Journal of Cleaner Production 517 (2025) 145889

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Optimal design of national food waste monitoring for the food service sector

Joel Kostensalo[a,*], Kirsi Silvennoinen[b], Marita Kettunen[b], Vesa Lampi[b]

[a] Natural Resources Institute Finland, Natural Resources, Yliopistokatu 6B, FI-80100, Joensuu, Finland
[b] Natural Resources Institute Finland, Bioeconomy and Environment, Latokartanonkaari 9, FI-00790, Helsinki, Finland

ARTICLE INFO

Keywords:
Food waste monitoring
Food service sector
Sample size

ABSTRACT

The countries of the European Union have committed to monitoring and lowering food waste (FW) levels, including in the food service sector. In this work, the relative importance of factors such as food service type, outlet size, seasonal and weekday variation, and length of measurement period for monitoring originally edible and total FW is explored. We provide the first sample size estimates needed for national-level monitoring, and take the length of the observation period carefully into account and whether the food service type, outlet size, and regional variation are controlled for, and what size of a change in FW one wants to be able to observe. Two datasets collected as part of the Finnish national monitoring system were used. The first consisted of 192 two-week measurements from outlets of various sizes. The second consisted of three long-term (1.5–2 year) monitoring efforts. The food service type is by far the most important factor, explaining 66 % and 54 % of the variance in edible and total FW, respectively. The next factor is monthly variation (13 % and 10 %), municipal level variation (5 % and 9 %), and weekday-variation (6 % and 5 %), with the outlet size being relatively unimportant (2 % and 8 %). At the smallest, a sample size of n = 68 is needed to observe a change of 30 % in the total national FW levels. With two-week measurements n = 72 is sufficient, highlighting the fact that longer measurement periods are not resource efficient, because between-outlet variation tends to be greater than within-outlet variation. The results can be used to develop national data collection in other countries, to optimize the limited resources available for monitoring, and to improve the comparability of measurements between years.

1. Introduction

Approximately 20 % of the food in households, retail, and food services is wasted globally, i.e. 132 kg/person/year of which 36 kg is wasted in food services (UNEP, 2024). Food waste (FW) is both an environmental and an economic issue, and minimizing FW is crucial to ensuring the long-term viability of the global food system (Willett et al., 2019; Foley et al., 2011). Greenhouse gas emissions and other environmental costs of food production occur whether the food is consumed or not and food wasted at the end of the food chain, i.e. in food services and households, thus has the largest impact. This is especially problematic as the food service sector, just like households, contributes significantly to the total amount of FW (Eurostat, 2024). In Finland, 46 % of FW is generated in households and 25 % in the food industry. The share of food services (12 %), retail sector (9 %), and primary production (8 %) adds up to about a third of the total FW. About 641 million kilogrammes of FW is generated annually over the entire food chain, of which originally edible FW accounts for more than half (Riipi et al., 2021).

The revised Waste Frame Directive of the European Union (EU) from 2018 requires member states to monitor and reduce FW at each stage of the supply chain and to report back regarding the progress made (European Commission, 2019). The member states are currently required to take the necessary steps to ensure that FW levels are lowered by 10 % in processing and manufacturing and by 30 % jointly in restaurants, food services, and households (EU, 2024). To make sure the target is met, robust and accurate methods for estimating the amount of FW need to be developed. While measuring household FW is more challenging than for production and manufacturing, there are established methodologies utilising waste composition analyses to provide reliable and repeatable estimates (Silvennoinen et al., 2022). In contrast, quantifying the total amount of FW from food services is inherently more difficult due to the significant diversity in the type and size of food service providers, ranging from day care centres and schools to

* Corresponding author.
E-mail address: joel.kostensalo@luke.fi (J. Kostensalo).

https://doi.org/10.1016/j.jclepro.2025.145889
Received 19 December 2024; Received in revised form 29 May 2025; Accepted 31 May 2025
Available online 1 June 2025

restaurants, cafés, health services, and social services. In Finland, free of charge school lunches for all pupils, subsidized student lunches for university students, and lunches purchased at workplace staff restaurants make up a large proportion of food services, and about one third of Finns are using these services daily (Finnish Food Authority, 2023).

The total amount of FW from food services has been estimated in different countries using various sample sizes, measurement periods, and levels of representativeness of the food service sector. In Finland, estimates based on two-week measurements from 51 and 79 outlets, including a variety of schools, day-care centres, staff restaurants, student canteens, dining restaurants and cafés have been reported (Silvennoinen et al., 2019a, 2019b). In Sweden, 30 communal food service outlets were monitored for three months (Eriksson et al., 2017) and another study investigated how FW is quantified in public food services (Eriksson et al., 2017), Eriksson et al. (2018) also presented a methodological framework for FW quantification in public food services addressing the method limitations. Beretta et al. (2013) quantified food losses and the potential for reduction in supply chain and food services in Switzerland, and they made an uncertainty estimation for the results of the losses of vegetarian and animal products. Subsector studies have been carried out, e.g. in Switzerland with two outlets in the education and business sectors monitored for 5 days (Betz et al., 2015), in Florida, the United States of America, with three schools monitored for 5–8 days (Wilkie et al., 2015), in Italy with 5 school canteens (Boschini et al., 2018), and in the United Kingdom with 39 schools monitored for three weeks (WRAP, 2011). Some studies have larger sample sizes, but may be limited to, e.g. plate waste such as a Chinese study with 195 lunch and dinner restaurants located cities (Wang et al., 2017).

However, adequate attention has not been paid to ensuring that the sample size is sufficient to have enough statistical power to observe the 30 % decrease target setting by the EU, let alone a smaller decrease between two estimates some years apart. There is an urgent need to conduct sample size calculations and improve sampling designs to ensure, that the monitoring efforts are not statistically under- or over-powered. The necessary sample size will depend on factors such as the distribution of FW amounts between food service providers, the length of the measurement period, and how successful the stratification of food service providers has been (see, e.g. Lohr, 2021). For example, it is not possible *a priori* to say whether 51 two-week measurements or 30 three-month measurements would provide a more accurate estimate, as this will depend on whether the variation in FW levels within or between outlets is larger. Additionally, confounding factors such as carrying out the measurements at different times of the year need to be considered.

In this work, the aim was to quantify and rank the challenges for national-level monitoring of both originally edible and non-edible FW and then provide sample size calculations to optimize the resource needs for national-level monitoring. The work was done as part of an EU funded project to estimate FW in food services for the purposes of optimizing the monitoring methodology and sampling design in Finland. The FW data collection has been done in collaboration with the national FW monitoring of food services.

