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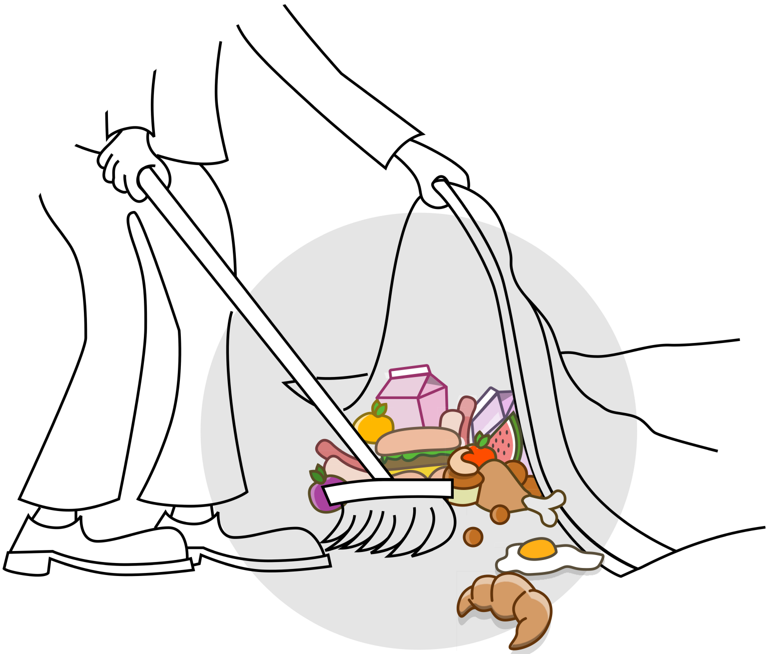
Christopher Malefors



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Cover: Food waste swept under the carpet
(Illustration: A Olsson)

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Abstract

Food waste is attracting global attention and there are stated ambitions to halve food waste by 2030. This thesis presents detailed information on quantities of food waste in the food service sector, with particular focus on the Swedish public catering sector. It examines where waste occurs, why it occurs, what can be done to reduce it and whether the ambitions to halve food waste by 2030 is achievable. The information collected covered the period 2010-2020 and originated from 3 386 kitchens operating in canteens, care homes, hotels, hospitals, preschools, schools and restaurants throughout Sweden, Norway, Finland and Germany. The results indicate that 18% of food served in the sector is wasted, although there is large variation between catering units. The main risk factor for food waste generation was identified as being amount of food prepared relative to number of guests attending, an issue that kitchens can tackle by improved forecasting. Forecasting as a waste reduction measure was tested in Swedish school canteens, alongside awareness campaigns, introducing tasting spoons and a plate waste tracker providing feedback to guests to nudge their behaviour. All these measures reduced food waste, but only forecasting and the plate waste tracker reduced total food waste more than in a set of reference canteens that had none of these measures in place. The mass of food waste generated in Swedish preschools, primary schools and secondary schools has declined by 25% since 2016. The amount of food waste to be halved by 2030 was estimated to 21,000 t for preschools and schools, which corresponds to 21 g/guest. Systematic work on food waste reduction, with quantification as a core step to evaluate current ambitions, is necessary to achieve a more sustainable food system.

Keywords: Kitchens, quantification, risk factors, forecasting, reduction measures

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Matsvinnsminskning inom offentliga måltider

Sammanfattning

Matsvinn har fått global uppmärksamhet och det finns ambitioner att halvera matsvinnet till 2030. Den här avhandlingen presenterar detaljerad information om mängden matsvinn inom storköks- och restaurangbranschen med särskilt fokus på svenska offentliga måltider. Den insamlade informationen sträcker sig från 2010-2020 och kommer från 3 386 kök som lagar mat till arbetsplatser, hotell, sjukhus, förskolor, skolor, restauranger och äldreboenden i Sverige, Norge, Finland och Tyskland. Resultaten visar att 18 % av den mat som serveras slängs, även om det finns en stor variation inom sektorn. Den största riskfaktorn är att kök lagar för mycket mat i förhållande till antalet gäster där överskottet blir svinn, vilket kan adresseras med hjälp av bättre närvaroprognoser. Prognostisering som åtgärd för att minska mängden matsvinn testades parallellt med åtgärderna att använda informationskampanjer, smakskedar eller en tallrikssvinnsvåg som ger gästerna återkoppling för att påverka dem att slänga mindre mat. Alla testade åtgärder minskade matsvinnet, men endast prognostisering och tallrikssvinnsvåg minskade det totala matsvinnet mer än referensköken som inte nyttjade dessa åtgärder. Matsvinnet i svenska skolor och förskolor har minskat med 25% mellan 2016 och 2020. För år 2020 beräknas mängden matsvinn till 21 000 ton vilket ska halveras till 2030 så att verksamheterna då uppnår en nivå på maximalt 21 g/gäst. Ett systematiskt arbete mot matsvinn, med mätning som grund för att utvärdera om de nuvarande åtgärderna är tillräckligt ambitiösa, är nödvändig för att nå ett mer hållbart livsmedelssystem.

Keywords: Matsvinn, matsvinnsmätning, matsvinnsminkning, riskfaktorer, storkök

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Dedication

To my daughter Maiken for keeping me in the present.

Contents

List of publications

This thesis is based on the work contained in the following papers, which are referred to by their respective Roman numeral in the text:

I. Malefors, C., Callewaert, P., Hansson, P-A., Hartikainen, H., Pietiläinen, O., Strid, I., Strotmann, C., Eriksson, M. (2019). Towards a baseline for food-waste quantification in the hospitality sector - quantities and data processing criteria. *Sustainability* 11, 3541.

II. Steen, H., Malefors, C., Röös, E., Eriksson M. (2018). Identification and modelling of risk factors for food waste generation in school and preschool catering units. *Waste Management* 77, 172-184.

III. Malefors, C., Strid, I., Hansson, P-A., Eriksson, M. (2020). Potential for using guest attendance forecasting in Swedish public catering to reduce overcatering. *Sustainable Production and Consumption* 25,162-172.

IV. Malefors, C., Sundin N., Tromp M., Eriksson, M. (2022). Testing interventions to reduce food waste in school catering. *Resources, Conservation and Recycling* 177, 105997

V. Malefors, C., Strid, I., Eriksson, M. (2022). Food waste changes in the Swedish public catering sector in relation to global reduction targets. *Resources, Conservation and Recycling* 185, 106463

Papers I-V are reproduced with the permission of the publishers.

The contribution of Christopher Malefors to the papers included in this thesis was as follows:

I. Planned the paper in cooperation with the co-authors and performed the data collection and analysis. Wrote the paper with support from the co-authors.

II. Planned the paper together with the co-authors. Supervised the data collection and analysis of data and provided input to writing the manuscript.

III. Planned the paper and developed the modelling approaches together with the co-authors, performed the modelling and analysed the data. Wrote the paper with support from the co-authors.

IV. Planned the paper and developed the testing scenarios together with the co-authors, performed all calculations and interpreted the results. Wrote the paper with support from the co-authors.

V. Planned the paper with input from the co-authors and performed the data collection, calculations and interpretation of the results. Wrote the paper with support from the co-authors.

Papers produced but not included in this thesis:

VI. 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 Management* 67, 415-422.

VII. 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. *Resources, Conservation and Recycling* 130, 140-151.

VIII. Eriksson, M., **Malefors, C.**, Callewaert, P., Hartikainen, H., Pietiläinen, O., Strid, I. (2019). What gets measured gets managed – Or does it? Connection between food waste quantification and food waste reduction in the hospitality sector. *Resources, Conservation and Recycling* X (4), 100021

IX. Bergström, P., **Malefors, C.**, Strid, I., Hanssen, O.J., Eriksson, M. (2020). Sustainability assessment of food redistribution initiatives in Sweden. *Resources* 9(3), 27

X. Eriksson, M., **Malefors, C.**, Bergström, P., Eriksson, E., Persson Osowski, C. (2020). Quantities and quantification methodologies of food waste in Swedish hospitals. *Sustainability* 12(8), 3116.

XI. **Malefors, C.**, Secondi, L., Marchetti, S., Eriksson, M. (2021). Food waste reduction and economic savings in times of crisis: The potential of machine learning methods to plan guest attendance in Swedish public catering during the Covid-19 pandemic. *Socio-Economic Planning Sciences*, 101041.

XII. Eriksson, M., **Malefors, C.**, Secondi, L., Marchetti, S. (2021). Guest attendance data from 34 Swedish pre-schools and primary schools. *Data in Brief* 36, 107138.

XIII. Persson Osowski, C., Osowski, D., Johansson, K., Sundin, N., **Malefors, C.**, Eriksson, M. (2022). From old habits to new routines – A case study of food waste generation and reduction in four Swedish schools. *Resources* 11(1), 5.

1. Introduction

Feeding the current and future population poses significant challenges, since the global food system in its current state is a major driver of climate change, land use, depletion of freshwater resources and pollution of aquatic and terrestrial ecosystems through excessive nitrogen and phosphorus inputs (Springmann *et al*., 2018). Current population growth and consumption trajectories highlight the importance of finding solutions that meet food demand sustainably and fairly (Raworth, 2012; Wheeler & Braun, 2013). Transitioning today's global food system into one that fulfils all future requirements is not an easy task and is likely to involve a multitude of options, implemented simultaneously, that need to be monitored (Fanzo *et al.*, 2021). Reducing food waste is proposed as one solution and has the potential to be used immediately with very high mitigation and adaptation potential (IPCC, 2019). It is also less controversial than, for instance, increasing production limits by genetic modification or advocating dietary changes (Godfray *et al*., 2010).

Reducing waste is also acknowledged in the United Nations Sustainable Development Goals (SDGs), which state that food waste should be halved by 2030 (United Nations, 2015). Some claim that this goal is not ambitious enough and that a 75% reduction needs to be in place by 2050, together with simultaneous implementation of other options to keep the planet within the safe planetary boundaries and avoid a future food crisis (Nellemann *et al*., 2009; Campbell *et al*., 2017; Springmann *et al*., 2018).

Since food is lost, spoiled or wasted all along the food supply chain (Parfitt *et al.*, 2010), efforts to reduce waste in all steps will be necessary to achieve the reduction target (FAO, 2019). Reducing waste might seem like a simple problem, but is more complex than it appears at a first glance. This because food waste is not just a problem, but also a solution to other issues which are currently a higher priority, such as economic profit and public health regulations requiring food to be discarded due to strict hygiene standards. In addition, food waste occurs for many reasons, which makes it difficult to fix the issue quickly once and for all. It is therefore likely that several different options will need to be available to reduce food waste. Methodologies to quantify food waste across the food supply chain will also be required to track developments, evaluate the effects of countermeasures against food waste and supply primary data, which are urgently needed to understand the problem better (Xue *et al.*, 2017). To drive developments in food waste reduction, the European Union (EU) requires all member states to quantify food waste since 2020 and report national levels for the first time by mid-2022 (European Commission, 2019). The revised version of the European Waste Framework Directive also calls on member countries to reduce food waste levels and report progress (European Commission, 2018), ambitions that align well with the overarching Sustainable Development Goal.

The consumption stage of the food supply chain comprises households, retail and the food service sector (Stenmarck *et al.*, 2016). Food waste at this stage means that more value is lost, since resources are accumulated for every previous step in the food supply chain (FAO, 2013). The current global estimate of food waste generated in 2019 indicates that households are the largest contributor (569 Mt), followed by the food service sector (244 Mt) and retail (118 Mt) (United Nations Environment Programme, 2021). Thus while current global estimates indicate that households generate the most waste, the food service sector is still an important contributor and its importance is rapidly increasing since more people are obtaining the financial means to eat out and are more willing to pay for food services (Yi *et al.*, 2021). The food service sector consist of actors who are obliged to follow the same kinds of directives and legislation, although the sector itself is diverse and covers a wide range of sub-actors (such as major chains, small privately-owned business and public catering establishments). Thus potential successful measures implemented in relatively few places in the food service sector could have a large impact.

However, the current understanding of the food waste situation within the food service sector is mainly based on waste quantification by individual establishments or sub-groups of establishments, resulting in limited scope and in associated difficulties of accurately scaling up and extrapolating the data to nationwide estimates (United Nations Environment Programme, 2021). This problem is apparent in the Swedish food service sector, where the earliest studies from 2004 comprised only four units (Engström & Carlsson-Kanyama, 2004). A later study by Eriksson *et al*. (2017) covered 30 kitchens in a public catering organisation. In a subsequent mapping of food waste quantification methodologies used by the food services in Swedish municipalities, 55% of 290 municipalities surveyed reported that they quantify food waste on central level (Eriksson *et al*., 2018a). Since then, there has been rapid progress and the issues of food waste, food waste quantification and systematic improvements are gaining increasing traction within the Swedish public catering sector.

A remaining challenge is to compile food waste quantifications performed at the level required to provide a detailed overview of the situation and to identify key factors that contribute to food waste generation. Moreover, there is a need to identify actions that can help to reduce food waste and ways to monitor changes over time to ensure that the sector is on track to meet the target of halving food waste by 2030.

2. Aim, objectives and structure of the thesis

The overall aim of this thesis was to provide new knowledge on food waste quantification and on how to reduce food waste in the food service sector, with particular focus on the Swedish public catering sector. Specific objectives were to:

- Quantify food waste in the food service sector, compare different sector segments and identify hotspots of food waste generation (Paper I).
- Identify risk factors for food waste generation in school and preschool catering units (Paper II).
- Develop and apply models to forecast guest attendance, in order to optimise catering practices to lower overproduction in school catering units (Paper III).
- Demonstrate interventions and how they affect levels of food waste in school catering units (Paper IV).
- Track changes in food waste in the Swedish public catering sector (Paper V) and compare developments against the global food waste reduction goals.

The research to fulfil these objectives was performed according to the principles of a systematic and continual improvement process. Figure 1 illustrates how it built on previous knowledge, but also the need for further research. In **Paper I**, quantities of food waste in the food service sector were determined, to understand the scale of the problem, find potential hotspots and develop a structure for further work. The quantities were analysed in **Paper II**, to identify causes and risk factors that contribute to waste generation, focusing on Swedish preschool and school catering units. Food waste reduction measures were then designed based on the knowledge gained from **Paper II**, with the focus on public catering organisations maintained also in **Papers III** and **IV**. In **Paper III**, special attention was devoted to understanding guest attendance dynamics and to developing forecasting models that canteens could apply in their daily operations. In **Paper IV**, the forecasting concept was evaluated alongside other interventions, to determine their ability to reduce food waste. The work in **Paper V** involved monitoring changes in food waste levels over time in Swedish public catering establishments in relation to the global goal of halving food waste by 2030, in order to determine whether the sector is heading in the right direction and at a sufficient pace.

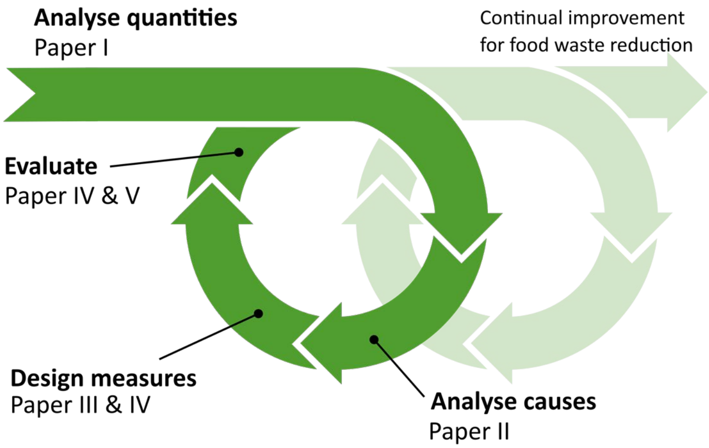

Figure 1. Schematic illustration of the work performed in Papers I-V in this thesis and their interrelations.

3. Background

3.1 Definitions of food waste and food waste reduction

Some researchers argue that food waste is a "wicked problem" (Närvänen *et al.*, 2020), where such problems are defined as unstructured, cross-cutting and persistent (Rittel & Webber, 1973). Food waste is certainly an unstructured problem, because exact and precise causes and effects are difficult to identify and a common problem definition is lacking *(*Bellemare *et al.*, 2017). Since the definitions of food waste also differ substantially and, according to Chaboud and Daviron (2017), are inconsistent, this has the potential to result in differing estimates, which might lead to different approaches to the problem and targeted issues. For instance, the Food and Agriculture Organization (FAO) of the United Nations distinguishes between food loss and food waste. It considers food losses as occurring along the food supply chain from harvest/slaughter/catch up to, but not including, the retail level, whereas food waste is the decrease in quantity and quality of food[1] resulting in the actions by retailers, food services and consumers. This is in contrast to, for instance, the definition by the European Commission-funded project Fusions, which states: "*Food waste*

[1]According to FAO (2019), food refers to any substance, whether processed, semi-processed or raw, intended for human consumption. It includes drink, chewing gum and any substance used in the manufacture, preparation or treatment of food, but does not include cosmetics, tobacco or substances used only as drugs. Food products can be of animal or plant origin and are considered food from the moment that: (i) crops are harvest-mature or suitable for their purpose; (ii) animals are ready for slaughter; (iii) milk is drawn from the udder; (iv) eggs are laid by a bird; (v) aquaculture fish is mature in the pond; and (vi) wild fish are caught with fishing gear.

is any food, and inedible parts of food, removed[2] *from the food supply chain to be recovered or disposed (including composted, crops ploughed in/not harvested, anaerobic digestion, bio-energy production, co-generation, incineration, disposal to sewer, landfill or discarded to sea)"* (Östergren *et al*., 2014). This definition does not distinguish between loss and waste and focuses more on the use of resources in food systems. It also does not differentiate between edible and inedible parts of food products. The concept of edibility encompasses terms such as "avoidable", "possibly avoidable" and "unavoidable" food waste (WRAP, 2011). However, what is defined as edible is highly subjective, as pointed out by Schneider (2013), who also notes the discrepancies between theoretically defined food waste and the information that can be collected in practice. Generation of detailed food waste data is often limited by financial restrictions, which impacts sample size and level of detail.

All this may not matter to the farmer, who might not know the exact intended use of the crops cultivated, or the canteen manager, who might not reflect on whether food waste is 'avoidable' or 'unavoidable', since the core business revolves around serving food. Where it matters is if quantities of food waste based on different definitions are merged together and used as through defined similarly, which can create target-related issues. Inclusion or not of animal feed as a food waste is an example which makes a large difference, as illustrated by estimates reported by the Institution of Mechanical Engineers (2013) based on FAO (2011) and Lundquist *et al.* (2008) showing that 30-50% of all food produced is never consumed by humans. In those data sources, Lundquist *et al.* (2008) include animal feed but FAO does not, which might explain the 30 to 50% range and which means that the value can actually be both 30% and 50%, depending on how waste is defined. If nothing is defined as food waste, there is nothing to prevent or to reduce. Prevention of food waste can encompass various biological waste treatment options, such as composting or anaerobic digestion. Diverting surplus food to animal feed or donating food to charity can also be viewed as reduction measures. However, in this thesis the focus

[2]The term 'removed from' encompasses other terminology such as 'lost to' or 'diverted from'. It assumes that any food produced for human consumption, but which leaves the food supply chain, is 'removed from' it regardless of the cause, point in the food supply chain or method by which it is removed.

was solely on source reduction when the food is used for its intended purpose, which is to feed the guests of a food establishment.

3.2 Definitions and description of the food service sector

The Statistical Classification of Economic Activities in the European Community (NACE) defines the food service sector as *"establishments or actors providing complete meals or drinks fit for immediate consumption, whether in traditional restaurants, self-service or take-away restaurants, whether as permanent or temporary stands with or without seating. Decisive is the fact that meals fit for immediate consumption are offered, not the kind of facility providing them"* (EUROSTAT, 2008). Another term for the sector is the 'eating-out-of-home sector'. Based on current population growth and consumption trajectories, the sector is estimated to grow as the population becomes more urbanised and with increasing tourism (Satterthwaite *et al.*, 2010; Knorr *et al.*, 2018). This might lead to more food service outlets and more food waste being generated.

According to Eurostat (2018), the food service sector accounted for 8.5% of total employment in the EU in 2018. As with all structural business statistics, only enterprises that provide food, beverages or accommodation as a principal activity are covered by this definition and included in statistics, which means that it can be difficult to pinpoint the exact number from official records to determine the size of the sector. For instance, businesses that offer food and drinks as a complement to their services are not included, which in some cases might represent a significant secondary activity, such as in cinemas and sports arenas.

All actors within the sector either focus on providing food on a free market or are active under the public catering umbrella, meaning that their activities are funded and organised totally or partly through government support. This can take many forms, *e.g.* a company can be procured to operate a hospital canteen, while in other cases this is operated entirely by a public catering organisation. This is a common set-up in Sweden and Finland, where the majority of public catering is organised by municipal authorities, which are responsible for preschool and school meals, along with meals for the elderly in care homes or similar. In Sweden, the municipalities fall into one of 21 regions, another layer of administration that is responsible for healthcare, transport and regional development. The regions share many of the characteristics of the municipalities, as they vary in geographical size and population density and in how they are organised. Table 1 shows how the food service sector is comprised in Sweden, covering both public catering and private businesses. The majority of actors are located in the private sector. It is difficult to estimate the exact number of people using their services, especially during COVID-19 restrictions, but according to the Swedish Agency for Economic for Economic and Regional Growth (2020), in 2019 restaurants were responsible for 9.2% of tourist consumption. According to the Swedish Competition Authority (2015), the Swedish food sector had total turnover of around 151 billion SEK (excluding VAT) in 2013, where the food service sector accounted for 57%.

Table 1. *Food service situation in Sweden. Guests per day refers to the number of guests during normal operating days*

Establishment	Units (n)	Guests/day (n)	Source
Public			
Preschools	9 600	520 000	National Agency for Education (2021)
Schools	4 800	1 200 000	National Agency for Education (2021)
Secondary schools	1 300	370 000	National Agency for Education (2021)
Care homes	1 700	110 000	National Board of Health & Welfare (2019)
Hospitals	103	25 000	National Board of Health & Welfare (2019) Delfi (2015)
Jails	45+32	5000+2000	Swedish Prison and Probation Service (2019)
Armed Forces		24 000+	Swedish Armed Forces (2022)
Private			
Hotels	2 100		Statistics Sweden (2022) SNI: 55101
Restaurants	33 000		Statistics Sweden (2022) SNI: 56

In contrast, the public catering sector in Sweden purchased food items for around 8 billion SEK per year in 2013 (excluding costs for staff and premises) according to the Swedish National Food Agency (2019a). However, public catering plays a central role within the Swedish food service sector, since it is estimated that 50% of all midday meals are served through public catering organisations (Delfi, 2015). A contributing factor to this is that all pupils have the legal right to one free meal on every school day (Swedish Parliament, 2010). Therefore, lunch is indisputably the most common meal served, while a majority of preschools also serve breakfast and a snack. During the Covid-19 pandemic, 76% of Swedish municipalities also offered meals in conjunction with distance learning (Swedish National Food Agency, 2022).

Elderly care is a diverse term that can encompass many different types of operations. The elderly within care homes (see **Table 1**) are offered all meals during the day. However, in addition to the care home residents referred to in Table 1, approximately 48,000 elderly people living in their own home take part in a food service programme, where they normally receive one meal each day in the form of a lunch box. On top of this, some elderly people not covered by the above statistics take part in some daily activities where food may be served. Sweden's 21 regional authorities govern the country's 103 hospitals, where it is estimated that 25,000 people per day are served food when they are receiving healthcare.

The number of units displayed in Table 1 for preschool, primary school and secondary schools is the number of school units, which is not necessarily the same as the number of canteens operating within the sector. The actual number of canteens serving meals to this age group is probably lower than that displayed in Table 1. The number of guests/day for this age group is based on the number of students enrolled in formal education.

The food service sector is made up of a range of different actors and enterprises that operate under vastly different types of settings, such as the types of customers they target, size of their operation and establishment, whether food is a primary or secondary activity, opening hours, and types of meals and number of options served. A solution to reduce food waste in one place may therefore not necessarily reduce food waste in another establishment, and an effective solution for reducing food waste at a lunch meal might not work at all for a breakfast buffet in the same location. Therefore, it is important to have quantification practices in place that allow canteens to determine the effectiveness of their actions to reduce food waste.

3.3 Quantification methodologies and previous studies

To quantify food waste, it is essential to find common ground and establish what should be quantified, when should be quantified and for how long, if the goal is to compare different facilities with each other. Quantification can also be an internal tool for canteens to understand their situation and identify potential problems that they might want to address.

A factor in common for all establishments within the food service sector is that food arrives (either as raw food items or ready-made meals from some other actor) at the location and is served and consumed. However, this is very simplistic view of the processes involved, since in many cases there are intermediate steps in which food waste can occur. A detailed mapping of the food flows and waste processes performed by Eriksson *et al*. (2018b) is summarised in Figure 2.

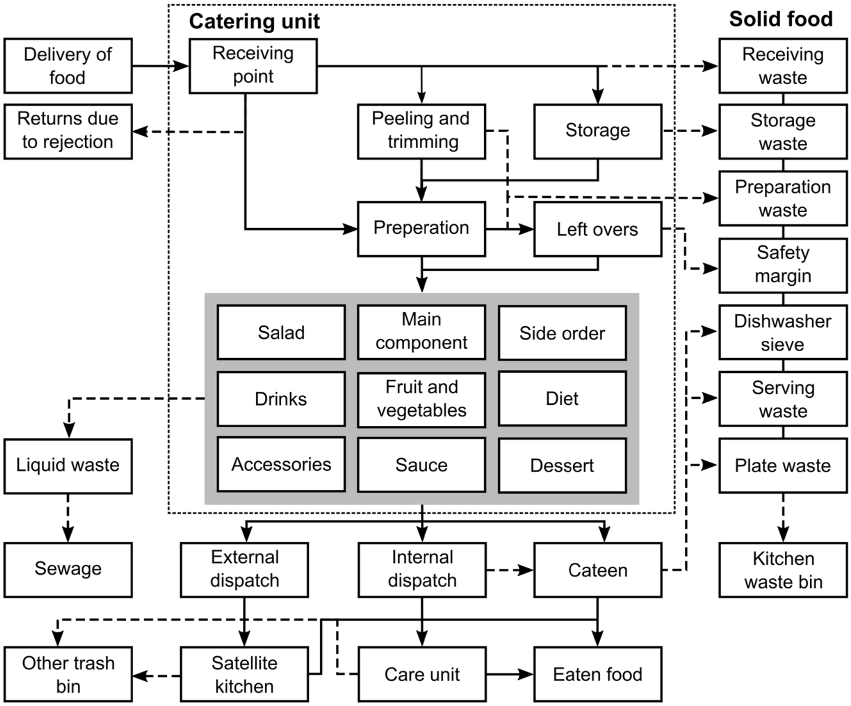

*Figure 2***.** Mass flow diagram for catering establishments illustrating the processing-based waste categories. The grey area indicates food prepared in the production (catering) unit, but dispatched for consumption in different places.

Figure 2 also considers liquid and liquid waste and divides the preparation into different food categories before being dispatched. This example illustrates a production kitchen, where all food is prepared on-site. Another common type of catering unit is the satellite kitchen, which prepares some meals but relies on deliveries from a production kitchen. Since food waste can be generated in a multitude of processes, there is a need for a systematic way of framing how food waste quantification should take place. Several frameworks have been developed to structure and unify the quantification process (*e.g.* Hanson *et al.*, 2016; Tostivint *et al.*, 2016; Eriksson *et al.*, 2018b; Swedish National Food Agency, 2019b). Regardless of the framework used, it is necessary to define waste-generating processes, which is done in Table 2. These waste processes can be further broken down to capture categories. For instance, the serving waste process can be refined to capture whether the waste derives from the main component or side dishes, as illustrated in Figure 2. This approach can be further refined down to food item level.

Table 2**.** *Definitions of different waste processes that generate food waste*

Name	**Definition**
Kitchen waste	
Receiving waste	Waste that occurs from goods delivered to the kitchen, but never stored or used. Also known as reclamation waste in other sectors such as retail.
Storage waste	Stored goods that become waste for whatever reason.
Preparation waste	Waste from the preparation and/or trimming of food, such as peel, bones and fat.
Safety margin waste	Waste from food produced which did not leave the kitchen for consumption and was not saved for another meal.
Serving waste	Food served that did not reach the plates of guests.
Plate waste	All waste from the plates of guests. May contain inedible parts such as bones and peels.
TOTAL WASTE	Sum of mass from the different food waste processes.

However, there is also a need to balance quantification efforts between the level of detail required against what is practically possible to achieve, especially when considering longer quantification periods. One simplification is to bundle 'receiving, storage, preparation and safety margin waste' together and call it 'kitchen waste', which is common practice within Swedish public catering organisations (Swedish National Food Agency, 2019c). Another aspect to consider is the type of method deployed when quantifying waste. Some studies have used visual observation (Connors & Rozell, 2004; Hanks *et al.*, 2014), which is reported to have a tendency to underestimate the levels of food waste generated compared with quantification by weighing (Comstock *et al.*, 1981; Liz Martins *et al.*, 2014).

Quantifying the mass of food thrown away is rarely sufficient if the goal is to compare establishments with each other, since a large kitchen is likely to report more waste than a small kitchen. Therefore, kitchens would need to use some relative indicator, such as ‘mass of waste per guest’ or ‘mass of waste in relation to mass of food served’, which are common indicators. The ‘waste per guest’ indicator uses the number of portions or number of guests to estimate how many guests have generated the amount of waste thrown away. The idea is to allocate the waste to the number of guests that have taken part in a meal, with waste possibly also divided into the different waste processes (*e.g*. kitchen waste per portion, serving waste per portion, plate waste per portion). The other type of indicator, ‘waste of food served’, uses an observation point located in the middle of all kitchen processes. Figure 3, adapted from Eriksson *et al.* (2018b), illustrates where the point of observation is located. The reason for not using the end-points as a reference point for the indicator is that serving food as a process is the only step that takes place on a certain day. The steps before serving may take place days before, due to long storage and preparation times. Leftovers might also play a role, since they can be seen as prepared food until served, which is likely to be a day or so after they are cooked. Another reason for having the point of reference in the middle of the kitchen flow is practical, since it is much easier to quantify the amount of food served compared with the amount eaten or taken by guests.

There are other types of indicators based on economic values, such as ‘food discarded per Euro’ or turnover. However, this may be sensitive information for commercial catering actors, while in the public catering sector the values might not be known even to those in charge of food waste quantification. Therefore, food waste quantification initiatives often put the emphasis on a practical approach, to make sure that quantification takes place and is not abandoned because it is too difficult.

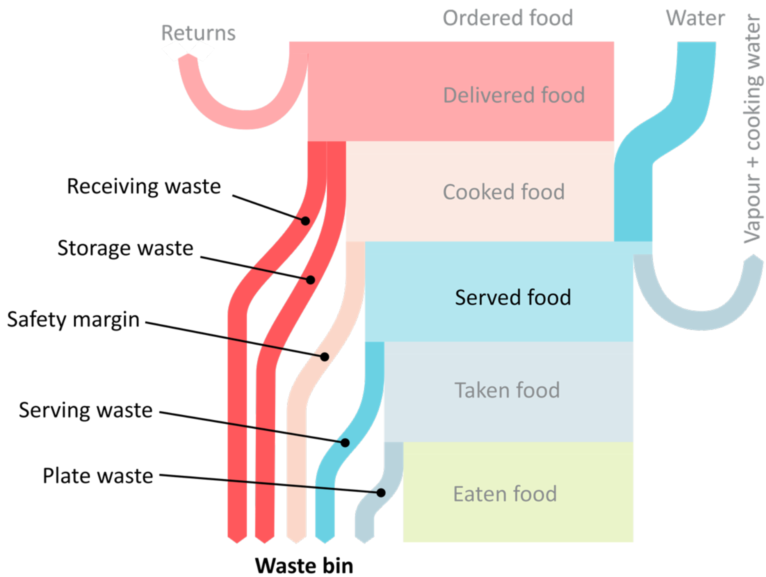

Figure 3. Sankey diagram displaying the mass flows through a canteen unit. Flows are not to scale, and liquid waste and dispatched food have been omitted for simplicity.

Most previous studies of the food service sector are case studies, limited by the researchers' access to data. Table 3 summarises some such studies sharing the feature that they all used some kind of physical observation to quantify food waste. Since the aims, scope, unit/s, location and duration of the studies were different, it is difficult to compare the results directly. For instance, Engström and Carlsson-Kanyama (2004) studied two restaurants and two school canteens and divided food waste into storage loss, preparation loss, serving losses, plate waste and leftovers, quantified for two days, whereas Barton *et al*. (2000) examined food waste as plate waste and tray waste during 28 days in one hospital. Some studies distinguish between net and gross weight and quantify waste on food item level (*e.g.* Betz *et al*., 2015). Other studies, such as those by Silvennoinen *et al*. (2015) and Katajajuuri *et al*. (2014), take a whole sector approach, while Juvan *et al*. (2017) investigated edible parts discarded from the plate in one hotel. These studies reached very different conclusions, which is understandable when considering the differences in how they were performed and what they encompassed.

Table 3. *Summary of studies in the literature quantifying food waste in the food service sector*

Kitchen type	Country	Units (n)	Duration	Waste/portion (g)	Waste (%)	Source
Schools & catering	UK	12+2			10+13-18,23	Bender *et al.* (1977) Singer (1979)
Hospital	UK	1	28 days	-	>40	Barton *et al.* (2000)
Catering	Egypt	-	-	126,131,166	23-51	El-Mobaidh *et al.* (2006)
Schools & restaurants	Sweden	4	2 days	92.5	20	Engström & Carlsson-Kanyama (2014)
Hospital	UK	3	2 days	-	19-66	Sonnino & McWilliam (2011)
University	Portugal	1	4 weeks	280	24	Ferreira *et al.* (2013)
Food service sector	Finland	72	1 day – 1 week	-	8-27	Katajajuuri *et al* (2014)
Preschool	USA	1	5 days	210	45.3	Byker *et al.* (2014)
Schools	Portugal	21	1 month	49.5	27.3	Martins *et al.* (2014)
Hospital	Portugal	1	8 weeks	953	35	Dias-Ferreira *et al.* (2015)
Schools	Italy	3	92+33 days	-	15.31	Falasconi *et al.* (2015)
Schools & restaurants	Switzerland	2	5 days	86 & 91	7.69 & 10.73	Betz *et al.* (2015)
Food service sector	Finland	51	5 days	58-189	19-27	Silvennoinen *et al.* (2015)
Hotel	Malaysia	1	1 week	1100	-	Papargyropoulou *et al.* (2016)
University	South Africa	9	21 days	555	-	Painter *et al.* (2016)
Schools	China	6	1 day/unit	130	21	Liu *et al.* (2016)
Public sector	Sweden	30	3 months	75 (33-131)	23 (13-34)	Eriksson *et al.* (2017)
Hotel	Slovenia	1	63 days	15.2	-	Juvan *et al.* (2017)
Schools	Italy	4-5	5-10 days	-	27	Boschini *et al.* (2018)
Schools	Italy	1	12 days	151	-	Lagorio *et al.* (2018)
University	Qatar	3	40 days	980, 757	~50	Abdelaal *et al.* (2019)
University	China	6	2-3 days	73.7	-	Wu *et al.* (2019)
Hospitals	Saudi Arabia	1	3 weeks	412	-	Alharbi *et al.* (2020)
Hospitals	Sweden	20	2013-2019	111	-	Eriksson *et al.* (2020)
Schools	Italy	78	740 days	160	-	Boschini *et al.* (2020)
Catering	Germany	239	4 years	74-280	-	Leverenz *et al.* (2020)

Some researchers argue that in order to facilitate long-term data collection that could be maintained by kitchen staff, it is necessary to simplify or automate quantification procedures (Jacko *et al.*, 2007; *Mui et al.*, 2022). Although this might lead to less detailed information being collected, it could still serve a purpose in allowing kitchens to observe and act upon their levels of food waste.

Canteens, kitchens and their guests all throw away food, so it is important to shift from method development in order to answer specific research questions to quantification methods that are easy to deploy in kitchens. This would provide canteens with the tools to evaluate their levels of food waste and assess whether actions they take to reduce food waste actually work.

3.4 Causes of food waste and reduction strategies

Kitchens have different prerequisites in dealing with food waste, with some of these prerequisites being bound to questions relating to infrastructure. For instance, Eriksson *et al*. (2017) showed that production kitchens have significantly lower food waste than satellite kitchens, but that there can be large variations even within the same type of kitchen.

There are also other factors that are not linked to the infrastructure of kitchens, such as socio-demographic and psychographic factors that affect food waste behaviour for consumers. For instance, research examining the role of religion and food waste behaviour at home and away has so far demonstrated a limited association between religiosity and wasteless behaviour (Filimonau *et al*., 2022b).

