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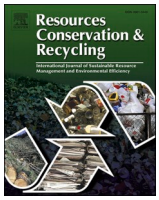

Full length article

Food waste changes in the Swedish public catering sector in relation to global reduction targets

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ABSTRACT

Global food waste reductions are difficult to evaluate. The global ambition is to halve food waste by 2030. In this study, eight years of food waste quantification data from Swedish public catering were used to monitor changes and evaluate progress towards global reduction targets. A 15–30% reduction was observed and the current trend was a declining level of food waste within the sector. The goal of halving food waste by 2030 appears to be achievable, provided that all canteens perform in line with those studied. However, the canteens studied may represent the best-performing, so the actual change or current levels of food waste may have been underestimated. The present situation (2020) is that approximately 19,000–21,000 tonnes of food waste are generated annually in Swedish preschools and schools. Therefore, canteens in these establishments need appropriate tools to monitor waste levels and progress, and incentives encouraging them to continue reducing food waste.

1. Introduction

High food waste levels are attracting global attention, and food waste reduction is one of the targets within the sustainable development framework developed by the United Nations (United Nations 2015). The target states that "By 2030, halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses". The overall goal is to contribute to a more sustainable food system. However, setting goals for food waste reduction is not a new phenomenon. For instance, during the first World Food Conference in 1974, reducing post-harvest losses was identified as part of the solution in addressing world hunger. Overall estimates of 15% post-harvest losses were suggested at that time and a 50% reduction by 1985 was proposed. However, a study in 2010 concluded that no progress had been made towards achieving the 1985 post-harvest loss reduction target (Parfitt et al., 2010). The UK was early in acknowledging that landfilling of biodegradable municipal waste was an environmental problem and set targets to reduce this fraction to 75% by 2010, with the eventual aim of landfilling only 35% of the 1995 amount (DEFRA, Ev 47 2005). In 2008, the Stockholm International Water Institute proposed that food loss and waste should be halved by 2025 and argued that food waste is water waste (Lundqvist et al., 2008). Some national goals have also been proposed in Sweden, e.g., the Swedish Environmental Protection Agency initially suggested reducing food waste by 20% between 2010 and 2020 (Swedish Environmental Protection Agency 2013), but more recently updated the target to a reduction of 20% (in terms of weight) between 2020 and 2025 (Swedish Environmental Objectives System 2020). This since the earlier suggestion was not followed up. More recent research examining different scenarios in which the food system can be kept within safe planetary boundaries established two food waste reduction pathways: (i) reducing food waste by 50% by 2030 compared with the baseline year of 2010 (which is in line with UN Sustainable Development Goals for 2030) and (ii) an ambitious scenario with reductions of 75% (Springmann et al., 2018). Fig. 1 summarizes the content of the abovementioned examples, which differ in scope and in the reduction targets set.

Progress in achieving the reduction targets set to date by different bodies has been difficult to track, mainly due to methodological problems in data collection (Grolleaud 2002), ultimately leading to a lack of primary food waste data (Xue et al., 2017). Therefore, a prerequisite to evaluating whether food waste reductions are on track is good availability of robust food waste quantification data. This was recently acknowledged by the UN in its food loss and waste index (FAO 2018; United Nations Environment Programme 2021), which aims to oversee progress towards the Sustainable Development Goals (SDGs). To enable monitoring of progress in a European Union context, the European Commission states that all member countries must report food waste. The first reference year for reporting was 2020, data for which must be

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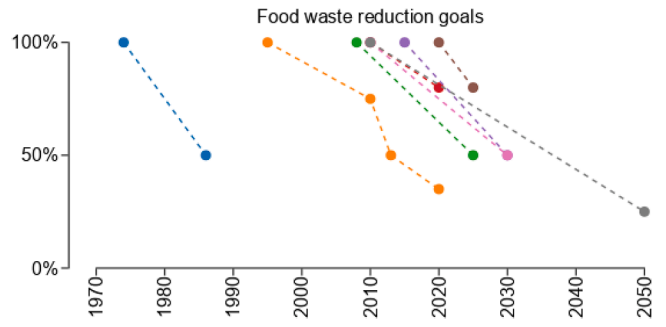

Fig. 1. Targets and achievement deadlines set for some previous food loss and waste reduction goals. ● FAO 1974 goal of reducing post-harvest losses, ● DEFRA, Ev 47, ● Lundqvist et al. (2008), ● Swedish Environmental Protection Agency (2013), ● SDG 12.3, ● Swedish Environmental Objective Goal ● Springmann scenario waste/2 (2018) ● Springmann scenario waste/4 (2018).

registered before 30 June 2022 (European Commission 2021). One challenge associated with this type of reporting is uncertainties in the underlying data, associated with the method of choice, when aggregating data on national level and comparing results (Caldeira et al., 2019). For instance, some previous studies have concluded that approximately 90 Mt of food waste are generated annually in European Union member states, with no change between reference years (2006, 2012, or 2019[1]) (European Commission. Directorate General for the Environment. 2011; Stenmarck et al., 2016; United Nations Environment Programme 2021). Similar static development on national level is apparent in Swedish food waste data published by the Swedish Environmental Protection Agency every other year since 2012, in which the total food waste level ranges from 1.1 to 1.3 Mt with the goal that 75% of this waste should be treated biologically via anaerobic digestion or composting as of 2023 (Swedish Environmental Protection Agency 2022). However, there is some variation within the food supply chain. For instance, in the case of food store waste, the level varied between 30,000 and 45,000 tonnes/year for almost a decade, but in the last available report the level suddenly increased to 100,000 tonnes/year due to a change in the recording methodology (Swedish Environmental Protection Agency 2020). This indicates that variation will be present in the data and it will be difficult to evaluate whether there has been any systematic change in the levels of food waste, unless standardized quantification mechanics are put in place alongside reliable methods to assess progress and detect changes.