We consider variations related to the food service type, temporal variation (between months and weekdays), regional variation, and size of the service provider as measured by the number of customers served. Our goal is to identify which factors are the most important to address, and which factors could be neglected without causing significant bias in national-level estimation. The length of the measurement period is also considered.

2. Materials and methods

The food services are categorised into seven different categories based on a classification used by the Finnish Statistical authorities (STAT) for the private sector and schools, and a classification by the Finnish Institute for Health and Welfare (THL, 2024) for the public sector excluding schools. The private-sector categories are *"Staff restaurant"; "Restaurant"; "Cafés",* and the public-sector categories *"Schools"; "Day care centres"; "Health services"* and *"Social services"* (Table 1).

The definition used for *food waste* (FW) is the one by Commission Delegated Decision (EU) 2019/1597: According to the definition, FW is any food, and inedible parts of food, removed from the food supply chain. Hence, FW also includes food material that is not normally eaten, e.g. coffee grounds, peelings, shells, bones, and skins. Other term used here is *Originally edible FW,* which means all food that could have been eaten before discarding.

2.1. Monitoring data

During a FW monitoring period, each food service unit's kitchen staff weighed FW and recorded the amounts with an online application (Lukeloki, 2024), and the staff had been given in advance guidance on how to measure FW daily. To make measuring and recording easy, menus were imported by researchers into the application in advance. The daily monitoring practice included weighing and recording waste fractions by kitchen waste, serving waste, storage waste, and plate leftovers, and food produced according to the day's menu and the number of clients each day. In public services, the menu normally included a lunch served from the buffet line, and in some cases a breakfast or afternoon snack (e.g. day care centres). In private companies, the food was served either in a buffet or à la carte format.

In total there were 201 two-week measurements, of which 192 had valid data. For the other nine the numbers were not internally consistent, i.e. the amount of FW reported, and its breakdown did not match the food eaten and the total amount of food prepared. The data was taken from 162 distinct locations, with two-week measurements from the staff restaurants discussed in Section 2.2 for three years included. More than a dozen measurements from different departments of a large hospital (Health services) were counted as one distinct location, and 14 schools/Day care centres with measurements from two different years were used. The measurements were carried out in 2022–2024. However, for the long-term monitoring of staff restaurants the first measurement from 2021 was also included.

In general, there were 10 monitoring days over a two-week period in *schools*, *day care centres*, and *staff restaurants*, whereas for *health services, social services*, and some *cafés*, this was 14 days. Depending on the monitoring period, some days could be missing, e.g. due to school holidays. In total, there were 1933 monitoring days for an average of 10 days per measurement. The number of measurements and monitoring days is presented in Table 2, broken down by food service type.

The total FW is presented broken down by source (kitchen waste, storage waste, serving waste, plate waste, and kitchen bio waste) in

Table 1
Food service categories and description of included outlets.

Type	Business type	Description (STAT, THL)
Staff restaurant	Private business	Food services based on contractual arrangements with the customer, for a specific period of time. The food is usually prepared in a central unit.
Restaurants	Private business	Restaurant preparing food in their own kitchen and serving meals. Indoor dining places are available.
Cafés	Private business	Café-restaurant, cafés and coffee bars: preparing food in their kitchen and serving meals and beverages. This is including also fast-food outlets, hamburger and kebab restaurants and pizzerias.
Schools	Public service	Primary school, grammar school and other secondary education facility.
Day care centres	Public service	Early childhood education and care.
Health services	Public service	Primary and specialised healthcare, e.g. hospitals.
Social services	Public service	Elderly, disability, and child caring institutions.

Table 2
The total number of two-week measurements (Measurements) and monitoring days (Days) for each food service type (Type). Our sample for schools included both primary schools and secondary education facilities, covering ages 7–18. Our health service data originates from one large central hospital.

Type	Measurements	Days
Staff restaurant	15	149
Cafés	4	52
Schools (Primary school, secondary education facility)	91	878
Day care centre	52	496
Restaurants	10	101
Health services (Hospital)	14	192
Social services	6	65
Total	192	1933

Supplementary Fig. 2. Kitchen FW is generated in kitchens and storage rooms as a result of spoiling or mistakes in food preparation; serving FW is unused food resulting from overproduction, e.g. surplus food from a buffet or serving trolley; plate waste is the scraps of food left on plates by customers, but never eaten. Plate waste in our study included both originally edible food, and, depending on the local menu, some inedible FW such as fruit skins or bones from meat, fish skins etc. Kitchen bio waste is food material that is not normally eaten, e.g. coffee grounds, peelings, shells, bones, and skins.

In this paper, the sources of FW are not analysed, but it should be noted that serving waste was the largest contributor for most food service types, with kitchen waste also being significant for cafés and inedible kitchen bio waste for the type *Restaurants*.

2.2. Long-term longitudinal data

As a second data set, we had long-term longitudinal data from three locations. The monitoring periods were close to two years in each location, with the monitoring being continuous in two locations and consisting of four two-month long monitoring periods in the third location. The monitoring periods, food service types, and number of monitoring days are given in Table 3. For locations A and B, the monitoring was continuous without long breaks. These locations were *Staff restaurants*, which were open from Monday to Friday. The monitoring data from location C, which was a hospital ward (14 departments, *Health Services*), consisted of four two-month long monitoring periods with roughly four months between the measurements. Food was served seven days a week in this location. The time series of the longitudinal dataset is presented in Supplementary Fig. 1.

2.3. Statistical methods

The explanatory power for the month, weekday, food service type and size (number of customers), geographical variation at the municipal level and between urban and rural areas, and the length of the observation period on originally edible and total FW were estimated using a linear modelling approach. No transformation of the variables was necessary to ensure that the assumptions of the models were sufficiently well met.

First, the monthly and weekday variation was studied using the longitudinal dataset. A standard linear model was fitted to the data for each location with 1) month 2) weekday as the covariate, and the proportion of variation explained was estimated as the mean of the R^2 values. Next, the role of the food service type was estimated by fitting linear mixed effects models to the monitoring data with 'type' as a fixed variable and 'location' nested in 'municipality' as the random effects. This was done to account for the fact that in a few cases the same location was measured twice in different years and for the possible homogeneity of results at the municipal level. The proportion of variance explained was estimated as the marginal R^2 value. As a sensitivity check, the analyses were also run with a basic linear model assuming that all observations were independent, and obtained very similar results, though with a few percentage points higher R^2 values. The role of the 'size' effect was estimated by adding it as a second fixed effect to the mixed effects model and observing how much the marginal R^2 improved. An alternative model with the 'size' as the only fixed effect was also explored, but the dependence of the 'size' on the 'type' makes the interpretation of this model challenging. Regional variation was studied by changing the 'municipality' from a random effect to a second fixed effect in the first mixed effects model and observing how much the marginal R^2 increased. In an alternative model, the 'municipality' was divided into two groups with a cutoff at 50,000 residents. The resulting classification quite well divided the municipalities into urban and rural areas, as the included municipalities tended to be either much larger or smaller than 50,000 residents.