The Swedish National Food Agency has developed a handbook with suggestions on what canteens could do to prevent or reduce food waste (Swedish National Food Agency, 2020b). This handbook has similarities to the checklist developed by Kinasz *et al*. (2015) for prevention of food waste, which is based on expert opinion, but notes that more research is needed to identify food waste generation and to support proposed interventions with studies on circumstances in which they might work best. Both the checklist and the handbook suggest that a calm meal environment and knowledge about the diners are factors resulting in lower levels of food waste in public catering. This confirms findings by *e.g*. Byker *et al*. (2014) in a study within an educational setting based on actual food waste quantification efforts, which suggested that portion size, noise levels, time available for eating and age of the guests are factors that contribute to the level of food waste.

Some studies suggest that gender drives food waste and especially plate waste, with *e.g.* plate waste from females in an out-of-home and university context being higher than plate waste from men in the same context (Kuo & Shih, 2016; Vizzoto *et al.*, 2021)).

Another factor that contributes to plate waste in educational settings can be competing options (such as a cafeteria) within close distance to the dining hall (Marlette *et al*., 2005). Early studies within the field identified that when school children in years 1 to 3 had a break scheduled before lunch, this reduced food waste by around 10% (Getlinger *et al*., 1996). Niaki *et al*. (2017) found that younger elementary school students wasted more food than their older colleagues, but they also pointed out that the younger students had their lunch two hours earlier and that serving lunch at 10 am might not be optimal.

To target food waste, it is common to deploy information campaigns, based on the argument that if all staff and guests are informed they will stop wasting food. For instance, Whitehair *et al.* (2013) demonstrated that university students who receive information have the potential to achieve a reduction of around 15%. However, only 40% of the students approached in that study agreed to participate. Nudging in conjunction with an information campaign is another option to explore. An information campaign and game-based intervention performed by Dolnicar *et al*. (2020) in sun-and-beach hotel restaurants reduced plate waste, while Kallbekken and Sælen (2013) reduced plate size in a hotel and observed significantly reduced plate waste. Removing trays has also been shown to reduce plate waste in a university dining hall (Thiagarajah & Getty, 2013). A study using communication tools in the right context saw a reduction of 14.4% in edible plate waste generated by hotel guests (Antonschmidt & Lund-Durlacher, 2021). A similar finding was made by Cozzio *et al*. (2021), who concluded that appeals in messages can nudge hotel guests towards more active engagement in avoiding food waste. Nudging has also been shown to be a successful measure in school canteens, where such strategies were found to prevent 41% of plate waste and result in 27.2 g of food waste per portion in one study (Vidal-Mones *et al*., 2022)

Studies often focus on one fraction of the food waste problem, disregarding potential spill-over effects. Therefore, the British organisation WRAP (Waste and Resources Action Programme) tested three interventions in 39 schools that involved i) improving familiarity and appreciation of school meals, ii) improving dining experience and iii) making it possible to order meals in advance of cooking (WRAP, 2011). The results indicated a reduction of 4%, which was not statistically significant. A LEAN philosophy was proposed by Barr *et al.* (2015) with the idea that continuous improvement would reduce overproduction and thereby food waste. This approach was tested in Swedish schools, but it was not possible to assess whether the concept achieved any reduction in food waste at the time, due to insufficient waste quantification.

Therefore, when evaluating food waste reduction efforts, it is important to have solid waste quantification in place as a basis for the systematic approach. This has been demonstrated by Eriksson *et al.* (2016), who investigated six risk factors in a Swedish public catering organisation which had food waste quantification in place. The study investigated the role of satellite kitchens and also concluded that serving more than one option generated most food waste. Informing guests about waste quantification and offering a flexible lunch alternative reduced waste, but the effects were smaller than those of having a production kitchen and serving only one option (Eriksson *et al*., 2016). The claim that larger kitchens (in terms of how many guests they serve) generate more waste than smaller kitchens was confirmed for plate waste, but serving waste and overall waste was reduced slightly as kitchen size increased. The study also established that the claim that "popular" dishes generate more food waste is untrue, since these types of dishes were discarded to a lesser extent than other dishes (Eriksson *et al*., 2016).

Some researchers have identified that staff add some extra margin in the their meal production (Boschini *et al*., 2020), in order to avoid running out of food, which would be a negative outcome in the eyes of the guests (Wang *et al*., 2017) and a source of shame for the kitchen staff. To combat this, there have been suggestions to use forecasting techniques to better understand guest attendance dynamics (Ryu *et al*., 2003; Ryu & Sanchez, 2003; Sel *et al*., 2017), but little is yet known about whether such techniques contribute to lower food waste.

There are also arguments that food waste quantification in itself is an intervention, since those who perform the quantification become aware of the issue and its magnitude, and start to change their behaviour. Tests on this issue in 735 hotels and restaurants, primarily based in Sweden and Norway, found that 61% of the catering units had reduced their waste and that initial waste per guest was the most altered factor, since the staff had the largest opportunities for its reduction (Eriksson *et al*., 2019).

Filimonau and Coteau (2019) concluded that managers or similar staff need to reflect on their role. Since kitchen staff are those who decide and are responsible for activities and decision making on the floor, by determining what food to order and cook and how to serve it, they have expert knowledge in relation to causes of food waste generation. Moreover, Filimonau and Coteau (2019) argue that the underlying causes are connected to the challenges of effective mitigation, for instance irresponsible consumer behaviour brings about large food wastage, but managing consumer behaviour in the hospitality context can be difficult due to high competition, volatile customer loyalty and limited in-house resources. The challenges of food waste reduction can be categorised as internal or external to operations, depending on the extent of control managers can exert. The willingness of managers to address waste challenges is in turn determined by their beliefs on the value/benefits of food waste reduction. Food waste challenges are costs to businesses that need to be carefully evaluated when deciding on mitigation options.

3.5 Tracking developments on a larger scale

Monitoring food waste is one of several monitoring aspects of the food system that needs to be in place to guide food system transformation towards the current global goals (Fanzo *et al*., 2021). Setting global goals for food waste reduction (like the United Nations Sustainable Development Goal 12.3 to halve global food waste until 2030) is not new. For instance, during the first World Food Conference in 1974, reducing post-harvest losses was identified as part of the solution to addressing world hunger. Overall estimates of 15% post-harvest losses were suggested at that time and a 50% reduction by 1985 was proposed (Parfitt *et al.,* 2010)

One challenge associated with food waste quantification data reported to a central entity, such as the European Commission, is uncertainties in the underlying data (associated with the method of choice) when aggregating data on national level and comparing results (Grolleaud, 2002; Caldeira *et al*., 2019). The current strategy to monitor food waste across the food supply chain in the European context is reflected within the European Commission delegated decision (EU) 2019/1597 that covers the topic of a common methodology and minimum quality requirements for the uniform measurement of levels of food waste. The requirement is that amounts of food waste must be measured in metric tons of fresh mass by either direct measurement, performing a mass balance, waste composition analysis, counting/scanning items or using diaries or coefficients (a representative number for a sector based on secondary data). Further, the measurements conducted must be based on a representative sample of the population to which its results are applied, and adequately reflect the variations in the data on food waste amounts to be measured (European Commission, 2019)

The key here is that there is a balance between robust quantification and feasible quantification and that there can be large variation between *e.g.* direct measurement and diaries or secondary data and type of data available. Swedish public catering organisations represent a unique opportunity in this context, since they have been active in quantifying food waste by direct observations for years (even if organisations often focus quantification on a couple of weeks per semester) and since the quantification data are publicly available for study as they fall under the Swedish Public Access to Information and Secrecy Act (Swedish Parliament, 2009). This means that it is possible to study how different aggregations would affect the results when scaled to national level and how this changes over time with relatively high precision, since many organisations and canteens are active with food waste quantification.

As a way to make it easy for both kitchens and organisations to quantify food waste, the Swedish National Food Agency has established a quantification standard for the public catering sector that includes both standardised nomenclature (as described in Table 2) and a suggestion on how to quantify waste, which means that kitchens and organisations can compare themselves on equal terms (Swedish National Food Agency, 2019c). The quantification standard aligns well with that proposed by Eriksson *et al*. (2018b), which puts weight on flexibility and comparability, but with the notable difference that the National Food Agency's standard does not go deeper than the process level (kitchen waste, serving waste, plate waste).

Apart from that, the National Food Agency's standard defines waste processes such as kitchen waste (either aggregated or as separate sub-processes), serving waste and plate waste. It also requires number of guests to be recorded, together with the amount of mass thrown away in each waste process. This makes it possible to calculate the relative indicator 'waste per guest' and to allocate waste to the different processes, so that kitchens get an understanding of where they have the largest potential for improvement. Under the standard, it is possible to record the amount of food served and hence derive the indicator 'waste in relation to mass of food served'. It is also possible to monitor the amount of food consumed (as a proxy at least).

However, the National Food Agency's quantification standard does not consider liquid waste and omits certain food items, such as bread and butter, with the aim of making the standard more practical. Another simplification to make the standard easier to handle is that if the amount of food served is quantified, it is enough to quantify one container of each component (if they are somewhat equal) and then multiply the weight by the total number of containers of each component.

While standards and frameworks to quantify food waste are relatively new, food waste quantification is not completely new for canteens and kitchens. A survey conducted by the organisation School Food Sweden (*Skolmat Sverige*) in 2012 showed that about half of Swedish schools quantified food waste at a frequency of one week per semester or more at that time (School Food Sweden, 2013). A later study conducted in 2018 showed that 160 of 290 Swedish municipalities quantified food in some form. According to the study, they most commonly quantified serving and plate waste from school lunches during two weeks per year. The first municipality to quantify food waste started measurements in 2000, but only 17 municipalities had started on quantification before 2010 and a rapid expansion has taken place in the past decade (Eriksson *et al*., 2018a). All this quantification work has taken place without official guidelines or policies requiring the municipalities and their canteens to do so.

Since the launch of the National Food Agency's food quantification standard, two major mappings of the food waste situation within Swedish public catering have taken place. The first mapping, which involved 211 of

290 municipalities contributing some kind of data, indicated a median waste level of 60-70 g per portion served, excluding drink, and was a combined result for both preschools and schools (Swedish National Food Agency, 2019a). In the second mapping, in 2020, fewer municipalities participated (159 of 290) and the conclusion was that in order to detect any trends, food waste needs to be monitored over a more extended period (Swedish National Food Agency, 2020b). Both mappings revealed large variations in reported levels of food waste between different organisations. The National Food Agency collects food waste data by asking municipalities to complete a survey on how much food waste the organisation produces in aggregated terms. This means that potentially valuable information gets lost in the aggregation process. At present, no hospitals and no actors in the private sector are encompassed by the Agency's mapping. Instead, the official food waste figures for Sweden are the responsibility of the Swedish Environmental Protection Agency, which monitors the situation every other year. According to the latest report, restaurants and hotels account for around 65,000 tonnes of food waste per annum and the public catering sector generates around 33,000 tonnes (Swedish Environmental Protection Agency, 2022)

Since there is interest from both the food industry and authorities in addressing food waste, a negotiated agreement between actors is underway in Sweden. It is similar to the existing agreements in Norway and UK (KuttMatsvinn, 2020; WRAP, 2021b). In this process, data collection is an important aspect to track whether the agreement has any effect and find potential hotspots to target across the value chain (IVL, 2020). To this end, Strid (2019) proposed a national data centre for food waste data collection that can help to identify hotspots and monitor developments.

4. Materials and Methods

The material used for the analyses in **Papers I**, **II** and **V** was food waste data. **Paper II** used a subset of these data, but with additional collected data on parameters for identification and modelling of risk factors. The material used for **Paper III** consisted of measured data on the number of guests and metadata on the canteens, to understand demand dynamics. **Paper IV** used food waste quantifications as a basis for evaluating four interventions of different complexity designed to reduce food waste in school canteens. **Paper V** focused on the changes in food waste over time. The principal ways in which the material and methods are linked are shown in Figure 4.

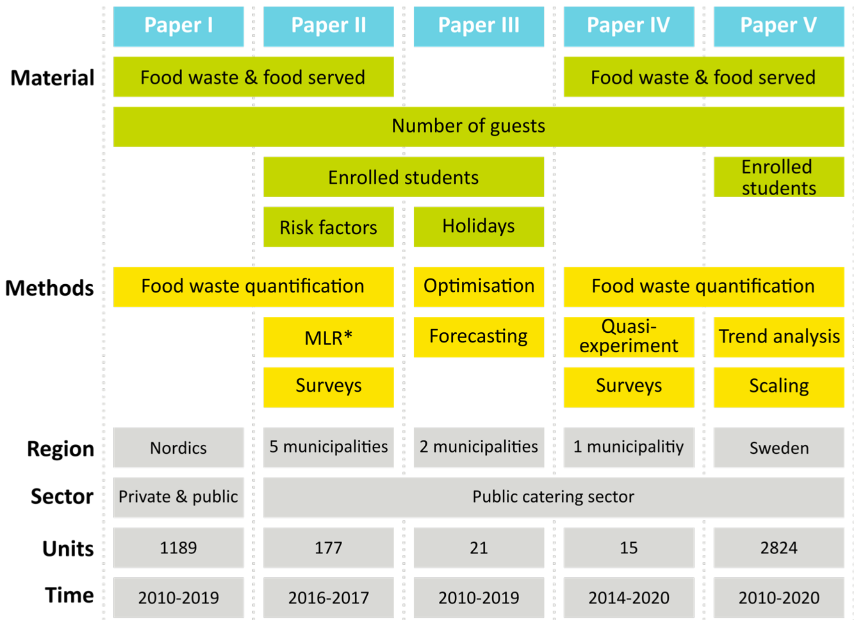

Figure 4. Overview of the different sets of data, methods used and scope of the studies reported in Papers I-V. *MLR = Multiple Linear Regression.

4.1 Quantities of food waste

All food waste quantifications were performed by the kitchen staff themselves, with the focus on weighing waste masses using various kitchen scales. The results of the quantifications were documented manually on paper or in spreadsheets, although some of the kitchens also used dedicated food waste quantification applications provided by different software companies and some kitchens used dedicated food waste tracker scales to help in quantification. In a few cases in data collection for **Paper I**, researchers helped with the collection procedure by categorising and weighing food waste in some kitchens, which might have influenced the results for those few cases. Additional information, such as the number of guests served and, when available, amount of food served was collected to calculate different indicators. Data were summarised on a daily basis per meal for each kitchen and most data only covered lunch, although establishments such as care homes, hospitals, hotels and preschools typically serve other meals as well.

In **Papers I** and **V**, most of the data analysed originated from organisations that were already quantifying food waste and were willing to share their data, while the remaining data were taken from previously published studies (Katajajuuri *et al*., 2014; Eriksson *et al*., 2017, 2018a; Strotmann *et al*., 2017).

The food waste quantification data used are summarised in Table 4. Most data originated from primary schools, preschools, care homes and canteens. Quantification of food served requires more effort than just quantifying food waste, as reflected by hotels, which did not quantify the amount of food served at all, while canteens, hospitals and restaurants rarely made the effort. Therefore, it is not appropriate to derive any indicators directly from Table 4, since this would give inaccurate answers. Rather, Table 4 serves the purpose of indicating the segments of the food service sector from which quantification data on food waste were obtained and to what extent. The (workplace) canteens represented data from 178 units in Norway, 106 in Germany and four in Finland. Care homes for the elderly were represented by 182 units in Sweden and 42 in Germany. The data encompassing hotels originated from 50 establishments located in Norway and 43 in Germany. Twenty-one of the hospitals from which data were obtained were located in Sweden and one in Germany. Preschool data mainly originated from 1372 units in Sweden, 19 units in Germany and 15 preschools in Finland. Primary school data were also dominated by the 1141 units located in Sweden, together with 27 units located in Germany and 20 in Finland. Restaurants were represented by 48 units, of which 39 were located in Norway and nine in Finland. The secondary school segment had many similarities with the primary school segment, apart from the fact that guests were older (age 15-19 in Sweden and Finland, 10-19 in Germany). The material comprised 117 such kitchen units, of which 108 were in Sweden, six in Finland and three in Germany.

Table 4. *Summary of the data collected for this thesis. The values shown are raw data rounded to 2-digit precision, except for number of quantification days and number of units. The values shown are not suitable for calculation of waste-related indicators*

Segment	**Days (n)**	**Units (n)**	**Waste (t)**	**Served (t)**	**Guests (10^6)**
Canteens	16 130	288	520	4.4	9.9
Care homes	14 062	224	63	170	1.3
Hospitals	2 102	22	200	9	1.0
Hotels	12 583	93	570	0	4.7
Preschools	72 897	1 406	260	270	5.5
Primary schools	96 750	1 188	1 300	2 100	29
Restaurants	3 453	48	40	2.4	1.1
Secondary schools	9 051	117	300	430	4.3
Total	227 028	3 386	3 300	3 000	57

4.2 Material used for identifying and modelling risk factors

In **Paper II**, the focus was on identifying and modelling risk factors, which was done in two steps. The first step involved identification of risk factors from previous studies, while the second step involved collecting quantitative data that could be used as indicators of potential risk factors, in combination with quantified food waste data. In the second step, a questionnaire was sent to the public catering managers in the five municipalities that participated, to retrieve information about the dining systems in preschools and schools for the units that also had food waste quantification data. The information collected was primarily quantitative data on the age of the students, number of students enrolled, number of employees working in the kitchen and gender of the kitchen staff. The questionnaire also covered whether students eat in a designated dining space or in the classroom and the distance between the dining space and the classroom, together with the number of seats available. The number of meal options on the menu was also recorded, along with information regarding how many semesters the kitchens had been active in food waste quantification. Type of kitchen (satellite or production) was noted and portion size was calculated from the available quantification data as the amount of food served divided by the number of portions served. To assess attendance, the standard deviation in the number of guests attending meals was calculated. Some factors, such as number of students enrolled and dining hall capacity, may fluctuate over time, but the fluctuations were assumed to be sufficiently small to allow general trends to be detected.

4.3 Material used for modelling attendance

The data collected in **Paper III** consisted of the number of guests attending lunch meals in 21 canteens. The procedure applied for obtaining the data was to count the number of plates after each lunch. This counting procedure was done by the kitchen staff themselves.

Figure 5. Number of guests over time at school kitchens in a municipality, where ● indicates a normal day and ● indicates holiday with less activity. The line represents the number of students enrolled and can be seen as the maximum number of guests that needed to be provided with food.

In addition to the number of plates, information was collected on when holidays and breaks occurred and on the number of students enrolled in each school year in the units studied. Figure 5 displays the seasonal characteristics of a public catering organisation studied and indicates how the attendance fluctuated in relation to the number of students enrolled. All information collected was used to build forecasting models for the number of guests that would attend meals and to optimise the amount of portions to be produced from an economic perspective. Therefore, economic data were also obtained from 17 of the 21 kitchens studied and used to determine portion costs.

4.4 Ways of determining food waste quantities

Two indicators were used in this thesis to determine food waste levels: 'waste per guest' and 'waste of food served'. Since canteens and their food waste quantification processes are not perfect all the time, a criterion system was developed as a concept to filter the data in **Paper I** and applied in the remaining papers that used food waste quantifications as a core component. The concept was based on including only daily observations that quantified the waste processes 'serving waste', 'plate waste' and 'number of guests' when calculating the 'waste per guest' indicator and with the additional parameter 'amount of food served' for the indicator 'waste in relation to mass of food served'. Figure 6 illustrates the concept developed in **Paper I** and applied in **Papers I, II, IV** and **V**. Both the indicators selected use the sum of masses for the waste processes, divided by either the total number of guests or the total amount of food served depending on the indicator examined.

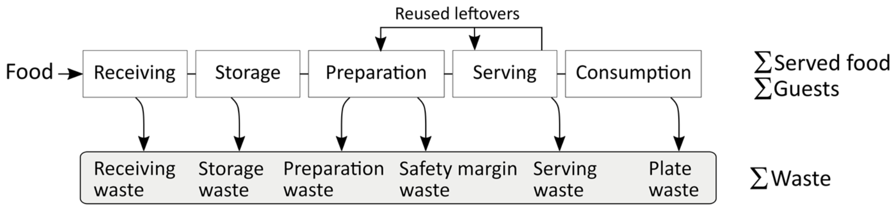

Figure 6. Waste processes captured in the quantification step in different types of catering establishments, together with information regarding food served and number of guests.

The reason for having this filter was to compare canteens on equal terms. The need for this is evident from Table 4, where for instance restaurants and canteens rarely quantified the amount of food served and therefore calculations on the raw data material would produce unfair and unrealistic results that would not be comparable. This also meant that canteens which only focus on quantifying one waste process were excluded from further analysis.

Descriptive statistics on both indicators, based on daily observations for all years for which data were available, were illustrated as boxplots, to gain an understanding of the scope of the food waste issue across the different parts of the sector. To identify which waste process was most dominant in each segment, the waste was divided between the waste processes and displayed as a stacked bar plot. When canteens quantified the amount of food they served, this made it possible to determine the portion size per guest, which was used as an indicator in **Paper II**.

4.5 Methods for analysing risk factors

In **Paper II**, statistical correlation was used to examine the relationship between suggested drivers of food waste identified and the amount of food waste generated in schools and preschools. Correlations between the parameters ‘total waste per guest’, ‘serving waste per guest’ and ‘plate waste per guest’ were examined and visually inspected before each correlation test, to ensure that monotonic patterns appeared in the sample examined. To quantify the impact of influencing factors on food waste, three multiple linear regression models were developed for each food waste quantity per guest (‘plate waste’, ‘serving waste’ and ‘total waste’). Backwards elimination was used to pick the best-performing models. The adjusted R^2-value, which considers the number of explanatory variables, was used to determine the best-performing model.

As part of **Paper IV**, an attempt was made to understand whether canteens have the ability to identify their own risk factors and problems and whether there is alignment between perceived problems reported by kitchen staff and actual quantified outcomes. To test for such differences, a short survey was conducted with the head chefs of the 15 participating canteens, who were asked what sort of food waste (plate waste or serving waste) they have most of, the portion sizes they serve and how many daily guests they serve on average. The reported portion sizes were considered correct if they were within 100 g of the observed value and the number of guests was considered correct if it was within ± 10% of the observed value.

4.6 Models for optimising number of portions

Paper III focused on forecasting models and optimising the margin, which would be of potential help for kitchens in determining the number of guests for which they should provide food. This was done in two steps. First, different forecasting techniques were tested to determine which approach was the most promising. The second step assessed how large a margin a forecast should have to be of practical use and focused on finding an optimum.

The forecasting models evaluated were: Last-value forecasting, moving-average forecasting (with two-day and five-day forecast horizon), a prophet forecasting model and a neural network model. In deciding which of the models was most promising for each kitchen, the mean average percentage error was used as an evaluation criterion. All forecasting models developed were benchmarked against a reference scenario where food was prepared for all students enrolled. Since school kitchens always need to provide their guests with food, shortages are unwelcome and forecasts need to have some margin to be of practical use. Therefore, the actual demand in 2019 with different forecasting margins (0-10, 15, 20, 25 and 30 %) was used to determine the number of days on which the forecast was an underestimate, and by how much demand was underestimated in terms of portions, for the worst day observed. This was done by counting the number of underestimation days and the magnitude of the underestimation for the different forecasting margins. The days with a forecasting underestimation were then categorised into three ranges: 1-9 portions, 10-19 portions and 30+ portions, which is roughly equivalent to having 1, 1-3 and 3+ standard GN (Gastro Norm) 1/1 containers of food as backup to be used when the forecast underestimates demand.

One way of balancing the risk of overcatering against the risk of shortages is to find the optimal number of portions to produce in relation to stochastic demand. This was explored using inventory theory (Hadley, 1963) and performed in economic terms in **Paper III**.

4.7 Testing the potential of interventions to reduce food waste

The work in **Paper IV** involved testing interventions of ranging complexity aimed at reducing food waste in primary and secondary schools. Pre-intervention quantification of food waste took place between 2014 and spring 2020 in 15 school canteens, to establish a baseline level of food waste. Four interventions (tasting spoons, awareness campaign, plate waste tracker, forecasting) were selected by the public catering managers of the participating organisation, in collaboration with the researchers. All interventions were implemented in parallel during summer-autumn 2020, followed by a food waste quantification period to determine the effects of the interventions. Each of the interventions was introduced in at least two school canteens, while the remaining canteens acted as a reference group. Three of the interventions (tasting spoons, awareness campaign, plate waste tracker) primarily targeted plate waste, whereas forecasting was intended to help kitchens better understand demand and act accordingly to lower serving waste.

The main idea with providing tasting spoons is to allow guests to try a dish before scooping up too much food and this approach has shown promising results in other schools and establishments (Tocco Cardwell *et al.*, 2019). During the implementation in **Paper IV**, several trays of disposal tasting spoons were placed on top of the serving stations during lunchtime in two school canteens.

The awareness campaign involved having 'table talkers' placed on the tables and on top of the serving stations with messages such as: "Eat as much as you can – but throw away as little as you can". They also encouraged guests to start with smaller portions and then take a second helping.

To have two-way communication with the guests, a plate waste tracker was introduced in two school canteens. The plate waste tracker used comprised a tablet computer running dedicated software that interacted with the guests. The tablet was connected to kitchen scales that weighed the bin where plate waste was deposited. The interface showed the guests how much food each student wasted and the impact of this waste. The interface also gave the option to provide feedback on why guests wasted food.

Forecasting guest attendance was introduced in two school canteens and was based on the neural network approach developed in **Paper III**. At the end of the week, the head chef received a forecast for the coming week to take into consideration in their meal planning and when ordering necessary food ingredients. A reference group consisting of seven canteens that had no active special measures in place to reduce food waste during the test intervention implementation phase was used to examine whether the interventions actually achieved net food waste reductions. The interventions needed to reduce food waste to a greater extent than in the reference group before any actual effect related to the intervention could be claimed, additional to effects from general awareness, waste quantification *etc*. The efficacy of food waste reduction by the interventions was analysed based on grams per guest for all four interventions, divided into plate waste, serving waste and total waste (which also included waste from the kitchen if this was quantified). This was done by calculating the median values for the different waste processes with a median confidence interval of 95% for the levels of food waste before and after the intervention, to determine which interventions gave a significant reduction in food waste.

4.8 Tracking food waste changes over time

Paper I presented an early concept of how food waste developments over time can be monitored, using material that encompassed the Swedish public catering sector. This concept was further expanded upon and explored in **Paper V**.

To get a sense of developments over time, ‘waste per portion’ in grams was aggregated on a yearly basis for the Swedish public catering organisations that provided data, and displayed as boxplots.

To calculate and compare the amount of food waste (in tonnes) generated in the education part of 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 to scale the indicators. The portion per year factor considers the number of enrolled students on national level based on national statistics, an assumed attendance level, the number of days open and the number of meals served per day. Calculations were performed for all years for which data were available 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. The procedure and input parameters are further explained in Table 5.

To get an indication of the direction of trends, in **Paper V** the sector segment with most available data (primary schools) was used to forecast a scenario of food waste levels to 2025, using the *prophet* package (Taylor & Letham, 2017). The forecasting was performed using previous food waste levels aggregated on a monthly basis for all primary school canteens (ranging from October 2012 to December 2020). The width of the uncertainty interval for the scenario was set to 95%. Food waste levels for 2016 and 2020 were used as reference to evaluate the scenario, with 2016 representing the year when the United Nations SDGs were rolled out and 2020 representing the European Commission's baseline year.

Table 5. *Parameters used in calculations of food waste in tonnes per year*

Parameter	Description
Number of enrolled students	Based on statistics provided by the Swedish National Agency for Education (2019)
Attendance level	Set to 90% based on **Paper III** and the Swedish Food Agency (2021a)
Number of days open	Set to 180 for primary and secondary schools* based on Swedish Parliament (2011)
	Set to 230 for preschools
Meals per day	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)	
Median waste/guest	Median waste/guest per segment and year
Average waste/guest	Average waste/guest per segment and year
Waste/guest	Sum of waste divided by the sum of guests for each segment and year
Median of waste categories	Median waste (g/guest) and waste category**
Median waste/portion/canteen	Median waste (g/guest) aggregated on canteen level***
Median waste/portion/organisation	Median waste (g/guest) aggregated on organisation level***

*60 days removed for secondary school canteens in 2020 due to being closed because of COVID-19.
**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 using aggregated data on organisation level.
***Data aggregated from daily values to canteen or organisation level.

5. Results

5.1 Food waste quantities

All of the data collected in **Papers I** and **V** indicated that around 18% of all food served was wasted within the food service sector units studied in all years for which data were available. This was based on 33,408 quantification days spread across 1453 kitchen units where only quantifications considering serving waste, plate waste and the amount guests and the amount of food served on a daily basis were included and analysed. Primary schools showed the lowest 'waste in relation to mass of food served' and also had the most kitchens providing data. Restaurants and canteens had the highest 'waste in relation to mass of food served', but also had fewest kitchens that could supply data (Appendix Table A3 and Table A4). Hospitals and hotels gave no indication, since they did not meet the requirements for the strictest criterion and, as stated earlier, hotels did not quantify the amount of food served at all.

The indicator 'waste per guest' provided a complementary picture since more observations from each part of the sector could be obtained. The median value ranged from 43 to 179 g per guest (Figure 7), based on data from 159,924 daily observations and 2826 kitchen units between 2010 and 2020. Primary schools were again the segment with the lowest waste levels and the largest segment in terms of recorded data, with 79,475 (around 50%) of the observations made in this part of the sector. For this indicator, canteens were able to provide vastly more data, with 11,083 quantification days coming from 230 units, and recorded a median of 57 g/guest, which is almost equal to the preschool segment (which was the second largest segment in terms of daily observations) (Appendix Table A1). **Paper I** illustrated how the different waste processes are distributed in each segment of the food service studied. Figure 8 does the same, but updated with data from **Paper V**. 'Plate waste' appeared to be the dominant type of waste in canteens and secondary schools and was almost equal to 'serving waste' in the hospital and hotel segments. 'Serving waste' was the major contributor to food waste for primary schools, preschools and care homes, whereas 'kitchen waste' was the dominant waste fraction in restaurants (Figure 8).

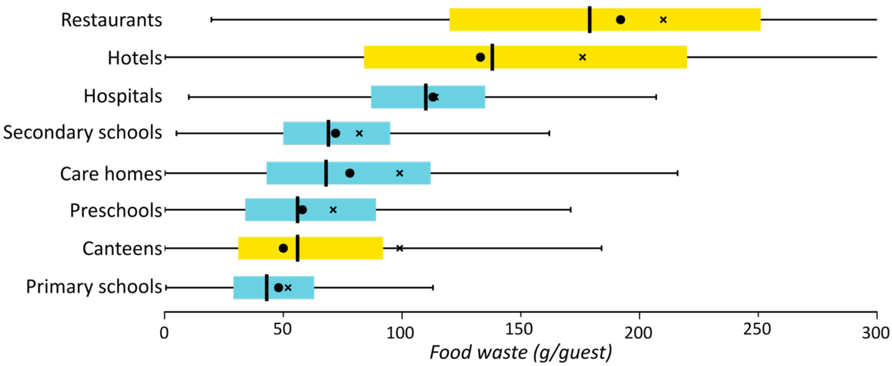

Figure 7. Boxplot of the indicator 'Waste per guest (g)' based on daily food waste quantification data in the food service sector, where | indicates the median waste level; box limits indicate the 25th and 75th percentiles; whiskers illustrate minimum and maximum values and outliers are omitted. A cross (×) indicates the mean and (●) indicates the calculated waste/guest. ■ indicates kitchens within the private sector and ■ kitchens operating in the public catering sector

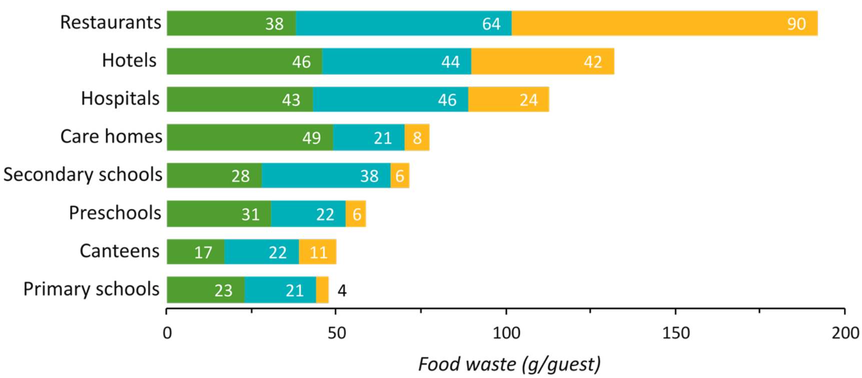

Figure 8. Contribution of the different waste generation processes to total waste for the different catering segments studied, based on the calculated waste per guest in terms of: ■ serving waste, ■ plate waste and ■ waste generated within the kitchen

5.2 Risk factors for food waste generation

Analysis of causes and risk factors for food waste in the food service sector is important in order to progress from identifying the most dominant waste fractions and waste flows to actual reduction. The connections between the different factors and their influence on food waste are illustrated in Figure 9.

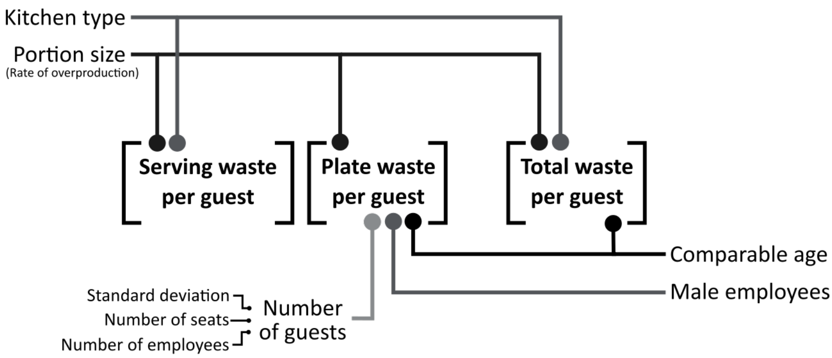

Figure 9. Schematic illustration of the interactions between different factors for food waste and their influence on food waste quantities.

The analysis performed in **Paper II** indicated that the factors 'number of seats in dining space', 'number of employees', 'standard deviation in the number of guests' and 'number of guests' were strongly correlated. This was expected, since more guests would require a larger dining space and more employees to run the operations. Plate waste per guest was significantly positively correlated with 'portion size', 'comparable age', 'number of guests', 'number of seats in dining space', 'standard deviation in number of guests', 'number of employees' and 'gender of staff' (male employees). Serving waste per guest was significantly positively correlated with portion size. Satellite kitchens had significantly higher serving waste than production kitchens. Total waste per guest, which is the sum of serving waste and plate waste per guest, was significantly positively correlated with portion size and comparable age. *Total waste per guest* was best explained by the multiple linear regression (MLR) model which included the factors portion size and kitchen type. Together, these factors explained 92.2% of the variation in total waste per guest between the schools used in the analysis. *Serving waste per guest* was best explained by the MLR model described by portion size and the interactions between portion size and kitchen type. These factors explained 85.1% of the variation in serving waste. *Plate waste per guest* was best explained by the model that included the factors comparable age and portion size, which explained 87.1% of the variation in plate waste per guest.

Since the mapping referred to actual problems in general terms, canteens could have had the perception that they have other problems. **Paper IV** included a knowledge test regarding the agreement between the staff perceptions and quantified results. As Figure 10 illustrates, all (responding) canteens except one perceived their greatest problem to be serving waste. Seven out of 12 canteens also had an accurate perception that their main problem was serving waste. When it came to understanding how many guests attended the meals (which is important for accurately planning the number of portions to prepare), seven of the canteens (S2, S5-S8, S10 and S12) gave answers that were within 10% of the actual value, while canteens S4 and S11 overestimated the number of guests by 52% and 67%, respectively. Half of the canteens had a good understanding of portion sizes (were within 100 g of the observed value) (Figure 10).

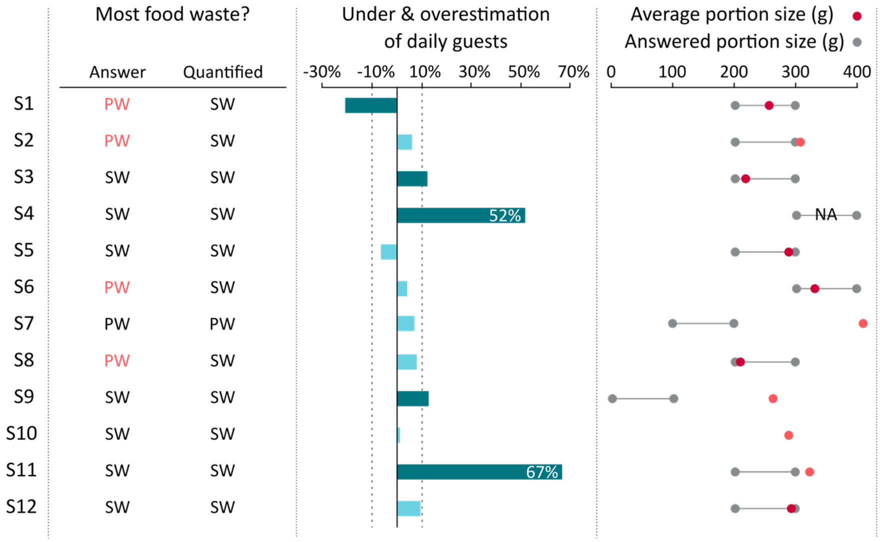

Figure 10. Comparison of responses by canteen head chefs with quantified data. PW = plate waste, SW = serving waste. Canteens S13-15 were unable to answer due COVID-19. Canteen S4 could not provide data on the amount of food served and hence portion size could not be calculated. Canteen S10 reported that they did not know their portion sizes.