Even if households are estimated to generate the majority of food waste (70%) followed by retail (11%), public catering organizations (4%) in Sweden are important (Swedish Environmental Protection Agency 2020). This since they serve a majority of the meals in an educational setting and such institutions play an important role by shaping the sustainability outlook of their dinners (Filimonau et al., 2022). Public catering organizations in Sweden are also an exception in that they have a relatively long history of food waste quantification (Eriksson et al., 2018a). They are also committed to achieving the SDG 12.3 reduction goal and the results of their data collection work are publically available under the Swedish Public Access to Information and Secrecy Act (Swedish Parliament 2009). Thus public catering waste data are available for analysis, providing a unique opportunity to assess a whole sector and determine the direction of food waste generation over time. Previous research in the area has so far only comprised relatively small case studies for individual organizations (Hansson 2016; Eriksson et al., 2017) or parts of the sector. For instance, Malefors et al. (2019) tried to establish a baseline scenario for the Swedish food service sector as a whole and concluded that around 20% of food served ends up as waste, which is consistent with findings in several other studies (Engström and Carlsson-Kanyama 2004; Sonnino and McWilliam 2011; Ferreira et al., 2013; Liz Martins et al. 2014; Boschini et al., 2018). There is an urgent need to identify the direction in which food waste levels are heading and to move beyond small case studies and determine whether additional resources or policy interventions are needed to push food waste reductions for the public catering sector. To evaluate whether the sector is on the right track, it is essential to have sufficient information on food waste levels, originating from primary data sources, available for analysis to determine the direction of change and account for data uncertainties.

The aim of this study was therefore to monitor food waste levels in the Swedish public catering sector over time, and detect trends in relation to established reduction targets. The overall aim was to assess whether the Swedish public catering sector is heading in the right direction and at a sufficient pace to achieve a more sustainable food system.

2. Material and methods

2.1. Description of data collection

The material analyzed in this study comprised food waste data collected in Swedish public catering organizations (municipal level) that provide food to preschools, schools, and care homes. All public catering organizations in the 290 self-governing municipalities in Sweden were contacted by email in the first quarter of 2021, with a request to send all of their available food waste data (since there is no central organization that collects the food waste quantification data), and those which did not respond to this request were later contacted by telephone and email. The request specified that the organization in question should provide food waste data obtained as close to the source as possible (daily observations within canteens) and not involving any form of aggregation. The request also specified that the organization should provide all its quantification data, regardless of format. In total, 121 of the 290 Swedish municipalities contacted provided food waste quantification data. Of the remaining municipalities, 99 stated that they did not have, or could not give, any data, 23 could not be reached at all despite multiple attempts, and 47 agreed to share data but for various reasons did not deliver any data, even after multiple reminders by phone and email. Of the 121 municipalities that shared data, 24 did so in aggregated form, leaving a total of 97 municipalities with raw data (daily observations from individual canteens) that could be verified and assessed in this study. The area of study is illustrated in Fig. 2.

2.2. Description of study material

The study material from the public catering organizations came in different shapes and formats, but most organizations used some form of spreadsheet or dedicated software (Eriksson et al., 2018a) for their food waste quantification. Most also followed roughly the same principles and used the same terms and definitions as in the food waste quantification standard described by Eriksson et al. (2018b) and the Swedish National Food Agency (2019). The standard defines the different waste processes, what should be included and not during quantification and also suggest how long food waste quantification should take place. Since public catering organizations may have different ambitions, they may also encompass different types of canteen within their organization. Some may focus their quantification efforts on school canteens, even if they also operate canteens for preschools and elderly care homes. This means that the quantification periods used by different organizations can differ in length and in the types of units and level of detail they comprise (Eriksson et al., 2018a). However, most organizations and canteens quantify more than the 10 days per year suggested by the standard.

All food waste data collected by the participating organizations were quantified at canteen level by canteen staff themselves, who weighed all

[1] EU 9.78% of 931 Mt/year ≈ 91 Mt/year.

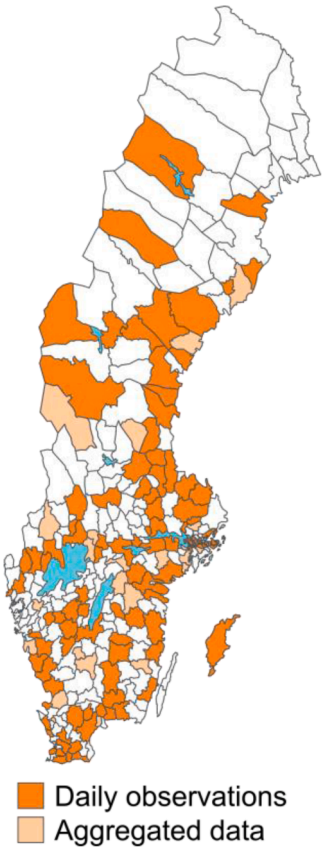

Fig. 2. Geographical plot of the municipalities that shared their food waste quantification data.

food waste according to the standard established by the Swedish National Food Agency (2019). According to this standard, food waste is divided into kitchen waste (which can be further sub-divided into storage waste, preparation waste, and safety margin waste), serving waste, and plate waste. The number of guests that attend each meal for which food waste has been quantified is also part of the quantification process, to calculate the relative indicator 'waste per guest' (in grams). The study material covered the period 2012–2020.