The role that the length of the observation period played was studied using the two continuous two-year long datasets from staff restaurants. The health service data were not suitable here, as it consisted of separate two-month segments. The intra-location variation was estimated by taking 10,000 bootstrap samples (i.e. sampling the original data with replacement) from both outlets starting from Mondays for one, two, three, or four weeks. The sampling error was estimated as the standard deviation of the mean estimates. We use the two-week period as a reference, as this is currently used by the Finnish national monitoring.

Finally, sample size calculations were carried out based on an analysis of different scenarios. A statistical power (probability of statistical significance when a difference of a given size exists in the population) of 80 % ($\beta = 1-0.80$) with $\alpha = 0.05$ as the limit for statistical significance was assumed along with a linear model with standard *t*-distributed parameters and a two-tailed alternative hypothesis. In practice, the calculation boils down to the standard power formula (see, e.g. Chow et al., 2017)

$$n = \left(\frac{z_{1-\frac{\alpha}{2}} + z_{1-\beta}}{ES} \right)^2,$$

where the cumulative normal distribution values are $z_{1-\frac{\alpha}{2}} = 1.96$ and $z_{1-\beta} = 0.84$, and the effect size *ES* is the effect size (ratio of difference to standard deviation), corresponding to 10 %, 20 %, or 30 % of the mean divided by the standard deviation, which has been calculated for a two-week period: 1) directly as the sample standard deviation, 2) as the residual standard deviation for a linear model controlling for the 'type', 3) controlling for the 'type' and 'municipality', and 4) controlling for the 'type', 'municipality', and 'size'. For one- and four-week observation periods the standard deviation (SD) was adjusted upwards or downwards based on how much a smaller SD could be expected, under the reasonable assumption that the error related to observation period (intra-location error) is independent of the sampling error (inter-location error).

All statistical analyses were carried out using the statistical software R (R core team, 2024).

Table 3
The monitoring periods, number of monitoring days (Days) for each food service type (Type) for the tree locations with long-term longitudinal data.

Location	Type	Monitoring period	Days
A	Staff restaurant	16/11/2020–25/10/2022	403
B	Staff restaurant	16/11/2020–03/10/2022	353
C	Health Services	25/02/2022–17/10/2023	252

3. Results

3.1. Monthly and weekly variation

The FW levels are presented by month in Fig. 1. Some trends are visible in the originally edible FW, while the kitchen bio waste levels do not have an obvious pattern. In the staff restaurants, the peak times for FW seem to appear around the summer and December–January. In the health service C, possible peaks are around May and September. These peaks are probably due the difficulty of predicting the number of customers and amount of food that should be produced during the festive season, and possibly due to waves in communicable diseases. The measurement month explained 10 % of the variation in the originally edible FW in staff restaurant A, 12 % in staff restaurant B, and 15 % in Health service C. When kitchen bio waste is also included, the corresponding numbers are 5 %, 9 %, and 15 %. Thus, we estimate that the effect of monthly variation on the originally edible FW is of the order 12.5 % ≈ 13 %, while for total waste it is 9.7 % ≈ 10 %.

The FW levels are given for each weekday in Fig. 2. Weekday explained 10 % of the variation in originally edible FW in staff restaurant A, 5 % in staff restaurant B, and 3 % in Health service C. When total FW is also included, the corresponding numbers are 8 %, 4 %, and 3 %. Thus, we estimate that the effect of the weekday variation on the originally edible FW is of the order 6 %, while for the total waste the figure is 5 %. It should be noted that food was served seven days a week in the health service C and from Monday to Friday in the staff restaurants, so the higher FW seems to be related to the weekend shut down. This is also visible in Fig. 2, where the originally edible FW on Friday is higher than on the other days. In addition, in staff restaurant A the kitchen bio waste is higher on Friday, while the levels are relatively constant in staff restaurant B. The increase in the amount of waste on Fridays is probably due to the coming of the weekend. All excess food accumulated during the week must be thrown away.

3.2. Food service type and size

The food service ‘type’ turns out to be the most important explanatory variable for FW, clarifying 66 % of the variance for originally edible FW and 54 % of the total FW (originally edible and kitchen bio waste) (see Fig. 3). Adding the food service size (number of customers) classification increases the explanatory power to 68 % and 62 % for originally edible and total FW, respectively (see Fig. 4). Thus, size accounts for