This type of mapping is important to understand where measures should be implemented to have the greatest food waste reduction potential.

5.3 Modelling attendance and optimal portion quantities

Among the different models for forecasting guest attendance, those based on a simple sequential neural network performed best (with mean absolute percentage error score of 2-3%) for 11 of the 21 kitchens studied. According to **Paper III,** the moving average with a two-day window was the best-performing model for seven of the canteens, and the prophet model was the best-performing model for three canteens. Nonetheless, there was sometimes very little difference between the models. The moving average and the neural network models consistently performed better than the benchmark scenario in 18 of 21 cases. The current business-as-usual scenario, where food is prepared for all students enrolled at a school, gives an error of 20-40%.

It is not sufficient simply to produce a forecast, because on some days the forecast will underestimate the demand, leading to shortages. Since it is easier to throw away food than to cook new food, there needs to be some margin to a forecast for it to be of practical use. Figure 11 shows how often the forecast underestimated the actual value and, depending on the margin added to the forecast, by how much, in terms of number of portions lacking in the worst case during the forecasting period.

With no added margin, in the worst case the forecast underestimated demand on 105 days out of 178 school days for kitchen 6, while in the best case it underestimated actual demand on 71 days for kitchen 13. The first case in which the forecast margin gave zero days of underestimation was for kitchen 14 at a 5% margin. Using a 10% margin resulted in 10 of the kitchens having zero days of underestimation. Even at 30% margin on the forecast, five kitchens did not have a single day without underestimation.

The margin that needs to be added for a forecast be sufficient is therefore to some extent a trust issue, but it can be optimised. To find an optimal solution, in **Paper III** the amount of portions to produce was optimised from an economic perspective for each kitchen that could participate with economic data. The optimal amount of portions was also subjected to a sensitivity analysis, to get a deeper understanding of how concepts such as goodwill and waste penalty costs affected the optimal quantity that kitchens should produce in each individual case. This procedure and the results are described in detail in **Paper III**.

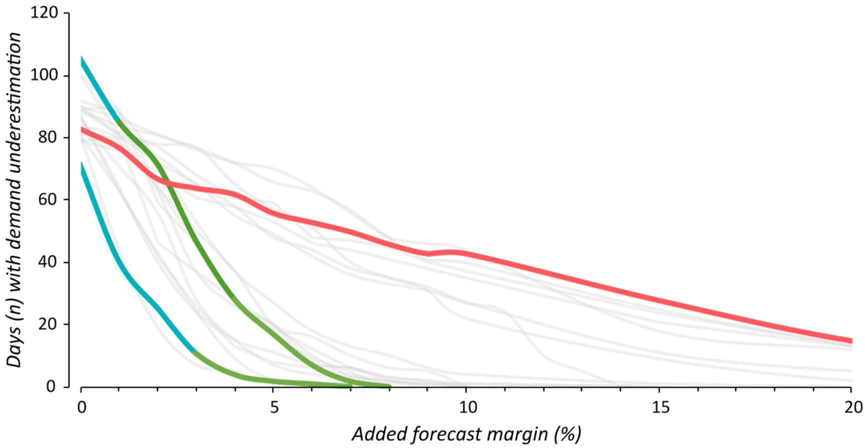

Figure 11. Added forecast margin (%), number of days on which the amended forecast underestimated actual demand for 2019 and number of portions by which demand was exceeded, displayed in ranges of 1-9 portions (■), 10-29 (■) portion and 30+ portions (■) for three example kitchens. Axis capped at 20% added forecast margin. Diagram based on data and a table from Paper III.

5.4 Interventions to reduce food waste

It is important to progress from quantification to actually doing something about the food waste problem. **Paper IV** focused on testing some interventions in an organisation that had been actively working with the topic of food waste quantification and reduction for some years. The results for the different interventions, divided into total waste, serving waste and plate waste per portion, are displayed in Figure 12.

The awareness campaign targeting guests and plate waste in the school canteens gave a significant reduction in plate waste. The median waste per portion for plate waste was 37 g per portion before the intervention, while after the intervention it was 24 g per portion, a 35% reduction. Serving waste and total waste were also reduced in the canteens that implemented the awareness campaign.

Providing tasting spoons to allow guests to taste the food before serving themselves, in order to reduce plate waste, resulted in a significant reduction in plate waste (22% decrease) from 27 g to 21 g per portion. It also resulted in a reduction in total waste per portion but, due to overlapping confidence intervals, no significant difference was seen. However, the median level of serving waste increased after introducing the tasting spoons, from 25 g per portion to 30 g per portion (20% increase).

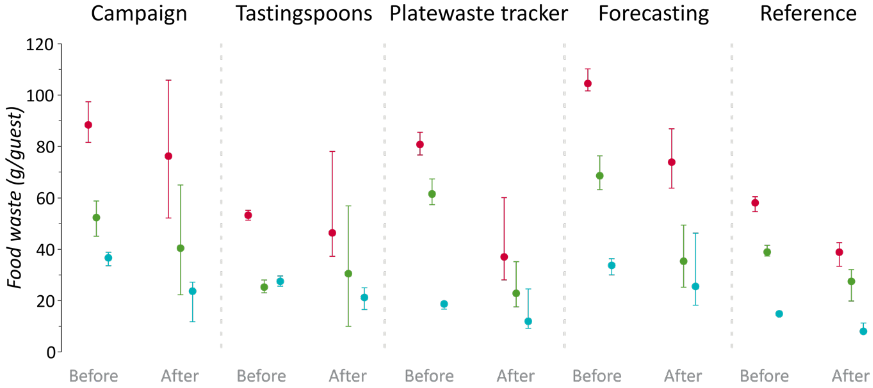

Figure 12. Waste (g/guest) as median values, with uncertainties as 95% confidence intervals, before and after implementation of measures to reduce food waste in school canteens. ● Total waste per guest, ● serving waste per guest ● plate waste per guest

After introducing the plate waste tracker (targeting plate waste), both total waste and serving waste per portion were significantly reduced and showed the largest waste reduction of all interventions tested (Figure 13). A reduction from 19 g to 12 g of plate waste per portion was observed after implementation of the plate waste tracker, which corresponded to a reduction of 37%.

The canteens that introduced forecasting to help staff assess future demand so they could plan accordingly, with the main aim of reducing serving waste, proved successful in waste reduction. The initial serving waste for the canteens was 69 g per portion and that after implementation of forecasting was 35 g per portion.

The canteens in the reference group also showed a significant reduction in all waste processes during the study period. Since the canteens in the participating public catering organisation generally achieved a reduction in their levels of food waste for the years for which data were available, the interventions implemented had to give an improvement better than the general reduction trend observed for the reference group. Figure 13 shows the difference in waste reduction per portion for the different waste processes, per measure, before and after the intervention quantification phase.

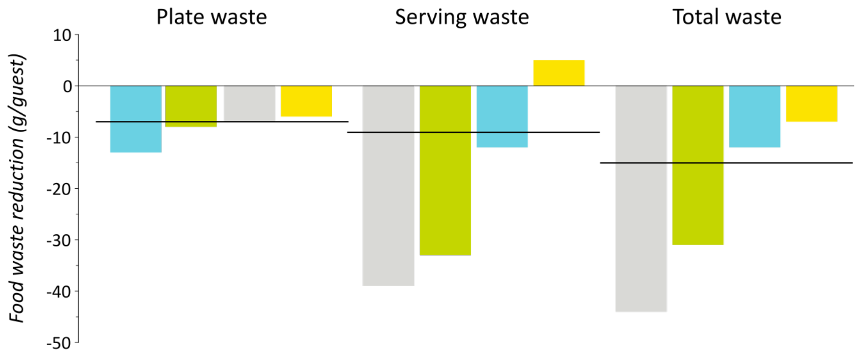

Figure 13. Median reduction in food waste per portion after implementation of the interventions; ■ Awareness campaign, ■ forecasting, ■ plate waste tracker, ■ tasting spoons, in relation to the reference group ▬, for plate waste, serving waste and total waste per portion. Total waste also includes waste from the kitchen if this was quantified.

For the plate waste fraction, only the canteens that implemented the awareness campaign (reduction of 13 g per portion) and forecasting (reduction of 8 g per portion) achieved a greater reduction for plate waste than the reference group.

The reduction in serving waste achieved by forecasting was 34 g per portion compared with before implementation. However, the canteens that used the plate waste tracker reduced serving waste even more, by 38 g per portion, even though the intervention was not intended to reduce this type of waste. Canteens that implemented the awareness campaign also reduced their serving waste compared with the reference group, but not to the same degree as observed for the plate waste tracker and the forecasting interventions.

5.5 Changes in food waste over time

Figure 14 shows changes in the 'waste per guest' indicator over time for units in the Swedish public catering sector, primarily based on data from **Paper V**. The hospital data derive mainly from **Paper I**.

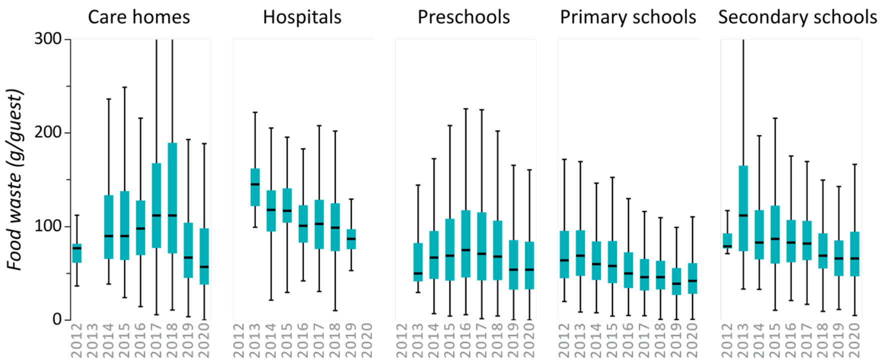

Figure 14. Boxplot of changes over time (2012-2020) in food waste in different parts of the Swedish public catering sector. The median waste level (g/guest) is indicated by ▬; box limits indicate 25th and 75th percentiles; whiskers illustrate the minimum and the maximum values; and outliers are omitted. Axis is capped at 300 g/guest.

Primary school canteens decreased their level of food waste by 40% by 2020, from a peak median waste of 69 g/guest in 2013 to 42 g/guest. The hospitals that provided data decreased their levels of food waste to the same degree as primary schools, with a reduction of 40%. However, the reduction in hospital canteens was from a higher initial waste level, with a reduction from 145 g/portion in 2013 to 87 g/portion in 2019. A similar reduction pattern was observed for secondary schools, although with slightly lower values for median waste per guest and wider variation between years.

Preschools showed declining levels of food waste after 2016, with a 29% decrease (from 75 to 53 g/guest) by 2020. The lowest median value (50 g) for a preschool was reported in 2012, but was only based on primary data from six canteens, whereas 822 preschools provided data in 2020. This illustrates the need for a sufficiently large sample to draw relevant conclusions. Care homes was the segment with the greatest variation between the years and 2018 showed the widest spread, from 11 g/portion to 366 g/portion and median waste of 112 g/portion. Note, however, that Figure 14 displays data for all canteens which provided data in a non-aggregated way, irrespective of whether they quantified food waste for only one semester or for several years, and therefore might emphasise canteens that quantified food waste sporadically.

Another way of displaying changes over time is presented in Figure 15, where the ‘waste per guest’ indicator is scaled to national level in tonnes using six different approaches for preschools, primary schools and secondary schools. The largest observed difference (-45% from 2015 to 2020) was found when scaling by taking the median of each waste process and segment and then adding them together (a method employed by the Swedish Food Agency). The smallest difference (-20%) was found when taking the mean of each organisation and year. Independent of scaling method, the results for 2020 were the lowest to date, although the difference between the different scaling methods for 2020 ranged between 19,500 and 24,200 tonnes. After 2016, the average reduction was 25% for the different scaling methods and the mass of food waste generated in 2020 was estimated to be 21,000 tonnes.

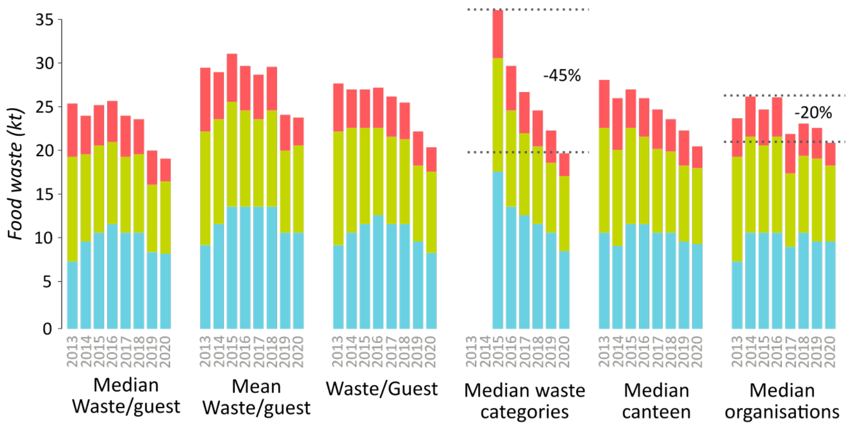

Figure 15. Food waste in tonnes for Swedish preschools ■, primary schools ■ and secondary schools ■, based on different 'waste per guest' factors when scaling to national level.

Given current developments in primary school canteens, Figure 16 illustrates a forecasting model 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/guest) might be within reach for primary school canteens. Halving of the 2020 level (to 21 g/guest) is within the realm of possibility, but farther away from the lowest point generated by the forecast model. The model results were associated with significant uncertainties and there are indications of a plateau at around 30 g/guest from late 2020 onwards in the model.

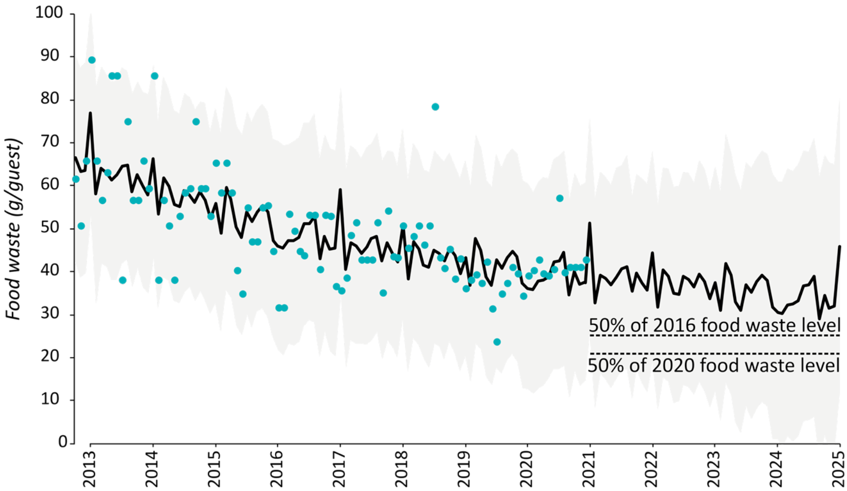

*Figure 16***.** Monthly median food waste (●) over time for Swedish primary school canteens, where – indicates the model fitted to data, with the shaded area illustrating model uncertainty.

6. Discussion

6.1 Quantities and quantification of food waste

The results presented in this thesis indicate that 18% of the food served in the food service sector ends up as waste. However, this figure is subject to variation, as primary and secondary schools had around 17% waste and canteens 26% waste in relation to the amount of food served. The wide variation between these different segments was verified by the ‘waste per guest’ indicator, which varied in magnitude from 48 g/guest for primary schools to 192 g/guest for restaurants. This variation was expected and also in line with previous findings (see Table 3).

Most of the food waste quantification data used in the analysis originated from the Swedish public catering sector. For canteens active in this sector, the results were consistent with the outcomes of national mappings orchestrated by the Swedish National Food Agency (2019a, 2021a). Its first mapping concluded that preschools and primary schools have around 60-70 g of food waste per guest (median values) and its second mapping gave a value of 50-70 g, *i.e.* of similar magnitude as found in this thesis.

For an individual canteen, food waste quantification can help to reveal areas where there is potential for improvement. Some canteens might have a problem with plate waste from the guests and some might have a larger problem with waste from the serving line or within the kitchen. If canteens are experiencing problems with serving waste, it would be logical for measures to reduce this type of waste to be given priority, since their potential to reduce waste is probably higher. Based on the findings in this thesis, in general such measures would be most applicable to kitchens in the public sector (primary schools, preschools and care homes), since they had larger fractions of serving waste than of plate and kitchen waste. Measures to reduce plate waste should instead be the focus in workplace canteens and secondary schools. Hospitals and hotels showed equal levels of plate and serving waste, and measures to reduce waste could be focused on the areas that would provide the greatest opportunity for waste reduction in establishments operating in these segments. Restaurants in general have a larger problem with waste generation from food preparation processes inside the kitchen, so efforts to reduce waste could best focus on this process. All of this is where kitchens in general have the largest potential for improvement. However, this is subject to change over time and should be considered a moving target. For instance, in **Paper I**, data for care homes suggested that the largest fraction of waste came from plates, whereas updated data from **Paper V** indicated that serving waste was the largest fraction in care homes. This does not mean that care homes should stop focusing on measures to reduce plate waste, but it indicates that figures aggregated to national level can change over time and that national figures might not represent problems that individual kitchens are facing.

Therefore, it is important that canteens understand their own problem before implementing solutions. However, quantification is of value only if it can generate a good basis for change and if this change is implemented. According to the principles of continual improvement and the (Observe), Plan, Do, Check, Act cycle, canteens would first quantify waste to identify where they have a problem, then implement measures and finally repeat the process to determine whether the measures were successful or not. This is also advocated by the British organisation WRAP, which has established a variant of this approach called "Target, Measure, Act" (WRAP, 2022). Some argue that quantification itself might be a measure to reduce food waste, at least where there is a large problem to start with (Eriksson *et al*., 2019), since the quantification process may bring awareness of the problem and add an element of systematisation.

Organisations that have decided to embark on food waste quantification also need to decide on strategies, *e.g.* on how long quantification should take place and whether all canteens should participate. According to the Swedish National Food Agency (2020b) and Eriksson *et al*. (2018a), it can be reasonable to start by quantifying food waste five days per semester, and then evaluate. It can also be reasonable to start within a small set of canteens as a pilot project and then extend efforts over time. This practice was reflected in the results in this thesis, since most of the quantifications took place in schools. One feature in common for all the organisations that participated with data was that quantification of food waste took place sporadically and that the efforts differed. It is uncertain if all the kitchens that provided quantification data for this thesis reacted to their own quantifications. A trend observed within the data set collected in **Paper V** was that organisations tended to quantify for longer and to include more canteens. Some organisations even have a requirement in place that all canteens should monitor food waste every day, as part of their improvement work.

This is similar to mechanisms that have been in place for years in the retail sector, which has invested in quite advanced support systems to simplify quantification and, more importantly, reviews the collected information in weekly meetings, making it possible to act upon the information and reduce waste (Eriksson, 2015). Working according to a systematic improvement approach across all kitchens would provide opportunities for canteens experiencing problems with food waste to learn from canteens that perform better, so that hopefully they can perform on a par with the best over time. Since the variability with an organisation can be quite large, as illustrated *e.g.* by Eriksson (2017), this learning transition could have a large impact if adopted and implemented successfully on a large scale.

6.2 Use of different indicators and data quality

To compare canteens, organisations and countries with each other, it is important that the indicators used are based on the same kind of input data and that calculations are based on the same premises. This is exemplified by the ‘waste per guest’ indicator, where the value obtained can change drastically if the number of expected guests is based on the number of students enrolled, rather than actual attendance data. For example, the number of students enrolled as displayed in Figure 5 would in most cases give a lower ‘waste per guest’ value compared with the actual outcome of how many guests attended a certain meal. This is problematic if different kitchens and even organisations use different approaches to determine how many guests were present for a meal, since it can give unfair results that are not comparable. For instance, Östergren and Backlund (2019) studied the effects of an organisation that used a model based on quantifying serving waste between 2013 and 2018 in 530 kitchens. The waste per guest indicator was calculated by that organisation based on number of students enrolled, but according to the researchers from the organisation that performed the work, collecting data on the actual number of people eating every day would have added a substantial amount of extra work for the kitchen staff.

An indicator associated with even more quantification work i 'waste of food served', as indicated by the results in this thesis where around half (1453 of 2826) of the kitchens studied quantified the data required for this indicator at some point. The large benefit that this indicator provides over the 'waste per guest' indicator is that it allows kitchens to calculate and understand roughly how much their guests eat, which is important from a public health perspective and in particular for the catering sector (Swedish National Food Agency, 2020b).

As a way to ensure data quality when comparing results, a system based on criteria was established in **Paper I**. This system does not overcome problems with using different sources of input data for calculation of the different indicators, but it ensures that the same level of detail is compared. The strictest criterion, which was applied in this thesis, only allowed calculation of indicators if there were records of 'number of guests', 'serving waste' and 'plate waste' for the indicator 'waste per guest' and with the additional parameter 'amount of food served' for the indicator 'waste of food served'. However, since establishments might have different ambitions in their quantification efforts and might focus on *e.g.* one waste process, this criterion would be too strict. Regardless of system or framework, it is important when calculating indicators to be transparent about what the indicators reflect and what they include or not.

6.3 Risk factors for food waste generation

A majority of the risk factors identified in **Paper II** as possible drivers of food waste can be difficult to address, since they relate to aspects that kitchens and organisations cannot change easily, *e.g.* infrastructure or age of the guests. For instance, rebuilding or converting satellite kitchens into production kitchens would be expensive. It might also be difficult to expand dining hall capacity or add/remove seats, since the hall might already be full and removing seats might mean guests having to eat their lunch outside standard lunchtime hours. Thus reducing one risk factor might just create another problem. To further expand upon and capture risk factors, one way forward could be to include quantification of noise levels as a direct indicator of stress and assess how noise levels and food waste are linked. Another option could be to include food waste data on the menu, to show how different dishes interact with the levels of food waste (Eriksson *et al.*, 2016; Painter *et al.*, 2016). For this to be useful and provide value, quantification of food waste would need to be expanded beyond process level to include category level, or even down to single food items (Eriksson *et al.*, 2018b). This would be a suitable step to perform for organisations that have quantified food waste for a while. Another factor to examine is the availability of options and distance to an alternative food outlet. In some cases, especially for older students, a school cafeteria that sells snacks to students competes with the lunch alternatives provided by the school kitchen, as found by Painter *et al*. (2016) and Marlette *et al.* (2005). This is confirmed by a recent report by the Swedish Food Agency (2021b). Another option could be to examine how the kitchen staff are working in the kitchen and how this affects the levels of food waste. Earlier studies have indicated that the levels of food waste can decline drastically following personnel changes (Malefors *et al*., 2017). However, it might be easier to provide staff with training material or courses on food waste as a first step, and give staff and managers the option to alter their own behaviour (Filimonau & Coteau, 2019). Quantification of waste and comparing the outcome with staff perceptions, as done in **Paper IV**, could be a powerful and relatively simple procedure to encourage staff to reflect and use the large influence they have over operations, as they ultimately decide if change will take place. This was also demonstrated by *e.g.* Principato *et al*. (2018), who highlighted the importance of the attitude of restaurant managers to food waste reduction.

The models developed and described in **Paper II** explained a large share of the variation (>85%) in the amount of food waste generated, so the focus could be on implementing and evaluating measures to reduce food waste. One such measure with large potential is to match the amount of food served to the number of guests that attend a meal, which reduces the risk of having a portion provision that is not in line with actual demand.

This is a factor that is within the complete control of kitchen staff, since they decide how much food to order and take the decision on the kitchen floor on how much should be cooked. It should be noted that the situation is more complicated in satellite kitchens, since they rely on a production kitchen. For them forecasting can play a role, especially if the forecast also gives information regarding how often the forecast value is likely to be wrong and by how much, so that kitchens can be ready with a sufficient instant backup option.

6.4 Food waste reduction measures

Balancing supply against demand for food is one measure that can be taken to reduce food waste, since the surplus often goes straight to the bin. Other ways of preventing waste can relate to infrastructure, in which case kitchens and organisations would need to balance the costs of implementing the measures against benefits these measures might provide. It would be unrealistic to propose that all organisations should abandon the concept of satellite kitchens and convert them to production units. A better option would be (when feasible) to supply satellite kitchens with equipment to handle surplus food, such as cooling or heating equipment. This infrastructure-related change, together with forecasting, could be a promising approach for kitchens to match portion provision to the actual number of guests. In **Paper IV**, the four different interventions tested were chosen according to best available technology accepted by the staff in a catering organisation. One of these interventions (forecasting) aimed at reducing serving waste, whereas the other three measures primarily targeted reduction of plate waste.

6.4.1 Awareness campaigns

Awareness campaigns are simple measures by which organisations can either educate their staff about issues with food waste or educate guests who eat in the organisation’s premises. In practice, this often involves displaying message boards so that staff or guests easily receive the message. The canteens that implemented the awareness campaign in **Paper IV** did so with the ambition of lowering their guests’ plate waste. In the canteens where the awareness campaign was deployed, plate waste was reduced from 37 g to 24 g per guest, corresponding to a 35% reduction.

Influencing guest behaviour is no easy task, however, and is often met with varying success. For instance, Visschers *et al*. (2020) examined the effects of an awareness campaign with the effects of reducing plate size in two university canteens. They found that reducing plate size achieved an actual reduction in food waste, whereas the awareness campaign alone was not sufficient to reduce food waste. This may indicate that campaigns affect age groups differently depending on how they are designed, or if other or prior measures have influenced the guests. Another approach suggested by Filimonau *et al.* (2022a) is for preschools and parents to work together to raise children's awareness of food waste. This may have the potential to lower food waste not only in the educational setting, but also in families (Liz Martins *et al*., 2020)

6.4.2 Tasting spoons

The fairly simple measure of providing tasting spoons in canteens gave a reduction in plate waste of 22%, to 21 g of food waste per guest. However, there was also an observed tendency for a shift towards more serving waste. Tocco Cardwell *et al.* (2019) concluded that providing tasting spoons, together with clear and consistent instructions regarding portioning, can reduce the edible food waste fraction significantly. Providing tasting spoons together with awareness campaigns is a cheap tool that canteens can implement easily as a starting point, since it has a low entry barrier and requires very little in terms of material and time from kitchen staff.

6.4.3 Plate waste tracker

The canteens in **Paper IV** that used the plate waste tracker had normal levels of plate waste (median levels of around 19 g/guest) and saw a reduction to 12 g per guest, which represents a very low level of plate waste. To put this in perspective, the plate waste fraction for primary schools that contributed data to **Papers I** and **V** was around 21 g per guest. This is in line with plate waste values reported by the Swedish National Food Agency food in a mapping covering the year 2020, where the median plate waste in primary school was 20 g per guest. A larger reduction in plate waste might have been observed if the plate waste tracker had been placed in canteens with higher initial plate waste levels. However, in the canteens that used the plate waste tracker, the level of serving waste was strongly reduced, from 61 to 23 g per guest (62% reduction). This indicates that there is a need to monitor waste processes that are not the intended target for the intervention, so that potential spill-over effects can be detected (as in the case of the tasting spoons, where there was a tendency to shift waste to the serving waste fraction). The plate waste tracker also enabled the staff to get an understanding of why meals were wasted on a daily basis, making it possible to adjust their meal planning.

The plate waste tracker could possibly also be used to monitor the level of food waste achieved by other simultaneous measures, such as pedagogic meals, where teachers devote some lesson to food waste or a similar topic connected to food and also eat with their pupils. Since the plate waste tracker enables waste to be displayed when it is recorded, there is potential to connect this information to the teaching schedule, to get a rough idea of classes taking part in the pedagogic meal and whether this educational concept reduces food waste.

6.4.4 Forecasting guest attendance

Paper III demonstrated that by using forecasting techniques, it was possible to predict quite accurately the number of guests that would attend a certain meal. The overall best-performing forecasting model identified, based on neural network, was tested in **Paper IV.** The forecasting intervention, which targeted serving waste, was successful overall, with a reduction of 49% in the two canteens that implemented this intervention. This was higher than the anticipated 20-40% reduction indicated in **Paper III**, although it was difficult to isolate cause-effect relations in the type of quasi-experimental set-up used in **Paper IV**. A drawback with forecasts is that they are sometimes wrong and that they underestimate actual demand quite often if they include no margin, which would lead to shortages of food. Shortages of food in canteens are undesirable and therefore there needs to be some safety margin in place, along with some sort of backup food option. Figure 11 showed margins associated with a forecast and number of portions that would be need to taken from a backup source and how often. Even with a 10% margin, kitchens that serve many guests would still need to have 30+ portions ready for 22-43 days of a school year according to the findings in **Paper III**. For kitchens that have a steady stream of guests and less attendance variability, it would be sufficient to have a 10% margin (or even lower) to their forecast and achieve zero days of underestimation. However, it is possible to have an ‘optimal’ margin in place, as illustrated in **Paper III**, which optimised the margin from an economic perspective. Today, kitchens do not seek to identify the optimal number of portions to make because the system is designed in most cases to produce meals for all students enrolled, due to fear of shortages. One way of overcoming this fear could be by step-wise adjusting the portion numbers downwards, applying appropriate margins, knowing approximately how many times a shortage is likely to occur and having a backup stock of food ready, which would hopefully lead to less food waste. A solution to deal with food shortages might be to meet unexpected demand using the food stock in the contingency plan that is now being established across strategic public catering establishments (Swedish National Food Agency, 2020a). This stock is intended for emergency situations, but if replaced instantly could meet two purposes, namely reducing food waste in daily operations and ensuring that the emergency stock is fresh and ready to use. Another policy-oriented solution could involve making it more expensive to throw away food, as indicated by the waste penalty cost and the sensitivity analysis in **Paper III.**

6.4.5 Reference canteens

In **Paper IV**, the canteens that had none of the intervention measures in place reported total waste of 58 g per guest. This was reduced to 41 g per guest (a reduction of 29%) after the interventions were rolled out. The plate waste fraction for the reference canteens decreased from 15 g to 7 g per guest, a reduction of 53%, and the serving waste decreased from 39 to 28 g per guest, a reduction of 28%. This indicates that the ongoing systematic work to reduce food waste in the participating organisation, which has quantification data since 2014, seems to be having an effect and that further interventions should be targeted at specific canteens that have identified potential problems. The questionnaire used in **Paper IV** asked three questions: What process generates the most waste? How many dinners do you anticipate? and What size of portions do you serve?. It was thus fairly simple, but could be used to identify areas for further improvement that could be targeted by specific interventions. This would make implementation of the intervention more precise and would potentially maximise the potential for waste reduction, making it a helpful tool for kitchen staff and managers. In particular, canteens that have greater problems with serving waste than plate waste, and clearly have a need to better understand how many guests might arrive, would benefit from targeting these areas and get the most out of their food waste reduction efforts.

6.5 Limitations, generalisations and uncertainties

All the work in this thesis was only possible thanks to organisations and kitchens that generously shared their experiences and data. However, this might mean that only kitchens and organisations interested in the topic of food waste were covered in the analysis, so the results might not give a representative picture of the whole food service sector and the canteens included might already have the lowest amount of food waste. This problem of selection arose in Papers I-V and occurs in most food waste studies. A similar type of problem arose from the use of non-randomised canteens to implement the interventions in **Paper IV,** which induced a selection bias. However, it is problematic to force canteens to quantify food waste or to use untested measures against food waste. There needs to be an element of trust (especially for interventions that require extra efforts from the staff) and that the problem the intervention is trying to solve needs to be acknowledged. A related problem is that it is difficult to know what a canteen might have done if they had not used any of the test interventions. Therefore, in **Paper IV** a set of reference canteens was used as a control group when evaluating the effects of the intervention. However, there are always activities and factors that take place in canteens which might influence the levels of food waste, and staff are generally interested in trying to keep waste levels low. Moreover, since efforts may vary in intensity over time, it can be difficult to pinpoint cause and effects, since an observed reduction might not necessarily be attributable to implementation of the intervention alone.

It should also be noted that the results presented in **Paper IV** are not general findings that will solve the food waste issue for all canteens in the whole food service sector. The same reasoning is applicable to the work in **Paper II**, as there is room for further improvement and *e.g.* for incorporating more factors. However, the focus in **Paper II** was on parameters that could be quantified, since there are biased public views on dining systems in education establishments (Persson Osowski, 2012). Therefore, soft parameters and other dimensions to capture the food waste problem might have been missed. However, the coefficient of determination values obtained showed that more than 85% of the food waste generated was explained using the risk factors analysed, indicating that other factors are likely to explain a minor part of food waste generation. Other factors that are more difficult to quantify could also have a large impact on the food waste levels and including these would help to further improve the models developed. In addition, there could be factors that co-vary with quantified factors that are the actual cause of food waste.

It should also be noted that food waste in itself is a moving target and that guests and staff change over time, so examining risk factors and assessing interventions to reduce food waste would probably need to be repeated so that the effects of *e.g.* an intervention that targets guests are not lost when new students arrive and older students leave. The same applies to canteen staff, as engagement, awareness and knowledge can be very individual and therefore change drastically following staff changes. This highlights the need for routines to be put in place and acted upon, so that food waste quantification and the information it generates become a natural part of managing a kitchen operation with less food waste.

The focus in this thesis was on establishments in the 'Nordic region', with special emphasis on units operating in the Swedish public catering sector. In future work, there is a need to determine the generalisability of the findings to other establishments in other parts of the food service sector and in other countries. The next logical step would be to involve private companies to a larger extent, assuming that such companies will agree to share their food waste quantification data or any other related business statistics. A voluntary agreement approach has the potential to include more actors from the private sector, but also faces the risk of only attracting the most interested establishments. Regardless of whether such an agreement is in place, it is important to lower the threshold for participation by having standards for quantification that are easy to use and support systems that have adopted the standard.

Among the risk factors for food waste generation established in **Paper II** based on data from schools and preschools, the issues that involved infrastructure, rate of overproduction and the need to have an optimal production margin in place are probably even more relevant outside the public catering sector. For instance, economic optimisation of the margin during forecasting, as performed in **Paper III**, would probably be greatly improved if done in a setting where point-of-sales data were available. The same applies for the systematic testing of interventions in **Paper IV**, which was based on one organisation and four interventions. For the results to be more generalisable, testing would need to be expanded to cover more organisations, canteens and interventions.

In **Paper V,** variation in the data was dealt with by applying the criterion system developed in **Paper I**, so as to compare the same things at least. **Paper V** was also concerned with scaling the waste per guest indicator to tonnes for the education sector, in order to compare the findings with other studies. The scaling process involved assumptions that are subject to uncertainties, *e.g.* on guest attendance, which was based on the best available information and findings from **Paper III**. This type of scaling is important when tracking changes over time on the way to halving food waste by 2030. In such efforts, there is also a need to further balance the level of detail and the number of canteens that could provide data against the cost of analysing the collected data. It should also be noted that since the collected data are based on self-reporting, there will always be an element of uncertainty embedded in the reported data from canteens.

6.6 Future research: How to halve food waste by 2030

Each canteen has its own challenges and may have progressed to different degrees relative to other canteens in terms of food waste reduction and the overarching Sustainable Development Goal of halving food waste by 2030. According to the findings in **Paper V**, a level of around 9-10% waste of food served would be required for the sector to reach that target (based on the canteens that provided data). Some claim that this is not enough and that further reductions (75%) need to be in place by 2050, which would imply waste levels of around 4-5% of food served. To put this in perspective, this would mean that school canteens (the segment with most observations in this thesis) would need to have a median waste level of around 21 g/guest by 2030. This level of food waste would probably be achievable (as illustrated by the forecast in *Figure 16*), but would require school canteens to act accordingly. It might be easier for kitchen units in other parts of the food service sector to reduce their waste, since in general they have greater problems to start with and can probably solve some of their problems by implementing fairly simple solutions. It is also reasonable to assume that food waste reduction is subject to the law of diminishing returns, where reductions might be quite easy initially, but become more difficult to achieve in later stages of the target period.

The target for halving food waste by 2030 does not specify a start year, which has resulted in different interpretations. For instance, the UK uses 2007 as a baseline year, but it appears that Sweden and other European Union members will use 2020 as their baseline year (European Commission, 2018; WRAP, 2021b). This means that a large part of the reduction might already have taken place, at least in the case of canteens that are actively serving meals in the Swedish public catering sphere and which provided data for this thesis. According to the results in Figure 15, where the 'waste per guest' indicator is scaled to tonnes with data from schools and preschools in **Paper V**, the observed reduction can vary between 45% and 20% for the years up to 2020 depending on which indicator is used in the upscaling process. This means that schools and preschools would need to reach around 9,500-12,000 tons of food waste by 2030 if the goal of halving food waste were to be fulfilled (depending on the indicator used for scaling) and 2020 were used as the baseline year. The type of scaling described in **Paper V** is performed every other year by the Swedish Environmental Protection Agency, to track developments in the food service sector and the whole supply chain. The most important aspect in this process is for the scaling to use a waste factor based on representative establishments. This is exemplified by comparing the findings for 2016 in this thesis with the Swedish Environmental Protection Agency's estimate of 50,000 tonnes for preschools, primary schools and secondary schools in that same year (Swedish Environmental Protection Agency, 2018), where the difference was up to 48%. However, the underlying assumptions in that report were based on considerably higher waste per guest factors, *e.g.* waste per guest 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 75^{th} percentile according to Figure 14. The most recent report, with data from 2020, contains updated waste per guest factors and now states around 33,000 tonnes for establishments active in the Swedish public catering sector (Sörme *et al.*, 2021). These recent results are in line with the results in this thesis, since the studies were based on the same material.