2.3. Food waste quantification framework and evaluation

The daily observations provided by all organizations were transformed into a common framework for data analysis developed by Malefors et al. (2019). This framework considers metadata relating to the canteen, the date of food waste recording, the meal in question, the waste processes quantified, and the number of guests who attended the meal. All data fed into the framework were subjected to a cleaning process, where doubtful data (such as food waste recorded in grams instead of kilograms) were corrected. Other metadata relating to the canteen, such as whether it serves a preschool, primary school, secondary school, or elderly care home, were also collected. Kitchen type, e.g. if the canteen is a production or satellite kitchen, was also noted. The main intention with applying the framework was to establish a basis for analyzing the canteens on equal terms, i.e., only data from canteens that quantified the amount of serving waste, plate waste, and guests per meal and day were selected for further evaluation. If a canteen did not quantify one of these parameters on a particular day, all data for that day were discarded. To enable robust analysis of the key performance indicator 'waste per portion' (g), the median value was used to reduce the impact of outliers or extreme values (Quinn 2002).

2.3.1. Changes over time

Boxplots for the indicator 'waste per portion' in grams for each part of the public catering sector (preschool, primary school, secondary school, care home) were used to illustrate the change in food waste over time for all canteens. To assess how representative the figures were for each year and part of the sector, the number of canteens that contributed data was divided by the total number of units in the relevant part of the sector. A proxy value for the number of units was used, since there are no official Swedish records on the exact number of canteens operating in each part of the public catering sector. For preschool canteens, the number of preschool units was used as the proxy, while for canteens serving meals to primary and secondary schools, the number of primary and secondary school units, respectively, was used (Swedish National Agency for Education 2019). In the case of multiple school units at the same physical location, only one was counted, as they are likely to share the same canteen (Malefors et al., 2021). For canteens serving food to elderly care homes, 1700 units was assumed for every year in the study period (Swedish Association of Local Authorities and Regions 2020).

2.3.2. Upscaling, sensitivity analysis, and uncertainty

To calculate and compare the amount of food waste (in tonnes) generated in the Swedish public catering sector with that reported in other studies, the waste per portion (g) factor was multiplied by a portion per year factor according to Eqs. (1) and 2. This scales the waste per portion factor to the amount of guests (population) that take part of the meals and yields a calculated value in tonnes per year. Monte Carlo simulation was used to complement the calculated value and to estimate the uncertainty range in the final tonnes per year factor, which also included uncertainty ranges for some of the parameters in the tonnes per year model. Distributions were assumed based on the data collected, the

Table 1
Parameters and estimated uncertainty values used in calculations and Monte Carlo simulations.

Parameter	Distribution	Uncertainty & Description
Number of enrolled students	Fixed	Based on statistics provided by the Swedish National Agency for Education (2019)
Attendance level	PertBeta	Min: 0.7, Mode: 0.9 Max: 1.0 Estimated based on a previous study (Malefors et al., 2021) and Swedish Food Agency (2021)
Number of days open	Triangular	Min:178, Mode:180 Max: 200 Estimated for primary and secondary schools* based on Swedish Parliament (2011) Min: 200 Mode: 230 Max: 248 estimated for preschools
Meals per day	Fixed	One meal per day was assumed to be served in primary and secondary schools, 1.5 meals per day were assumed to be served in preschools
Waste (g/portion)	LogNormal	Fitted from collected data
Median waste/ portion		Median waste/portion per sector and year
Average waste/ portion		Average waste/portion per sector and year
Waste/portion		Sum of waste divided by the sum of guests for each sector and year
Median of waste categories		Median waste (g/portion) and waste category**
Median waste/ portion/canteen		Median waste (g/portion) aggregated on canteen level***
Median waste/ portion/ organization		Median waste (g/portion) aggregated on organization level***

*60 days removed for secondary school canteens during 2020 due to being closed because of COVID19.
** Kitchen, serving and plate waste – Similar method as proposed recently by The Swedish Environmental Protection Agency and also used by the Swedish National Food Agency but in their case with aggregated data.
*** Data is aggregated from daily values to canteen or organization level.

literature, and our own assessment (Table 1). Calculations and simulations were performed for the same years as the future scenario (2016 and 2020) for preschools, primary schools, and secondary schools. Six different ways of calculating waste per portion were tested, to assess how this factor influenced the results. A variance-based sensitivity analysis (Sobol′ 2001) was performed to evaluate the contribution of each variable input parameter to the output variance.

$$Portions\ per\ year = Enrolled\ students * Attendence\ level * Number\ of\ days\ open * Meals\ per\ day \quad \text{(Eq. 1)}$$

$$Tonnes\ per\ year = portions\ per\ year * waste\ (g)\ per\ portion * 10^{-6} \quad \text{(Eq. 2)}$$

2.3.3. Trend evaluation

Trends were evaluated in two ways. The first method used linear regression in which each part of the sector was handled separately and the response, median waste (g/portion), was calculated yearly for each canteen. To give a fair comparison, the canteens were grouped and analyzed by the year in which they started to quantify food waste, to evaluate the direction of change for each group of canteens per sector and year. To also handle non-linearity, the second approach used generalized additive models (Hastie and Tibshirani 1986), while the toolbox for visualizing trends in large-scale environmental data developed by von Brömssen et al. (2021) was amended to use annual values. Each canteen that could provide more than three years of data was included and used by the screening toolbox to detect the proportion of canteens that, for a given year, observed significant trend changes in their levels of food waste and whether the levels were increasing or decreasing (or stationary). The proportion of canteens for a given year was also visualized, along with the trend proportion.