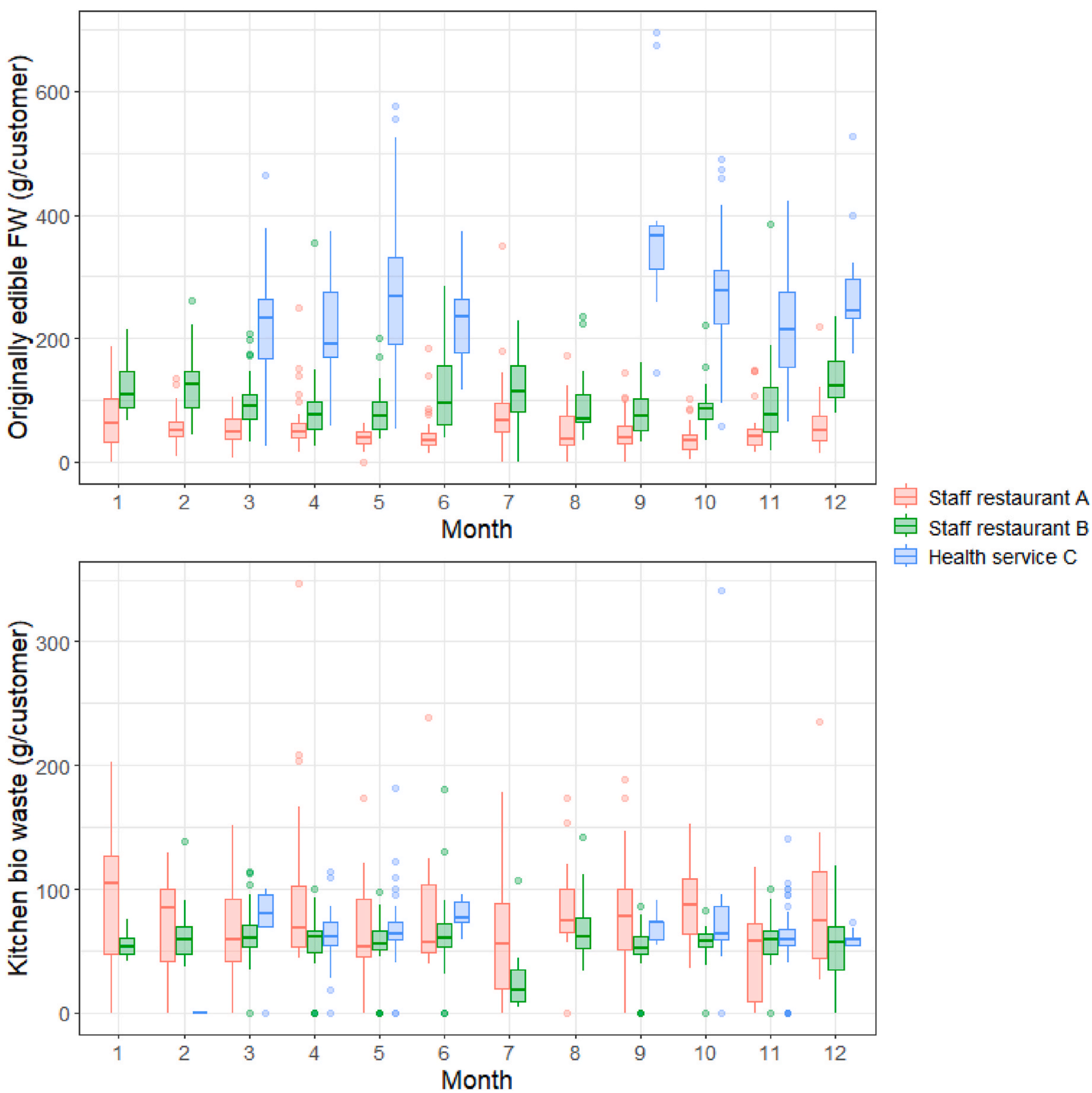

Fig. 1. Originally edible food waste (FW) and kitchen bio waste in three locations broken down by month.

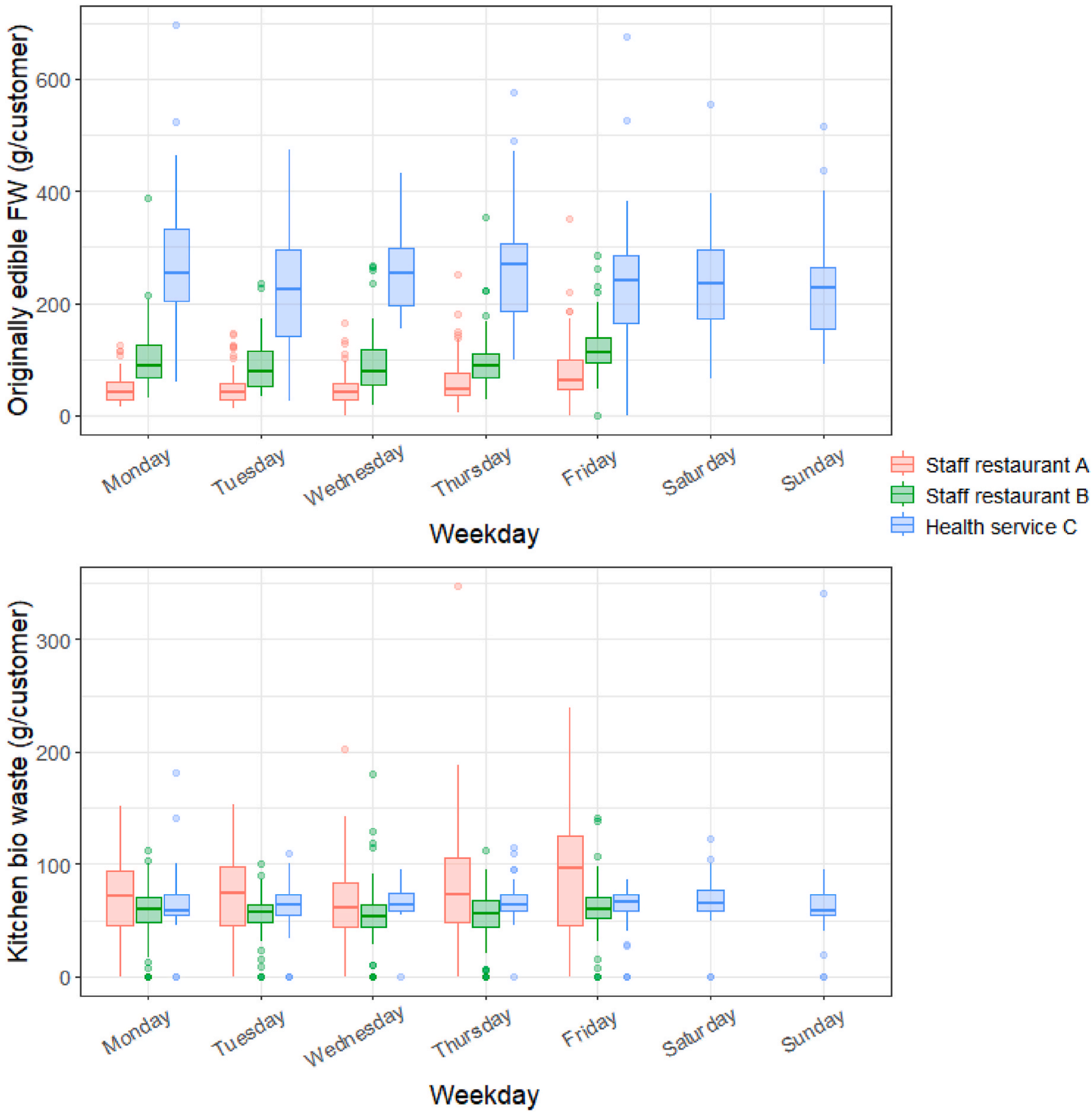

Fig. 2. Originally edible food waste (FW) and kitchen bio waste in three locations broken down by the weekday.

roughly 2 % of the variance for originally edible FW and 8 % for total FW. It should be noted that the size and type are not totally independent aspects. If one would only include the size classification as an explanatory variable of FW without controlling for the type, the percentage of variance explained would be 18 % and 21 % for originally edible and total FW, respectively. However, as the type has a much stronger explanatory power, this variable takes precedence. 'Size' shows some connection with originally edible FW in *schools* and *day care centres*, with smaller locations producing more FW per customer. In addition, there is one outlier in the *restaurants* category, with a large total FW amount, which also happens to be in the smallest size category.