This thesis used the approach of including all canteens when looking at changes in the level of food waste over time, regardless of whether they quantified for a week or several years. In **Paper V**, a different approach was also used to track the performance of canteens depending on when they started to quantify food waste. This raises an important question of where the focus should be directed when monitoring the sector, *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 (as in a longitudinal study). All such related questions could be handled by a dedicated data centre, which would be responsible for monitoring the food service sector and exerting stronger influence over the whole food supply chain. It would thus have a long-term responsibility that would cover more than one term of office.

The momentum that has been built up and the engagement by many public organisations in reducing food waste systematically now needs to continue. This engagement is reflected by the share (70%) of Swedish municipalities that have set their own targets for reduced food waste, with more than one-third having taken their own initiative in setting reduction targets for the climate impact of food consumption (Swedish National Food Agency, 2022). This development has taken place spontaneously, without any legally binding regulations.

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. These could embed food waste quantification and make it possible for canteens to supply data in a standardised way to a central organisation for monitoring if the actions they introduce to reduce food waste have the desired effect. This could overcome the problem of limited waste statistics in a broader perspective when providing estimates of food waste levels, which is the current situation according to Calderia *et al*. (2021). A final note regarding waste statistics is that liquid waste, and methods that encompass this waste flow, remain undeveloped, a research area that needs special attention.

While the interventions tested in this thesis can be regarded as best available technology, all were of a fairly simple nature so that they could be implemented and used for long or recurring periods by the participating canteens. There are thus tools available with the potential to reduce food waste. The next step is broader implementation and use of these tools, which will require policies that enforce reductions in food waste or, even better, reduced negative impact from the food system, where reduced food waste is one of many components. As a future recommendation, all catering organisations should have access to a toolbox of interventions that could be used in individual canteens to solve individual problems, so that efforts are targeted where they can make the largest impact.

Even though the current situation looks promising, further work still needs to be done. The developments observed so far can be attributed to the will of individual municipalities and, to some extent, information policies. The next step to push developments further is to explore other policy instruments, so that organisations not actively reducing their food waste are incentivised to contribute. This can take the form of economic policies that make food or waste management options more expensive, thus pushing organisations to invest in the best available technology. It could also take the form of legal policies that force canteens to act and use the best available technology. One such legal option is already in place in Sweden and could be used in accordance with the Swedish Environmental Code and the general rules of consideration, which state that it is forbidden to waste natural resources and that the best available technology should be applied (Ministry of the Environment, 1998). For this to be of practical use, there needs to be some level of food waste that is considered illegal. This type of research could explore other food waste reduction pathways that go far beyond the voluntary agreement approach (Eriksson *et al.*, 2022). Regardless of whether food waste should be considered illegal, interventions to prevent wasteful behaviour can still be useful. What is needed from organisations is investments to reduce food waste and move away from the concept that food waste reduction will happen effortlessly. Without money or time invested, a successful reduction in food waste is unlikely to occur. It is therefore time for policies that can encourage more organisations to work systematically to reduce food waste and drive development of new tools and strategies, so that the sector can reach established reduction targets and contribute to a more sustainable food system with less food waste.

Conclusions

This thesis showed that establishments in the food service sector waste 18% of the food they serve, although with large variations between units and over time. Food waste levels were found to range from 48 g/guest in primary schools to 192 g/guest in restaurants, with waste from the serving line being the main contributor in primary schools, preschools and care homes. Plate waste was in general the largest fraction in canteens and secondary schools.

The main risk factors influencing the levels of food waste in schools and preschools were identified as being rate of overproduction, age of the guests, type of kitchen and other issues related to infrastructure. Combined models containing these factors explained over 85% of the variation in food waste generation. One factor that canteens can address is the rate of overproduction, by better matching the number of portions prepared to actual guest demand. Here different forecasting approaches could be useful, as the best forecasts had a mean average percentage error of 2-3%. In contrast, the current business-as-usual scenario, where food is prepared for all students enrolled at a school, gives an error of 20-40%. Even the simplest forecast is always better than the existing practice where kitchens prepare food for all students enrolled at the school, whether they show up or not. For a forecast to be of practical use, some margin needs to be in place, together with a way of handling shortages if the margin is not adequate.

In terms of food waste reduction, the canteens which tested forecasting reduced their serving waste by 49%. The other interventions tested were designed to target plate waste. Awareness campaigns reduced plate waste by 35%, tasting spoons resulted in a 22% reduction of plate waste but increased serving waste by 20%, and the plate waste tracker reduced both plate waste and serving waste, by 37% and 62%, respectively. However, only the canteens that used the plate waste trackers and the forecast procedure reduced waste more than canteens in the reference group. Four different interventions were tested in this thesis, but the most important message is that there are tools available to reduce food waste. What is needed now is large-scale use of these or other tools and a systematic approach to reducing food waste.

All segments of the Swedish public catering sector showed decreasing levels and trends in food waste. 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 analysed 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. The mass of food waste generated in Swedish preschools, primary schools and secondary schools has declined by 25% since 2016, to an estimated 21,000 tonnes in 2020. The forecasting scenario developed for primary schools indicated that halving the 2020 food waste level (to 21 g/guest) by 2030 is within the realm of possibility.

Quantification of food waste is key for canteens to evaluate their food waste reduction efforts, but also to determine how the sector is performing over time and assess whether the pace is sufficient, or whether extra efforts are needed to reach the goal of halving food waste by 2030 and thereby contributing to a more sustainable food system.

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Popular science summary

Food waste is a global problem. This thesis examined food waste in the catering sector in Sweden, Norway, Finland and Germany, with particular focus on Swedish public meals in health care, schools and care homes.

The starting point was to map the extent of food waste and identify the factors contributing to food waste. The results were used to formulate measures to reduce food waste and assess their effectiveness, and to follow developments over time to determine whether halving food waste by 2030 is reasonable given the current trends.

The results indicated that 18% of the food served in the catering sector is thrown away. Some factors contributing to food waste were linked to kitchen infrastructure and the age of guests, for example older secondary school pupils tended to generate more plate waste than preschool pupils and satellite kitchens tended to have more food waste than preparation kitchens, as the former do not have the equipment to save leftover food for subsequent use. These factors may be difficult, or even expensive, for kitchens to change.

The factor that contributed most to food waste was kitchens preparing too much food relative to the number of guests that arrived, with the excess becoming waste. Therefore, the potential for using attendance forecasting to help kitchens match the amount of food prepared to the number of guests was explored. Relatively simple waste reduction measures, such as the use of information campaigns and tasting spoons, were also explored. In addition, some kitchens tested a plate waste tracker providing guests with individual feedback on how much food was being thrown away, which was intended to influence their behaviour to throw away less food. Guests were given the opportunity to provide feedback to the kitchen about the food via the plate waste tracker. In order to compare and ensure that the measures worked, a set of reference kitchens that did not have any of the measures in place was also studied. All measures tested reduced the amount of food waste, but only the kitchens using attendance forecasting and the kitchens using the plate waste tracker reduced food waste more than the reference kitchens.

Monitoring of food waste reduction efforts over time indicated that food waste has decreased significantly in recent years. For all public meal services, food waste decreased by 43% between 2012 and 2020, which corresponds to a reduction from 68 to 47 g/guest. Although food waste did not always decrease compared with previous years, the trend over several years was clearly downward. In many Swedish municipalities, primary schools began early to systematically measure food waste and work on this issue and, over time, have decreased their waste level from 69 g/guest at the peak in 2013 to 42 g/guest in 2020. Primary schools are also a segment for which data uncertainties are lowest, as measurements are available for a large number of establishments, with up to 20% of all Swedish primary schools contributing food waste measurements in 2020. Food waste in preschools and schools amounted to 21,000 tonnes in 2020 and it is reasonable to halve this by 2030 given the current trends. Systematic work to reduce food waste, with measurement as a basis to evaluate whether the current measures and ambitions are on the right track, is necessary to achieve a more sustainable food system.

Populärvetenskaplig sammanfattning

Matsvinn har på senare tid blivit uppmärksammat som ett globalt problem. Den här avhandlingen fokuserar på matsvinnsfrågan i storköks- och restaurangsektorn i Sverige, Norge, Finland och Tyskland med ett speciellt fokus riktat mot Svensk offentlig måltid inom vård, skola och omsorg.

Utgångspunkten har varit att kartlägga hur stort matsvinnet är, vilka faktorer som bidrar till matsvinn, undersöka åtgärder och dess effektivitet för att minska svinnet samt att följa utvecklingen över tid för att ta reda på om en halvering av matsvinnet är rimligt till 2030 givet nuvarande trend.

Resultaten pekar på att 18% av den mat som serveras slängs. En del faktorer som bidrar till matsvinn är knutna till kökens infrastruktur och besökarnas ålder. Detta är faktorer som kan vara svåra, alternativt dyra, för köken att ändra på. När det kommer till ålder så tenderar exempelvis gymnasieelever att slänga mer mat från tallriken än förskoleelever och mottagningskök har i regel mer matsvinn än tillagningskök, detta då mottagningskök inte har tillgång till utrustning för att kunna spara mat som blir över till ett senare tillfälle. Den faktor som bidrar mest till matsvinn är att kök lagar för mycket mat i förhållande till antalet gäster som kommer och där överskottet blir svinn. Därför undersöker avhandlingen potentialen i att använda närvaroprognoser som ett hjälpmedel för att köken ska kunna anpassa mängden mat som lagas till antalet gäster på ett bättre sätt. Vidare så testades även relativt enkla åtgärder som att använda sig av informationskampanjer och att introducera smakskedar. Några kök fick även testa konceptet med att använda en tallrikssvinssvåg vilken gav gästerna individuell återkoppling på hur mycket mat som slängdes vilket var tänkt att påverka dem att slänga mindre mat. Vidare gavs gästerna möjlighet att lämna återkoppling till köket om maten via tallrikssvinnsvågen. För att jämföra och säkerställa att åtgärderna fungerar så användes en uppsättning med referenskök som inte hade någon av ovanstående åtgärder på plats. Alla åtgärder minskade mängden matsvinn, dock så var det endast köken som använde närvaroprognosen och köken som använde tallrikssvinsvågen som minskade matsvinnet mer än referensköken.

När det kommer till att följa upp arbetet med att minska matsvinnet så pekar resultaten mot att matsvinnet har minskat betydligt under de senaste åren. För alla verksamheter inom den offentliga måltiden har matsvinnet minskat med 43% under åren 2012 till 2020, vilket motsvarar en minskning från 68 g/gäst till 47 g/gäst. Matsvinnet minskar visserligen inte alltid jämfört med föregående år, men trenden är tydligt nedåtgående när man ser på utvecklingen under flera år. I många kommuner är det grundskolor som har varit tidiga med att systematiskt mäta matsvinn och arbeta med frågan och, över tid har matsvinnet minskat från 69 g/gäst vid toppen 2013 till 42 g/gäst 2020. Grundskolor är även den verksamhetsgren där osäkerheterna är minst då vi fått tillgång till mätningar från ett stort antal verksamheter, hela 20% av alla Sveriges grundskolor bidrog med matsvinnsmätningar under 2020. Matsvinnet i förskolor och skolor uppgår 2020 till 21,000 ton och det är rimligt att halvera detta till 2030 givet rådande trend. Ett systematiskt arbete mot matsvinn, med mätning som grund för att utvärdera om de nuvarande åtgärderna är tillräckligt ambitiösa, är nödvändig för att nå ett mer hållbart livsmedelssystem.

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Appendix

Table A1. *Waste per guest (g) based on daily observations in the different sectors for all years for which data were available*

Segment	N	Min	Max	Q_1	Q_2	Q_3	Mean	Std	Waste
Canteens	11 083	0	24 256	32	57	93	100	508	52
Care homes	6 514	0.1	5 536	43	68	111	97	121	77
Hospitals	925	10.2	444	87	110	135	114	44	113
Hotels	7 884	0.2	18 850	84	138	220	176	255	133
Preschools	46 337	0.1	5 600	34	56	89	71	66	58
Primary schools	79 475	0.6	7 000	29	43	63	52	56	48
Restaurants	89	20	967	120	179	251	210	146	192
Secondary schools	7 617	5	7 030	50	69	95	82	116	72
Total	159 924	0	24 256	33	51	81	71	160	59

Table A2. *Waste per guest (g) aggregated on kitchen level in the different sectors for all years for which data were available*

Segment	N	Min	Max	Q_1	Q_2	Q_3	Mean	Std	Waste
Canteens	230	3	440	36	62	103	83	74	52
Care homes	132	20	790	71	106	143	124	94	77
Hospitals	18	27	206	95	115	131	117	42	113
Hotels	83	6	405	83	124	194	140	81	133
Preschools	1 129	1	600	46	68	101	81	53	58
Primary schools	1 112	9	314	38	51	68	56	29	48
Restaurants	15	117	430	154	212	306	232	98	192
Secondary schools	107	23	202	55	74	97	78	32	72
Total	2 826	1	790	42	62	92	76	56	59

Table A3. *Waste in relation to mass of food served (%), based on daily observations in the different sector segments for all years for which data were available*

Segment	N	Min	Max	Q_1	Q_2	Q_3	Mean	Std	Waste
Canteens	41	5	62	20	24	28	26	13	26
Care homes	2 063	0	124	13	20	29	22	15	17
Hospitals	-	-	-	-	-	-	-	-	-
Hotels	-	-	-	-	-	-	-	-	-
Preschools	12 138	0	178	14	21	31	24	16	22
Primary schools	17 503	0	198	11	16	24	19	13	17
Restaurants	9	15	35	19	24	26	24	7	24
Secondary schools	1 660	2	95	12	17	23	19	10	17
Total	33 408	0	198	12	18	27	21	14	18

Table A4. *Waste in relation to mass of food served (%), aggregated on kitchen level in the different sector segments for all years for which data were available*

Sector	N	Min	Max	Q_1	Q_2	Q_3	Mean	Std	Waste
Canteens	5	22	35	25	29	33	29	5	26
Care homes	82	4	65	15	22	28	24	13	17
Hospitals	-	-	-	-	-	-	-	-	-
Hotels	-	-	-	-	-	-	-	-	-
Preschools	601	1	170	16	23	32	26	13	22
Primary schools	695	4	162	13	17	23	19	9	17
Restaurants	9	15	35	19	24	26	24	7	24
Secondary schools	61	8	41	14	19	23	19	6	17
Total	1453	1	170	14	20	27	22	12	18

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Towards a Baseline for Food-Waste Quantification in the Hospitality Sector—Quantities and Data Processing Criteria

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Abstract: There is an urgent need for primary data collection on food waste to obtain solid quantification data that can be used as an indicator in the goal of halving food waste by 2030. This study examined how quality baselines for food waste can be achieved within the different segments of the hospitality sector, encompassing establishments such as canteens, elderly care units, hospitals, hotels, preschools, primary schools, restaurants, and upper secondary schools. The empirical material comprised food-waste quantification data measured in 1189 kitchens in Sweden, Norway, Finland, and Germany for 58,812 quantification days and 23 million portions. All the data were converted to a common format for analysis. According to the findings, around 20% of food served became waste. Waste per portion varied widely between establishments, ranging from 50.1 ± 9.4 g/portion for canteens to 192 ± 30 g/portion for restaurants. To identify the measurement precision needed for tracking changes over time, we suggest statistical measures that could be used in future studies or in different food-waste tracking initiatives.

Keywords: quantification; baseline; sustainable development goals; benchmark; waste per portion; restaurants; hotels; schools; measurements

1. Introduction

Issues relating to food waste have attracted significant attention in recent years, but there seems to be no obvious all-round solution for dealing with these issues. On a global level, it is estimated that one third of the food produced for human consumption, corresponding to roughly 1.3 billion tons per year, is wasted at some point. These vast volumes have a significant environmental impact, since resources such as land, water, and energy associated with the different stages of food production and supply chain are used in vain. There is also an asymmetry regarding food losses and waste within the food production chain, with developed countries being more inclined to waste food later in the supply chain, whereas food waste in developing countries occurs early in the food chain [1]. On top of these aspects, there is also the ethical and moral problem of the severe imbalance between surplus food suitable for human consumption being wasted in the developed countries [2] while people in poverty locally or in societies in countries or regions suffering from famine have insufficient food [3]. However, political and global communities have started to address the challenges associated with food waste. In 2015, the topic was brought to the attention of world leaders when it became one of the targets of the United Nations (UN) Sustainable Development Goals (SDGs) for 2030. The target itself aims to: "By 2030, halve per capita global food waste at the retail and consumer level and reduce food losses along production and supply chains, including post-harvest losses" [4]. The European Union (EU) has committed to this goal [5], and other initiatives have been taken simultaneously to cut food waste on various levels and with different methods and ambitions [6]. There is also a suggestion that the ambition set by UN is not strict enough and that further food-waste reductions need to be achieved in order to keep the planet within the planetary boundaries and counter climate change [7].

To approach and achieve the global directive to reduce food waste and overcome the structural problem of food waste, it is necessary to gain insights into where, why, and how much food and/or inedible associated parts are removed from the food supply chain [8]. The UN's Food and Agriculture Organization (FAO) has recently released a methodology for monitoring food losses on global level in the supply chain [9], while an equivalent version covering the retail and consumer part of SDG 12.3 with a food-waste index is still under development. However, there are several standards and frameworks that can provide insights about the food-waste situation on global and local level and also promote consistency and transparency in food-waste quantification [10]. The use of standards and frameworks can help identify hotspots with the greatest potential for waste reduction, thus providing users with indications on where to take action and guiding further work [11].

Moreover, use of a standardized framework and its output in terms of quantification data can help establish baselines, against which measures intended to reduce food waste can be evaluated to determine whether they give the appropriate reduction in food waste [12]. Establishing baselines for food-waste quantification in order to identify problems has been identified as a vital step in waste reduction [13]. Clear baselines would also make it possible for different actors to compare, communicate, and benchmark different results with each other and within the community. Knowledge of effective measures can be spread and shared between actors sharing similar features and organizational characteristics, or used to overcome unique problems.

The hospitality sector has been identified as a sector with great potential for food-waste reduction [14–16]. The sector includes actors within the food system that provide food in establishments such as restaurants, hotels, canteens, and catering. In a food system perspective, the hospitality sector is complex in that it has a plethora of actors ranging from small privately owned restaurants on street corners to global chains present in almost all countries of the world. The range of actors within the sector, the type of target groups they serve, and the conditions in which they operate give rise to different waste generation patterns [17,18]. For instance, the portion size provided by a typical preschool in Sweden differs from that served by a tourist hotel in Saudi Arabia [19]. The kinds of meals served within the hotel segment of the hospitality sector also differ, e.g., some hotels do not serve any meals, some only breakfast, and some serve breakfast, lunch, and dinner, and provide bar food. Previous quantifications of food waste within the different segments of the hospitality sector are summarized in Table 1.

Table 1. Food-waste quantification results from previous studies, expressed as "Waste (%) of food served".

Kitchen Type	Country	Kitchen Units	Quantification Length	Waste (%) of Food Served	Waste/Portion (g)	
Preschool	USA	1	5 days	45.3	210	[20]
Hospital	UK	1	28 days	>40	-	[21]
Hospital	UK	3	2 days	19–66	-	[22]
Catering	Egypt	-	-	23–51	126, 131, 166	[23]
Hospital	Portugal	1	8 weeks	35	953	[24]
Schools	Portugal	21	1 month	27.5	49.5	[25]
Schools	Italy	4–5	5–10 days	27	-	[26]
Hospitality and catering sector	Finland	72	1 day–1 week	8–27	-	[27]

Table 1. *Cont.*

Kitchen Type	Country	Kitchen Units	Quantification Length	Waste (%) of Food Served	Waste/Portion (g)	
University	Portugal	1	4 weeks	24	280	[28]
Public sector	Sweden	30	3 months	23 (13–34)	75 (33–131)	[14]
Schools	China	6	1 day/unit	21	130	[29]
Schools and restaurants	Sweden	4	2 days	20	92.5	[30]
Schools	Italy	3	92 + 33 days	15.31	-	[31]
Schools and Restaurants	Switzerland	2	5 days	7.69 and 10.73	86 and 91	[32]
Preschool	Sweden	4	2 weeks	-	145	[33]
University	Turkey	3	3 weeks		61.7 (48.5–75.2)	[34]

Although much research has already been performed within a few industrialized countries [35], primary data are badly needed. The studies performed so far have used a relatively small number of quantification days and have had different aims and methods, making it difficult to compare the results. Higher-resolution data covering different segments of the hospitality sector are needed to put these previous findings into perspective. There is therefore an urgent need for a systematic method to examine how different segments of the hospitality sector perform and establish more useful reference points for further food-waste reduction efforts.

The aims of the present study were to evaluate how much food waste is generated within the different segments of the hospitality sector and to develop a method for quantifying waste and comparing the different segments using available data. The focus was on the "big picture", rather than on detailed descriptions of segments, to create a foundation for further food-waste reduction actions and evaluations that can provide a robust and representative baseline. Hence, key performance indicators to monitor food waste were assessed and attempts were made to identify indicators of data quality and the desired level of data.

2. Materials and Methods

It is essential to define the hospitality sector and its constituent segments. The Nordic Council of Ministers [17] defines the hospitality sector as comprising actors such as restaurants, hotels, canteens, and catering establishments. This sector is commonly split into profit and cost sub-sectors according to the British organization Waste and Resources Action Program (WRAP) [36]. The profit sub-sector consists of hotels, guesthouses, restaurants, cafés, canteens, catering, convenience stores, and pubs/bars (Horeca), while the cost sub-sector consists of businesses where providing hospitality services is not the main focus and where the aim is not to maximize profit, such as catering and accommodation services within schools, universities, hospitals, nursing homes, prisons, military facilities, staff canteens, etc. [36]. However, there are a plethora of different types of kitchens operating under different conditions, making the boundaries unclear and with overlap between the different kinds of actors. This study focuses on restaurants, hotels, canteens, and catering units in schools, universities, hospitals, nursing homes, and companies, across the profit and cost sub-sectors within the hospitality sector. Prisons and military facilities are not included.

To achieve transparent food-waste quantification, it is necessary to define clearly the waste arising from each kitchen process. In this study, definitions for the different waste processes (Table 2) used by the Swedish National Food Agency [37], together with the process definitions identified by Eriksson [38] are used. However, waste processes alone are not sufficient indicators, and other indicators, such as amount of food served, need to be identified and defined.

Table 2. Definitions used in the food-waste quantification process.

Name	Definitions
Waste process	
Receiving waste	Waste that occurs from goods delivered to the kitchen, but never stored or used. Also known as reclamation waste in other sectors, such as retail.
Storage waste	Stored goods that become waste for whatever reason.
Preparation waste	Waste from the preparation and/or trimming of food, such as peel, bones, and fat.
Safety margin waste	Waste from food produced which did not leave the kitchen for consumption and was not saved for another meal.
Serving waste	Food served that did not reach the plates of guests.
Plate waste	All waste from the plates of guests. May contain napkins and/or bones.
Waste	Sum of mass from the different food-waste processes. Used for calculation of key performance indicators (KPIs) for food-waste quantification baselines.
Served food	The amount of food that left the kitchen intended for consumption.
Portions	The recorded number of portions served for a given meal. One portion is defined as the amount one person eats per meal.
Meal	Breakfast, lunch, dinner, or snack, depending on when the food is served.
Kitchen type	
Production unit	A kitchen that prepares all meals from raw materials.
Satellite kitchen	Kitchen that can prepare some meals, but relies on deliveries from a production unit, especially for food that needs to be cooked.
KPI	Key performance indicator.
Waste/portion (g)	Waste (kg) divided by the number of portions × 1000.
Waste (%)	Waste (kg) divided by served food (kg) × 100.

Past food-waste studies seldom include all waste processes within a kitchen establishment. The most commonly included processes are "Plate waste", "Serving waste", and "Preparation waste" [26,39]. Figure 1 sets the different definitions in Table 2 in context and indicates where the different waste processes usually occur.

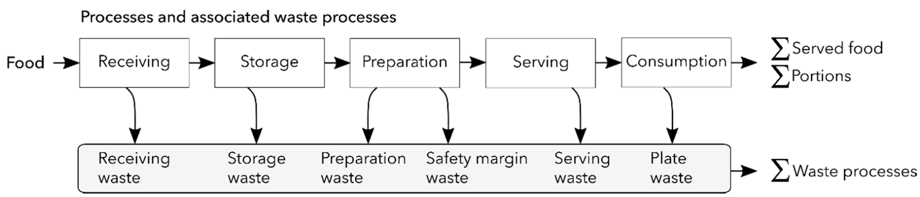


Figure 1. Different waste-generating processes within a kitchen. Food is prepared and wasted during the different steps of work in the kitchen.

2.1. General Data Collection

Some of the data used in this study were obtained from organizations that have been quantifying food waste and were willing to share their data, while the remaining data were taken from some previously published studies [14,27,39–41]. All the food-waste quantifications performed by the organizations involved weighing waste masses using various kitchen scales. The results of quantification were documented manually on paper or via spreadsheet software, some kitchens used dedicated food-waste quantification web applications provided by different software companies, and some kitchens used a dedicated smart scale for documentation of the quantification process. Features in common in all cases were that the kitchen staff itself performed the data collection and that the data were sent to a central unit or management within the organization for further compilation and analysis. In a few cases, we helped in the collection of data by sorting out and weighing food waste in the kitchen establishments. Since the organizations that provided data had somewhat different approaches to food-waste quantification, we needed to find common ground between the different set-ups, ambitions, waste process/es monitored, and methods regarding food-waste quantification used by the different organizations. Therefore, all the food-waste quantification data obtained from the organizations were extracted, transformed to a standard format according to Table 3.

Table 3. Format used for extraction, transformation, and loading of food-waste quantification data from the participating organizations.

Variable	Definition	Type of Data
Date	Date of quantification	Date format YYYY-MM-DD
Organization	Organization which provided the data	Text
Kitchen	Kitchen where the data came from. Name of kitchen or code	Text
Type	Kitchen type	[Production unit, Satellite kitchen]
Sector	Segment to which the kitchen belongs	[Canteen, Elderly care, Hotel, Hospital, Preschool, Primary school, Restaurant, Upper secondary school]
Meal	Type of meal	[Breakfast, Lunch, Dinner, Snack]
Waste processes	Quantified mass from the waste processes	kg
Waste	Sum of the mass from all the waste processes	kg
Served food	Quantified mass of the served food	kg
Portions	Recorded portions for a given meal	Number

To achieve consistency and transparency, the transformation step included rearranging the quantification data daily per meal and mapping the different waste processes used by the individual kitchens relative to those defined in this study. For instance, when what was defined as "Serving waste" in this study was called something different by a kitchen according to a local standard, the data were transformed and included in the serving waste process [38]. The number of portions recorded for each meal and the amount of food served were compiled and summarized as key performance indicators (KPIs). Since the different organizations used different ways of indicating missing values, all missing values were transformed to a zero value. Figure 2 shows a schematic illustration over the study.

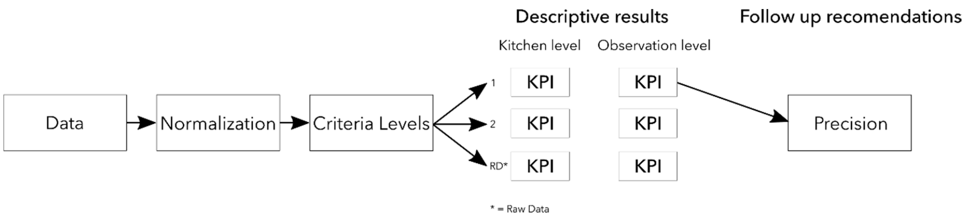


Figure 2. Schematic overview of the study.

2.2. Cost Sub-Sector of the Hospitality Sector

This section describes the materials and methods used for the cost sub-sector of the hospitality sector, which includes schools, preschools, elderly care units, and hospitals. Information about food-waste quantification and the data obtained come from establishments in three countries, Sweden, Finland, and Germany. The organizations and companies in the different countries were selected due to willingness to participate and share their data. A total of 760 kitchen establishments from the cost sub-sector were included in the study. Each organization performed waste quantification individually and therefore the quantification periods differed in ambition and in granularity, i.e., number of days the quantification period lasted, number of kitchens participating in quantification, waste processes monitored, and KPIs used for communication. These features also changed over time, e.g., one organization changed the duration of its quantification period from 5 days a year to 15 days a year and included more of its kitchens in quantification work overtime. The earliest food-waste quantification data are from 2010 and the latest from quarter 1 in 2019, but not all organizations actively quantified food waste during the whole period. Despite the different ambitions and granularity in food-waste quantification by the different organizations, most only covered lunch, although preschools and especially elderly care establishments typically also serve other meals such as breakfast, snacks, and dinner. Table 4 shows the scope of the material collected for the cost sub-sector of the hospitality sector.

Table 4. Summary of quantified data representing the cost sub-sector of the hospitality sector. All figures rounded to 2-digit precision except for number of quantification days and number of units. The values shown are raw data not subjected to any data cleaning process and may therefore be unrealistic in further calculations.

Actors in the Cost Sub-Sector	Quantification Days (n)	Units (n)	Waste (tons)	Served Food (tons)	Portions (10^3)
Elderly care	2155	62	110	19	880
Hospitals	1018	17	110	9	990
Preschool	6462	290	32	61	420
Primary school	15,183	343	270	740	4600
Upper secondary school	1828	48	84	180	1100
Total	26,646	760	600	1000	8000

2.2.1. Study Material for Elderly Care Units

Elderly care kitchen units were represented by food-waste quantifications from 20 kitchens in Sweden and 42 in Germany. The total extent of quantification for this segment was 2155 days with waste, served food, or portions quantified.

The definition used for elderly care units in this study was an establishment serving food to people in a retirement home. Some of these establishments are also open to the public, in that relatives can eat in a dining hall with the person living in the establishment.

2.2.2. Study Material for Hospitals

Hospitals were represented by food-waste quantifications from 16 hospitals within Sweden and one in Germany. The total number of quantification days was 1018.

Hospitals were defined as large establishments whose purpose is to treat sick people.

2.2.3. Study Material for Preschools

Preschool establishments typically care for and educate children ranging from age 1 to 6 years. The food-waste quantification data were obtained from a total number of 290 preschool kitchens, 256 of which were within Swedish municipalities, 15 were in Finland, and 19 were in Germany. Preschools were represented by a total of 6462 quantification days.

2.2.4. Study Material for Primary Schools

The material covering the primary school section of this study comprised 296 units from public catering services in Swedish municipalities, 20 units from Finland, and 27 units from Germany. Primary schools were defined as education units where students from around age 6 to 15 participate in education, based on the school system in Sweden and Finland. However, the German school system refers only to the ages 6 to 10 as primary schools.

The number of quantification days for primary schools was a total of 15,183 days. The public catering services for the Swedish municipalities and the Finnish equivalents have a unique position, since the legislation in those countries guarantees pupils and students the right to free meals during school days from pre-primary and primary education until completion of upper secondary education [42–44]. Swedish and Finnish kitchen units typically serve school meals that consist of a warm main course, vegetables, bread, table spread, and a drink [42].

2.2.5. Study Material for Upper Secondary Schools

Upper secondary school kitchens share some of the characteristics of primary school units, apart from the fact that the guests are older (age 15–19 years in Sweden and Finland, 10–19 in Germany).

The material used in this study comprised 48 such kitchen units, of which 39 were in Sweden, 6 in Finland, and 3 in Germany, with a total of 1828 quantification days.

2.3. Profit Sub-Sector of the Hospitality Sector

This section describes the material and methods used for the profit sub-sector of the hospitality sector, which includes canteens, hotels, and restaurants. Information about the food-waste quantifications and the data obtained come from three countries, Finland, Germany, and Norway. These organizations in this case were also selected due to willingness to participate and share their data. A total of 429 kitchen establishments from the profit sector were included in the study. The earliest food-waste quantification data are from 2010 and the latest from quarter 1 in 2019. Table 5 shows the material representing the profit sub-sector of the hospitality sector. In the dataset, it was uncommon for kitchens belonging to the profit sub-sector to quantify the amount of served food.

Table 5. Summary of quantified data representing the profit sub-sector of the hospitality sector. All figures rounded to 2-digit precision except for number of quantification days and number of units. The values shown are raw data not subjected to any data cleaning process and may therefore be unrealistic in further calculations.

Actors in the Profit Sub-Sector	Quantification Days (n)	Units (n)	Waste (tons)	Served Food (tons)	Portions (10^3)
Canteen	16,130	288	520	4	9900
Hotel	12,583	93	570	0	4700
Restaurant	3453	48	40	2	1100
Total	32,166	429	1100	5	15,000

2.3.1. Study Material for Canteens

The data for canteens represented 288 units, of which 178 were in Norway, 106 were in Germany, and four were in Finland. Most of the canteens are in company buildings and serve food to the employees, mostly lunch. In some cases, breakfast and dinner are also served. A small number of the canteens also serve food to students in private or public high schools, who by definition fall within the cost sub-sector of the hospitality sector.

2.3.2. Study Material for Hotels

The hotel data represented 43 hotels in Germany and 50 hotels in Norway. The dataset represented a diverse range of hotels, ranging from large conference centers to rather small tourist hotels that only serve breakfast. Most of the hotels in Norway recorded food waste over multiple months, thereby covering both the tourism high season in summer and conference activities during the rest of the year.

2.3.3. Study Material for Restaurants

The food-waste quantification data representing restaurants included 48 units, of which 39 were in Norway and nine in Finland. The total number of days during which the quantifications were conducted was 3456. Restaurants are a heterogeneous group, but their defining characteristics are that serving dishes is their primary and only function and they also serve dinner, as opposed to canteens. Most of the restaurants in this study have an à la carte system, where dishes are selected from a menu.

Restaurants that focus mainly on the "takeaway" segment of the market are also included in this group. Some units also offer a buffet lunch during the day. In Finnish restaurants, food-waste quantification period lasted for one day and included all the meals the restaurant offered, which were usually lunch and dinner.

2.4. Food-Waste Quantification and Calculation of KPIs

This section describes the calculation of various KPIs, techniques for handling asymmetry in the data, and some precision-related topics that can serve as a foundation for tracking food-waste quantification baselines over time.

A harmonized method for developing high-quality baselines is necessary to develop roadmaps for accomplishing the sustainable development goal of reducing food waste by 50% by 2030. The first step is to decide which KPIs to trace over time. In this study, we chose to focus on "Waste per portion" and "Waste (%) of served food". "Waste per portion" was chosen as this indicates how waste is influenced by the number of portions served, but since the portion size varies between different customer groups, it can be argued that food waste in relation to served mass (Waste (%) of served food) is a better KPI. These indicators are also those used by the organizations that provided the data for internal and external communication. The second step in establishing a sound baseline is ensuring a certain level of data quality. This can be addressed by agreeing within the community which waste processes should be quantified and how this should be done. Typical decisions are whether edible and inedible parts of food should be handled in the quantification work, how long the quantification period should last, how missing data should be handled, and what establishments should take part in the quantification to be representative for the whole segment. Some of these decisions can be taken on a local level, while others need to be addressed on a global level, regarding e.g., how data should be aggregated from local to global level and issues regarding asymmetry and representativeness of the data. However, there is also a need for flexibility, because kitchens locally have different individual problems that they try to solve. For instance, a kitchen might have discovered that it has a problem with serving waste and might therefore only focus on monitoring this form of waste, while neglecting other waste processes. Because of the actions taken on a local level, it is essential to have strict requirements at global level on handling missing and/or skewed data to achieve overall comparability.

2.4.1. Description and Calculation of "Waste per Portion"

The data from the organizations were used to calculate the KPI "Waste per portion" for each segment, according to Equation (1), where *i* represents a daily measurement and *n* is the total number of quantification days in each segment:

$$Waste\ per\ portion\ per\ segment = \frac{\sum_{i=1}^{n}(Waste\ from\ the\ waste\ processes)_i}{\sum_{i=1}^{n}(Number\ of\ portions\ served)_i} \quad (1)$$

However, the dataset underlying this calculation was not complete, as it contained missing values and did not compensate for the fact that different kitchens monitor different waste processes. For instance, a kitchen could have forgotten to record the number of portions served for some days and or omitted to quantify waste, skewing the result of the calculation. Another challenge to consider is that different kitchens quantify different waste processes, since they focus on identifying different food-waste sources, which causes a problem for the "Waste per portion" indicator on a global level because the underlying data can be inconsistent and can give different results. There is therefore a need for a method that locates missing data points and excles them from the calculation, but also compensates for the fact that kitchens monitor and focus on quantifying different waste processes. As a result, criteria at three levels (Levels 1–3) were used in this study for calculating the "Waste per portion" KPI.