To get an indication of the direction of the trend, the part of the sector with the most available data (which is the primary schools) was used to forecast a scenario to 2025 using the prophet package (Taylor and Letham 2017), in which the underlying mechanisms are similar to those in generalized additive models. The future scenario was modeled using previous food waste levels aggregated monthly for all primary school canteens. Values for missing months were imputed using the MICE package in the statistical software R (Buuren and Groothuis-Oudshoorn 2011). Food waste levels for 2016 and 2020 were used as reference to evaluate the scenario, with 2016 representing the year when the United Nation SDGs were rolled out and 2020 representing the European Commission's baseline year. The width of the uncertainty interval for the scenario was set to 95%.

3. Results

In the following presentation, the results obtained are split into three main parts: the change in food waste over time for each sector, scaling to national levels including and comparing the two reference years, and trends in the data.

The main finding, based on primary data comprising 141,900 observations. was that food waste in the Swedish public catering sector decreased by 43% between 2012 and 2020, which corresponded to a reduction from 68 g/portion to 47 g/portion. Since primary schools and preschools dominated the material, the observed food waste reduction was mainly due to reductions in those cases.

3.1. Change in each part of the sector

Each part of the public catering sector showed decreasing levels of median food waste (g/portion) and increasing numbers of canteens collecting food waste data, as illustrated in Fig. 3. Primary school canteens decreased their level of food waste by 40% by 2020, from a peak median waste of 69 g/portion in 2013 to 42 g/portion. A similar pattern was observed for secondary schools, although with higher values reported for median waste per portion and wider variation between years. Preschools showed declining levels of food waste after 2016, with a 29% decrease (75 to 53 g/portion) by 2020. The lowest median value (50 g) for a preschool was reported in 2012, but was only based on primary

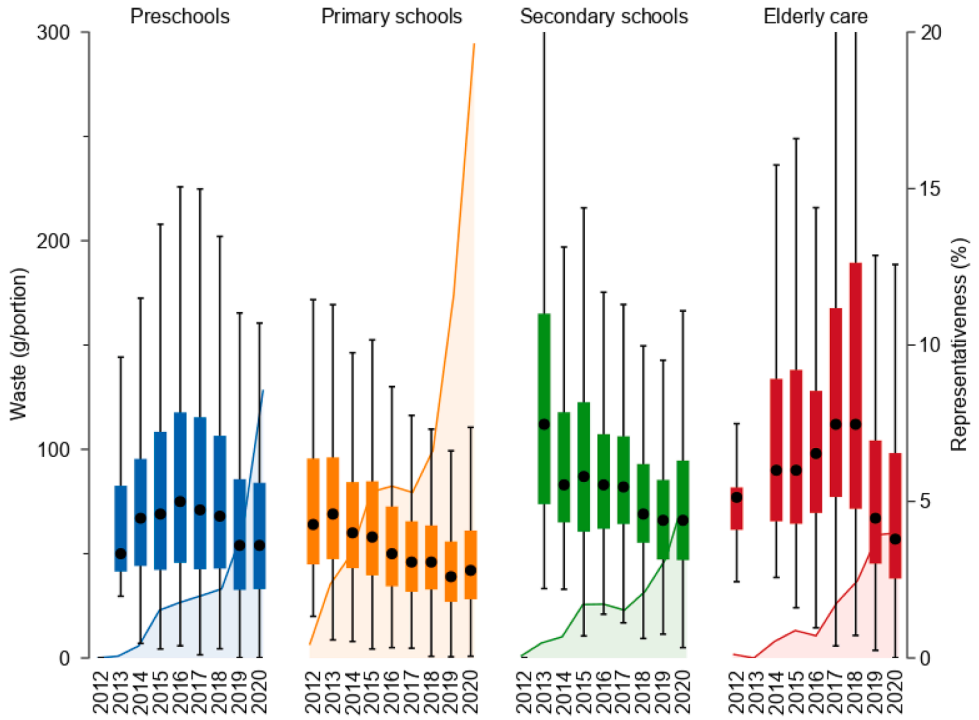

Fig. 3. Boxplot of changes over time (2012–2020) in food waste in different parts of the Swedish public catering sector. ● shows the median waste level (g/portion); box limits indicate the 25th and 75th percentiles; whiskers illustrate the minimum and maximum values, and outliers are omitted. The representativeness (%), defined as the number of canteens providing data divided by the total number of canteens in each sector and year, is also shown. Y-axis is capped at 300 g/portion.

data from six canteens, whereas 822 preschools provided data in 2020. This illustrates the need for a sufficiently large sample to draw relevant conclusions. Elderly care was the sector with the greatest variation between the years and 2018 had the most extensive spread, from 11 g/portion to 366 g/portion and median waste of 112 g/portion. Fig. 3 displays data for all canteens that provided data in a non-aggregated way, irrespective of whether they quantified food waste for only one semester or for several years. Therefore, the diagram might emphasize canteens that quantified food waste sporadically.

3.2. Upscaling, sensitivity analysis, and uncertainty

To assess how waste per portion (g) contributed to total waste in preschools, primary schools, and secondary schools expressed in tonnes on a national level, this factor was scaled with the number of portions per year factor. Table 2 illustrates calculated values and Monte Carlo simulated values for the years 2016 and 2020, where 2016 represents the year when the SDGs were established and 2020 the European Commission's baseline year. Irrespective of how the waste per portion factor was calculated or simulated, all values showed decreasing levels of food waste between 2016 and 2020. The largest change (−30%) was in the factor based on the median of the waste categories. The average results from the simulation for 2020 were slightly higher than the calculated value for the same year, but the calculated values were still within a two-sigma effect from the simulated outcome. The simulated values mostly overlapped with the calculated results, with differences arising from uncertainty in variability and uncertainties in input parameters to the tonnes per year model. There was also some variation between the different waste per portion factors for the calculated figures, with a difference of up to 4000 tonnes, or 13–17%.