3.3. Regional variation

When the municipality was included as a fixed effect in the linear mixed effects model in addition to the 'type', the proportion of variance explained was 71 % for originally edible FW and 63 % for total FW. Thus, regional variation at the municipal level seems to account for roughly 5 % of the variation in originally edible FW and 9 % for the total FW. When dividing the data into urban and rural areas with 50,000 residents as the cutoff, no additional explanatory power (<1 %) was gained compared to the base model with only the 'type' as a fixed effect. Therefore, there seems to be some small-scale regional variation, but not necessarily between small towns and large cities.

3.4. Length of the observation period

The food service 'type', municipality, and size explain about 75 % of the variation of originally edible FW and 71 % for total FW. Thus, increasing or decreasing the measurement length would have an impact on the residual variance only. Furthermore, the between-location variation is not affected. In staff restaurant A the long term mean for originally edible FW was 55 g per customer and in staff restaurant it was B 101 g per customer, while the corresponding numbers for the total FW were 130 g and 158 g, respectively (see Table 4). From these one can extract sample standard deviations of 32.5 g and 19.8 g as approximations for the between-location variation. Assuming these two sources of error are independent, moving to a one-week measurement period for originally edible FW would increase the variation by 3 % (analogous to −3 % of the variance explained), while moving to a three- or four-week

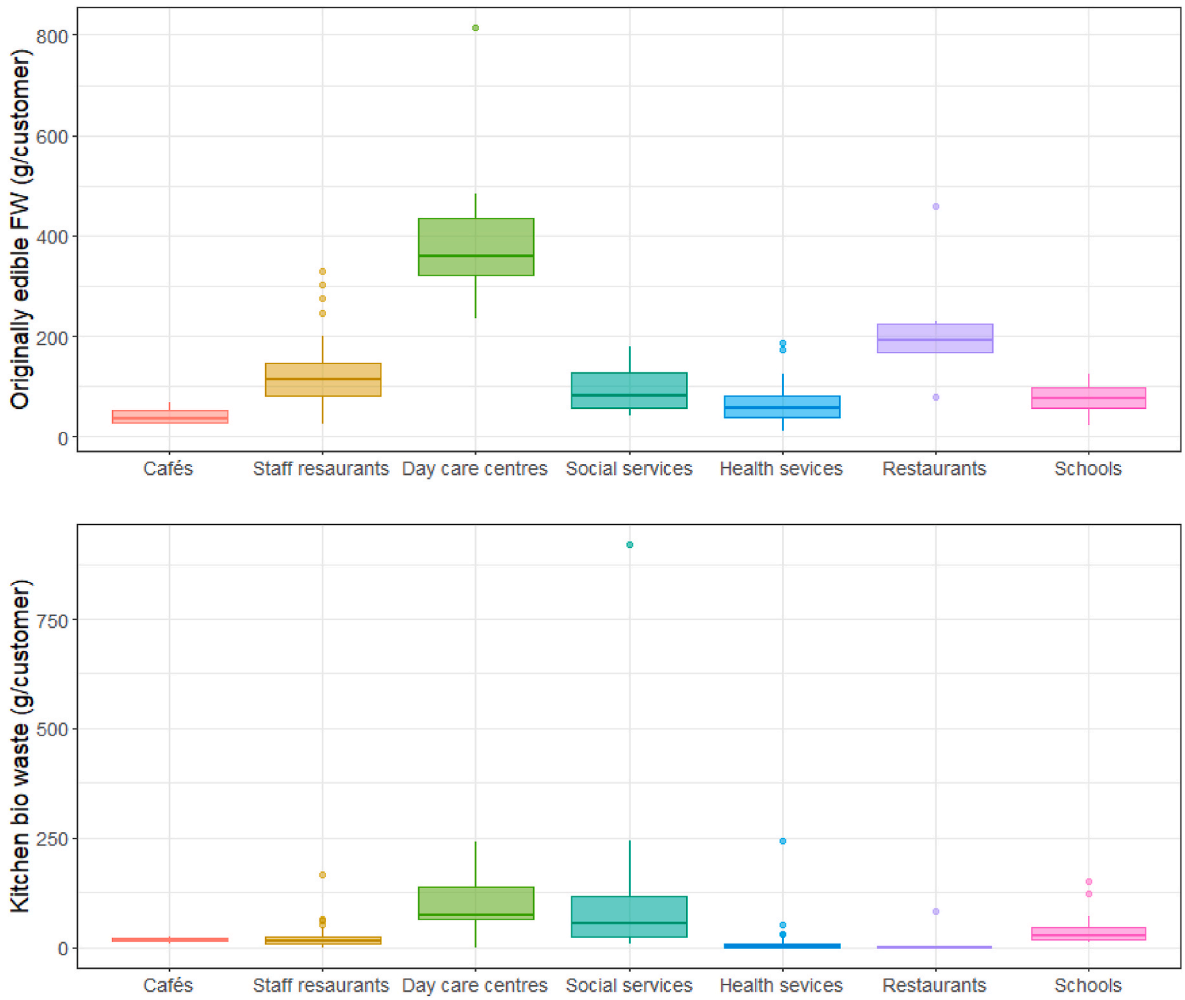

Fig. 3. Originally edible waste (FW) and kitchen bio waste in the cross-sectional data broken down by the food service type.

observation period would decrease the variance by −2 % or −3 %, respectively. For the total FW the corresponding numbers are 7 %, −4 %, and −6 %.

3.4.1. Rank ordering monitoring challenges

The estimated proportion of variance explained in the national-level FW estimate by each variable is presented in Table 5. For both originally edible and total FW food service type is the most important variable. The next largest sources of variation are the monthly and regional variation at the municipal level. The food service size (no of customers) seems to have a trivial effect concerning originally edible FW, but for the total FW this explains a similar amount of the variance as the monthly and municipal-level variation. Finally, the length of the measurement period seems to be of the order 3 % of variation for originally edible FW and 6–7 % for total FW.

3.5. Sample-size calculations

The sample sizes needed to observe a change of 10 %, 20 %, or 30 % in the national-level originally edible or total FW are presented in Table 6. With simple random sampling, observing a change of 30 % in the total FW would require sample sizes of 198, 194, or 191 depending on whether the measurement period is one, two, or four weeks, respectively. When controlling for 'type', the necessary sample sizes are significantly reduced to 88, 84, and 80. If the size and municipality can also be accounted for, the numbers drop down further to 75, 72, and 68. However, if one wishes to observe changes of 10 % or 20 % at the national level, the sample sizes need to be in the hundreds, or even over 1000 depending on the length of the measurement period.