The strictest criterion (Level 1), and that regarded as the most accurate, included only kitchens that had quantified portions and the waste processes "Plate waste" and "Serving waste", since those waste processes have been identified as the most significant contributors of waste in previous food-waste quantification studies [14]. When any of these indicators or processes was missing, the quantification for a given day was not included in the assessment.

Based on the medium criterion (Level 2), the calculation needed to include the waste (sum of all waste processes) and portions served, and when one of these two was missing the data were excluded.

The lowest criterion (Level 3) had the same input parameters as Level 2, but with the difference that there was no condition for excluding any missing values for the waste or portion inputs. This can be seen as the raw-data level where data gaps and mistakes are still present.

Descriptive statistics for the Level 1 criterion were calculated according to Equation (2) on kitchen level, using all available quantification data over the years, to examine the results in detail for kitchens belonging to a specific segment of the hospitality sector.

$$Average\ waste\ per\ portion = \frac{1}{n}\sum\nolimits_{i=1}^{n}\left(\sum\nolimits_{j=1}^{m_i}\frac{Waste\ from\ the\ waste\ processes_{i,j}}{Number\ of\ portions\ served_{i,j}}\right) \quad (2)$$

where n represents the number of kitchens in a segment and m_i is the number of quantification days for kitchen i in that segment. In addition to producing a table of descriptive statistics, the average waste per portion and the average number of portions on kitchen level were plotted against each other to get a graphical indication of the distribution of the data.

2.4.2. Description and Calculation of "Waste (%) of Served Food"

The KPI "Waste (%) of served food" was calculated in a similar matter to "Waste per portion" by dividing the calculations into different strict levels by constraining the input parameters for the calculation by various degrees. The reasons for doing this were the same as for calculation of waste per portion and involved compensating for missing input values and for skewness created by the fact that far from all the participating kitchens quantified the amount of served food. The indicator for each segment was calculated based on Equation (3), where i represents aaily measurement and n is the total number of quantification days in each segment:

$$Waste\ (\%) = \frac{\sum_{i=1}^{n}(Waste\ from\ waste\ processes)_i}{\sum_{i=1}^{n}(Mass\ of\ served\ food)_i} \times 100 \quad (3)$$

The strictest criterion (Level 1) for calculating the indicator was to remove any quantification day that lacked information on plate waste, serving waste, or number of guests, with the additional condition that the amount of served food needed to be recorded.

The medium criterion (Level 2) only summed the mass from the waste processes if the amount of served food and number of portions were quantified. It also had the condition to include served food if any waste and portions were quantified for a given day, thus disqualifying all those days for which this information was not present.

The lowest criteria (Level 3) added all the mass from the waste processes and divided it by the mass of served food with no condition at all. This can be seens the raw-data level where data gaps and mistakes were still present.

Descriptive statistics for Level 1 were calculated on kitchen level to examine the results in detail, based on the Equation (4):

$$Average\ waste\ (\%) = \frac{1}{n}\sum\nolimits_{i=1}^{n}\left(\sum\nolimits_{j=1}^{m_i}\frac{Waste\ from\ the\ waste\ processes_{i,j}}{Mass\ of\ served\ food_{i,j}}\right) \quad (4)$$

where n represents the number of kitchens in a segment and m_i is the number of quantification days from kitchen i in that segment.

2.4.3. Evaluation of the KPIs

To understand how the KPI changed with the results from computations using the different criteria levels the results were arranged in tables, one for "Waste per portion" and one for "Waste (%) of served food".

2.4.4. Distribution of the Waste Processes per Sector

To get an understanding of how the waste quantifications for the different segments were distributed and to identify where the main waste occurs, the "Waste per portion" indicator obtained with the strictest criterion (Level 1) was used.

T results from each waste process were displayed as a stacked bar plot to reveal the dominant waste processes in each segment of the sectors.

2.4.5. Precision of the Key Performance Indicator "Waste per Portion"

To compare KPIs, it is necessary to determine the measurement precision of the indicator over time. Since it is relatively easy to quantify waste and the number of portions compared with quantifying the amount of served food [26,39], the question is how many quantification days are needed to ensure a certain level of precision for "Waste per portion". The first step in this was to determine the distribution of the data for the strictest criterion. The data analyzed in this study were highly skewed for the different segments (Figure 3), but according to the central limit theorem, the average can be approximated as a normal distribution if the sample size is sufficiently large [45].

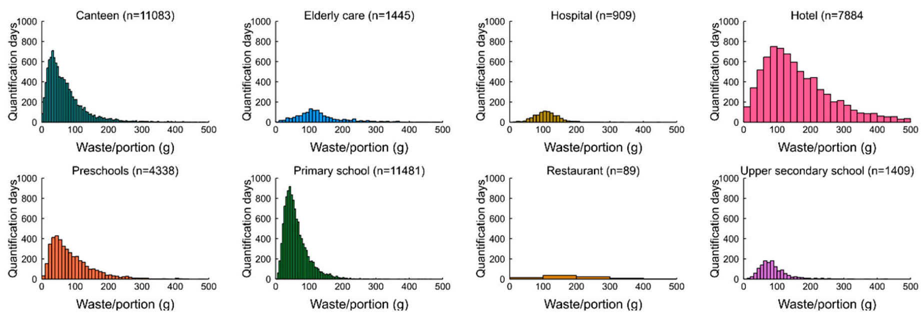


Figure 3. Histograms showing "Waste per portion" according to the strictest criterion for kitchens within the hospitality sector of the organizations studied: canteens (●), elderly care (●), hospitals (●), hotels (●), preschools (●), primary schools (●), restaurants (●), and upper secondary schools(●). X-axis capped at 500 g/portion.

This makes it possible to calculate the confidence interval I_μ (Equation (5)) and the length of the confidence interval (Equation (6)), which in this case is the precision in quantification of "Waste per portion". To find out how this changes with the number of observation points, in our case quantification days, equation 4 can be solved for n to give the number of observation points needed to get a certain quantification precision in grams (Equation (7)):

$$I_\mu = \left(\bar{x} \pm t_\alpha\left(\frac{\sigma}{\sqrt{n}}\right)\right) \quad (5)$$

$$L = 2t_\alpha \frac{\sigma}{\sqrt{n}} \quad (6)$$

$$n = 4\left(t_\alpha \frac{\sigma}{L}\right)^2 \quad (7)$$

where I_μ is confidence interval, $\bar{x}$ is sample mean, t_α is confidence level for different α, σ is standard deviation, n is observation point, and L is interval length given by Equation (6).

Both the observations *n* (5) and interval length *L* (4) are plotted against each other, to provide an illustration of how the measurement precision changes with the number of observation points per segment studied. In this study, a 95% confidence interval of $\alpha = 0.025$ was used according to the t-distribution. This approach gives information about the precision regarding the average "Waste per portion" for the strictest criterion.

2.4.6. Waste per Portion over Time

To get a sense of the change over time in the "Waste per portion" indicator for the strictest criterion, the precision attached to this indicator was plotted as grouped bar plots per segment together with the precision information for the different years and the number of quantification days per year.

3. Results

The results showed that around 20% of all food served was wasted within the hospitality sector organizations studied (Table 6), based on the strictest criterion (Level 1) for all years for which data were available.

Table 6. Waste (%) of served food in the different segments of the hospitality sector according to the strictest criterion (Level 1), aggregated on kitchen level for all years for which data were available.

Sector	Kitchens (n)	Min (%)	Max (%)	1st Quartile (%)	Median (%)	3rd Quartile (%)	Mean (%)	Std. Dev. (%)	Waste (%)
Canteen	5	22.5	35.8	24.6	28.6	33.0	28.9	5.0	26.3
Elderly care	8	15.9	62.2	18.4	23.3	25.1	26.4	14.0	20.6
Hospital	-	-	-	-	-	-	-	-	-
Hotel	-	-	-	-	-	-	-	-	-
Preschool	148	6.7	111	16.5	23.8	32.1	25.9	13.0	22.3
Primary school	226	6.8	42.9	14.9	18.4	23.1	19.2	6.0	19.7
Restaurant	9	14.9	35.1	18.9	24.1	26.1	24.2	6.3	24.3
Upper secondary school	35	8.2	39.1	15.7	19.5	23.0	20.0	6.1	17.8
Total	**431**	**6.7**	**111**	**15.5**	**20.2**	**25.6**	**21.9**	**9.8**	**20.0**

The data underlying the calculations in Table 6 comprised 9061 quantification days. Upper secondary schools showed the lowest "Waste (%) of served food" (17.8%). However, only 35 upper secondary schools provided data for this calculation, as a result of the strict criterion disqualifying schools with incomplete and or lacking data. Primary school kitchens had the second lowest value of served food wasted (19.7%) and provided most data in terms of number of kitchens. The value for elderly care was 20.6% of served food, while preschools reported that 22.3% of served food was wasted. Canteens and restaurants reported higher waste levels, 26.3% and 24.3% of served food, respectively. Hospitals and hotels gave no indication for the strictest criterion, since none met the requirements for Level 1.

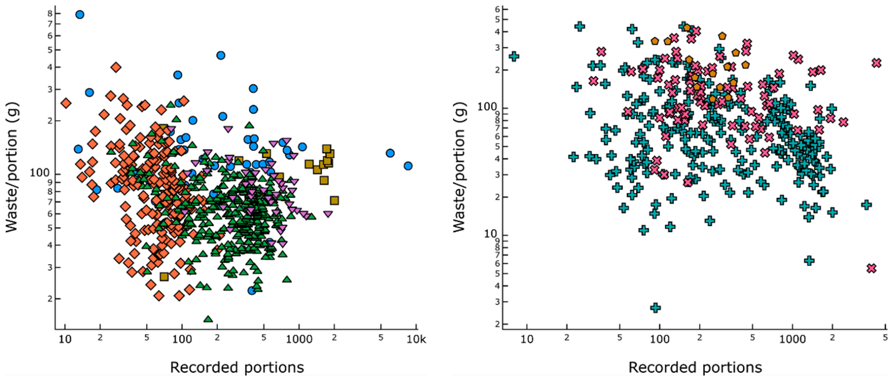
The other KPI studied, "Waste per portion", gave a more varied picture, with an average of 50 to 192 g per portion wasted within the hospitality sector (Table 7) according to the strictest criterion.

Table 7. Waste per portion (g) in the different segments of the hospitality sector according to the strictest criterion (Level 1), aggregated on kitchen level for all years for which data were available.

Sector	Kitchens (n)	Min (g)	Max (g)	1st Quartile (g)	Median (g)	3rd Quartile (g)	Mean (g)	Std. Dev. (g)	Waste/Portion (g)
Canteen	230	2.70	440	36.0	62.0	103	83.5	73.9	50.1
Elderly care	49	22.2	790	94.1	122	157	154	122	129
Hospital	16	26.6	181	93.8	114	122	108	32.7	113
Hotel	83	5.50	405	83.7	125	195	144	81.7	141
Preschool	193	20.8	399	53.2	87.0	116	94.6	56.2	81.0
Primary school	322	15.2	244	47.0	60.2	78.5	65.5	28.8	59.0
Restaurant	15	118	430	153	212	304	231	94.1	192
Upper secondary school	46	40.8	181	63.0	81.5	104	88.8	33.5	78.9
Total	**954**	**2.70**	**790**	**48.9**	**72.6**	**108**	**91.4**	**69.1**	**75.3**

Canteens had the lowest waste per portion (50.1 g) and were also the second largest segment in terms of recorded data, with 11,083 quantifications days for the 230 units that delivered data meeting the strictest criterion. Hotels had the second highest value for waste per portion (141 g), based on 83 kitchens and 7884 quantification days. Elderly care reported slightly lower waste per portion (129 g), based on 49 kitchens and 1445 quantification days. Hospitals reported 113 g waste per portion, with data from 16 kitchens and a total of 909 quantification days. Preschools and upper secondary school units reported similar waste per portion (81 g and 78.9 g, respectively). Primary schools had the second lowest waste per portion (59 g) and had the largest number of kitchens providing data for the calculations, with 322 kitchens and 11,481 quantification days in total. Restaurants was the segment with most waste per portion (192 g), based on data from 15 kitchens and 89 quantification days. The total number of quantification days, independent of segment studied, was 38,638 days (from 954 kitchen units) according to the strictest criterion.

Comparing the results for "Waste per portion", aggregated on kitchen level for all available data according to the strictest criterion (Table 7) against the average number of reported portions (Figure 4), revealed that preschools as a segment typically serve fewer portions than e.g., upper secondary schools, but displayed quite a broad range of "Waste per portion". Upper secondary schools, on the other hand, serve rather many portions but were quite consistent in their "Waste per portion" levels. Primary schools occupied an intermediate position, with 490 recorded portions and 60–70 g per portion, and showed a similar pattern as upper secondary schools, but with somewhat lower "Waste per portion" levels and a broader spectrum of recorded portions. Elderly care units rarely go under 100 g per portion, with some exceptions, and serve quite a broad range of portions on average. Hospitals show the same characteristics as upper secondary schools, but with a higher number of recorded portions. Canteens display quite a broad range in terms of both number of recorded portions and average waste per portion, while hotels have slightly higher average waste per portion. Restaurants are quite few, but centered on 200 portions and quite high waste levels, ranging between 100 to 200 g per portion.



(a) Cost sub-sector **(b)** Profit sub-sector

Figure 4. Scatterplots of average waste per portion and average number of portions served according to the strictest criterion (Level 1) for the kitchens of the organizations studied within (**a**) elderly care (●), hospitals (■), preschools (◆), schools (▲), and upper secondary schools(▼) in the cost sub-sector and (**b**) canteens (✚), hotels (✖) and restaurants (⬟) in the profit sub-sector. Axis by logarithmic scale.

3.1. Distribution of Waste

Comparing the waste distribution among the different segments of the sectors and waste processes, "Plate waste" appeared to be the dominant type of waste in canteens, elderly care, hotels, and upper secondary schools and almost equal to "Serving waste" in the hospital segment (Figure 5). "Serving waste" was the major contributor to the waste processes for preschools, primary schools, and hotels. "Preparation waste" was the largest contributor to restaurant waste. "Storage waste" was quite a small proportion of waste in the different segments and there were no records of "Receiving waste" at the strictest criterion for any of the segments studied.

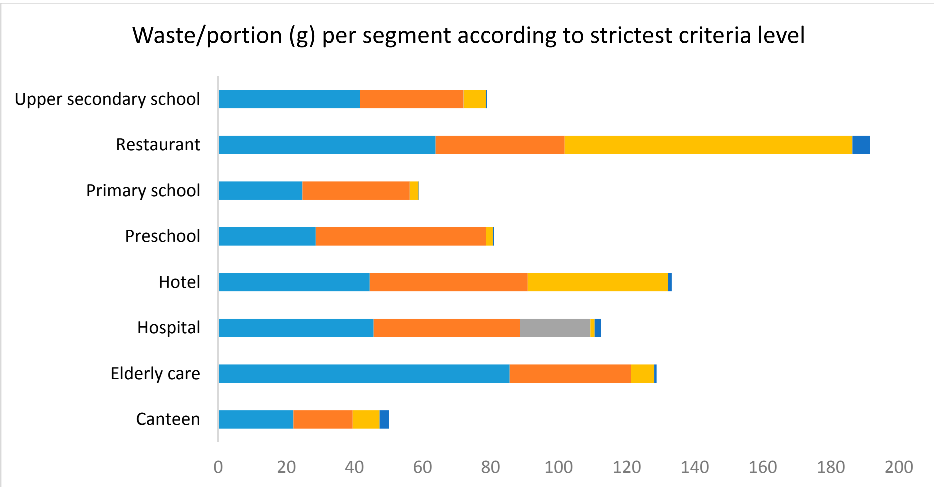


Figure 5. Contribution of different waste generation processes to total waste according to the strictest criterion (Level 1) for the different segments: (■) "Plate waste" (■) "Serving waste" (■) "Safety margin waste" (■) "Preparation waste", and (■) "Storage waste".

3.2. Precision of the KPIs

Figure 6 shows how the measurement precision of the KPI "Waste per portion" changes with the number of quantification days. Based on the strictest criterion, hospitals with 909 eligible quantification days achieved precision of ± 2.7 g. Primary schools, with 11,481 quantification days, achieved precision of ± 0.8 g. Preschools, which according to Level 1 reported 4388 quantification days, achieved precision of ± 3.2 g. Elderly care (1445 quantification days) achieved precision of ± 5.8 g and upper secondary schools (1409 quantification days) precision of ± 12 g. Restaurants (89 quantification days according to the strictest criterion) achieved precision of ± 31 g, hotels (7884 observation points) precision of ± 6.4 g, and canteens (11,083) quantification days precision of ± 9.4 g.

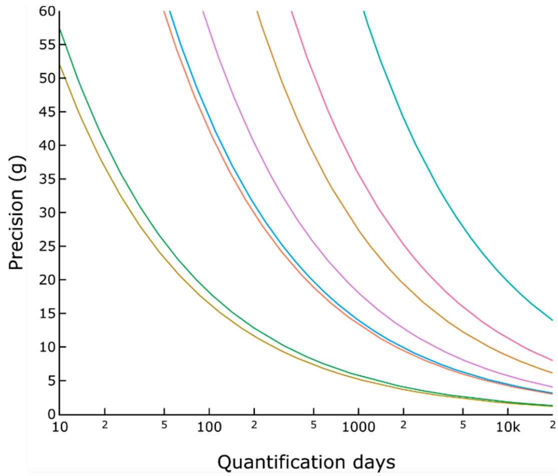


Figure 6. Measurement precision in the key performance indicator "Waste per portion" and number of quantification days for hospitals (—), primary schools (—), preschools (—), elderly care (—), upper secondary schools (—), restaurants (—), hotels (—), and canteens (—).

The differences between the criteria levels are shown in Tables 8 and 9. These differences show that the KPIs "Waste (%) of served food" and "Waste per portion" can vary depending on the input used.

When data were available for computation of "Waste (%) of served food", the results for the strictest and medium criteria (Levels 1 and 2) did not vary greatly within segments (Table 8). However, the lowest criterion gave no reliable results for the segments canteens, elderly care, hospitals, and restaurants. For instance, for the canteen segment, the calculation based on Level 3 resulted in a value of 11,839% for "Waste (%) of served food", because very few canteens quantified the amount of served food and the waste part dominated the calculation, producing unreliable results. A similar tendency was observed with the Level 3 criterion for upper secondary schools, with a 28 percentage-point difference between Levels 2 and 3.

Table 8. "Waste (%) of served food" in the different sectors for the criteria levels and number of quantification days that the levels include. Digits rounded for the columns "Recorded waste" and "Served food". "-" indicates that no data were available for the calculation, "NR" that results were not reasonable.

Sector	Quantification Days (n)	Recorded Waste (tons)	Served Food (tons)	Waste (%)
Canteen				
Level 1: Strictest	41	1	3.8	**26**
Level 2: Medium	43	1.1	4.4	**25**
Level 3: Lowest	NR	NR	NR	**NR**
Elderly care				
Level 1: Strictest	288	1.9	9.2	**21**
Level 2: Medium	442	3.3	16	**21**
Level 3: Lowest	NR	NR	NR	**NR**
Hospital				
Level 1: Strictest	-	-	-	**-**
Level 2: Medium	83	2.4	9.5	**25**
Level 3: Lowest	NR	NR	NR	**NR**
Hotel	-	-	-	**-**
Preschool				
Level 1: Strictest	2512	11	50	**22**
Level 2: Medium	2788	12	55	**22**
Level 3: Lowest	3105	32	61	**52**
Primary school				
Level 1: Strictest	5573	120	600	**20**
Level 2: Medium	5922	120	630	**19**
Level 3: Lowest	6739	270	740	**36**
Restaurant				
Level 1: Strictest	9	0.6	2.4	**25**
Level 2: Medium	9	0.6	2.4	**25**
Level 3: Lowest	NR	NR	NR	**NR**
Upper secondary school				
Level 1: Strictest	638	29	160	**18**
Level 2: Medium	689	30	170	**18**
Level 3: Lowest	757	84	180	**46**

Table 9 provides a similar picture for "Waste per portion" as shown in Table 8 for "Waste (%) of served food". The most significant difference was that waste per portion remained quite consistent over the different criteria levels and did not fluctuate as drastically as the "Waste (%) of served food" indicator. The most significant difference between the Level 1 and Level 3 criteria was found for restaurants, which according to Level 1 reported waste of 192 g/portion with 89 quantification days and according to Level 3 waste of 58.5 g/portion with 3453 quantification days.

Table 9. "Waste per portion (g)" in the different sectors for the criteria levels and number of quantification days that the levels include. Digits rounded for the columns "Recorded waste" and "Recorded portions".

Sector	Quantification Days (n)	Recorded Waste (tons)	Recorded Portions (10^3)	Waste/Portion (g)
Canteen				
Level 1: Strictest	11,083	420	8400	**50.1**
Level 2: Medium	15,290	510	9900	**51.7**
Level 3: Lowest	16,130	520	9900	**52.8**
Elderly care				
Level 1: Strictest	1445	100	780	**128**
Level 2: Medium	2065	110	880	**123**
Level 3: Lowest	2155	110	990	**124**
Hospital				
Level 1: Strictest	909	110	940	**112**
Level 2: Medium	1017	110	990	**112**
Level 3: Lowest	1018	110	990	**112**
Hotel				
Level 1: Strictest	7884	400	2900	**141**
Level 2: Medium	12,308	570	4600	**122**
Level 3: Lowest	12,583	570	4700	**122**
Preschool				
Level 1: Strictest	4338	24	300	**80.1**
Level 2: Medium	5589	30	400	**74.4**
Level 3: Lowest	6462	30	420	**74.7**
Primary school				
Level 1: Strictest	11,083	220	3800	**59.0**
Level 2: Medium	14,089	250	4600	**53.7**
Level 3: Lowest	15,183	270	4600	**57.8**
Restaurant				
Level 1: Strictest	89	4.2	22	**192**
Level 2: Medium	2092	38	500	**75.9**
Level 3: Lowest	3453	41	700	**58.5**
Upper secondary school				
Level 1: Strictest	1409	71	910	**78.9**
Level 2: Medium	1737	82	1100	**72.1**
Level 3: Lowest	1828	84	1100	**73.7**

3.3. Waste per Portion over Time

Figure 7 shows how the different segments of the hospitality sector performed according to the strictest criterion for "Waste per portion" over time when examining the data from a quantification day perspective. Primary schools were the only segment to show a decreasing trend that in the later years did not overlap in terms of quantification precision (error bars in Figure 7), except for the first quarter of 2019. Other segments showing decreasing waste per portion were upper secondary schools and hospitals, but those segments gave highly imprecise results due to overlap of error bars. The same is true for preschools, which appeared to have increasing levels of waste per portion, but again the error bars overlap, making this finding very imprecise. Elderly care was quite stationary, but for the first quarter of 2019 the calculated value appeared to increase relative to that in previous quantification periods.

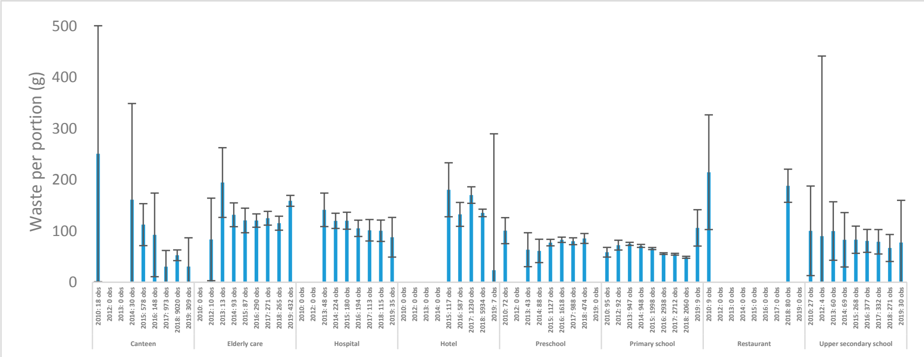


Figure 7. “Waste per portion (g)” with measurement precision (error bars) for the segments over time according to the strictest criterion (Level 1).

Restaurants could only provide results for 2010 and 2018 according to the strictest criterion. Hotels provided quite erratic results, but with 2018 showing a decrease compared with 2017. However, the error bars for 2016 overlapped both the 2017 and 2018 results. Canteens decreased their initial “Waste per portion” value the most, but again error bar overlap makes the result imprecise.

4. Discussion

4.1. Food Waste within the Different Segments of the Hospitality Sector

The dataset underlying this study is larger than in previous studies [14,20,22,23,25,27,28,30,32,34] and provides some perspective for previous findings. Among the organizations providing data for this study, it is quite normal to report around 20–26% waste, irrespective of the segment within the hospitality sector. However, this is higher than values reported by Betz [32] (10.7% and 7.7% waste for two kitchens investigated). The reason for those low values may that Betz quantified mass of delivered food, and not mass of served food as in the present study. However, the waste levels at the organizations contributing to this study are slightly lower than the 27% and 27.5% reported by Martins [25] and Boschini [26] according to the strictest criterion in this study. However, the variations in the results we observed when comparing criteria levels for “Waste (%) of served food” and when comparing the different segments indicate that the results from all previous studies can be regarded as falling within the “normal” range.

The KPI “Waste per portion” can vary widely between segments within the hospitality sector, ranging from around 50 g per portion for canteens up to around 192 g per portion for restaurants. These values are approximately in line with previous findings for the same segments of the hospitality sector, disregarding criteria levels and how much material to include when calculating this KPI.

The level of “Waste per portion” found for preschools in this study was intermediate relative to previous findings. In the study by Eriksson [14], preschools reported that around 45 g per portion served was wasted, which is lower than the value found in this study (~81 g). However, Byker [20] and Hansson [33] reported levels of 210 g and 145 g, respectively, which is in the upper end of our “Waste per portion” range. Use of more observation points would probably make the KPIs benchmarked here converge to an average in values in previous studies. Preschools have the potential to control food waste better than e.g., upper secondary school units, which for all years covered by the data reported a waste value of 78.9 g/portion, i.e., similar to that obtained for preschools. At first glance, the diagram showing “Waste per portion” in the different segments together with the error bars for the different years gives the impression that overall, preschools are increasing their waste per portion and upper secondary schools are decreasing theirs. However, the error bars for both segments overlap, creating uncertainty about whether the segments have made any progress.

The measurement error for the different years arises because the segments provided different numbers of quantification days for calculation of the indicator. For instance, preschools had 474 quantification days for 2018, resulting in precision of roughly ± 10 g, and upper secondary schools had 271 quantification days and precision of around ± 26 g, which resulted in an overlap and put the segments on a similar level. Looking at the precision in all the available data, it was around ± 11 g for upper secondary schools and ± 3 g for preschools, because the distribution of the data differed for these segments.

Considering the quite high values of "Waste per portion" for preschools and the seemingly increasing trend, there is considerable potential to reduce waste in this segment, especially since preschool units have lower levels of the risk factors involved in food-waste generation. For example, the carers eat with the guests and can therefore monitor and encourage the guests to minimize food waste. The guests in preschool units also usually have fewer options to choose from and cannot choose to eat elsewhere which, according to previous studies, should have a reducing effect on food waste [46,47].

The distribution of waste in the different segments of the hospitality sector was similar to that found in previous studies [14], which is interesting since it indicates that this parameter is unaffected by the amount of data collected. This provides a good opportunity for improvement, since kitchens with different set-ups and organizational characteristics can learn from other successful kitchens. For instance, measures that work to reduce plate waste in one kitchen establishment should at least be tried by others and evaluated.

4.2. Uncertainties and Limitations

This study did not include all sectors within the hospitality sector and omitted data from prisons and other such establishments in the public sector. To get a complete picture, these and other small actors in the profit sub-sector should be included in the analysis.

Organizations collected the data on which this study was based on their own and no random sampling was made among participating organizations. However, since food-waste quantification is not compulsory in the study countries, it was not possible to conduct a random selection of all units, only volunteering units. The data are more likely to have originated from organizations that are interested and have some ambition to lower their waste levels, so is highly likely that the results in this study are biased and that the actual waste levels are higher. Therefore, it cannot be claimed that the results presented are representative for whole segments.

The organizations conducted data collection in slightly different ways, which is clearly a limitation for this study since it introduces another bias. However, there will always be variation and error due to the human factor in any self-reporting system, and the risk is to some extent reduced using a larger dataset. Another limitation regarding data collection is the possible inclusion of napkins (and possibly other waste) in the plate waste fraction from some units and whether inedible parts were included or excluded. Lastly, there could be a significant variation in how liquid foods (soups, sauces, stews, etc.) are treated, since various amounts of the liquid phase could be included in food-waste quantification.

In this study, we tried to overcome some of the limitations by introducing different criteria levels. Level 1, the strictest, reflected the actual levels of waste, since quantifications based only on some waste processes and or served amount of food or with missing values were excluded. Applying this criterion also to some extent compensated for the highly skewed data, making calculations for the baselines fairer than they would otherwise have been. However, this is not a guarantee that the data included in the strictest criterion are correct, since they can be obtained in several ways. For instance, the number of portions might be incorrect, a kitchen might have forgotten to quantify a waste-generating process (which would not disqualify it under the strictest level), or the in-data could have been compromised by reporting of false information. A common mistake found during the conversion process was kitchens expressing values in grams and not kilograms. This was handled before the data were used for the calculations in this study, but it is an example of how data can be compromised in one way or another.

The different KPIs chosen in this study yielded quite different results, since one described the number of portions, which can vary widely between the segments in the hospitality sector, and the other the amount of served food that was wasted. It is necessary to have at least two indicators as input to a future baseline to give a complete picture of the situation. The different results reflect differences in quantification ambitions, where some organizations have been keener to quantify the amount of served food. One should also bear in mind that quantification of the amount of served food is a cumbersome task and the results can show great variation depending on the thoroughness of the individual kitchen staff. The best way to get precise information in food-waste quantifications would be for kitchens in all organizations to quantify waste all the time and to share their findings. Since this is an unlikely scenario, there is a need for recommendations to organizations already involved and interested in the matter.

4.3. The Road to 2030

Some national initiatives [48,49] have put forward quantification standards. This is an essential first step to increase the number of participating organizations and to make the quantification data comparable and representative among participating organizations. Having more quantification data would increase knowledge and allow the findings to be put into context and to be traceable over time. To halve food waste in the hospitality sector, it is essential that the KPIs that make up different future baselines have sufficient precision and resolution to be comparable over time. As an example, primary schools currently have a waste level of around 59 g per portion served based on the data for all years included under the strictest criterion in this study. To reach the goal of halving food waste, by 2030 primary schools would achieve a waste level of ~30 g per portion served, which is roughly a 3 g per year decrease (±1.5 g), to achieve SDG 12.3. To track development over time, the precision in quantification would need to be less than 3 g for the "Waste per portion (g)" key performance indicator if quantifications were performed every year. To achieve that precision, more data would need to be collected. The restaurant segment is an excellent example of this, with only 89 quantification days providing data for the precision calculation according to the strictest criterion. It is doubtful whether this can be seen as a sufficiently large number of observation points to perform the precision analysis.

To achieve the goal of halving food waste by 2030, it is essential that the baselines provided by different initiatives have sufficient precision and representativeness, to create trust in the values. The first step in achieving this is to establish the purpose of the baselines, when they are supposed to be followed up, and how. In that work, it is also essential to address the nature of the food waste, as there is currently limited information on the amount of e.g., edible food waste being generated. A general recommendation is that organizations participating in quantification should use the same method or framework, to make the underlying data for the baselines transparent. However, one must be pragmatic and meet organizations where they are [39], and minimum requirements for participating in delivering data to baseline quantifications should be smooth and not a reporting burden on the kitchen staff. One way of doing this is to use digitalization as a tool, which would hopefully enable instant feedback to the kitchen instead of delayed reports that make it impossible for kitchens to understand the effects of different measures. The levels of the waste process monitored should also be tailored to the kitchen's needs, while still fitting within a standard framework [38,39]. Recommendations for future work are thus to devise conventional means and methods of quantification and meet organizations where they are, but still have pressure to push development forward and e.g., include served food as a requirement for quantifications, in order to get a clearer picture of the KPI "Waste (%) of served food". National standards and frameworks are one way of doing this, but it is important to consider what the baselines are trying to achieve and to be clear about this in advance, to set criteria that enable the precision needed for follow-up. More quantification efforts are needed at canteens, elderly care establishments, hospitals, hotels, preschools, restaurants, and upper secondary schools, which will require greater precision of performance as they reduce their waste to show whether they are on target or not. Tools and measures for minimizing the actual causes of food waste and unnecessary overproduction [40,41] are also urgently needed, so that the things that get measured can be managed.

5. Conclusions

Overall, 50–192 g per portion or around 20% of served food are wasted. However, precision is crucial when monitoring different KPIs over time to detect trends. A decreasing trend, such as that observed here for hospitals, might emerge when comparing the average results from year to year, but the precision of quantification (measurement error) gives additional information about the trend. Hospitals are also a good example of a segment that provides quite similar quantification results over time, e.g., for "Waste per portion", and therefore fewer quantification days can provide quite accurate calculation of this KPI. Other segments have problems with this because they may have a lot of waste on some days, which influences the precision of "Waste per portion".

Depending on how the indicators are evaluated, somewhat different results can be obtained. Here, there were marked differences between the highest and lowest criteria (Levels 1 and 3) set for "Waste (%) of served food". In some segments, few kitchens quantify the amount of served food, making this KPI impractical to study. The indicator "Waste (%) of served food" is also more difficult to quantify and requires the different segments to quantify amount of served food. Applying the Level 2 criterion for analysis might be a reasonable compromise, since it would allow more quantification days as input for the precision analysis than Level 1, but still be accurate enough to trace changes over time. In that case, the restaurant segment would go from 89 quantification days, which can be considered a borderline number, to 2092, which would yield a more precise value for the segment. Schools are on the right track and should continue to do what they are doing at the moment, while other segments might have something to learn from the schools segment, even when they operate under different conditions. The quite large deviations between segments and even between kitchens within the same segment suggest that there is room for improvement and that food waste within the hospitality sector can be decreased.

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Identification and modelling of risk factors for food waste generation in school and pre-school catering units

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A B S T R A C T

Public sector food service is a major contributor to food waste generation in Sweden, with schools, pre-schools, elderly care homes, hospitals etc., producing approximately 70,000 tons of food waste each year. Sweden has appropriate infrastructure for handling food waste in place, recycling nutrients and energy, but there is still great potential to move upwards in the waste hierarchy and prevent waste. An important step in designing waste reduction measures is to identify and quantify the importance of different risk factors, in order to start by solving the problems with the greatest potential benefit and the lowest cost. This study sought to identify and quantify risk factors for food waste generation in public sector canteens by correlation analyses and statistical modelling. The empirical material comprised food waste quantification data for 177 kitchens in the Swedish municipalities of Falun, Malmö, Sala, Uppsala and Örebro, supplemented with quantifiable information about the kitchens obtained using a questionnaire. According to the findings, plate waste in schools and pre-schools increases with children's age. Schools with older children could potentially reduce plate waste by introducing more structured lunch breaks. Plate waste also increases with dining hall capacity, potentially due to rising stress and noise levels. Both plate waste and serving waste increase with greater overproduction, as indicated by calculated portion size, and could be reduced by schools and pre-schools estimating their daily number of diners and their diners' food intake more accurately. As serving waste was significantly higher in satellite units (which bring in cooked food), due to lack of cooling and storage possibilities, than in production units (which cook, serve and sometimes deliver hot food), satellite units in particular would benefit from more accurate quantification of the food required on a daily basis. These findings were confirmed by multiple linear regression models, which explained >85% of the variation in plate, serving and total waste per portion. When used for quantification after changing the value of different factors, these models confirmed that the main factors influencing serving waste and total waste per portion were type of kitchen and rate of overproduction, while plate waste was mainly influenced by children's age and factors indicating a stressful dining environment.

1. Introduction

Public sector food service is a major contributor to food waste generation in Sweden. According to the Swedish Environmental Protection Agency (SEPA), public food service, including schools, pre-schools, elderly care homes, hospitals etc., generates approximately 70,000 tonnes of food waste per year, which is roughly the same amount as for all other food services such as hotels and restaurants together (SEPA, 2016). Private households waste most food, 717,000 tonnes (SEPA, 2016), which can be explained by the much larger amount of food served in households compared with public catering units. Among all public facilities investigated by SEPA (2016), schools and pre-schools generated most of the total waste (67%), followed by elderly care homes (24%).

Landfilling of organic waste is banned in Sweden (Ministry of the Environment and Energy, 2001) and food waste is mainly managed through incineration (62%) and anaerobic digestion and composting (38%) (SEPA, 2017). In a global perspective, this can be considered fairly advanced waste management, but even the biological recovery options (digestion and composting) are still far from the waste reduction rates stated as the top priority in the EU Waste Framework Directive (EC, 2008). The environmental benefits of producing biogas are also much lower than the potential benefits of preventing waste or using it for higher priority valorisation options (e.g. reuse), thereby substituting for more resource-demanding products and services (Eriksson et al., 2015; Eriksson & Spångberg, 2017).