The variance-based sensitivity analysis for primary schools in 2020 (Table 3) showed that the waste per portion factor had the largest influence on the variance of the output, followed by attendance level and number of days open. Primary schools and the year 2020 were selected here for illustrative purposes, as the year and the sector in which most canteens contributed data.

3.3. Trends and future scenario

3.3.1. Linear trends

On examining the linear trends displayed in Fig. 4, canteens were grouped by the year in which they started to quantify food waste and analyzed until the last year for which they provided observations. This gave a fairer comparison between canteens and evened out differences and possible contributions of canteens that only participated sporadically. As can be seen in Fig. 4, all canteens that quantified their food waste had a decreasing trend line from when they started quantification to their last year of observations, except for secondary school and elderly care home canteens in some years. Visual inspection of the diagram revealed no obvious pattern, indicating that there would be an advantage from starting earlier with quantifying food waste. The canteens that started early with food waste quantification either did not utilize the time to lower their food waste to the levels achieved by canteens which started to quantify their waste later, or had a greater initial food waste problem and needed more time to solve that problem. It should also be noted that later quantification years were represented by more canteens which quantified their food waste.

3.3.2. Non-linear trends

Since non-linear trends were potentially also present in the data, a screening tool was used to account for any non-linear trends and analyze canteens that had quantified food waste for three or more years. The results showed the proportion of canteens within parts of the public catering sector that either significantly increased or decreased their levels of food waste per year (Fig. 5). The peak year, when most canteens participated in quantifying food waste according to the criterion of three or more years with consecutive quantification, was 2018–2019. According to the analysis, the number of primary school canteens with significantly decreasing levels of food waste remained fairly static during the study period (36–41% between 2015 and 2020). Secondary

Table 2
Food waste in tonnes (values rounded) covering Swedish preschools, primary schools, and secondary schools, calculated and simulated for different 'waste per portion' factors for 2016 and 2020, on scaling to national level. Uncertainties in the estimates are expressed as ± standard deviation of the Monte Carlo simulation results.

Waste per portion factor	Calculated (tonnes)			Simulated (tonnes)	
	2016	2020	% change	2016	2020
Median waste/portion	**26,000**	**20,000**	**−23**	**25,000 ±1000**	**19,000 ±1000**
Preschool	12,000	9000		11,000 ±960	8000 ±730
Primary school	9000	8000		9300 ±660	8200 ±660
Secondary school	5000	3000		4500 ±260	2500 ±190
Average waste/portion	**30,000**	**24,000**	**−20**	**30,000 ±1000**	**23,000 ±1000**
Preschool	14,000	11,000		14,000 ±1100	10,000 ±880
Primary school	11,000	10,000		11,000 ±670	10,000 ±730
Secondary school	5000	3000		5100 ±250	3000 ±200
Waste/portion	**28,000**	**21,000**	**−25**	**25,000 ±2000**	**19,000 ±2000**
Preschool	13,000	9000		11,000 ±1400	8000 ±1300
Primary school	10,000	9000		9400 ±1200	8300 ±1300
Secondary school	5000	3000		4400 ±610	2500 ±450
Median of waste categories	**30,000**	**21,000**	**−30**	**30,000 ±1000**	**23,000 ±1000**
Preschool	14,000	9000		14,000 ±1000	10,000 ±780
Primary school	11,000	9000		11,000 ±700	10,000 ±720
Secondary school	5000	3000		5000 ±270	2900 ±180
Median waste/portion per canteen	**26,000**	**22,000**	**−15**	**29,000 ±1000**	**23,000 ±1000**
Preschool	12,000	10,000		13,000 ±880	11,000 ±880
Primary school	10,000	9000		11,000 ±510	9500 ±520
Secondary school	4000	3000		4600 ±230	2700 ±140
Median waste/portion per organization	**26,000**	**22,000**	**−15**	**26,000 ±600**	**22,000 ±700**
Preschool	11,000	10,000		12,000 ±410	10,000 ±640
Primary school	11,000	9000		10,000 ±410	9600 ±370
Secondary school	4000	3000		4300 ±120	2600 ±120

Table 3
Results from variance-based sensitivity analysis of food waste levels in Swedish primary schools in 2020.

Parameter	First order effects	Total effects
Attendance	0.00789	0.0116
Number of days open	0.00243	0.0035
Waste per portion	0.98397	0.9895