4. Discussion

In this work, the most significant factors which need to be accounted for when designing national FW monitoring for the food service sector were studied. We analysed Finnish data from 192 outlets and seven subsectors ('type') to probe the relevance of the type and size of food service, length and season of the measurement period, and the regional variation to provide sample size estimates. The results show that some factors, such as the food service type, are crucial to account for, while some others are relatively insignificant when it comes to providing an accurate total estimate for the whole food service sector. The European FUSIONS-project has also recommended an approach to FW monitoring in food services, in which they highlight the importance of sample design and representativeness (Tostivint et al., 2016). In the UNEP report for 2024 it is recommended that at least three food service subsectors are included and if sufficient resources are available to study more subsectors. It should also be acknowledged that if some subsectors are not included, the total food service FW is almost certainly going to be underestimated (UNEP, 2024).

4.1. Ranking the order of measures for optimal method

For both the total FW and originally edible FW, the food service 'type' is the most important variable. Thus, it is crucial to use a stratified

Fig. 4. Originally edible food waste (FW) and kitchen bio waste in the cross-sectional data broken down by food service type and size classification, i.e. number of customers per day (a <50 customers/day, b = 50–99, c = 100–200, d = 200–500, e > 500).

Table 4
The standard error (SE) of the mean depending on the length of the measurement period for the two long-term staff restaurant datasets.

	Staff restaurant A		Staff restaurant B	
	SE of FW mean		SE of FW mean	
Length	Originally edible FW	Total FW	Originally edible FW	Total FW
1 Week	23.6	47.8	27.5	35.7
2 Weeks	20.4	43.7	23.2	29.7
3 Weeks	18.3	41.1	20.8	26.1
4 Weeks	16.9	39.9	18.8	23.5

sample, poststratification, or a similar approach which takes each subsector into account. Obviously, it is also important to classify food services under a proper group classification to begin with. When studying the food service types it can be noticed that *day care centres*, *health services,* and *social services* have very high amounts of serving waste accounting for between 25 and 40 % of all the food they produce. Additionally, the plate waste is high, especially in *health services*, *social services*, and *day care centres*. These three subsectors form a group that generate FW in a similar manner: they all serve several meals from breakfast to lunch and snacks, and they serve customers who generally need some level of help. The other group is formed by various private restaurants, cafés, and school canteens. This group, except for cafés, generates serving waste and plate waste, but in smaller amounts than the first group, amounting to about 15–20 % of all the food produced. This serving waste is overproduced food from buffet lines. The cafés serve fixed portions, and their FW is predominantly kitchen waste including coffee grounds. As these subsector groups differ in their function and FW generation it is important to get a representative number of outlets from

Table 5
The proportion of variance in the national-level FW data explained by each variable. Here 'type' refers to the seven-tier food service classification, while the length of measurement refers to the measurement period in a single restaurant, the temporal variation refers to the seasonal and weekly variation, regional variation refers to the municipal level variation and 'urban/rural' refers to a two-level classification with 50,000 residents as the cutoff, and 'size' refers to the size classification.

		Originally edible FW	Total FW
Type		66 %	54 %
Length of measurement	1 Week	−3 %	−7 %
	2 Weeks (ref.)	0 %	0 %
	3 Weeks	2 %	4 %
	4 Weeks	3 %	6 %
Temporal variation	Month	13 %	10 %
	Weekday	6 %	5 %
Regional variation	Municipality	5 %	9 %
	Urban/Rural	<1 %	<1 %
Size		2 %	8 %

both groups for the sample, though in an optimal situation the sample should also be fully representative of each subsector and not by this coarser grouping.

The next biggest source of variation was monthly variation, and this can be taken into account by always carrying out the measurements at the same time of the year or continuously throughout the year. There are at least two seasons affecting food services in Finland. First is the summertime when all schools, day care centres, and most staff restaurants are closed between June and July. The second is the winter holiday season in December–January which, in addition to the holidays, tends to include special menus and events.

Next, there is the regional variation at the municipal level. There is a bias–variance-trade-off here, as one can either carry out the measurements in the same municipalities each year and accept that these municipalities may not be fully representative of the country as a whole or collect data from different municipalities in different years and accept the additional sampling error associated with this. In the data collection for this study, we accepted all food services willing to participate not depending on their location. The sample was representative of the whole country, with measurements altogether from 31 municipalities.

The food service size (number of customers) seems to have a trivial effect on the originally edible FW, but for the total FW this explains a similar amount of the variance as the monthly and municipal-level variation (8 %). This means that for national-level estimation, it is not necessary to classify food service outlets according to size, as long as the food service type is controlled for.

Finally, the length of the measurement period seems to be in the order of 3 % of the variation for originally edible FW and 6–7 % for the total FW. Thus, while a longer measurement period does provide significantly better data from a single location, the fact that the between-outlet variation is larger than within-outlet variation makes the longer measurement period redundant when considering national-level estimates. A two-week period that has been typically used in Finland, seems to be long enough. This is consistent with the findings by Eriksson et al. (2018), who found that a 10-day-long measurement can be sufficient, though longer measurements may provide more robust results. Changing the observation period from two weeks to one week, three weeks, or four weeks was found to have only marginal effects (corresponding to 2–7 % variance). The period is also sufficient to avoid some difficulties that might happen, e.g. mistakes during the first days of measuring, which makes the use of shorter periods risky. If the outlets are measuring the amounts of FW continuously, the length is not a relevant issue because the data is easily available, but if the measurement is done only for research purposes this can be significant for personnel to participate. If the period is very long, many outlets may refuse to participate due to not wanting to increase their staff workload. Finally, a longer period also costs more for the researchers doing the study.

4.2. Minimum sample size

Based on our analysis, at the smallest, a sample size of $n = 68$ is needed to observe a change of 30 % in the national total FW levels. If a four-week measurement can be carried out in each location and for each food service type, the size, and municipal-level variation can be well controlled for. The size and municipality are relatively unimportant, with a sample size of $n = 80$ being sufficient if these cannot be accounted for. However, if the food service type is not controlled for, the sample size jumps to $n = 191$, even if a representative simple random sampling is performed. Minimum sample sizes of $n = 122$ and $n = 447$ are required if changes of 20 % or 10 % need to be observed between consecutive measurements. Therefore, when monitoring the national level FW, it is crucial to account for the food service type, while outlet size, regional variation, and temporal variation are much less important. Shorter measurement periods from multiple outlets are more valuable than long measurements from single outlets, as the between-outlet variation is greater than within-outlet variation. It should be noticed that most previous studies have had sample sizes which are well below these numbers.