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Only a few academic studies have examined the food waste generated in public serving units. Eriksson et al. (2017) quantified the food waste from 30 public kitchen units in the Swedish municipality Sala with regard to plate waste and serving waste and found that elderly care homes had the highest waste per portion (90 g), followed by schools (79 g) and pre-schools (51 g). In general, 23% of the food served in Sala's public kitchens was wasted, with 64% being serving waste and 33% plate waste. Production units (facilities which produce food in their own kitchens) had significantly lower waste than satellite units (facilities that receive food produced in another facility and often have few possibilities for cooling and storage of food leftovers). Pre-schools had significantly lower waste than schools. Overall, however, there was great variation between kitchens of the same type (Eriksson et al., 2017).

In a study quantifying the food waste in an American primary school based on a short measurement period of five days, Byker et al. (2014) concluded that portion size, noise levels, time available for food consumption and children's age were possible factors determining food waste in schools. Some other attempts to identify the drivers of food waste in educational establishments have been made, most of which have relied on surveys and have aimed at ensuring that pupils receive sufficient nutrients via their school lunch, rather than at reducing waste. Kinasz et al. (2015) developed a checklist for the prevention of food waste based on the votes of experts, but also concluded that more research is needed to identify the factors controlling food waste generation. In addition to factors concerning management in the service sector, they suggested dining ambiance and knowledge about the diners as potential factors influencing food waste in public facilities. Whitehair et al. (2013) examined whether food waste in universities was reduced when students received information about food waste and found that a reduction of 15% could be achieved. However, only 40% of the students approached agreed to participate in that study and let their trays be weighed. Kuo and Shih (2016) suggest that gender differences might be a factor influencing plate waste, as they found that female plate waste in universities was significantly higher than male plate waste. A significant decrease in plate waste was also found in a study where trays were removed from a university dining hall (Thiagarajah and Getty, 2013).

Statistical approaches examining the drivers of food waste in school kitchens have shown that plate waste increases when sixth graders purchase food outside the dining hall, referred to as competitive food items (Marlette et al., 2005). A study by Niaki et al. (2017) found that children's age is an important factor influencing food waste behaviour in schools which should be taken into account when examining the drivers of plate waste in school kitchens. According to that study, children attending pre-school had significantly higher plate waste than children in higher school years. However, the authors point out that the youngest participants in the study had lunch two hours earlier than the oldest participants. Differences in lunch break procedures should therefore be examined as a factor coupled to food waste behaviour (Niaki et al., 2017). For example, food waste has been shown to decrease by about 10% when primary school children in school years 1 to 3 have their break before eating lunch (Getlinger et al., 1996).

In WRAP (2011), three interventions (improving familiarity and appreciation of school meals; improving the dining experience; children ordering their meals in advance to cooking them) were tested in 39 schools and led to a 4% waste reduction, although this reduction was not statistically significant. Barr et al. (2015) introduced the LEAN philosophy (a systematic method including the elimination of waste within manufacturing) to reduce overproduction, and thereby food waste, in school canteens in Sweden, but was unable to demonstrate any reduction in food waste due to insufficient waste quantification. This highlights the importance of a systematic approach to evaluating food waste reduction measures. An important step is therefore to describe the problem by quantifying waste, but also to correlate this waste to factors that can be improved. Multiple linear regression models have previously been used to quantify risk factors for waste generation in supermarkets (Eriksson et al., 2014) and to simulate the effect of waste-reducing measures (Eriksson et al., 2016a), but this approach has not previously been applied to public sector food services.

The Food and Agricultural Organization FAO (2013) estimates that 1.3 Gtonnes of edible food are lost or wasted along the food supply chain each year, which answers to one third of all food that is intended for human consumption. The consumption stage contributes with 37% to the total carbon footprint generated along the food supply chain, due to food wastage of 3.3 Gtonnes CO_2 equivalents. Annually, the production and post-handling of food that is later wasted together require around 30% of the world's agricultural area. The blue water footprint caused by agricultural products for food waste answers to 250 km^3 of groundwater and surface resources. (FAO, 2013)

Although the agricultural stage has the biggest impact on the environment among all stages in the food supply chain, food consumption has a huge impact on the environment through the energy used for production, packaging, transportation and cooking among others (Schott and Cánovas, 2015). By preventing 1 kg of food waste, up to 29 kg of emitted CO_2 could be saved, depending on the type of food wasted (Eriksson et al., 2015). In addition to decreased greenhouse gas emissions, a 50% reduction in food wastage in developed countries is estimated to result in lowering the global water footprint by 59 Gm^3 according to calculations by Munesue et al. (2014). Furthermore, over 60 million people could be nourished as a result of a 50% reduction. Food waste prevention would save natural resources and diminish negative effects on the environment caused by agricultural economy (Munesue et al., 2014). Knowledge about the implications of food waste and its prevention should be an "urgent priority" according to Thyberg and Tonjes (2015).

This study therefore examined factors influencing food waste in schools and pre-schools, with the objective of identifying and analysing these factors. Another objective was to investigate and model the influence of factors that were significantly related to food waste, in order to create a base for effective measures to reduce food waste in schools and pre-schools.

2. Materials and methods

Risk factors potentially influencing food waste generation were identified from the literature (Section 2.1). Quantitative data that could function as indicators for different potential risk factors were collected, as were food waste data (Sections 2.3 and 2.4). The correlation between food waste and risk factors was then tested for each factor individually. Lastly, the factors were modelled together, in order to calculate their collective impact on food waste generation. The research approach was highly influenced by a previous study conducted by Steen (2017), but with additional analysis and material in order to expand the results.

2.1. Identification and selection of risk factors

Possible risk factors identified from the literature are summarised in Table 1. Although food waste is likely to be influenced by factors such as attitudes and opinions, such factors were excluded from the study due to the associated difficulties in quantification and generalisation. However, for some factors that are difficult to quantify, such as stress, secondary factors such as time available for eating were used as an indicator of how stress was

Table 1
Parameters that have, or might have, an influence on the amount of food waste generated in educational establishments according to the literature and hypotheses concerning the parameters and possibilities to quantify the parameter.

Parameter	Hypothesis according to literature	Quantification
Children's age or differentiation between schools and pre-schools	Food waste increases with age (Byker et al., 2014; Eriksson et al., 2017; Niaki et al., 2017)	School year could be used as a quantitative indicator for children's age
Type of kitchen	Production units generate lower food waste than satellite units (Eriksson et al., 2017)	This factor could be examined in a bivariate analysis
Portion size	Possible factor influencing food waste (Byker et al., 2014; Painter et al., 2016)	Portion size is recorded in grams and therefore quantitative data are available. This factor could be used as an indicator for overproduction and improvable management
Dining ambiance, noise level and pupils' physical or emotional condition	A calm ambiance in the dining hall reduces food waste (SEPA, 2009; Byker et al., 2014; Kinasz et al., 2015; Painter et al., 2016)	Dining ambiance, noise level and conditions evoking stress could be assessed using dining hall capacity and crowdedness as an indicator, quantified as number of seats in the dining space
Time available for lunch and point of time at which lunch is served	To decrease food waste, children should have enough time to eat during their lunch break (Getlinger et al., 1996; SEPA, 2009; Byker et al., 2014; Niaki et al., 2017)	Lunch time could be assessed using dining space capacity in relation to number of children as an indicator, quantified as number of seats in the dining space and number of diners. The longer a lunch break is, the more time is available for pupils' food intake. Time available for lunch is often restricted by schools' dining hall capacity
Management factors and knowledge of diners	Possible factor influencing food waste (Kinasz et al., 2015)	Some management factors and the knowledge of children could be assessed using the number of staff members in the dining facility as an indicator, which is a quantitative measure.
Awareness of food waste as an issue	Possible factor influencing food waste (Whitehair et al., 2013; Painter et al., 2016)	Awareness of food waste can be assessed using education/no education or information about food waste given to staff members and children as an indicator. This factor is quantifiable given suitable data
Distance between classroom and dining space	Possible factor influencing food waste (Painter et al., 2016)	The distance could be quantified as different categorical groups

correlated with food waste generation. Some parameters were also grouped into indicators for which quantification was possible (Table 1).

Other parameters that might have an influence but were not considered for analysis were day of the week (Byker et al., 2014; Eriksson et al., 2017), pairings of meal components (Ishdorj et al., 2015), popularity of meals (Painter et al., 2016), availability of competitive food items (Marlette et al., 2005; Painter et al., 2016) and the children's gender (Kuo and Shih, 2016). These factors were either difficult to quantify or lacked the information required for statistical analysis. As the quantity of food waste varied widely between the public catering facilities included in the analysis, direct statistical analysis was not appropriate for day of the week as a potential factor influencing food waste generation.

2.2. Area of study

Food waste data were available for the municipalities of Sala, Uppsala, Falun, Malmö and Örebro in Sweden, which represent both urban and more rural areas with different numbers of residents. Malmö is located in southern Sweden, while Sala, Uppsala, Falun and Örebro are spread across central Sweden.

Children in Swedish pre-school or "kindergarden" are between the age one and five. After pre-school, pupils can enter school year 0, also referred to as "pre-school class". At the age of seven, pupils start school in the first school year and continue their school path until high school, which contains three different school years. In Sweden, high schools are often separate schools that pupils transfer to after school year 9.

2.3. Food waste quantification

The measurements of food waste were performed by each municipality prior to this study and the data were collected as described by Eriksson et al. (2017), using Excel sheets for recording the waste, number of diners and mass of served food. The waste data were obtained from the municipalities and inserted into the Matomatic platform for food waste data (Matomatic, 2017) in order to achieve a uniform standard of data organisation. The data were aggregated in order to represent the same level of resolution for all municipalities in line with the framework described in Eriksson et al. (2018), which included plate waste and serving waste from lunches served.

Plate waste was defined as all waste scraped from plates handed out to the diners, including inedible parts such as bones or peel. In addition to the weighed plate waste, the number of used plates handed in was counted and used to define the number of portions served per day (Eriksson et al., 2016b)

Serving waste was defined as all food waste generated throughout the preparation and serving process, in both the kitchen and the dining hall, as well as left-overs from the serving trays. Inedible parts discarded during the preparation process were not included.

Some municipalities report a third category, 'other waste', referring to food waste generated through storage or other sources that are not included in the category 'serving waste'. However, this category tends to be insignificantly small compared with the other two and was therefore excluded from the present analysis.

In order to develop comparable values, the variables total waste per portion, plate waste per portion and serving waste per portion, per day, week and semester, were introduced for each school. Total waste per portion was defined as the sum of serving waste and plate waste per portion served. All incomplete measurements were excluded from the calculations. In addition to the three food waste quantities, background data about the number of semesters with food waste measurements, portion size and type of kitchen were included in the original data. As the reported measurements differed in terms of frequency, count and span of time between different kitchen units, the average for all semesters included in each kitchen's reported measurements was used as a comparable measure for analysis. Furthermore, information about the type of kitchen (satellite or production units) was available for 177 kitchens.

2.4. Collection of background data

In order to collect additional information about the dining systems in different preschools and schools in Uppsala, Falun, Sala, Malmö and Örebro, a questionnaire was sent out to the head chefs

Table 2
Information obtained in a survey of kitchen head chefs in Sala, Uppsala, Falun, Malmö and Örebro and included in the present analysis; description of the data by definition, type of data and estimated uncertainty.

Category	Definition	Type of data
Number of pupils	Number of pupils registered at the school in December 2016	Accurate or rounded number (truncation by five pupils)
Number of employees	Number of employees working in the school kitchen in January and February 2017	Accurate number
Number of female and male employees	Number of employees working in the school kitchen in January and February 2017 divided into male and female employees	Accurate number
School years	School years represented in the school	School years as a range of numbers, i.e. 1–9 or KG (“kindergarden”/pre-school) for pre-school with children aged 1 to 5
Dining hall capacity	Number of seats available for diners in the dining hall	Accurate or rounded number (truncation by five seats) or category ‘in classroom’ when the school had no dining hall and the children ate in their classrooms
Distance between dining space and classroom	Distance between dining space and classroom	As distance in metres or as a description, including whether the dining hall is in the same building as the classrooms; or as “in classroom” for schools with no separate dining hall
Number of meal options	Number of meal options planned by the kitchen staff	Accurate number or as a range, i.e. 2–3

responsible for the kitchens for which food waste data was available. If no response was received, the written questionnaire was followed up by a telephone call. The information collected consisted of quantitative data on number of pupils, dining space capacity, school years, number of meal options, number of employees, number of female and male employees and distance between dining space and classroom. Although some factors, such as number of pupils and dining hall capacity, can fluctuate over time, the fluctuation was assumed to be sufficiently small to allow general trends in the data to be detected (Table 2).

The responses to a question on whether information about food waste was given to children and staff differed widely and contained unacceptable uncertainty, so this information was not considered as a factor for analysis. In response to a question on whether there was a booking system to predict the number of diners, all kitchens replied that the number of diners was calculated based on the number of pupils registered at the school. In most cases, the kitchen required notification to avoid overproduction if pupils were unable to attend lunch in the dining hall, but most kitchens reported that they were often notified late or not at all.

Since none of the kitchens had a serving system with trays, the benefits of a trayless system could not be examined.

2.5. Correlation analysis

Statistical correlation analysis was used to examine the relationship between the factors listed in Table 1 and the amount of food waste generated in pre-schools and schools. In general, correlation analysis uses hypothesis testing to determine how one variable is affected by another. The null hypothesis states that there is no significant correlation between the two variables tested. If the calculated p-value is lower than the assigned significance level, the null hypothesis can be rejected and the two variables influence each other (Helsel and Hirsch, 2002). The significance level for this study was set to $p < 0.05$. Correlation analysis was performed in R (The R Foundation, 2017) and examined whether the data samples were normally distributed according to the Shapiro-Wilk test (Royston, 1991), creating a scatterplot to visualise the relationship between the variables tested and then deciding on a suitable method before performing correlation analysis.

The correlation between two variables can either be positive, meaning that one variable increases as the other increases, or negative, meaning that one variable decreases as the other increases. According to Helsel and Hirsch (2002), the three most common methods for correlation analysis are Pearson’s r, Spearman’s rho and Kendall’s tau. All three methods return a correlation coefficient between −1 and 1, indicating the correlation strength. As the correlation coefficients r, rho and tau are calculated differently, the correlation strength is measured on a different scale depending on the method. It is therefore difficult to compare the strength of correlations with different correlation coefficients. An overall standard states that a correlation coefficient between ±0.1 and ±0.3 indicates a weak relationship, a correlation coefficient between ±0.3 and ±0.5 indicates a moderate relationship and a correlation coefficient higher than 0.5 or lower than −0.5 indicates a strong relationship (Field et al., 2012).

Pearson’s r is the most commonly used method for correlation analysis and requires a normally distributed data sample. An exception can be made if one of the variables tested is bivariate and the second variable follows a normal distribution. Otherwise, the method requires the observed variables to be linearly dependent and to fulfil the conditions of interval or ratio data (Field et al., 2012). Outliers, which can be detected in a boxplot, must be excluded from the analysis as the method is not resistant to outliers (Helsel and Hirsch, 2002).

Spearman’s rho uses a weighed rank test and requires a monotonic relationship between the two variables tested (Helsel and Hirsch, 2002). As the method depends on a rank test, the data sample is not required to be normally distributed. According to Field et al. (2012), Spearman’s rho is not suitable for data samples containing <20 data points or data that do not fulfil the conditions to be ordinal.

In contrast to Pearson’s r and Spearman’s rho, Kendall’s tau is resistant to outliers, as the method is based on a simple rank sum test. However, it demands a monotonic relationship between the observed variables (Helsel and Hirsch, 2002). The method can handle ties in the data sample and does not require the variables tested to be normally distributed. Kendall’s tau is suitable for smaller sample sizes, especially if the sample contains many ties (Field et al., 2012).

2.6. Parameters investigated

The following parameters were analysed to determine whether there was a significant correlation between the suggested drivers for food waste in Table 1 and the food waste generated. Correlations between the parameters total waste per portion, serving waste per portion and plate waste per portion were examined. Visual analysis was performed manually on scatterplots before each correlation test, to ensure that only monotonic patterns appeared in the sample examined.

In preparation for multiple linear regression (MLR) and to develop an overview of the interactions between the parameters, a correlation matrix was created using the built-in function "cor" in R. To ensure that the results were not biased by ties or outliers in the data sample, the method was specified as 'Kendall's rank correlation'. The correlation matrix established contained all correlation coefficients between the parameters tested.

2.6.1. Number of pupils

'Number of pupils' was defined as the number of pupils registered at the school or pre-school in December 2016. With a sample size of 141 data points and a discrete range of 10 to 1300 pupils, the data did not contain many ties compared with the sample size. As the data sample had a non-normal distribution (Shapiro-Wilk test, $n = 141$, $p < 0.05$), Spearman's rank correlation was chosen as the most suitable method.

2.6.2. School years

'School years' was defined as the number of academic years represented in a school. Pre-school was counted as one year, since children in pre-school have the same routines and share the same location despite their different ages (1 to 5 years).

The data sample had a discrete range from 1 to 13 different school years and contained 35 data points. As the data were normally distributed (Shapiro-Wilk test, $n = 35$, $p > 0.05$), Pearson's product-moment correlation was chosen as the most suitable method.

2.6.3. Comparable age

In order to develop a relative measure to compare the children's age, 'comparable age' was calculated. It was defined as the sum of all school years represented at a school or pre-school, divided by the range of years. Some schools included a pre-school class. To calculate the sum of all school years represented, each year was assigned a number between 1 and 15, with 1 representing the pre-school class and 15 representing the last year of secondary school. The number 2 represented class 'zero', also named 'pre-school class'.

The data sample had a discrete range from 1 to 13 and consisted of 141 data points. As the data were non-normally distributed (Shapiro-Wilk test, $n = 141$, $p < 0.05$) and contained many ties compared with the sample size, Kendall's rank correlation was chosen as the most suitable method.

2.6.4. Number of employees

'Number of employees' was defined as the number of people working in the dining system's kitchen in January and February 2017. The data sample contained 35 data points with a discrete range from 1 to 11 employees and contained many ties compared with the sample size. As the data were non-normally distributed (Shapiro-Wilk test, $n = 35$, $p < 0.05$), Kendall's rank correlation was chosen as the most suitable method.

2.6.5. Gender of staff (percentage of male employees)

'Gender of staff' (percentage of male employees) was calculated by dividing the number of male kitchen employees by the total number of kitchen employees and multiplying the resulting number by 100. School kitchen staff are commonly dominated by women, and men were therefore chosen as the observed gender percentage. The data sample contained 35 data points on a continuous range from 0 to 100%. As the data were non-normally distributed (Shapiro-Wilk test, $n = 35$, $p < 0.05$) and some ties occurred, Kendall's rank correlation was chosen as the most suitable method.

2.6.6. Employees per pupil

'Employees per pupil' was introduced to develop a comparable measure, since it is likely that the number of employees increases with an increasing number of pupils at the school. The measure was computed by dividing the number of employees by the number of pupils and multiplying the resulting number by 1000 to enhance the scale. The data sample contained 35 data points on a continuous range from 4.55 to 37.04. Visualisation by boxplot showed the presence of one outlier. As the data were non-normally distributed (Shapiro-Wilk test, $n = 35$, $p < 0.05$) and did not contain any ties, Spearman's rank correlation was chosen as the most suitable method. This method is resistant to outliers.

2.6.7. Type of dining space

'Type of dining space' was divided into two categories. Schools in which the pupils ate lunch in their classrooms were assigned to category 1 and schools that offered a separate dining hall were assigned to category 0. The data sample was therefore bivariate and contained 36 data points. As waste per portion, serving waste per portion and plate waste per portion were found to be normally distributed (Shapiro-Wilk test, $n = 36$, $p > 0.05$), Pearson's product-moment correlation was chosen as the most suitable method.

2.6.8. Distance between dining space and classroom

'Distance between dining space and classroom' was divided into three different categories. The resulting data sample contained 34 data points on an ordinal scale with the following categories:

- No distance between dining space and classroom, meaning that pupils ate in their classroom.
- The dining hall is located in the same building as or within 100 m from the classrooms.
- The dining hall and the classrooms are located in separate buildings or are >100 m apart.

As the data sample included many ties due to the categorisation, Kendall's rank correlation was chosen as the most suitable method.

2.6.9. Number of seats in dining space

'Number of seats in dining space' was defined as the total number of chairs in the dining space. For schools without a separate dining hall, the number of seats was assumed to equal the number of pupils per class. According to Skolverket (2014), the average Swedish class has 19 pupils and one teacher, resulting in 20 seats per dining space.

The data sample consisted of 50 data points on a discrete range from 20 to 485 seats. As the data were non-normally distributed (Shapiro-Wilk test, $n = 50$, $p < 0.05$) and contained ties, Kendall's rank correlation was chosen as the most suitable method.

2.6.10. Seats per pupil

'Seats per pupil' was introduced to develop a comparable measure, since dining space capacity is likely to grow with increasing number of pupils. The measure was computed by dividing the number of seats in the dining space by the number of pupils.

The data sample consisted of 50 data points on a continuous range from 0.213 to 1.136. As the data contained ties and were non-normally distributed (Shapiro-Wilk test, $n = 50$, $p < 0.05$), Kendall's rank correlation was chosen as the most suitable method.

2.6.11. Variety of meal options

'Variety of meal options' was used as a measure of the flexibility in a kitchen to change the menu. Greater flexibility could give the kitchen possibilities to include left-overs in new dishes. As an example, a dining system that reported a usual number of 3–6 meal options had a variety of 4 meal options.

The data sample consisted of 33 data points on a discrete range from 1 to 4. As the data contained many ties and were non-normally distributed (Shapiro-Wilk test, $n = 33$, $p < 0.05$), Kendall's rank correlation was chosen as the most suitable method.

2.6.12. Comparable number of dishes

'Comparable number of dishes' was used as a measure of the total number of meal options generally offered at a school. The measure was calculated as average number of meal options offered in each dining system. As an example, a school with a span of 2–3 meal options had a comparable number of 2.5 dishes.

The resulting data sample consisted of 33 data points on a continuous range from 1 to 4.5. As the data were non-normally distributed (Shapiro-Wilk test, $n = 33$, $p < 0.05$) and contained ties, Kendall's rank correlation was chosen as the most suitable method.

2.6.13. Number of semesters with food waste measurements

'Number of school semesters with food waste measurements' varied between 1 and 8 for the different dining systems. As the data sample was non-normally distributed (Shapiro-Wilk test, $n = 177$, $p < 0.05$) and contained many ties compared with the sample size of 177 data points, Kendall's rank correlation was chosen as the most suitable method.

2.6.14. Type of kitchen

'Type of kitchen' was distinguished to be either 0 for production units or 1 for satellite units, resulting in a bivariate data sample with 177 data points. As waste per portion, serving waste per portion and plate waste per portion were normally distributed (Shapiro-Wilk test, $n = 177$, $p > 0.05$), Pearson's product-moment correlation was chosen as the most suitable method.

2.6.15. Portion size

'Portion size' (g) was calculated as the total amount of food served divided by the number of portions served. The data sample consisted of 128 data points on a continuous range from 182.7 to 725 g and contained two outliers at 583.6 g and 725 g. As the data were non-normally distributed (Shapiro-Wilk test, $n = 128$, $p < 0.05$), Spearman's rank correlation was chosen as the most suitable method. The method is resistant to outliers.

2.6.16. Standard deviation (STD) in number of diners

'Standard deviation (STD) in [the daily] number of diners' was calculated for 129 schools and pre-schools and the data sample had a range from 0.98 to 301.43. The data were non-normally distributed (Shapiro-Wilk test, $n = 129$, $p < 0.05$) and did not contain many ties compared with the sample size. Spearman's rank correlation was chosen as the most suitable method.

2.6.17. Comparable STD number of diners

'Comparable standard deviation (STD) in number of diners' was calculated by dividing the standard deviation of the number of diners by the number of pupils. The resulting data sample contained 112 data points on a range from 0.006 to 0.669. As the data were non-normally distributed (Shapiro-Wilk test, $n = 112$, $p < 0.05$) and did not contain any ties, Spearman's rank correlation was chosen as the most suitable method.

2.7. Multiple linear regression (MLR)

2.7.1. Model equation

In order to quantify the impact of significant influential factors on food waste, a multiple linear regression (MLR) model was developed for each food waste quantity. According to Uyanik and Güler (2013), the advantage of using an MLR model instead of diverse correlations is the ability to quantify the total effect from relevant factors on the model outcome.

In general, an MLR model includes an intercept (c0), unscaled model coefficients (c0, c1, c2, . . ., cn) and two or more explanatory variables (x1, x2, . . ., xn) that together explain the variation in the response variable (y). In most cases some unexplained noise remains, often referred to as the error (ε) in the model. (Eq. (1)); Helsel and Hirsch, 2002). If the model outcome is likely to depend on the interaction between two factors, an interaction term (x1*x2) can be added to the general model equation (Eq. (2); Helsel and Hirsch, 2002).

$$y = c_0 + c_1 * x_1 + c_2 * x_2 + \cdots + c_n * x_n + \varepsilon \quad (1)$$

$$y = c_0 + c_1 * x_1 + c_2 * x_2 + \cdots + c_n * x_n + a_1 * x_1 * x_2 + \cdots + \varepsilon \quad (2)$$

2.7.2. Assumptions and choice of explanatory variables

With respect to the results from the correlation analysis, a number of MLR models based on different factor constellations were tested for each food waste quantity. According to Field et al. (2012), the choice of explanatory variables should be based on theoretical reasons. Only factors that were significantly correlated ($p < 0.05$) or almost significantly correlated ($p < 0.1$) with food waste were therefore used for developing the model. Furthermore, the model outcome should be linearly dependent on all explanatory variables included in the model (Field et al., 2012). The explanatory variables should be independent and randomly distributed, while the response variable is assumed to be normally distributed (Uyanik and Güler, 2013). To allow the MLR model to be generalised beyond the data used for model development, the residuals should be normally distributed and not show any specific pattern (Field et al., 2012).

Since the food waste quantities expressed as plate waste per portion, serving waste per portion and total waste per portion were normally distributed (Shapiro-Wilk test, $n = 35$, $p > 0.05$), three different MLR models (A-C) with food waste quantities as response variables were developed. Graphical analysis confirmed that the assumption about linearity held for all explanatory variables included in the models. To avoid biased models, outliers were removed from the data used for modelling (Uyanik and Güler, 2013) and factors that were likely to cause multi-collinearity (tau > 0.6 according to correlation matrix) were eliminated before model development. Multi-collinearity between factors exists when a factor included in a model is dependent on another factor that is also included in the model. Due to the factors dependence on each other, the model outcome is biased and not representative of the true relationships between the model outcome and the factors included. (Helsel and Hirsch, 2002; Field et al., 2012)

2.7.3. Validation and choice of model

Backwards elimination was used to choose the best performing MLR models. All explanatory variables significantly or almost significantly correlated to the food waste quantity were included in the different models. Explanatory variables that were not significant for the model outcome ($p > 0.05$) were eliminated step by step until all remaining explanatory variables significantly influenced the variation in the response variable ($p < 0.05$) (Helsel and Hirsch, 2002).

To improve model performance, different interaction terms were then added through backwards elimination. The best performing model was chosen with respect to the coefficient of determination, R^2, and the number of explanatory variables. According to Helsel and Hirsch (2002), a good model explains as much of the variation in the response variables with as few explanatory variables as possible. As the R^2-value naturally increases with each explanatory variable included in the model, the adjusted R^2-value, which considers the number of explanatory variables, was used to determine the best performing model (Helsel and Hirsch, 2002). To ensure that the assumptions of linearity, normality and independence held for the chosen models, graphical analysis was performed on a residual and a quantile-quantile plot (Field et al., 2012).

3. Results

3.1. Correlation analysis

The findings from the correlation analysis are summarised in Fig. 1. The analysis showed that the factors 'number of employees', 'number of seats in dining space', 'STD in number of diners' and 'number of pupils' were strongly correlated (tau > 0.7). The strong correlation between these four factors is caused naturally, as a higher number of pupils requires a more generous dining space and a higher number of employees. A higher number of pupils also increases the probability of pupils being absent during lunch time, which increases the standard deviation in the number of diners at a facility. Most likely the number of seats in dining space is the factor directly influencing plate waste per portion, which is discussed in Section 4.2.

In graphical analysis performed on scatterplots before each correlation analysis, only monotonic trends were found when observing the relationship between food waste and the different parameters, verifying Spearman's and Kendall's rank correlations as appropriate methods for analysis. Furthermore, graphical analysis showed that the assumption about a linear relationship between food waste and factors analysed with Pearson product-moment correlation held, verifying the method as appropriate.

3.1.1. Correlations with plate waste per portion

'Plate waste per portion' was significantly positively correlated with 'comparable age', 'portion size', 'number of pupils', 'number of seats in dining space', 'standard deviation in number of diners', 'number of employees' and 'gender of staff' (male employees) (Table 3). The factors 'number of employees', 'number of seats in

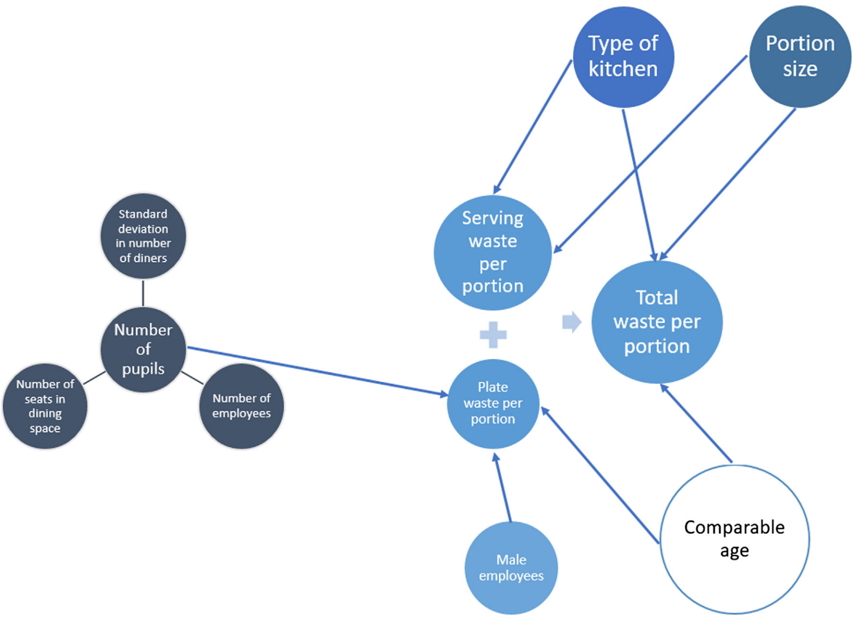

Fig. 1. Schematic model showing the interactions between factors and their influence on food waste quantities. Total waste per portion is the sum of serving waste and plate waste per portion.

Table 3
Significant correlations between different parameters and plate waste per portion; method, number of data points n, p-value and strength of the correlation according to the correlation coefficient; significance level p < 0.05.

Factor	Method	n	p-value	Correlation coefficient
Comparable age	Kendall	141	<0.001	tau = 0.21
Portion size	Spearman	128	<0.001	rho = 0.32
Number of pupils	Spearman	141	<0.0001	rho = 0.38
Number of seats in dining space	Kendall	50	<0.0001	tau = 0.42
STD in number of diners	Spearman	129	<0.01	rho = 0.27
Number of employees	Kendall	35	<0.001	tau = 0.45
Gender of staff (% male employees)	Kendall	35	<0.05	tau = 0.31

Table 4
Significant correlations between different parameters and serving waste per portion; method, number of data points n, p-value and strength of the correlation according to the correlation coefficient; significance level p < 0.05.

Factor	Method	n	p	Correlation coefficient
Portion size	Spearman	128	<0.0001	rho = 0.38
Type of kitchen	Pearson	177	<0.001	r = 0.28

Table 5
Significant correlations between different parameters and total waste per portion; method, number of data points (n), p-value and strength of the correlation according to the correlation coefficient; significance level p < 0.05.

Factor	Method	n	p-value	Correlation coefficient
Comparable age	Kendall	141	<0.05	tau = 0.15
Portion size	Spearman	128	<0.0001	rho = 0.48
Type of kitchen	Pearson	177	<0.01	r = 0.24

dining space' and 'STD in number of diners' were strongly positively influenced by 'number of pupils' (tau > 0.7).

3.1.2. Correlations with serving waste per portion

Serving waste per portion was significantly positively correlated with portion size. Satellite units had significantly higher serving waste than production units (Table 4).

3.1.3. Correlations with total waste per portion

Total waste per portion, i.e. the sum of plate waste and serving waste per portion, was significantly positively correlated with 'portion size' and 'comparable age'. Satellite kitchens had significantly higher waste per portion than primary production units (Table 5).

3.2. Multiple linear regression (MLR)

3.2.1. Plate waste per portion

Among the models tested, the food waste quantity plate waste per portion was best explained by MLR model A including the factors 'comparable age' and 'portion size' (Eq. (3)); Table 6). As a model is always a simplification of reality, the accuracy and robustness of a model decreases with each parameter. Thus, the amount of parameters for this model has been reduced to 'comparable age' and 'portion size' to avoid over-fit. Together, these factors explained 87.1% of the variation in plate waste per portion between the schools used for analysis (n = 121, p < 0.0001, adjusted R^2 = 0.871, multiple R^2 = 0.873) with a residual standard error of 10.56 g. As the red[1] line in the residuals plot shows (Fig. 2), the residuals for model A were randomly distributed and did not follow a pattern, indicating linearity and homoscedasticity (Fig. 2). Moreover, the standardised residuals in the quantile-quantile plot followed the dashed line and sufficiently satisfied the assumption of linearity (Fig. 3).

$$\begin{aligned} \textit{Plate waste perportion } [g] = \; & 0.952(\pm 0.3176) \\ & * \textit{Comparable age} \\ & + 0.067(\pm 0.0057) \\ & * \textit{Portion size} \pm 10.56 \; g \end{aligned} \quad (3)$$

3.2.2. Serving waste per portion

The food waste quantity serving waste per portion was best explained by MLR model B including 'portion size' and the interaction between 'portion size' and 'type of kitchen' (Eq. (4)); Table 7). Together, these explained 85.1% of the variation in serving waste between the schools used for analysis (n = 120, p < 0.0001, adjusted R^2 = 0.851, multiple R^2 = 0.853) with a residual standard error of 15.04 g. As the red line in the residuals plot shows (Fig. 4), the residuals for model B were randomly distributed and did not follow a pattern, indicating linearity and homoscedasticity. Moreover, the standardised residuals in the quantile–quantile plot followed the dashed line and sufficiently satisfied the assumption of linearity (Fig. 5).

Table 6
Multiple regression model A for plate waste per portion; significant factors and p-values.

Model A	Factor	p-value
	Comparable age	<0.01
	Portion size	<0.0001

$$\begin{aligned} \textit{Serving waste perportion } [g] = \; & 0.018(\pm 0.0086) \\ & * \textit{Type of kitchen} \\ & * \textit{Portion size} \\ & + 0.101(\pm 0.0050) \\ & * \textit{Portion size} \pm 15.04 \; g \end{aligned} \quad (4)$$

3.2.3. Total waste per portion

Among the models tested, total waste per portion was best explained by MLR model C including the factors 'type of kitchen' and 'portion size' (Eq. (5)); Table 8). Together, these factors explained 92.2% of the variation in total waste per portion between the schools used for analysis (n = 118, adjusted R^2 = 0.922, multiple R^2 = 0.924, p < 0.0001). As the red line in the residuals plot shows (Fig. 6), the residuals for model C were randomly distributed and the assumptions of linearity and homoscedasticity were fulfilled. Moreover, the standardised residuals in the quantile–quantile plot followed the dashed line, indicating that the assumption about normality was sufficiently fulfilled (Fig. 7).

$$\begin{aligned} \textit{Total waste perportion } [g] = \; & 7.288(\pm 3.516) \\ & * \textit{Type of kitchen} \\ & + 0.180(\pm 0.006) * \textit{Portion size} \\ & \pm 18.11 \; g \end{aligned} \quad (5)$$

4. Discussion

4.1. MLR models for explaining food waste in schools and pre-schools

Among the plate waste models tested, model A had the highest coefficient of determination and can be used to explain 87.1% of

[1] For interpretation of color in Figs. 2, 4, 6, the reader is referred to the web version of this article.

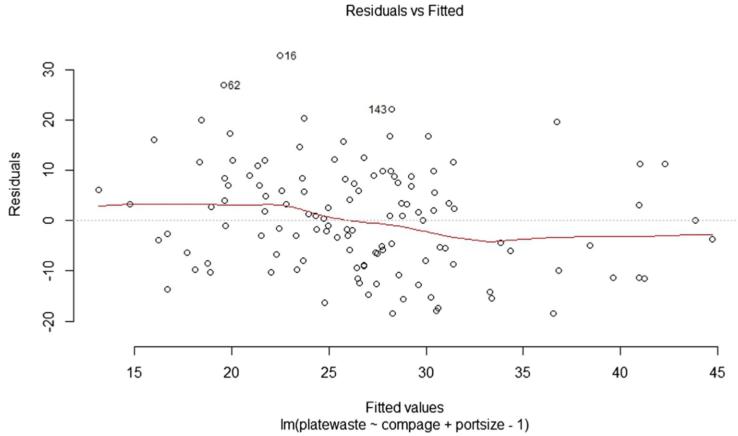

Fig. 2. Residuals plot for multiple linear regression model A for plate waste per portion. Note that the scale on the vertical axis is different from that in Figs. 4 and 6.