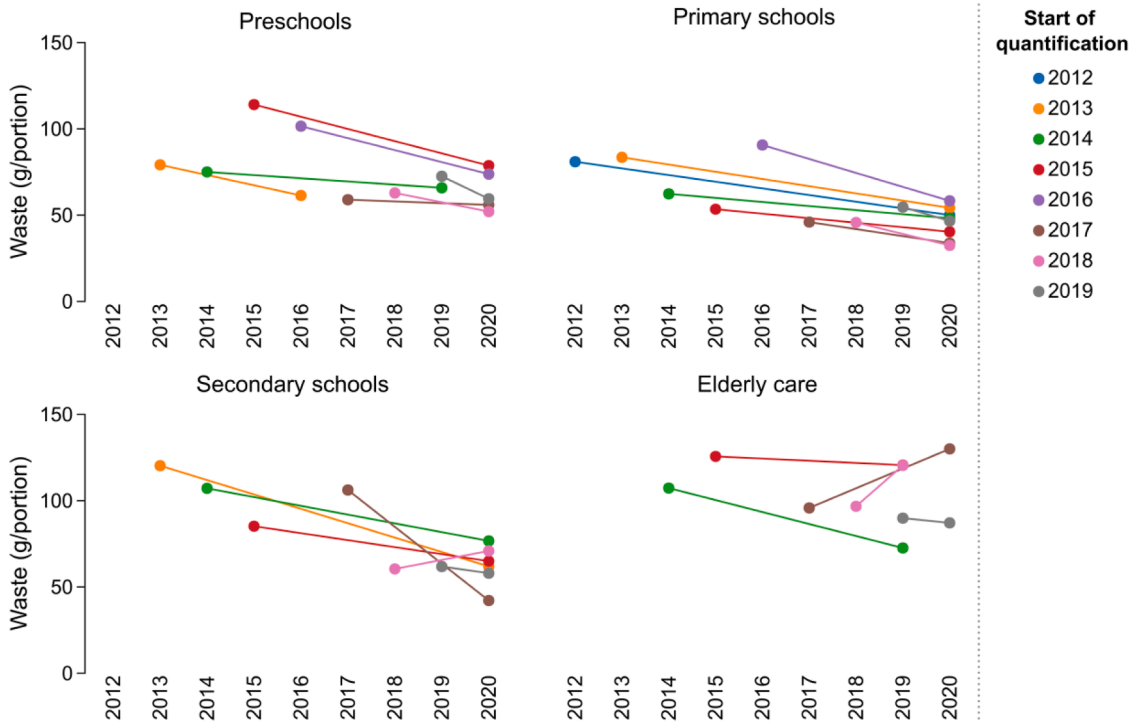

Fig. 4. Linear trends in food waste amounts for canteens in different parts of the public catering sector in Sweden. Canteens are grouped and tracked by the year in which they started to quantify food waste, e.g., school canteens that started to quantify food waste in 2012 and their levels of food waste for each year until 2020 were evaluated using linear regression.

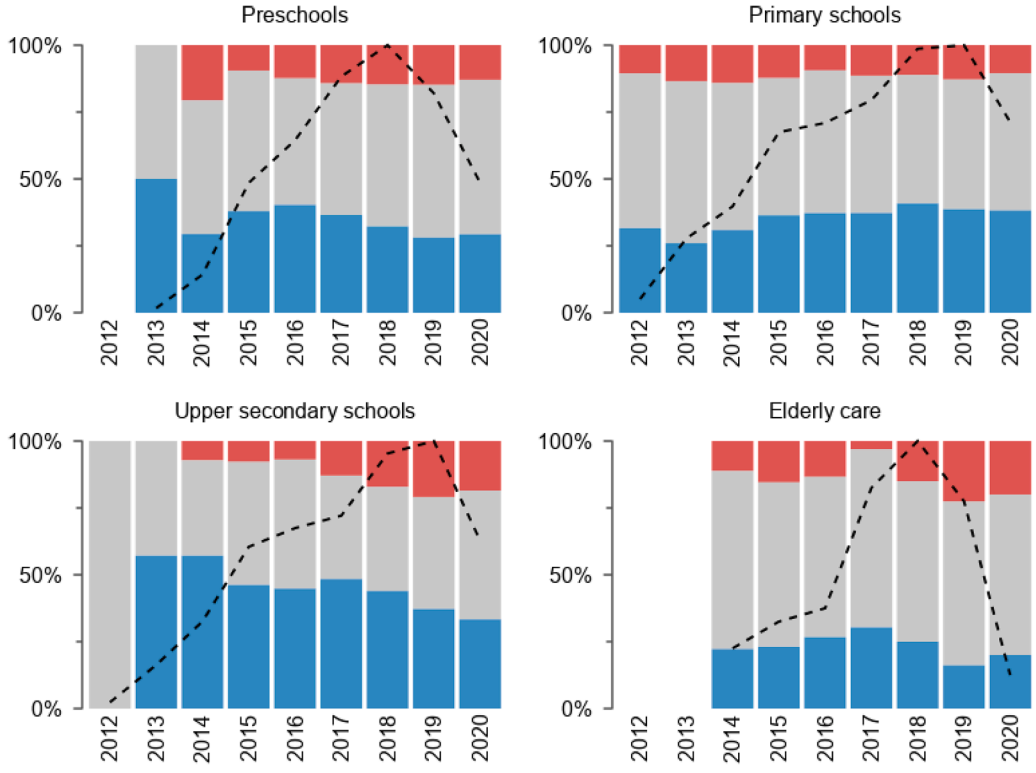

Fig. 5. Proportion plot illustrating the percentage of Swedish public catering canteens with significantly increasing (■) or decreasing (■) trends in food waste per portion (■ indicates no significant increase or decrease). A dashed line indicates the percentage of canteens observed for a specific year.

schools, on the other hand, tended to have fewer canteens with significantly decreasing levels of food waste over time. Preschools and elderly care units display similar trends as upper secondary schools in terms of the proportion of canteens with either decreasing or increasing levels of food waste (Fig. 5).

3.3.3. Scenario for food waste 2025

To predict future levels of food waste, knowledge of historical levels of food waste is essential. Given current developments in primary school canteens, Fig. 6 illustrates a concept where historical developments were used as the foundation for forecasting based on current trends and the assumption that no significant changes will occur in the future. According to the model, halving of the 2016 level (to 25 g/portion) might be within reach for Swedish primary school canteens (which is the part of the sector with the most available data), as the lowest point generated by the model was 29 g/portion in October 2024. Halving of the 2020 level (to 21 g/portion) is also within the realm of possibility, but further away from the lowest point generated by the forecast model. It should also be noted that the modeling results were associated with significant uncertainties and that there were indications of a plateau at around 30 g/portion from late 2022 onwards in the model (Fig. 6).

