02-16 | 2023-03-21 | 13 | 2023-03-22 | 2023-03-23 | 2023-04-19 | 12 | 2023-04-25 | 2023-05-04 | 7 |
| | A4 | 2023-03-22 | 2023-04-11 | 7 | 2023-04-12 | 2023-04-12 | 2023-04-26 | 9 | – | – | 0 |
| | A5 | 2023-03-20 | 2023-04-19 | 13 | 2023-04-19 | 2023-04-20 | 2023-05-15 | 7 | – | – | 0 |
| | A6 | 2023-03-27 | 2023-05-08 | 60 | 2023-05-09 | 2023-05-09 | 2023-06-01 | 14 | – | – | 0 |
| | A7 | 2023-04-24 | 2023-05-22 | 61 | 2023-05-23 | 2023-05-24 | 2023-06-22 | 45 | 2023-06-23 | 2023-06-29 | 8 |
| | A8 | 2023-02-20 | 2023-03-30 | 24 | 2023-09-19 | 2023-10-02 | 2023-10-17 | 10 | 2023-10-19 | 2023-11-14 | 9 |
| | A9 | 2023-10-02 | 2023-10-18 | 13 | 2023-10-19 | 2023-10-20 | 2023-11-17 | 12 | 2023-11-20 | 2023-11-27 | 6 |
| | A10 | 2023-10-16 | 2023-11-07 | 10 | 2023-11-08 | 2023-11-08 | 2023-11-14 | 5 | – | – | 0 |
| | A11 | 2023-11-09 | 2023-11-16 | 4 | 2023-11-23 | 2023-11-23 | 2023-12-14 | 5 | – | – | 0 |

## Data availability

Data will be made available on request.

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