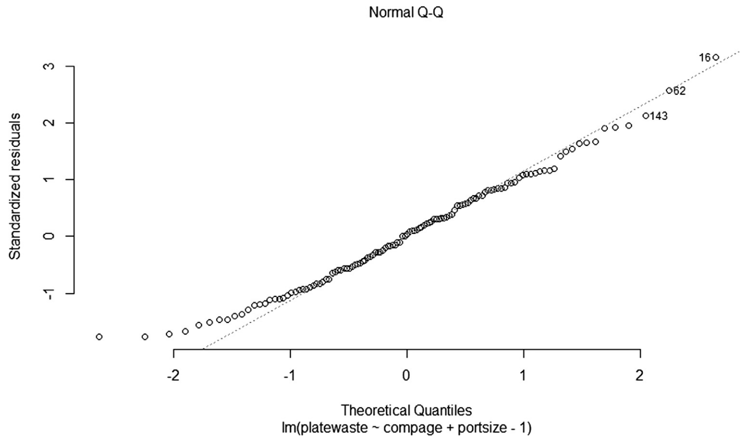

Fig. 3. Quantile-quantile plot for the standardised residuals for model A. The horizontal axis shows the theoretical quantiles and the vertical axis shows the standardised residuals.

Table 7
Multiple linear regression model B for serving waste per portion; significant factors and p-values.

Model B	Factor	p-value
	Type of kitchen: Portion size	<0.05
	Portion size	<0.0001

the plate waste generated in schools and pre-schools. According to this MLR model, the factors comparable age and portion size significantly contribute to plate waste. As the residuals were normally distributed and the assumptions of linearity and homoscedasticity held, model A can be generalised beyond the data range used for developing the model (Field et al., 2012). Thus, the plate waste per portion generated in schools and pre-schools is dependent on children's age and the rate of overproduction, indicated by the portion size, with a residual standard error of about 11 g (Eq. (3)). The finding that plate waste increases with children's age is in line with the results from the correlation analysis. Plate waste was also expected to increase with increasing portion size, which was confirmed by model A.

Among the models tested for serving waste per portion, model B could be generalised beyond the data range used for development, as the assumptions about linearity, homoscedasticity and normality held. The factor portion size and the interaction between type of kitchen and portion size contributed significantly to serving waste per portion and explained 85.1% of the serving waste generated in schools and pre-schools. The effect of the interaction was at its highest when portion size was large in satellite units (Eq. (4)), due to their difficulties in handling and storing food left-overs (Eriksson et al., 2017). Thus satellite units in particular would

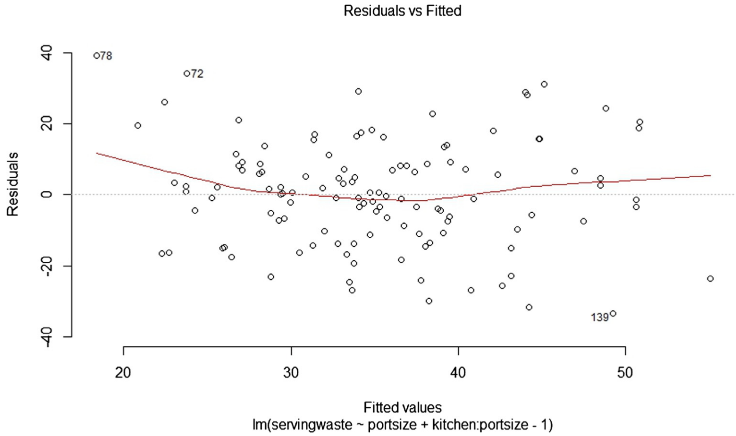

Fig. 4. Residuals plot for multiple linear regression model B for serving waste per portion. Note that the scale on the vertical axis is different from that in Figs. 2 and 6.

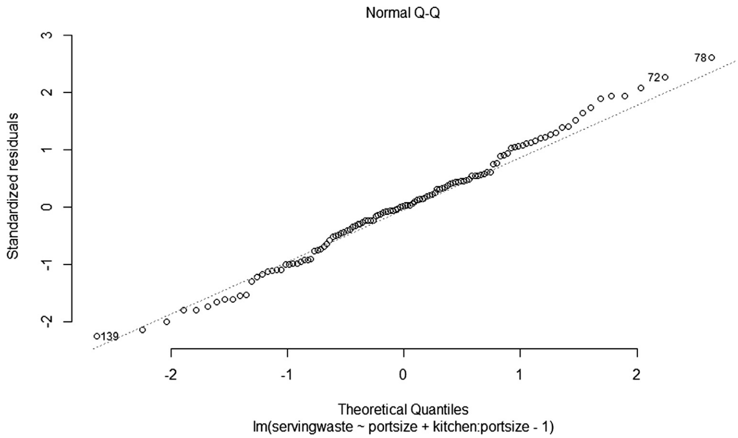

Fig. 5. Quantile-quantile plot for the standardised residuals for model B. The horizontal axis shows the theoretical quantiles and the vertical axis shows the standardised residuals.

Table 8
Multiple linear regression model C; significant factors and p-values.

Model C	Factor	p-value
	Type of kitchen	<0.05
	Portion size	<0.0001

benefit from more accurately planning their diners' intake on a daily basis. Other factors that might explain the variation in serving waste per portion could be management factors or stress (Kinasz et al., 2015), which might require a different approach for quantifying knowledge about diners.

Model C, including the factors type of kitchen and portion size, explained 92.2% of the variation in the total waste per portion for the given dataset, with a residual standard error of approximately 18 g.

Serving waste is reported to contribute two-thirds of the total waste per portion (Eriksson et al., 2016b), which explains the similarities between model B and model C. Since total waste per portion is the sum of both serving and plate waste per portion, the uncertainties in model C are higher regarding the residual standard error compared with those in models A and B.

4.2. Correlation analysis and significant influences on food waste in schools and pre-schools

Plate waste significantly increased with 'comparable age', meaning that children in higher school years produce more plate waste than children in lower years. Children in pre-school had the lowest plate waste, while pupils in secondary school generated the highest amount. In addition to plate waste, the total waste per portion significantly increased with childrens' age. As the correla-

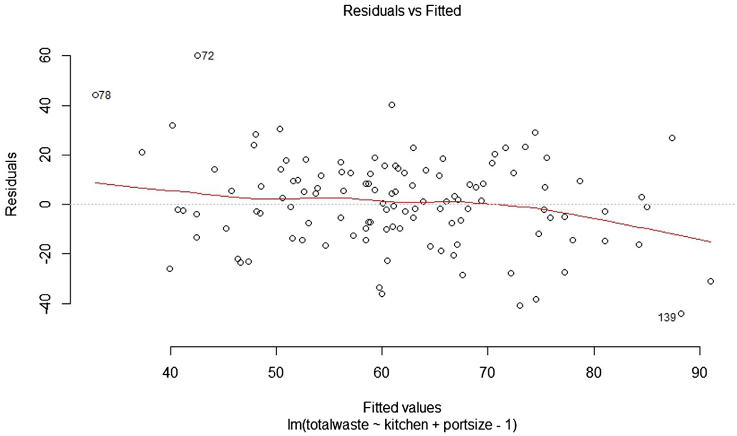

Fig. 6. Residuals plot for multiple linear regression model C for total waste per portion. Note that the scale on the vertical axis is different from that in Figs. 2 and 4.

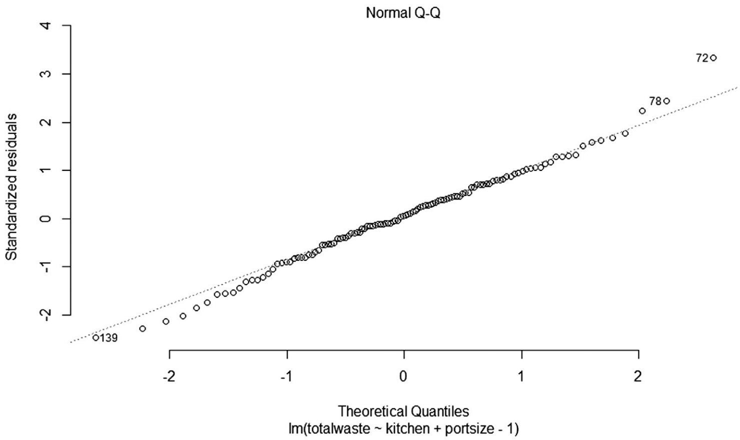

Fig. 7. Quantile-quantile plot for the standardised residuals for model C. The horizontal axis shows the theoretical quantiles and the vertical axis shows the standardised residuals.

tion (tau = 0.15) was weaker than that between plate waste per portion and comparable age (tau = 0.21), it is likely that serving waste per portion does not depend on children's age and that plate waste causes the correlation between total waste and comparable age.

A reason for the correlation between plate waste and comparable age could be that younger children often eat accompanied by their teachers and have more structured lunch breaks than older pupils. For example, pupils at Flogstaskolan in Uppsala eat with their teachers and have "quiet minutes" during their lunch breaks, which lets them eat without any distractions. Another reason for the correlation between children's age and plate waste could be that pupils in higher school years have the possibility to purchase food outside the dining hall, which according to Marlette et al. (2005) increases plate waste.

Schools with pupils in higher school years could most likely lower their plate waste by introducing more structured lunch breaks and should examine whether many of their students purchase food outside school or from the school cafeteria. Since pupils eat lunch for free in Swedish schools, it is unlikely that they tell anyone that they intend to eat elsewhere. Implementation of a booking system like that tested by WRAP (2011), where pupils had to pre-order the meal they intended to eat every day during a test period, could therefore help the kitchen to better plan their production and avoid overproduction.

Both plate and serving waste significantly increased with larger portion size. Since portion size is the total amount of food produced divided by the number of portions that are actually served, portion sizes increase when a facility has fewer diners relative to the amount of food prepared or overestimates its diners' food intake. The factor portion size can therefore be seen as an indicator of food overproduction. According to the municipalities concerned, schools and pre-schools do not plan their food production on a daily basis. Instead, food production follows the number of pupils registered at the school and often neglects knowledge about pupils that are not able to attend the meal due to illness or excursions (Falun, Malmö, Sala and Uppsala municipalities, personal communications, 2017). Due to the lack of information about the daily number of diners, the risk of food overproduction is high. The deviation in the daily amount of diners increases with the number of pupils registered at a school or a pre-school. In large schools, the daily number of diners can deviate by up to 300.

Food overproduction might reduce the staff's urge to balance the children's portion sizes and tempt children to take more food than they intend to eat, which could be an explanation for the correlation between plate waste and portion size.

Serving waste naturally increases with overproduction. According to model B, serving waste reached its peak when portion size was large in a satellite unit. Satellite units in general had significantly higher serving waste than production units, which confirms findings by Eriksson et al. (2017). Production units, rather than satellite units, have possibilities to cool and store left-overs and have a more flexible menu where left-overs can be used, which explains the correlation between type of kitchen and serving waste. For satellite units, the total waste per portion was also higher than the total waste in production units, although the correlation strength ($r = 0.24$) was similar to that of serving waste per portion and type of kitchen ($r = 0.28$), indicating that plate waste per portion is not affected by the type of kitchen.

Given that both serving waste and plate waste could be effectively reduced by preventing overproduction, especially in satellite units, schools and pre-schools would benefit from better data support when estimating the daily amount of diners. Accurate estimates of portion sizes and enhanced planning have also been suggested as solutions for decreasing food waste in schools by Cordingley et al. (2011).

In addition, plate waste was significantly influenced by the number of students, the number of seats in the dining space, the STD in number of diners and the number of employees. As all four factors strongly influenced each other ($tau > 0.7$), it is probable that only one of these four factors directly influences plate waste. Considering that Spearman's rho tends to be higher than Kendall's tau for monotonic relationships (Helsel and Hirsch, 2002) and that the number of data points differed between the factors, no direct conclusion about the strength of the correlations between factors can be drawn. However, the number of seats in the dining space is the parameter most likely to affect plate waste, as increased noise levels in the dining space and a stressful environment probably increase plate waste (SEPA, 2009; Byker et al., 2014; Kinasz et al., 2015; Painter et al., 2016). Considering the fact that Kendall's tau tends to be smaller than Spearman's rho, the correlation between number of seats and plate waste was the strongest among the four factors mentioned, followed by the number of employees, although the latter is not expected to increase plate waste.

The percentage of male staff employed in the kitchen appeared to significantly increase plate waste, but an expanded dataset is required to confirm the presence of male kitchen employees as a factor influencing plate waste. The factor was influenced by the number of pupils ($tau = 0.49$) and comparable age ($tau = 0.50$). Both the number of pupils and comparable age increased generation of plate waste and could therefore have influenced the correlation between the percentage of male employees and plate waste per portion.

A different definition for the number of employees should be considered to quantify knowledge of diners and management factors, as mentioned by Kinasz et al. (2015). Instead of defining the number of employees as the number of staff members in the dining facility, the accumulated number of work hours per week could be used to quantify staff resources, in order to detect theoretically reasonable correlations.

Considering that queue time increases and lunch breaks shorten with a decreased number of seats per pupil, both serving waste and plate waste can be expected to decrease if the number of seats per pupil increases (Getlinger et al., 1996; Byker et al., 2014; Niaki et al., 2017). The dataset used for the present study contained a narrow range and few kitchens with >0.6 seats per pupil. It is therefore likely that a negative relationship between food waste and seats per pupil could be detected in a dataset with a greater range. The same applies for the comparable STD in the number of diners and the number of employees per student.

According to correlation analysis, neither plate waste nor serving waste per portion was significantly influenced by the type of dining space. Whether children eat in their classrooms or in a separate dining hall therefore has no impact on the amount of food waste generated in schools and pre-schools. Other factors without significant correlations with food waste were distance between dining space and classroom, number of semesters with food waste measurements, range of school years, comparable number of dishes and variety of meal options. The latter two factors often vary on a daily basis, which increases uncertainties in the data used for analysis.

4.3. Uncertainties and limitations

Facilities located in different municipalities and different types of educational establishments complicated the collection of unified food waste measurements. The measured food waste data used for analysis and model development in this study therefore contained uncertainties. However, some general trends and associations could be detected with the material used.

Due to the biased opinions caused by public views on dining systems in educational establishments (Persson Osowski, 2012), only quantified factors were used for analysis. The coefficient of determination values obtained showed that over 85% of the food waste generated in schools and pre-schools can be explained using the risk factors analysed in this study, indicating that these factors are likely to explain the majority of food waste generation. However, other factors that are more difficult to quantify could also have a significant impact on food waste generation and including these would help to further improve the models developed here. Such factors could include information about management structures, knowledge about diners, awareness about food waste as an issue and a different definition of the number of employees. A dataset with a wider range regarding the factor seats per pupil should also be analysed. In addition, the variety of meal options should be examined with the aid of a more specific survey.

5. Conclusions

Plate waste in schools and pre-schools increases with children's age and could potentially be reduced by implementing more structured lunch breaks for schools with older pupils. Plate waste also increases with the number of seats in the dining space, probably due to rising noise and stress levels. Both plate waste and serving waste increase with larger portion sizes, indicating overproduction. Total food waste in schools and pre-schools could therefore be effectively reduced by more accurate estimation of the daily number of diners and their food intake. As serving waste is generally higher in satellite units than in production units, satellite units in particular would benefit from better information so that they could more accurately estimate the daily number of diners. There is therefore a need for waste reducing policies in municipalities to not just set goals for food waste reduction, but also to reduce risk factors causing waste. Sometimes there can be goal conflicts if some risk factors also provide benefits and therefore more detailed quantifications of risk factors can build the foundation for efficient and accurate policies and incentives.

Application of multiple linear regression models showed that over 85% of the variation in food waste generated in schools and pre-schools can be explained by children's age, the rate of overproduction and the type of kitchen. However since the age of the children cannot be changed the other parameters could be adjusted in order to compensate for higher age. Especially overproduction is something where the catering units could have the highest benefits by reducing the extra margin. There is also a need to actually test and evaluate interventions with the potential to reduce certain risk factors, since it should not be assumed that just reducing a risk only give the expected outcome.

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III

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Research article

Potential for using guest attendance forecasting in Swedish public catering to reduce overcatering

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ABSTRACT

Food waste is a significant problem within public catering establishments, caused mainly by serving waste arising from overcatering. Overcatering means that public catering establishments rarely run out of food but surplus ends up as food waste. The challenge is to find a solution that minimizes food waste while ensuring that sufficient food can be provided. A key element in this balancing act is to forecast accurately the number of meals needed and cook that amount. This study examined conventional forecasting methods (last-value forecasting, moving-average models) and more complex models (prophet model, neural network model) and calculated associated margins for all models. The best-performing model for each catering establishment was then used to evaluate the optimal number of portions based on stochastic inventory theory. Data used in the forecasting models are number of portions registered at 21 schools in the period 2010–2019. The past year was used for testing the models against real observations. The current business as usual scenario results in a mean average percentage error of 20–40%, whereas the best forecasting case around 2–3%. Irrespective of forecasting method, meal planning needed some safety margin in place for days when demand exceeded the forecast level. Conventional forecasting methods were simple to use and provided the best results in seven cases, but the neural network model performed best for 11 out of 21 kitchens studied. Forecasting can be one option on the road to achieve a more sustainable public catering sector.

1. Introduction

The global population is estimated to reach 9.6 billion people around 2050 (United Nations, 2019). To accommodate this, a series of changes are needed to keep Earth within its planetary boundaries and achieve a safe operating space for humanity (Rockström et al., 2009). Sustainably feeding a growing population is a challenge that needs urgent attention, since agricultural production is a significant driver for transgression of several planetary boundaries and poses a threat to boundaries currently regarded as lying in the safe zone (Campbell et al., 2017). Acute interventions are needed at global scale to achieve a sustainable food system that can deliver on-point. One of many interventions to create a sustainable food system is to target the vast amounts of food that are currently destroyed, spoiled, or dumped for various reasons, and reduce the level of food waste by 75% by 2050 (Springmann et al., 2018). The Food and Agriculture Organization of the United Nations (FAO) suggests that more effort is needed to map the food waste situation and identify how food waste reduction on an overarching level can be achieved (FAO, 2019). On a global scale, the United Nations targets food waste within its sustainable development goal 12.3, which states that by 2030 food waste should be halved (United Nations, 2015). However, primary data and methods to battle food waste are lacking, and improvements are badly needed in most cases (Xue et al., 2017).

In Sweden, most food waste occurs at the consumer level (SEPA, 2020), and different efforts are needed to obtain a sustainable food system. On such effort is to reduce the high rate of overcatering within the Swedish hospitality sector (Katajajuuri et al., 2014; Storup et al., 2016). This sector is currently growing as more people obtain the economic means to eat out (Bezerra et al., 2012; Kant and Graubard, 2004; Lachat et al., 2011; Nielsen, 2002). It can thus be a future hotspot for waste generation, but with great potential for improvement since food at the end of the supply chain have accumulated more resources and overall prevention of food wasted throughout the life cycle is beneficial (Abeliotis et al., 2015).

Previous food waste studies of the hospitality sector all report that roughly 20% of food produced ends up as waste (Boschini et al., 2018; Byker et al., 2014; Camilleri-Fenech et al., 2020;

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Engström and Carlsson-Kanyama, 2004; Falasconi et al., 2015; Silvennoinen et al., 2015; Sonnino and McWilliam, 2011). Waste at serving accounts for approximately two-thirds of this waste (Eriksson et al., 2020; 2017; Malefors et al., 2019). Public catering is a significant actor in Sweden, since approximately half of all midday meals in the food service sector are served in the public sector (National Food Agency, 2019), by catering establishments in hospitals, preschools, schools, and elderly care units. School kitchens are the most significant actor in the public catering segment, with almost 1.3 million meals served to Swedish pupils every day throughout the school year. School meals are provided to the students free of charge, funded by taxes (Swedish Parliament, 2010). Similar approaches to school meals are used in Finland (Tikkanen and Urho, 2009) and Estonia (Ministry of Education and Research of the Republic of Estonia, 2019), but otherwise it is rather unique. Because the meals are free of charge, the setting in which school kitchens operate is also unique, since planning the number of meals to serve can be based on the number of students registered in the school. However, despite these optimal conditions, fluctuations in canteen guest numbers still occur. This is one of the risk factors in food waste (Steen et al., 2018), since kitchen staff do not get appropriate information regarding the number of guests in time. One way of avoiding overcatering is the use of forecasting techniques, which could help catering establishments in the hospitality sector, and especially school kitchens, get a good grasp of how many guests will turn up to a specific meal.

This knowledge is often embedded within kitchen staff with many of years of experience, but can be difficult to acquire for newcomers to the sector. Moreover, even experienced staff can still have problems with changes in expected numbers of customers. Accurate models and tools for forecasting numbers of guests would thus be helpful for experienced kitchen staff, and also for establishments within the hospitality sector with high staff turnover. However, this would require kitchen staff to act upon the information provided by forecasting models and tools, hopefully leading to less overcatering and less food waste. Previous studies have shown that kitchen staff and food service providers generally add an extra margin in meal production (Boschini et al., 2020; Steen et al., 2018), in order to avoid running out of food, a negative outcome in the eyes of the guests (Wang et al., 2017) and a source of shame for kitchen staff. The problem is therefore two-fold; there is little knowledge about how many guests will turn up to a specific meal, and the kitchen needs to prepare an acceptable margin of food to avoid shortages and loss of goodwill (van Donselaar and Broekmeulen, 2012) and have a backup ready in case of shortages.

The first decision that kitchens need to take is in ordering food for a set menu. The order is usually placed one to two weeks before the meal takes place. The second decision is on how much food to produce, which is normally done on the same day, or the day before, the meal is served. These decisions are usually taken by the responsible kitchen chef. One way of dealing with this supply and demand problem is to use tools from operational research for managing inventory and forecast the anticipated future based on historical data, in order to identify the optimal quantity to produce (Hillier and Lieberman, 2014). Scientific inventory methods, combined with various classical and new approaches to forecasting problems, such as neural network models, are currently attracting increasing attention. However, these techniques have not been examined in the context of public catering, to assess their potential contribution to a more sustainable food service sector. The problem of overcatering is multifaceted and can be broken down into three major areas in the public catering context. The first type is food-dependent, and refers to food left by guests on the plate or discarded by kitchen staff during food preparation due to taste or appearance. The second type is also food-dependent and relates to portion size. The third type of overcatering problem is food-independent and is defined by supply exceeding demand. This study focused on food-independent overcatering, which can be addressed by forecasting guest demand, bridging the gap between supply and demand in order to optimize this system.

The aim of the study was to evaluate and apply forecasting models to estimate the number of daily guests in Swedish school kitchens and, based on the estimates, identify the optimal number of portions for the kitchens to produce. Loss of goodwill and penalties for food waste, along with practical limitations, were also assessed in light of creating a more sustainable public catering sector.

2. Materials and methods

The work comprised four steps (Fig. 1): data collection; modeling number of guests using different forecasting models; model evaluation to select the best-performing model; and model application to determine the optimal number of portions school kitchens should produce, with a sensitivity analysis of the findings.

2.1. Data

The data used for the analysis comprised material from 21 public school kitchens in Sweden, which were selected as suitable test subjects for forecasting models because they were willing to share their data upon request and had data available for several years. Thus no random selection of units was performed. All of the selected kitchens serve meals to students ranging in age from 6 to 19 years, thus excluding preschool kitchens and elderly care units, which are other common public catering services provided by Swedish municipalities. The students are offered without cost,

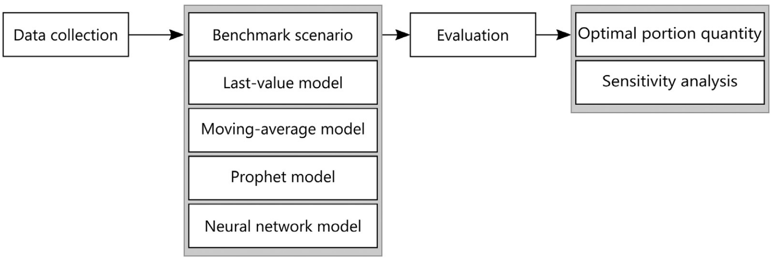

Fig. 1. Different steps of the present analysis, ranging from data collection to determining the optimal number of portions for school kitchens using the best-performing forecasting model.

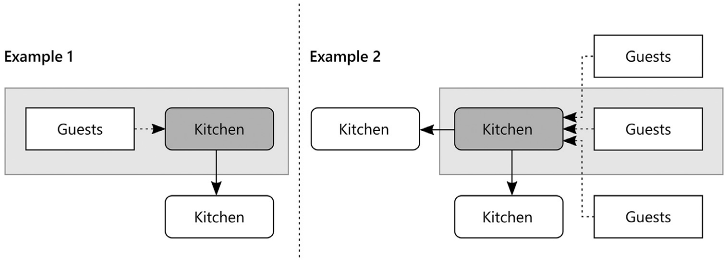

Fig. 2. Examples of different organizational situations within public catering establishments in Sweden. (Example 1) Straightforward case where a school has a kitchen and dining hall within the school facility, and also sends warm food to a satellite kitchen. (Example 2) Slightly more complex case where the school has a kitchen that also receives guests from other schools close by and produces food for several satellite kitchens.

Table 1
Characteristics of the 21 kitchens included in the study. Kitchens 10 and 13 are satellite kitchens, the others are production kitchens. Age denotes the age group of pupils normally served by the kitchen. Years of data states indicates number of years for which historical guest data were available. Amount of guests is number of students enrolled at the school in 2019/2020 (small = 50–200 guests, medium = 200–500, large = 500+.

Code	Age	Years of data	Amount of guests
1	6–9	10	Small
2	6–12	10	Small
3	6–12	10	Small
4	6–12	10	Small
5	6–12	10	Small
6	6–12	10	Small
7	6–12	10	Small
8	6–12	10	Small
9	6–12	10	Small
10	6–7	4	Small
11	10–12	5	Small
12	6–12	10	Small
13	6–12	10	Medium
14	6–12	10	Medium
15	13–15	10	Large
16	16–19	10	Medium
17	16–19	10	Medium
18	16–19	4	Large
19	16–19	4	Large
20	16–19	4	Large
21	16–19	4	Large

school meals every school day (Swedish Parliament, 2010), which in practice means that they do not bring any own lunch with them to the school. The most frequently served meal is lunch in the selected kitchens, although breakfast and snacks may also be served. Table 1 shows the characteristics of the studied kitchens and the target group that normally eats in the establishment, kitchen size in terms of number of guests enrolled in the school year 2019/2020 (categorized as small, medium, and large kitchens), and number of years for which data on guests were available. All of the kitchens operate under a budget set by the public catering organization and the average selling price for kitchens 1–17 to the school organization was 77 SEK/portion, with a purchasing cost for food items at around 22 SEK/portion. The actual values can differ slightly between kitchens, depending e.g., on demand for special diets, which are usually associated with higher ingredient prices, and thus purchasing costs. Kitchens 18–21 could not provide any economic data for the study.

Not all schools have a kitchen, which means that students need to walk some distance to get their lunch. Some of the kitchens are also responsible for preschools, whose children eat within the establishment, or provide cooked food for other schools. Fig. 2 shows some of the set-ups found within a public catering organization. In the straightforward case, guests eat within the same building as the kitchen, and the kitchen provides warm food to a satellite kitchen. In the more complicated case, the production kitchen provides food to several satellite kitchens and also has guests arriving from a number of places.

A school year in Sweden consists of at least 178 days between late August and early June (Swedish Parliament, 2011). The autumn term includes one week of holiday, usually at the end of October. A winter holiday of approximately 2–3 weeks covers Christmas and the new year. The spring term has one holiday week in mid-February and one week around Easter, plus scattered national holidays in May. Some schools remain open during the holidays and serve meals during this period to other establishments who are still open, such as preschools. The school kitchen typically offers students two lunch options, where one options usually consists of a main component like meat or fish with a supplementary component like potatoes, rice, pasta and vegetables or salad. The other option is usually a ‘greener’ version of the first option or soup. The menu follows a five- to seven-week cycle, where the heads of catering for the kitchens meet with public catering managers and set the menu together. Local adaptations are encouraged, and options can be shifted or removed depending on the local context and availability of seasonal and regional food items. In some cases the staff, such as teachers eat in the facility or the school kitchen get visitors which influence the number of portions to produce, however these meals are not for free as they are for the students.

2.2. Collection of data

Data on number of guests eating school meals were collected from 2010 to 2019 by the municipalities themselves, by counting plates after every lunch. One counting procedure involves drawing tally marks on the dishwasher for each full tray and then multiplying the total by the capacity of each tray (usually 18 plates). Another approach is to collect one plate from each full tray and all plates from the last incomplete tray, and calculate the total number of plates. In this study, it was assumed that one plate was equal to one portion, which is equivalent to one guest. However, this might not necessarily be accurate, since guests are allowed to re-fill their plate or take several plates. Plate data are thus an approximation of the number of guests served, since no point-of-sale data are available to extract information regarding guest flow as the meals are free of charge for the students. No significant changes were made in the way meals were served to the guest during the period for which data was obtained. Fig. 3 displays changes over time in

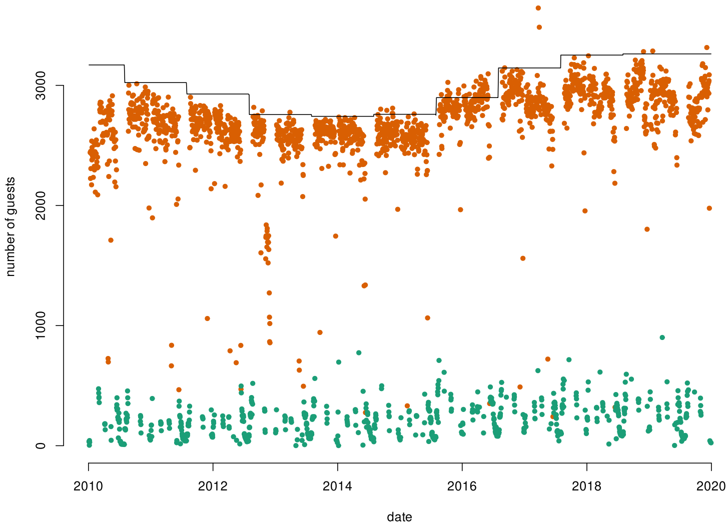

Fig. 3. Number of guests over time at school kitchens in a municipality (containing data from 15 schools who had a complete data set of 10 years) where ● indicates normal day and ● indicates holiday with less activity, where the schools provides meals to other establishments within the public catering organization. The line shows the number of students enrolled, and can be taken as the maximum of guests that need to be provided with food.

the number of guests in the school kitchens, with an indication of whether the day was a typical day or a holiday. The diagram also shows maximum number of enrolled students, which roughly indicates the carrying capacity of the municipality in terms of number of guests the kitchens should provide with food.

The following data were obtained during the period for all school lunches served within the municipality:

- Number of guests, taken as plate count per day for lunch.
- Dates for Holidays/breaks when less or no activity took place in the kitchens.
- Enrolled students per school and school year as of October (official numbers from the Swedish National Agency for Education 2019).

The number of guests in the form of counted plates acts as the basis for billing purposes that the public catering organization sends to other parts of the organization within the municipality, such as preschools, schools and elderly care units to get paid. Different municipalities apply different approaches, but most use some kind of guest indicator to determine the amount to charge internally, either by counting plates or by estimating the number of guests from a schedule or similar techniques. Since the municipalities use counted plates as an indicator of number of guests, the data can be seen as trustworthy. If the amount of plates is exceptionally large on one day for some reason, the ordering organization would react to this, since it is not keen on overpaying for meals.

2.3. Transformation and filtering of data

The data collected from the kitchens were transformed into a standardized format similar to that proposed by Eriksson et al. (2018). The focus was on forecasting typical days, so all holidays and extreme values defined as falling outside the interquartile range (Tukey, 1977) per school and school term were removed before entering the modeling step. This is because kitchens already have a good understanding of guest seasonality and when guests will be missing due to upcoming holidays, but struggle with the variability observed during normal weekdays. The intention was for the filter to remove known features (such as holidays and known study visits) from the dataset, in order to focus on the modeling aspects.

2.4. Identification, selection, and evaluation of forecasting models

Forecasts can be obtained using qualitative and quantitative techniques. This study focused only on quantitative approaches for statistical time series, i.e., a series of numerical values taken by a random variable over time. Forecasting in general involves analysis of past time-series data to estimate one or more future values of the time series. The forecast depends on a model of the behavior of the underlying time series (Hyndman and Athanasopoulos, 2018). Here, the focus was on capturing time series models that would be practically implementable by kitchen establishments, ranging from the most straightforward model (last-value forecasting) to more advanced approaches using neural networks. The intention was for the models to act as forecasting approaches that kitchen managers and chefs could implement. The performance of different models was compared to determine which model or combination of models would perform best under different circumstances. Since schools are obliged by law to provide food for all students (Swedish Parliament, 2010), all models were benchmarked against a reference scenario where food was prepared for all students enrolled, even if they did not turn up. In reality, the final number of portions prepared is adjusted somewhat based on kitchen staff's local knowledge of their guest situation, since not all students eat a school meal every day for various reasons, such as sickness, truancy (Ramberg et al., 2018) or because they choose to eat elsewhere, which is mainly done by older students. The best-performing model for each kitchen was then tested with different margins, to determine the number of days for which the model underestimated the number of portions. Finally, the optimal portion quantity was determined and sensitivity analysis of the quantity was performed.

2.4.1. Benchmark scenario

The benchmark scenario (all students enrolled are provided with food) was expressed as actual number of portions each day (A_t) relative to number of students enrolled for a defined time period:

$$Benchmark\ scenario = \frac{100\%}{n}\sum_{t=1}^{n}\left|\frac{Enrolled\ students - A_t}{Enrolled\ students}\right| \quad (1)$$

This scenario shows the average level of deviance regarding number of portions per day from the number of students enrolled per school year. It is the scenario that the public catering organization is required by law to deliver, and assumes that all students entitled to a meal turn up. This can be viewed as a business-as-usual scenario and as the outcome if no manual corrections are made by kitchen staff in their daily work.

2.4.2. Last-value forecasting

The most basic forecasting model is last-value forecasting, also often called naïve forecasting, where forecasting procedure uses the value of the time series observed at time $t(x_t)$ as the forecast at time $t+1(F_{t+1})$ yielding:

$$F_{t+1} = x_t \quad (2)$$

This simplified technique, stripped of seasonal influences, was compared here with more sophisticated techniques. All available data that passed the filter were used for this model, but for fairer comparisons with models that require training, only the last year of available data were used for evaluation.

2.4.3. Moving-average model

The moving-average forecasting procedure averages the data only for the last n periods and uses this information as a basis for the forecast for the next period:

$$F_{t+1} = \sum_{i=t-n+1}^{t}\frac{x_i}{n} \quad (3)$$

A clear limitation of this approach is that the input gets equal weight, so older information that might no longer be representative is treated the same way as more recent observations. In this study, periods of 2 and 5 days were used to capture recent trends for a working week and make decisions for the coming period. Since moving-average forecasting is within the same family as last-value forecasting, all available data that passed the filter were used for this model. However, for fairer comparisons with models that need training, only the last year of available data were used for evaluation.

2.4.4. Prophet forecasting model

To assess more complicated features of the time series, the open-source prophet package (Taylor and Letham, 2017) was applied. The model considers time series forecasting as a curve-fitting exercise and does not consider temporal dependence structures in the underlying data. The technique uses a decomposable time series model and is based on three main components (trend, seasonality, and holidays), which are combined in the following equation:

$$y(t) = g(t) + s(t) + h(t) + \epsilon_t \quad (4)$$

where $g(t)$ is a trend function that models non-periodic changes in the values of the time series, $s(t)$ represents periodic changes, and $h(t)$ represents holiday effects which occur at potential irregularity over one or more days. The error term ϵ_t represents changes which are not accommodated by the model. The model needs training to perform forecasting. We used data for the period January 1, 2010 to December 31, 2018 (90% of all data points) as training data and data from 2019 as test data. For kitchens which had fewer years of historical data, the last available year was used as test data and the rest as training data. Number of plates and holiday data were used as input to the model for making predictions based on the data from the training period.

2.4.5. Neural network model

To monitor potential complex nonlinear relationships, a simple sequential neural network was tested, using the network as a framework for learning representation of the data. A sequential multi-layer network with one input layer, two hidden layers with 32 neurons each, and one output layer was selected. It was implemented with the help of the Keras API (Chollet et al., 2015). The same data as in the prophet model were used, with number of plates and holiday data as input, but with additional information about number of students enrolled for each school year. The model was trained with data for each school from January 1, 2010 to December 31, 2018, and evaluated against data for 2019. For the kitchens with fewer years of available data, the last year was used for testing and the rest of the data for training of the models. Training was aborted once the model performance stopped improving and Adam optimization was used in the compilation step of the models.