4. Discussion

It is not uncommon for food waste studies in the food service sector, which are often small case studies, to report food waste ranging between 50 and 150 g per portion (Malefors 2021). In some cases, even higher levels of waste have been observed, with e.g., Abdelaal et al. (2019) reporting values of 757 and 980 g/sale. At the present time (2020), all parts of the Swedish public catering sector, which encompasses preschools, primary schools, secondary schools, and elderly care homes, report median food waste levels of between 42 and 66 g per portion. According to Fig. 3, which shows food waste on aggregated level for the different parts of the sector, the levels of food waste (g/portion) have generally decreased over time since 2012. All canteens except secondary school canteens have also achieved a notable decrease in median food waste from 2018 onwards, with the most prominent difference for elderly care home canteens (from 112 to 67 g per portion).

Evaluation of trends by assessing and following the same set of canteens in each part of the sector over time, depending on when they started to quantify food waste, raised the important question of where the focus should be directed, i.e., whether as many canteens as possible should provide data, or whether the same canteens should provide data every year for consistent monitoring over time. Tracking changes in food waste levels from 2010 onwards is difficult, as data are only available for a limited number of canteens and their willingness to participate may be low.

In this study, we attempted to gather as much previous food waste quantification data as possible in order to assess previous levels of food waste, and 42% of all municipalities in Sweden responded with data. However, 18% of the municipalities contacted claimed that they had data but, for various reasons, did not deliver these data. Therefore, a clear limitation of this study is that there was no random selection of participating canteens and municipalities. Additionally, the study relied on self-reported data and on the willingness of municipalities to contribute their data. Therefore, the representativeness of the participating canteens may be limited, as they may represent the best-performing or most interested canteens in each part of the sector, which ultimately means that scaling of the different waste per portion factors to tonnes per year might have given an underestimation or false representation of the actual situation. For instance, when comparing our findings for 2016 with the Swedish Environmental Protection Agency's estimate of 50,000 tonnes for Swedish preschools, primary schools, and secondary schools in that same year, the difference was up to 48%. However, the underlying assumptions in that report were based on considerably higher waste per portion factors, e.g., waste per portion in preschools was estimated to be 160 g and that in schools (primary and secondary schools) was estimated to be 110 g, with both values being above the 75th percentile according to Fig. 3. This was also reflected in the input distributions for the Monte Carlo simulations. This highlights a need for up-to-date and transparent waste per portion factors. Our results for 2020, in contrast, were in line with the mapping conducted by the Swedish National Food Agency, which reported 11,000 tonnes of food waste for primary schools and secondary schools in that year (Swedish National Food Agency 2021). Even if Swedish preschools and primary schools unlike in many other countries were open during the

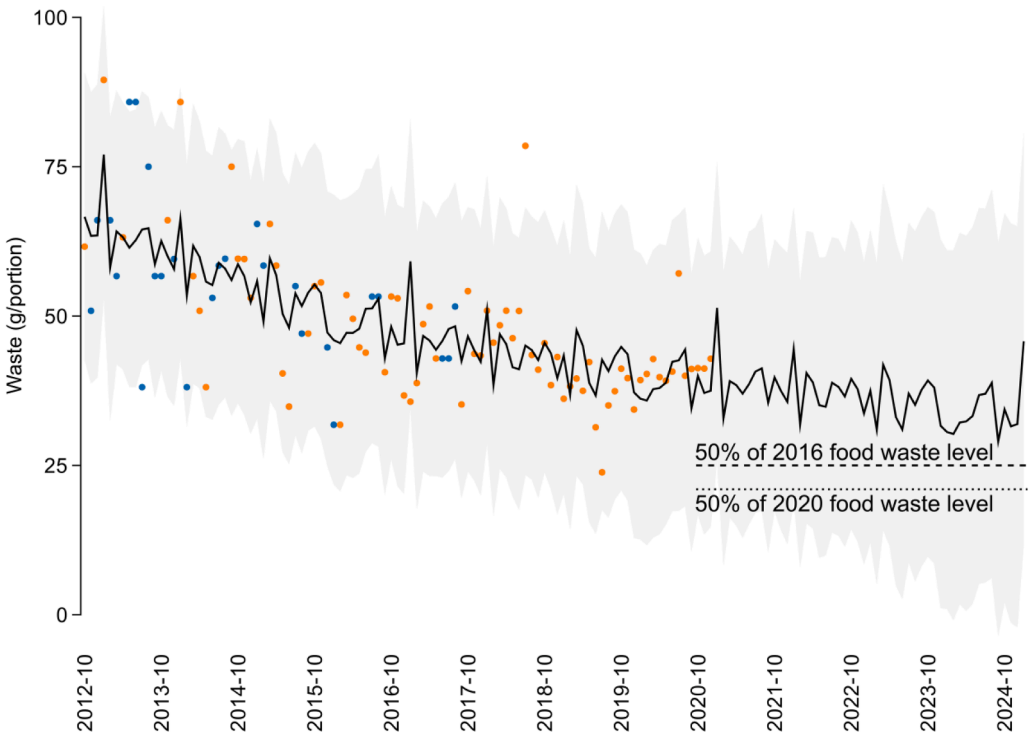

Fig. 6. Monthly median food waste in g per portion over time for Swedish primary school canteens. ● indicates monthly aggregated level of food waste between October 2012 and December 2020, ● indicates imputed monthly values. ─ indicates the model fitted to data, with the shaded area illustrating model uncertainty. Dashed lines indicate halving of food waste from the 2016 and 2020 levels.

whole COVID-19, the pandemic might have influenced consumption patterns and therefore the amount of waste generated. Upper secondary school canteens highlight this phenomena, since they were not open during parts of the pandemic, and it might look like their wastage in tonnes have decreased substantially between 2016 and 2020 (Table 2), but this change should be attributed to that students were at home and wastage is likely to have shifted to households instead (Vittuari et al., 2021).