It should be noted that most previous studies seem to be significantly underpowered and cannot be utilised in the context of monitoring FW. For example, Silvennoinen et al. (2019a) had a sample size of just $n = 51$, while Silvennoinen et al. (2019b) appears to be just barely sufficient for monitoring changes of the order ∼30 %. In Sweden, $n = 30$ was used (Eriksson et al., 2017) and in the UK $n = 39$ (WRAP, 2011). If these would represent subsamples for communal food service outlets and schools, respectively, with similar sample sizes from other subsectors, the resulting sample size could be sufficient for monitoring 20–30 % changes. However, it should be noted that if the interest regards a specific subsector, the sample sizes need to be similar to the ones we have

Table 6
Necessary sample sizes for a statistical power of 80 % with $p < 0.05$ as the level for statistical significance with a linear modelling approach depending on which variables can be controlled for and how long the measurement period is.

		Change in originally edible FW			Change in total FW		
Measurement period	**Stratification**	**10 %**	**20 %**	**30 %**	**10 %**	**20 %**	**30 %**
1 Week	*Nothing*	1548	387	172	1774	444	198
	Type	508	127	57	785	197	88
	Type, municipality	485	122	54	732	183	82
	Type, municipality, size	478	120	54	672	168	75
2 Weeks	*Nothing*	1524	381	170	1745	437	194
	Type	486	122	54	748	187	84
	Type, municipality	464	116	52	697	175	78
	Type, municipality, size	457	115	51	640	160	72
4 Weeks	*Nothing*	1507	377	168	1715	429	191
	Type	467	117	52	718	180	80
	Type, municipality	445	112	50	666	167	74
	Type, municipality, size	438	110	49	608	152	68

estimated with 'type' controlled for, so these studies by themselves give only limited information about the subsectors. The handful of observations by Wilkie et al. (2015) and Betz et al. (2015) do not appear to be sufficient for utilisation for the national monitoring of FW.

4.3. Procedure for an optimal method

The Delegated Decision 2019/1597 establishing a common EU methodology to measure FW entered into force in 2019 (European Commission, 2019). Using this approach, member states' data is collected according to the common EU FW measurement methodology and reported to the EU using a specific reporting format. Even though the reporting format is standardized, the national methodology is decided by each country and its relevant authorities. Based on our results, we introduce here one suggestion for the procedure of optimizing FW measurement in food services. Here we present our suggestions how our results could be utilised in developing monitoring systems in other countries. It should be noted that food service structures may be very different, which is why we have not, e.g. suggested how the sample should be allocated to different restaurant types, as this will vary locally. The suggestions rely on the assumption, that the rank ordering of the sources of variation in food waste is similar to our findings. This is a pragmatic assumption if no data are available. On the other hand, if such data are available, then the sampling design can be locally optimised.

1. Classification of food services

Because the type of food service is most important factor, the selection the categories should be made with consideration. The categories should be chosen based on available auxiliary statistics and taking account the business environment of the country. This allows for the utilisation of auxiliary statistics for upscaling the sample measurements to country-level estimates. The auxiliary statistics can be, e.g. number of employees, number of customers (e.g. pupils or patients), sales measured in currency, or number of outlets.

2. Measurement approach and period

To ensure robust and uniform results, the method for weighing and recording FW should be well planned and documented. The appropriate technical apparatus or application must be simple and easy for the staff to use. Our results demonstrate that longer measurement periods (in the range 1–4 weeks) only improved the national-level estimation marginally. Earlier studies have concluded that a two-week period has been widely accepted by and found to be suitable for most food service businesses in Finland (Silvennoinen et al., 2019c). To avoid problems related to seasonal variation, sampling should be always done the same way and preferably throughout the year. The measurements should be complete weeks to avoid any weekend-effects due to, e.g., the outlet being closed during the weekend or ingredients being shipped on specific days.

3. Designing the sampling; size and region

When designing the sampling procedure, it is crucial to account for the food service type. If possible, as many service outlets as possible should be invited to measure their FW in order to obtain data from all relevant subsectors. If a sample size of 70–80 can be reached and the food service type can be controlled for, it is possible to observe a change of 30 % in national total FW levels with a two-week measurement period. In our research, we have found that businesses are generally interested in participation when all the benefits of having FW data is explained, such as improvements in menu planning and information about customer preferences. As FW levels vary to some extent at the municipal level, efforts should be made to include outlets from different parts of the country. Small improvements can be obtained if the outlet size can also be controlled for in the stratification, but this appears to be the least important factor to consider.

4. Local considerations

It should be noted that our study used Finnish data, and significant differences in the food service sector structures in different countries should be considered when adapting the monitoring method in other countries. As discussed previously, Finnish schools offer pupils a free full (buffet) lunch, contributing to a significant part of the food service data we studied. In many European food cultures, pupils would bring their own lunch or visit home for a lunch break. Furthermore, Finnish working population typically have lunch similarly in buffet restaurants. These, categorised "restaurants" (open access), and "staff restaurants" (employment-bound, restricted access) also constitute to a large proportion of our FW data. Again, this type of wide buffet lunch culture is not widely popular in European context, where more typically plated food service results in significantly different FW composure. However, our results can be applied to similar, buffet service-weighted environments and/or FW data, regardless of the country. The separate monitoring of originally edible FW may be challenging in food cultures where the served food includes a significant amount of inedible parts, which is not typical in Finland, as this would complicate the monitoring of plate waste.

4.4. Limitations

There are several limitations to this study. Firstly, while we had a large sample of the two-week monitoring data, we only had three longitudinal data sets. Thus, the estimates for weekly and seasonal variation are likely more uncertain than the other estimates. Third, there are some outlet types like military catering and prisons which were not included in the dataset, since their effect was considered to be negligible, as they account for about 1 % of food served combined.

Secondly, it should be noted that while all plate waste was counted as originally edible FW, inedible parts such as chicken bones were not separated from the waste.

5. Conclusions

In this work, the relative importance of factors such as the food service type, outlet size, seasonal and weekday variation, length of measurement period for monitoring originally edible and total FW in the food service sector have been explored. Two datasets collected as part of the Finnish national monitoring system were used. The percentage of variation explained by each variable was explored with a linear modelling approach and the length of the observation period was examined using a non-parametric bootstrap method. The food service type is by far the most important factor, followed by monthly variation, municipal level variation, weekday-variation, and finally by outlet size. Thus, when monitoring national level FW, it is crucial to account for the food service type, while other factors are not important to control for. At minimum, a sample size of $n = 68$ is needed to observe a change of 30 % in the national total FW levels. This is significantly larger than most studies focusing on the food service sector have used. Thus, most studies in the field are likely to be statistically underpowered and are not going to be able to detect meaningful changes in FW levels. Shorter measurement periods from multiple outlets are more valuable than long measurements from single outlets, as the between-outlet variation is greater than within-outlet variation.