Scaling the waste per portion factor to national level gave a difference between methods for a single year of the magnitude of 13–17%, or 4000 tonnes in absolute terms, which indicates that the best option may be to adhere to one method and refine it over time. The method used by the Swedish National Food Agency for converting the waste per portion factor to food waste in tonnes per year is based on self-reported data from municipalities on kitchen waste, serving waste, and plate waste per portion. In this regard, the method be considered cost-effective, since it only requires a questionnaire to be sent out to the organizations. However, within this collection process, it is vital to verify that the reported values from the municipalities or organizations are reasonable, since the underlying data are not currently collected and analyzed. To quantify uncertainties, even with aggregated material, a Monte Carlo simulation approach could be used to give more a transparent estimate than that available today, which only consists of a one-point estimate per sector and year, with no uncertainties.

This kind of reporting or upscaling might also be possible to use in other countries and in the private sector, where canteens in a large business with multiple outlets report one value each year to a central unit. It compiles the information and passes it on to a national entity tasked with managing and reporting the data to the European Union, with associated uncertainties. Since this reporting chain is rather long, it is essential to have processes and well-balanced tools that help canteens in their reporting process and to ensure that the reporting itself helps canteens to act upon their food waste levels.

Swedish canteens and municipalities currently quantify food waste solely in order to address a problem they have identified (Malefors et al., 2022), since there are no legally binding procedures forcing them to perform quantification. Actions taken on national level to reduce food waste are communicated through informational policy instruments such as the national action plan for reducing food waste, which was released in 2018 and encompasses the whole food supply chain (Swedish National Food Agency 2018). Other informational policy instruments include the unified food waste quantification standard designed to be used within the public catering, and a recently released handbook on reducing food waste in public catering canteens (Swedish National Food Agency 2020). While the peak of reporting activity in our data (2018–2019) coincided with the release of some of these instruments, there is probably a lag between when information is released and when it is implemented in reality, and there is no guarantee that the information will reach end-users.

What is clear from our results is the presence of declining trends in food waste levels, irrespective of method used, with the exception of data for elderly care home canteens which are more difficult to evaluate. More previous data are needed to better explain the situation in care homes, as no clear trend emerged when analyzing these canteens based on the year in which they started to quantify food waste. According to the proportion plot (Fig. 5), elderly care homes also had the lowest number of canteens with significantly decreasing levels of food waste.

According to the forecasting scenario for primary schools, which was an attempt to illustrate one pathway until 2025, the level of food waste was half that observed in 2016 (Fig. 6). However, the forecasting model was associated with significant uncertainties and there is clearly little scope for canteens to significantly increase their levels of food waste. The model also indicated that there might be a plateau effect of 30–40 g per portion. Therefore, it is crucial to determine the scope of the food waste situation in canteens that are not quantifying or acting upon the problem at all, so that current ambitions do not stagnate. One reflection from this study on examining linear trends was that canteens which started to quantify later in the period tended to have lower initial food waste than those which started earlier. It is therefore possible that canteens which contribute (or do not contribute) data in the future might perform better than those analyzed here, although this remains to be confirmed. However, previous studies indicate that there is a vast difference in the potential for food waste reduction between individual canteens and that the greatest potential lies within canteens that have a large problem to start with (Eriksson et al., 2019). There might be untapped potential for those canteens to perform on a par with the most successful canteens.

Since the current system of working with sustainability issues and reducing food waste within the public catering sphere is not based on mandatory participation, a future route might involve incorporating food waste quantification into the Hazard Analysis and Critical Control Points (HACCP) analyses that are compulsory for all food business operators. This could embed food waste quantification and make it possible for canteens to supply data in a standardized way to a central organization for monitoring if the actions they introduce to reduce food waste have the desired effect. This could overcome the problem of limited waste statistics when providing estimates of food waste levels, which is the current situation according to Caldeira et al. (2021). It could also help to monitor the food waste situation, on both overall and canteen level, and indicate if and where further actions are needed to contribute to a sustainable food system.

5. Conclusions

All parts of the Swedish public catering sector showed decreasing levels and trends of food waste in the study period. When the reference year was set to 2016, primary schools achieved a reduction of 16%, to 42 g/portion, preschools a reduction of 26%, to 53 g/portion to 2020, secondary schools a reduction of 20% to 66 g/portion, and elderly care homes a reduction of 43%, to 56 g/portion. Food waste quantification data from primary schools dominated the material and had the highest representativeness, and therefore had a large influence on the overall results. This dominance reflects the fact that primary schools are the largest segment within the Swedish public catering sector. Between 2016 and 2020, food waste reduction in the sector on scaling the results to national level was between 15% and 30%, depending on the waste per portion factor used. The total mass of food waste generated in 2020 in the Swedish school catering sector, which encompasses preschools, primary schools, and secondary schools, was estimated to range from 19,000 to 23,000 tonnes. Halving this amount of waste is achievable, given the current situation and declining trends and provided that the untapped potential in food waste reduction for canteens that are currently furthest below the best-performing canteens is utilized. Achieving food waste goals on global or national level will require a good understanding of situations in which food is thrown away and canteens will need to be provided with appropriate tools and methods to help them reduce their food waste and report progress. When national entities collect food waste quantification data in an aggregated form from municipalities or business operators, random samples on the raw data (when available) could be taken to verify the aggregated data. Legal binding procedures to provide food waste quantification data might be an option to explore to encompass establishments not actively addressing the food waste issue today.

CRediT authorship contribution statement

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

Declaration of Competing Interest

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

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