CRediT authorship contribution statement

Joel Kostensalo: Writing – original draft, Visualization, Funding acquisition, Formal analysis, Conceptualization. **Kirsi Silvennoinen:** Writing – review & editing, Supervision, Project administration, Funding acquisition, Conceptualization. **Marita Kettunen:** Funding acquisition, Conceptualization. **Vesa Lampi:** Writing – review & editing.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Kirsi Silvennoinen reports financial support was provided by European Commission. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

Funded by European Health and Digital Executive Agency (HADEA) and Single Market Programme.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2025.145889.

Data availability

The authors do not have permission to share data.

References

Beretta, C., Stoessel, F., Baier, U., Hellweg, S., 2013. Quantifying food losses and the potential for reduction in Switzerland. Waste Manag. 33 (3), 764–773. https://doi.org/10.1016/j.wasman.2012.11.007, 2013.

Betz, A., Buchli, J., Göbel, C., Müller, C., 2015. Food waste in the Swiss food service industry - magnitude and potential for reduction. Waste Manag. 35, 218–226. https://doi.org/10.1016/j.wasman.2014.09.015, 2015 Jan.

Boschini, M., Falasconi, L., Giordano, C., Alboni, F., 2018. Food waste in school canteens: a reference methodology for large-scale studies. J. Clean. Prod. 182, 1024–1032. https://doi.org/10.1016/j.jclepro.2018.02.040.

Chow, S.-C., Shao, J., Wang, H., Lokhnygina, Y., 2017. Sample size calculations in clinical research. Chapman Hall/CRC 3. https://doi.org/10.1201/9781315183084.

Eriksson, M., Persson Osowski, C., Malefors, C., Björkman, J., Eriksson, E., 2017. Quantification of food waste in public catering services - a case study from a Swedish municipality. Waste Manag. 61 (Mar), 415–422. https://doi.org/10.1016/j.wasman.2017.01.035.

Eriksson, M., Persson Osowski, C., Björkman, J., Hansson, E., Malefors, C., Eriksson, E., Ghosh, R., 2018. The tree structure — a general framework for food waste quantification in food services. Resour. Conserv. Recycl. 130, 140–151.

European Commission, 2019. Commission delegated decision (EU) 2019/1597 of 3 may 2019 supplementing directive 2008/98/EC of the european parliament and of the council as regards a common methodology and minimum quality requirements for the uniform measurement of levels of food waste. http://data.europa.eu/eli/dec_del/2019/1597/oj.

EU, 2024. Food waste reduction targets. https://food.ec.europa.eu/food-safety/food-waste/eu-actions-against-food-waste/food-waste-reduction-targets_en.

Eurostat, 2024. https://ec.europa.eu/eurostat/web/products-eurostat-news/w/ddn-20240927-2.

Finnish Food Authority, 2023. Ruokapalvelut. https://www.ruokavirasto.fi/elintarvikkeet/terveytta-edistava-ruokavalio/ravitsemuksella-hyvinvointia/ruokapalvelut/.

Foley, J.A., Ramankutty, N., Brauman, K.A., Cassidy, E.S., Gerber, J.S., Johnston, M., Mueller, N.D., O'Connell, C., Ray, D.K., West, P.C., Balzer, C., Bennett, E.M., Carpenter, S.R., Hill, J., Monfreda, C., Polasky, S., Rockström, J., Sheehan, J., Siebert, S., Tilman, D., Zaks, D.P., 2011. Solutions for a cultivated planet. Nature 478 (7369), 337–342. https://doi.org/10.1038/nature10452.

Lohr, S.L., 2021. Sampling: Design and Analysis, third ed. Chapman and Hall/CRC.

R core team, 2024. R: a Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/.

Riipi, I., Hartikainen, H., Silvennoinen, K., Joensuu, K., Vahvaselkä, M., Kuisma, M., Katajajuuri, J.-M., 2021. Elintarvikejätteen ja ruokahävikin seurantajärjestelmän rakentaminen ja ruokahävikkitiekartta. Luonnonvara- Ja Biotalouden Tutkimus 49/2021. Luonnonvarakeskus. Helsinki. 72 s.

Silvennoinen, K., Nisonen, S., Pietiläinen, O., 2019a. Food waste case study and monitoring developing in Finnish food services. Waste Manag. 97, 97–104. https://doi.org/10.1016/j.wasman.2019.07.028.

Silvennoinen, K., Nisonen, S. ja, Lahti, L., 2019b. Ravitsemispalveluiden elintarvikejäte: jätteen määrä 2018–2019 ja seurannan kehittäminen. Luonnonvara- ja biotalouden tutkimus 1/2020. Luonnonvarakeskus. Helsinki 45. ISBN:978-952-326-894-4.

Silvennoinen, K., Nisonen, S., Pietiläinen, O., 2019c. Food waste case study and monitoring developing in Finnish food services. Waste Manag. 97, 97–104. https://doi.org/10.1016/j.wasman.2019.07.028.

Silvennoinen, K., Nisonen, S., Katajajuuri, J.-M., 2022. Food waste amount, type, and climate impact in urban and suburban regions in Finnish households. J. Clean. Prod. 378. https://doi.org/10.1016/j.jclepro.2022.134430.

STAT FI Standard industrial classification TOL 2008. Food and beverage service activities, human health and social work activities. https://stat.fi/en/luokitukset/toimiala/toimiala_1_20080101?code=56.

THL, 2024. The Finnish institute for health and welfare. Statist. Data. https://thl.fi/en/statistics-and-data/statistics-by-topic.

Tostivint, C., Östergren, K., Quested, T., Soethoudt, J.M., Stenmarck, A., Svanes, E., O'Connor, C., 2016. Food Waste Quantification Manual to Monitor Food Waste Amounts and Progression. BIO by Deloitte.

UNEP, 2024. Food waste index report 2024. https://www.unep.org/resources/publication/food-waste-index-report-2024.

Wang, L., Liu, G., Liu, X., Liu, Y., Gao, J., Zhou, B., Gao, S., Cheng, S., 2017. The weight of unfinished plate: a survey based characterization of restaurant food waste in Chinese cities. Waste Manag. 66, 3–12. https://doi.org/10.1016/j.wasman.2017.04.007.

Wilkie, A.C., Graunke, R.E., Cornejo, C., 2015. Food waste auditing at three Florida schools. Sustainability (Basel) 7, 1370–1387. https://doi.org/10.3390/su7021370.

Willett, W., et al., 2019. Food in the anthropocene: the EAT–lancet commission on healthy diets from sustainable food systems. Lancet 393 (10170), 447–492. https://www.thelancet.com/journals/lancet/article/PIIS0140-6736(18)31788-4/abstract.

WRAP, 2011. Food waste in schools. https://www.wrap.ngo/resources/report/food-waste-schools.