2.4.6. Forecasting errors and evaluation

There are multiple options for evaluating and assessing errors (Gooijer and Hyndman, 2006). In this study, mean absolute percentage error (MAPE) was selected for its interpretability. It is defined by:

$$MAPE = \frac{100\%}{n}\sum_{t=1}^{n}\left|\frac{A_t - F_t}{A_t}\right| \quad (5)$$

where A_t is the actual value observed and F_t is the forecasted value. Since some of the models needed training to perform a forecast, all models were evaluated against the last year for which the schools had data, to make a fair evaluation. Thus in the case of last-value forecasting and the moving-average model, only the last year of available data that passed the filtering process was used for evaluation. Since kitchens operate under different conditions (Eriksson et al., 2018), all models needed to include some kind of margin to be of practical use. Knowledge of number of days on which a forecast will underperform, and by how much, could provide kitchens with additional information that is currently lacking (Steen et al., 2018). Therefore the actual demand in 2019 with different forecasting margins ($\alpha = 0-10, 15, 20, 25$ and 30%) was used to determine how many days the forecast was an underestimate, and by how much in terms of portions for the worst day observed. This was done by counting the amount of underestimation days and the magnitude of underestimation for different margins according to:

$$\sum_{i=1}^{n}[(y-\hat{y}_\alpha) > 0], \max_i(y-\hat{y}_\alpha) \quad (6)$$

The days with the largest magnitude of underestimation were categorized into three ranges: 1–9 portions, 10–29 portions, and 30+ portions, which was roughly equivalent to having 1, 1–3, and 3+ standard GN (Gastro norm) 1/1 containers of food as backup.

2.5. Optimal portion quantity

Since kitchen staff face uncertainties in guest numbers, they need to balance the risk of overcatering against the risk of shortages and, in the classical example Hadley (1963), find an optimal number, Q^*, of portions to produce. Using an inventory model that recognizes the stochastic nature of demand, x, with a probability distribution function and a cumulative distribution function, and where food is perishable, leads to this kind of optimization problem. The portions produced, Q, have a cost per portion, v, and are sold at p per portion. If $Q \geq x$, then $Q - x$ portions are left at the end of this single period system and can theoretically be salvaged for per-unit revenue, g, which could be potential biogas value, for instance. If $Q < x$, then $x - Q$ portions represent a “lost” sales cost or goodwill loss, B, per portion. The problem can be stated as follows:

$$\Pi(Q, x) = \begin{cases} px - vQ + g(Q - x) & \text{if } Q \geq x, \\ pQ - vQ - B(x - Q) & \text{if } Q < x. \end{cases} \quad (7)$$

where the goal is to maximize the total expected profits according to:

$$E[\Pi(Q)] = \int_0^Q [px - vQ + g(Q - x)] f(x) dx + \int_Q^\infty [pQ - vQ - B(x - Q)] f(x) dx \quad (8)$$

The optimal order quantity (Q^*) is set such that:

$$\Phi(Q^*) = \frac{p - v + B}{p - g + B} \quad (9)$$

In order for kitchens to reduce their overcatering, one key solution is to have spare stock that is ready for instant serving when food from the ordinary menu runs out, since school kitchens need to serve all the guests. Our model did not allow shortages, which were instead dealt with using spare stock that can meet demand. Assumptions for the model were therefore:

- The system is a one-period model with no set-up costs.
- Demand is given by the actual outcome and the forecast value, for which the distribution is known
- Portions are sold for a price p per portion and at a cost v per portion
- There exists an unlimited amount of portions in spare stock that can be served instantly if the ordinary planned food runs out. The cost of this spare stock of food is included in B
- When using the spare stock, a goodwill cost of B SEK/portion will arise, which in this case is the cost of avoiding loss of goodwill and preventing shortages occuring, through the use of the spare stock.
- When the spare stock is used, the exact amount can be produced to satisfy customers and no considerable waste occurs. Portions are still sold for the price p per portion.
- Ordinary food from the planned menu that is overcatered and becomes waste has a small but limited value as a commodity, used for instance for biogas production, but the value can be offset by the cost of transportation and handling (Eriksson and Strid, 2013). In our case it was denoted g, which is also known as a holding cost in the literature. The parameter g can also be seen as a parameter for a “waste penalty cost”, which can be viewed as a fictive cost for handling or the associated share with throwing away food.

Fig. 4 illustrates the system today and our proposed approach, both of which are shown with a fictive demand distribution. The left-hand side reflects the condition today, a system where no shortages are allowed and production is always in-phase with the number of students enrolled at the school, even if they do not show up to eat lunch. Under these circumstances, the blue area displays the average overcatered amount, which today becomes waste. The right-hand side illustrates our proposed system, where shortages are allowed but dealt with, and the optimal number of portions to produce is known (in this case located at $x = 110$). When a shortage occurs in this system, food is taken from a spare stock, for instance a freezer, to serve all guests.

To find the optimal number of portions a kitchen should produce, the average economic data from kitchens that could provide such data were used (p = 77 SEK/portion and v = 22 SEK/portion), with the additional assumption that the loss of goodwill was 80 SEK per portion. This included the purchase cost of the food taken from the backup stock and the cost of supplying this to guests who might anticipate getting food from the ordinary menu. The optimal portion quantity was then compared against different values of goodwill in a sensitivity analysis, to get an understanding of how goodwill impacts the optimal quantity produced. The goodwill costs tested were 50, 80 (base case), 200, and 1000 SEK/portion. The parameter g was also explored in a sensitivity analysis as a “waste penalty cost”, in order to asses how the optimal production quantity changed when a penalty was applied to the food waste generated. The values of g tested where, 1, 10 and 20 SEK/portion and the goodwill cost in that analysis was fixed at 80 SEK/portion.

3. Results

Overall, the neural network model performed best and was the model with the lowest MAPE score for 11 out of 21 kitchens. The moving-average model with a two-day window was the best-performing model for seven kitchens, the prophet model was the best-performing model for three kitchens. However, there was sometimes very little differences between the models, as indicated by the results in Table 2, where the moving average model with a five-day window was equally good as its moving average equivalent with a two-day window or the neural network model in two of the cases (Kitchen 3 and 8). The moving-average and neural network models consistently performed better than the benchmark scenario, and the last-value approach was better than the benchmark scenario in 18 of 21 cases. The prophet model performed better than the benchmark scenario in 14 of 21 cases.

A good model needed to achieve a balance, and not just produce a forecast. A key element in this was to have some associated margins in place, since the forecast for some days will underestimate guest demand and that for other days will overestimate demand. Table 3 shows how often the forecast was an underestimate, depending on the margin added to the forecast, and by how much, in terms of how many portions were missing in the worst case during the period. It is easier to throw away food than to cook new food, so a balance is needed to obtain a feasible margin that is acceptable and practical. At 0% there was no margin and, for the 2019 data, in the worst case the forecast underestimated actual demand on 105 days out of roughly 178 school days for kitchen 6, while in the best case it underestimated actual demand on 71 days out of 178 for satellite kitchen 13. The first observation where the forecast margin yielded 0 days of underestimation was for kitchen 14 at 5% margin. At 6% margin, one more kitchen (12) was on the safe side and kitchen 13 was close, having just one day of underestimation. On passing the threshold of observing 0 days of underestimation, the amount of portions underestimated also dropped to zero. At 10% margin, 10 of the kitchens had 0 days of underestimation. Larger units struggled and, even at 30% margin for the proposed forecast, five large kitchens did not have a single day of the school year without underestimation. They would need to have at least 10–29 portions or 30+ portions to meet the demand for the 1–5 days when they would be short of food.

A good margin is to some extent a trust issue, but can be optimal. To find an optimal solution to the supply and demand problem, Eq. (9) was used to determine the optimal production quantity for each kitchen shown in Table 4. The optimal production quantity has some margins in place, since $\Phi(Q^*)$ was 0.86, which exceeded the average value of 0.5, so in most cases there

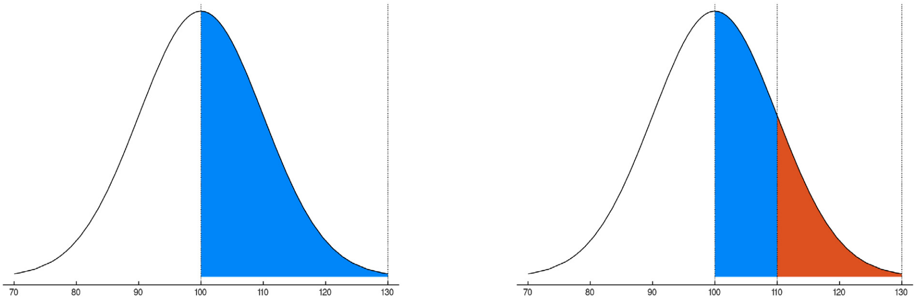

Fig. 4. Fictive distribution of demand to illustrate the problem of overcatering. (Left) The current situation, where the line at 100 is the average number of portions and the line at 130 indicates the level of service applied today. In this scenario there is no shortage of portions, and hence the area between 100 and 130 represents overcatering and associated waste generated on average. (Right) A proposed system where shortages are allowed and the optimal number of portions to produce is known, in this case located at $x = 110$. On average, this system will have some overcatering, but if food runs out guests are served food from a backup system, such as ready-to-eat food from a freezer. This is represented by the area between 110 and 130 which indicates the probability of such events.

Table 2
Mean absolute percentage error (MAPE, %) values obtained for the different models compared against the benchmark scenario (%). Unreasonable results are indicated by -. The best model for each kitchen is highlighted.

Code	Benchmark	Last-value	Moving-avg (2)	Moving-avg (5)	Prophet	Neural Network
14	3	9	**1.3**	1.4	–	1.5
12	3.2	2.8	**1.7**	1.8	5.2	1.8
13	3.7	2.3	2.2	2.1	5.9	**2**
5	5.8	2.9	2.3	2.3	11.9	**2.2**
2	6.5	7	6.1	5.1	8.7	**4.3**
7	6.9	2.4	**2.1**	2.2	3.9	2.3
10	6.9	3.9	**2.8**	3	4.1	3.1
3	7.8	3.9	**2.8**	**2.8**	7.5	3.2
9	7.9	3.3	3	3.1	10.4	**2.9**
8	8.8	2.9	2.6	**2.5**	26.9	**2.5**
1	11.1	8.8	5.4	4.7	10.9	**4.6**
21	13.8	14.7	11.4	10.3	9.4	**9**
4	13.9	4	**3.4**	3.6	12.9	3.7
11	20.4	16.3	14.3	12.2	**10.2**	10.5
15	21.1	10.1	8.6	7.7	9.4	**6.9**
16	24.6	15.8	13	11.2	13.2	**8.9**
18	24.6	15.1	13.8	13.2	**10.1**	10.4
17	30.7	12.6	9.4	8.7	28.6	**8.2**
6	32.8	3.1	**2.6**	2.7	4.4	2.7
19	42.9	13.8	12.6	11.4	**9.8**	10.3
20	45.4	14.6	12.1	11.3	11.9	**10.1**

Table 3
Added forecast margin (%), number of days on which the amended forecast underestimated actual demand for 2019, and the number of portions by which demand was exceeded, displayed in ranges of 1–9 portions (🔵), 10-29 portions (🟡) and 30+ portions (🟠).

Code	0%	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%	15%	20%	25%	30%
3	81 🔵	80 🔵	46 🔵	37 🔵	28 🔵	16 🔵	9 🔵	5 🔵	0 🔵	0 🔵	0 🔵	0 🔵	0 🔵	0 🔵	0 🔵
1	79 🔵	78 🔵	64 🔵	50 🔵	37 🔵	20 🔵	16 🔵	10 🔵	6 🔵	5 🔵	0 🔵	0 🔵	0 🔵	0 🔵	0 🔵
4	92 🔵	88 🔵	59 🔵	46 🔵	27 🔵	19 🔵	12 🔵	6 🔵	3 🔵	2 🔵	0 🔵	0 🔵	0 🔵	0 🔵	0 🔵
6	105 🟡	85 🔵	71 🔵	47 🔵	28 🔵	17 🔵	7 🔵	2 🔵	0 🔵	0 🔵	0 🔵	0 🔵	0 🔵	0 🔵	0 🔵
12	87 🟡	63 🔵	43 🔵	24 🔵	9 🔵	2 🔵	0 🔵	0 🔵	0 🔵	0 🔵	0 🔵	0 🔵	0 🔵	0 🔵	0 🔵
14	81 🟡	44 🟡	19 🔵	7 🔵	5 🔵	0 🔵	0 🔵	0 🔵	0 🔵	0 🔵	0 🔵	0 🔵	0 🔵	0 🔵	0 🔵
10	87 🟡	64 🟡	40 🔵	24 🔵	15 🔵	11 🔵	7 🔵	6 🔵	2 🔵	1 🔵	0 🔵	0 🔵	0 🔵	0 🔵	0 🔵
7	86 🟡	71 🟡	56 🔵	28 🔵	15 🔵	7 🔵	4 🔵	3 🔵	2 🔵	0 🔵	0 🔵	0 🔵	0 🔵	0 🔵	0 🔵
5	81 🟡	63 🟡	42 🟡	26 🔵	13 🔵	8 🔵	6 🔵	4 🔵	1 🔵	1 🔵	1 🔵	0 🔵	0 🔵	0 🔵	0 🔵
13	71 🟡	40 🟡	25 🟡	11 🔵	4 🔵	2 🔵	1 🔵	0 🔵	0 🔵	0 🔵	0 🔵	0 🔵	0 🔵	0 🔵	0 🔵
2	89 🟡	88 🟡	72 🟡	53 🟡	37 🟡	27 🟡	18 🔵	13 🔵	10 🔵	6 🔵	4 🔵	1 🔵	0 🔵	0 🔵	0 🔵
8	100 🟡	89 🟡	64 🟡	46 🟡	28 🟡	20 🟡	10 🔵	3 🔵	2 🔵	1 🔵	0 🔵	0 🔵	0 🔵	0 🔵	0 🔵
9	100 🟡	81 🟡	63 🟡	37 🟡	26 🟡	20 🟡	8 🟡	6 🟡	3 🟡	2 🔵	1 🔵	0 🔵	0 🔵	0 🔵	0 🔵
17	82 🟠	78 🟠	77 🟠	65 🟠	57 🟠	51 🟠	40 🟠	35 🟠	32 🟠	27 🟠	24 🟠	10 🟡	5 🟡	0 🔵	0 🔵
16	89 🟠	81 🟠	77 🟠	68 🟠	61 🟠	59 🟠	48 🟠	47 🟠	45 🟠	40 🟠	37 🟠	24 🟡	13 🟡	3 🔵	2 🔵
15	90 🟠	81 🟠	74 🟠	65 🟠	58 🟠	48 🟠	44 🟠	38 🟠	35 🟠	31 🟠	22 🟠	9 🟠	2 🟠	1 🟡	0 🔵
21	84 🟠	80 🟠	72 🟠	65 🟠	55 🟠	49 🟠	42 🟠	36 🟠	33 🟠	31 🟠	27 🟠	11 🟠	5 🟠	2 🟡	0 🔵
11	90 🟠	86 🟠	81 🟠	76 🟠	72 🟠	70 🟠	64 🟠	56 🟠	48 🟠	46 🟠	44 🟠	18 🟠	12 🟠	5 🟠	1 🟡
18	89 🟠	84 🟠	81 🟠	77 🟠	72 🟠	66 🟠	63 🟠	57 🟠	48 🟠	41 🟠	40 🟠	25 🟠	14 🟠	8 🟠	2 🟠
19	79 🟠	76 🟠	69 🟠	61 🟠	58 🟠	53 🟠	46 🟠	44 🟠	41 🟠	38 🟠	35 🟠	21 🟠	13 🟠	5 🟠	2 🟠
20	83 🟠	77 🟠	67 🟠	64 🟠	62 🟠	56 🟠	53 🟠	50 🟠	46 🟠	43 🟠	43 🟠	28 🟠	15 🟠	8 🟠	5 🟠

Table 4
Optimal portion quantity Q^* and sensitivity analysis for goodwill costs and "waste penalty cost" for the different kitchens in the study according to Eq. (9), with selling price set to 77 SEK and purchase cost to 22 SEK. The optimum is based on an estimated goodwill cost of 80 SEK/portion, which gives $\Phi(Q^*) = 0.86$. Kitchens 18–21 are excluded because they could not provide any economic data.

	Optimum	Goodwill (SEK)			Wastepenalty cost (SEK)		
Code	Q^*	50	200	1000	1	10	20
1	**71**	70	74	78	71	70	69
2	**86**	85	89	94	86	85	84
3	**90**	89	91	95	89	89	88
4	**98**	97	100	105	98	97	96
5	**114**	114	116	118	114	114	113
6	**138**	137	139	144	138	137	136
7	**149**	149	151	154	149	148	147
8	**113**	112	114	117	113	112	112
9	**142**	141	144	149	142	141	140
10	**130**	129	132	136	130	129	128
11	**155**	152	165	180	156	150	146
12	**205**	204	206	210	205	204	203
13	**233**	232	235	240	233	231	231
14	**322**	322	325	331	322	321	320
15	**607**	600	626	658	609	596	587
16	**171**	169	177	194	171	168	165
17	**359**	353	371	396	358	351	344

was no shortage of food, but the food not eaten became waste. The optimal portion quantity was based on a goodwill cost of 80 SEK/portion.

To get an understanding of how the goodwill cost (which is difficult to quantify) affected the optimal portion quantity, a sensitivity analysis was performed (Table 4). Table 4 also shows the fictional "waste penalty cost" (g) which is the cost associated with throwing away food. Overall, lower goodwill cost pushed the optimal portion quantity closer to the expected average of portions. The same occured when a "waste penalty cost" was introduced, which for higher costs pushed the optimal portion quantity closer to the average. This is all in line with the underlying mechanics of equation 9. When comparing the different goodwill costs, the largest difference between the optimal portion quantity was found for kitchen 11, a fairly small kitchen serving guests aged 10–12 years, which for a goodwill cost of 1000 SEK/portion deviated by around 14% from the optimal order quantity at a goodwill cost of 80 SEK/portion (base case). The smallest difference was observed for kitchen 14, a medium-sized kitchen serving guests aged 6–12 years, which for a goodwill cost of 50 SEK/portion did not differ at all compared with the optimal portion quantity for the base case of a goodwill cost of 80 SEK/portion. On examining the "waste penalty cost", the largest deviation in optimal portion quantity was again observed for kitchen 11, for which for a "waste penalty cost" of 20 SEK/portion deviated by around 6% from the optimal portion quantity (Table 4). The second largest deviation was observed for kitchen 17, quite a large upper secondary school, which deviated by around 4% at a "waste penalty cost" of 20 SEK/portion. No difference regarding the optimal portion quantity was observed at a 'waste penalty cost' of 1 SEK/portion for kitchens 5–14 and 16, and the remaining kitchens had in absolute terms a difference of around one portion.

4. Discussion

By using quite simple forecasting techniques, it proved possible to predict quite accurately the number of school meals to produce. However, the outcome depends on the kitchen and the underlying guest patterns. Using simple methods appears tempting, but it is uncertain whether the forecasts they produce lead to the desired goal of reducing overcatering and food waste. Kitchens would need to be willing to change routines and to act upon the information provided by forecasting, an issue which would need to be tested in practice. This study sought to provide some answers on what forecasting strategy to use and in what way. Since kitchens are not all the same and there is no silver bullet solution that will work in all cases, strategies need to be developed individually to meet the different challenges that arise in different kitchens. Large kitchens with older students are more inclined to have a larger variability among the guests, making this scenario harder to forecast than for smaller kitchens who serve younger students, who usually don't walk away from the school meal. On the other hand larger kitchens might have the capacity and the resources to handle shortages better with a backup option. One obvious drawback of all forecasting strategies is that there needs to be reliable data on hand in order to make forecasts in the first place. When looking at plate data for some of periods included in the present analysis, it is clear that there were some uncertainties in the reported data for various reasons. For example, the same amount was reported for several days or there were missing data for some days. The data were collected using a self-reporting system, so there will always be some associated flaws. However, the same data are used for internal book-keeping, so the same kind of challenge will be transferred to the public catering management level. The first step before implementing any kind of forecasting system is to review organizational structures, since some public sector management falls within different municipal departments that operate under different budgets. This means in practice that the school management organization issues instructions to the public catering organization on how many portions to produce, but the number of portions may exceed the number of students enrolled at the school, which implies that the school organization adds some margin. Conversely, since the public catering organization gets paid by the school for how many portions they produce, the number of portions may in some cases be over-reported in order increase revenue to the organization. Last but not least, communication is a key element since no forecasting model can capture future disruptive events, including simple events such as study trips planned by the school, but not communicated to the kitchen. Even on normal days communications (or the lack of them) between the school organization and kitchen organization (WRAP, 2011) have the potential to play a major role for the kitchens ability to produce the right amount of food.

The neural network approach was the model that suited most kitchens best in the present analysis. While it was quite a simple model by neural network standards, it was still quite complex compared with the classical approaches, which could easily be implemented with no prior forecasting experience. The problem with all forecasting models is that they are uncertain and need to have some margins in place, or a backup plan ready so that kitchens can serve food to all students (who turn up), according to Swedish law. These margins can be quite large for small kitchens or for satellite kitchens that depend on an external production kitchen and therefore have problems storing backup food on-site for days when the forecast produces an underestimate. This is illustrated by the case of satellite kitchen 13, a medium-sized satellite kitchen that needed at least 7% margin on the forecast to be on 'the safe side'. To avoid excess food, satellite kitchens would need to have some kitchen equipment to store and serve backup stocks on days when demand exceeded supply, or have other means to supply all guests with food. For instance, kitchen 12 could implement the simple neural network with a 5% margin to be ready for two days per school year when the forecast underestimated the number of portions needed, and for those days have 1–9 portions on standby from the freezer. Smaller satellite kitchens appeared not to be as vulnerable and could manage well by implementing forecasting with some margin. This would be of special interest to preschools, which are often connected to a larger school where the kitchen is not far from the guests in reality. Smaller production kitchens did not suffer from the same kind of problems as satellite kitchens. They could benefit from reducing their production quantity stepwise or could implement a forecast with almost no margin at all, if they have some backup food, for instance saved from another day, ready for instant heating. Another aspect that needs to be considered is holidays, when most school kitchens serve fewer guests, and accurately forecast demand during such periods. One solution could be to use some kind of simple forecasting method or tune the neural network by training on holiday data alone. A further aspect that needs to be considered is how to forecast demand during extreme external events that cause a severe drop in guest numbers. In such cases, neural networks trained with data from several kitchens with similar characteristics (such as age of guests served) could potentially be very useful, if these kitchens can get access to historical data and some indication of how to model the anomalies in demand observed during extreme events.

In this study, economic data were used to find an optimal portion quantity in terms economic value, an approach that can be extended to encompass and optimize other aspects. Depending on the unit studied, the approach has potential to cover different kinds of values kitchens should optimize. This is also pointed out in a previous study by Schneider and Eriksson (2020), which showed that different types of products in supermarkets contribute differently to the share of food waste depending on the units applied in the analysis. For instance, a low mass of wasted meat can have a much larger share of environmental impact and cost. Applying this reasoning to the food service sector, it could be appropriate to allow higher margins on 'green' alternatives compared with more meat-heavy dishes. Thus kitchens experiencing large fluctuations in number of guests would greatly benefit from serving greener options, provided that backup stock is maintained and can properly serve all guests when food on the regular menu runs out. Waste that still occurs depending on the aspects selected for optimization can have som value depending on how it is handled and the waste management options available (Eriksson et al., 2015). However, prevention of waste has the highest priority according to various guidelines on managing food waste (USEPA, 2015; WRAP, 2014).

Estimating goodwill in economic terms is difficult, especially for a system that does not completely obey market rules. The same guests are very likely to come back to school catering establishments, since most do not have the option of eating elsewhere, so goodwill is different in this context. School kitchens could lower the number of portions produced in steps, inform guests that on some days the ordinary menu will run out and backup stock will be used to make up the shortfall, and explain why this was necessary. This could be a successful way of gaining acceptance for the change. In reality, the economic data for school kitchens may deviate, since some kitchens may have to serve more special diets, which are more expensive, and therefore influence the portion selling price and the purchasing cost of the ingredients. Overall, some kitchens make a financial loss and the portions they produce cost more than the revenue they bring in if all associated costs are taken into account. Kitchens that make a loss are 'subsidized' by other kitchens within the organization that make a profit. On an overarching level, the goal of the school catering organization is not to make a profit, but to break even, so the system is somewhat of an artificial economy. However, the approach used in this study to investigate goodwill costs and "waste penalty costs" yielded some interesting results suggesting that each kitchen has its own challenges and thus that individual measures will be needed for different kitchens. Overall, for some kitchens high goodwill cost will have a large impact on the optimal portion quantity related to the base case, pushing the optimal portion quantity closer to the current situation where the kitchens provide food for all enrolled students, whereas other kitchens will not be greatly affected. The same reasoning applies to the "waste penalty cost", which in most cases would need to be very high to push the optimal portion quantity closer towards the expected portion quantity average. Combining forecasting with a backup stock approach can lower overcatering. In the present analysis, the benchmark scenario suggested that kitchens could reduce MAPE from around 20–45% to as low as around 2–3% in the best case, even if some margins were added to the forecast. Today, kitchens do not seek to identify the optimal number of portions to produce and the system is optimized to produce close to 100% service level, due to fear of shortages. By stepwise adjusting the service level downwards, applying appropriate margins, knowing approximately how many times a shortage is likely to occur, and having a backup stock ready, fear of unknown shortages could be overcome.

It is difficult to assess the potential of forecasting if it were broadly introduced in all public catering establishments. However, as a result of forecasting in this study, the weighted average went down from around 16% in the benchmark scenario to, in the best case, 5% for the neural network model, an improvement of around 10 percentage units. If kitchens applied this best-case model combination in practice, they would need to have some margin in place, of around 5%, to be assured in their everyday work, which implies that today's level of overcatering food waste of around 20% would drop to 15%. Applying this improvement to the official Swedish food waste figures for public catering at the current level of 73,000 tons (SEPA, 2020) would lower the amount of food waste by around 18,250 tons. Introducing forecasting would not be free of charge, but the costs are difficult to estimate exactly. Assuming that the cost of introducing such a system is 10 MSEK and that the food thrown away is worth 20 SEK per kg, the potential saving would be roughly 350 MSEK annually for this prevention measure in the public catering sector alone. It is however doubtful if these savings can be observed since the money might be allocated to something else since municipalities have a broad range of responsibilities.

This study provide insights that can help school kitchens deal with an uncertain future or can at least provide them with a plan for trimming production based on forecasts, to address the problem of overcatering and thereby reduce food waste. The study was based on data from Swedish school kitchens, which is a specific case, however school catering is not something unique for Sweden and even if some of the settings might differ these have a lot in common with other cases where a frequent guest basis exist, such as workplace canteens, hospitals and hotels (Silvennoinen et al., 2015; Wang et al., 2017) where overcatering is a problem (Aamir et al., 2018). There is therefore a great potential for such food service actors to use concepts as forecasting put forward by this study and others (Ryu et al., 2003; Ryu and Sanchez, 2003; Sel et al., 2017) to reasonably balance supply and demand. If this is also combined with knowledge on how to deal with shortages by having a backup stock ready, this might be a useful combination of tools to minimize overcatering, prevent food waste, and achieve a more sustainable food system.

5. Conclusions

By using different forecasting approaches, in the best case guest demand in school catering establishments was predicted with a mean average percentage error of 2–3%. Even simple forecasting methods revealed potential to lower overcatering and address food waste levels. Our recommendation for kitchens is to start with a simple forecasting technique with some acceptable margins and be prepared to handle shortages if the margin is not adequate. Having some sort of forecast will always be better than the existing system, where kitchens prepare food for all enrolled students even if they show up or not. To lower food waste there is a need to reduce overcatering in public sector establishments and allow shortages, but to have backup stock ready for instant serving. By reducing the production rate stepwise, an optimal and feasible level of portion numbers can be achieved, with great potential to lower food waste. Satellite kitchens would benefit greatly from having some kitchen equipment, such as a freezer and oven, together with a forecast with some margin to properly handle fluctuating demand. However, all information on guest numbers provided to kitchens needs to be acted upon by kitchen staff in order to reduce overcatering. It is important to take the findings of this paper and test in reality in order to gain knowledge on how this can be a useful tool to reduce food waste, as technical aid might not always be used to their full potential.

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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Supplementary material

Supplementary material associated with this article can be found, in the online version, at 10.1016/j.spc.2020.08.008.

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Testing interventions to reduce food waste in school catering

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ABSTRACT

Food waste is a problem that needs to be addressed to achieve sustainable development. There is a need for interventions that can reduce food waste, including in organisations already aware of the food waste problem. Swedish school canteens have experience of food waste reduction, but need tools to achieve further reductions. This study tested four interventions (tasting spoons, awareness campaign, a plate waste tracker and a guest forecasting tool) designed to reduce food waste in school canteens. Each intervention was introduced in two school canteens, while seven school canteens acted as a reference group. The interventions were compared with baseline food waste before the intervention and with the reference group. All interventions reduced total food waste (by 6 to 44 g/guest) compared with the baseline, but the reference group also reduced its food waste. The awareness campaign reduced plate waste most, by 13 g per portion, which was 6 g/portion more than the plate waste reduction in the reference group. The forecasting and plate waste tracker interventions reduced serving waste most, by 34 and 38 g/portion, compared with 11 g/portion in the reference group. Some interventions also had an effect on waste fractions they were not designed to target, affecting the total waste by shifting the waste. Interventions should always be seen in a context and be implemented in combinations that increase overall sustainability. Thus forecasting is an effective way to reduce serving waste, plate waste tracker and awareness campaign are effective tools to reduce plate waste in school canteens.

1. Introduction

There is a global problem with food waste in the food service sector, with some studies claiming that approximately 20% of all food served is wasted (e.g. Engström and Carlsson-Kanyama 2004; Katajajuuri et al. 2014; Eriksson, Persson Osowski, Malefors, Björkman, and Eriksson, 2017; Malefors, 2021; Malefors et al., 2019; Silvennoinen, Heikkilä, Katajajuuri, and Reinikainen, 2015). For school meals, which are part of the food service sector, studies have found that food waste levels ranging from 33 to 160 g/guest are not uncommon (Boschini, Falasconi, Cicatiello, and Franco, 2020; Eriksson et al., 2017). Food waste of this magnitude raises a series of issues. For example, it compromises public health regarding goals set for school meal schemes and jeopardises the nutritional needs of school children (Cohen, Richardson, Austin, Economos, and Rimm, 2013; Smith and Cunningham-Sabo 2014). Food waste is also associated with major waste of resources, with high cost and environmental implications (Cohen et al., 2013; Falasconi, Vittuari, Politano, and Segrè, 2015; García-Herrero, De Menna, and Vittuari, 2019; Scholz, Eriksson, and Strid, 2015). Ultimately, it can lead to transgression of planetary boundaries (Campbell et al., 2017; Springmann et al., 2018). Efforts are underway to curb the food waste problem. One such global initiative is the United Nations framework for sustainable development (United Nations, 2015), which includes reduction of food waste under target 12.3 of the Sustainable Development Goals: "By 2030, halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chain". However, some argue that this level of ambition is not high enough and that further reductions are necessary to create a food system that can meet the target by 2050 (Beretta and Hellweg 2019; Springmann et al., 2018).

In a Swedish perspective, the food service sector is an important actor in the food chain, since it comprises a large number of public catering establishments, organised through municipalities and regions, providing food to preschools, schools, hospitals and elderly care homes. It has been estimated that half of all lunches in Sweden are served within this sector (Delfi, 2015). This is mostly because school children aged 6 to 16 receive a warm cooked meal every school day, free of charge, regardless of parental income (Swedish Parliament, 2010). These school meals are regulated by the Education Act, which only applies to school children aged up to 16 years, but in practice many young people in

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upper secondary school (aged 17–19 years) are also encompassed by the scheme. The Education Act states that school meals must be funded by tax revenue and that they must be nutritious (Swedish Parliament, 2010). Balanced nutrition that meets the physiological needs of children is essential for their growth and development (Nordic Council of Ministers, 2008). Nutritious school meals can also have a positive influence on cognitive function and thus the academic performance of school children (Hayes, Contento, and Weekly, 2018; Lennernäs, 2011). School meals are therefore planned based on the official nutrition recommendations and must supply approximately 30% of the daily nutrient and energy needs of children (Swedish National Food Agency, 2019b). However, for school meals to fulfil their nutritional goal, it is critical that the dishes served are consumed as planned, generating as little waste as possible.

Extensive food waste quantification has emerged as a first step to identify existing issues in public catering establishments (Eriksson, Lindgren, and Persson Osowski, 2018a). However, quantifying food waste is seldom enough, but is merely a tool necessary for initial identification of the problem and for subsequent checks on whether interventions made have had the desired effect (Eriksson et al., 2019). An important next step is to identify interventions that reduce food waste most efficiently, which canteens should prioritise. There is potential to reduce negative environmental impacts from wasteful behaviour and to ensure that children's energy and nutrient needs are met, for their healthy development. Some previous studies investigating the effect of single interventions mainly targeting plate waste, such as information campaigns (with written messages such as posters and table talkers), have reported a range of results, from no food waste reduction to a 28% reduction (Visschers, Gundlach, and Beretta, 2020; Whitehair, Shanklin, and Brannon, 2013). Other interventions, including redesigning schedules so that lunch is in relation to recess (Getlinger, Laughlin, Bell, Akre, and Arjmandi, 1996), introducing tasting spoons (Tocco Cardwell, Cummings, Kraft, and Berkenkamp, 2019) and nudging initiatives (Kallbekken and Sælen 2013; Thiagarajah and Getty 2013), have been found to reduce food waste by up to 20%. Forecasting has also been identified as a potential solution to reduce food waste and especially serving waste, in theory by 20–40% (Malefors, Strid, Hansson, and Eriksson, 2021b; Ryu and Sanchez 2003; Yurtsever and Tecim 2020), although few studies have examined how well actually forecasting works in terms of food waste reduction. The British organisation (2011) made three interventions (improving familiarity and appreciation of school meals, improving the dining experience, children ordering their meals in advance) and could show a 4% waste reduction, but the reduction was not statistically significant (WRAP, 2011). To conduct intervention studies, food waste quantification is required. It can therefore be argued that quantification itself is an intervention that affects the level of food waste, by raising awareness (Eriksson et al., 2019; Pancino, Cicatiello, Falasconi, and Boschini, 2021).

No previous study has investigated the food waste-reducing effects of interventions in an organisation that has actively quantified and worked with food waste for several years, and no study has assessed interventions targeting both plate waste and serving waste. Therefore the present study examined the effects of four interventions (all based on best available technology) on food waste levels in a Swedish public catering organisation that has actively quantified its amount of food waste since 2014. The interventions tested were: i) an information campaign directed at school children with the aim of reducing plate waste; ii) providing tasting spoons in canteens so that school children could taste dishes before serving themselves, with the ambition of lowering plate waste; iii) a plate waste tracker that communicated different educational messages on the impact of food waste to school children and gave them feedback on how much they wasted per portion; and iv) guest attendance forecasting, so that canteens could gain a better understanding of future demand and adjust their production accordingly.

The ability of these four interventions to reduce food waste in school canteens was tested both in relation to the baseline prior to implementation and in relation to a reference group. The objective was to identify interventions that could be scaled up so that school canteens can achieve the larger-scale reductions in food waste necessary for a sustainable food system.

2. Material and methods

The study comprised three main steps (Fig. 1): 1) food waste quantification to establish a baseline in participating school canteens; 2) design and implementation of interventions to reduce food waste; and 3) post food waste quantification to determine and evaluate the effect of the interventions.

2.1. Description of data collection and study material

Collection of data took place in a public catering organisation that provides food to preschools, schools and care homes in a Swedish municipality. The organisation operates a total of 30 kitchen units, half of which serve meals to school children aged 6–19 years. The majority of meals that the organisation serves are within the school segment, as schools are normally larger than preschools and care homes. The organisation has worked actively with the question of food waste and has regularly quantified its levels of food waste since 2014.

The pre-intervention quantification of food waste phase took place between 2014 and spring 2020 in the 15 school canteens, to establish a baseline level of food waste. All data were collected through self-monitoring by the kitchen staff, who weighed food waste as part of a daily routine during the quantification periods. The quantification periods varied in duration, but aimed to cover one period in the middle of the spring semester and one period in the middle of the autumn semester, when the canteens had full activity. Thirteen of the canteens serve meals to children aged 6–16 years and the remaining two school canteens serve children aged 17–19. All participating canteens quantified food waste by weighing the mass of waste (in kg with two decimals) using kitchen scales and reporting the information in a standardised format, as described by Eriksson et al. (2018b)) and Malefors et al. (2019). The waste processes recorded were kitchen waste (waste from goods delivered to the kitchen, but never stored or used or waste from preparation and/or trimming of food or waste from food produced which did not leave the kitchen for consumption and was not saved for another meal), serving waste (food served that did not reach the plates of the guests) and plate waste (waste from the plates of the guests, may contain napkins and/or inedible parts) for lunch meals served within the public catering organisation. The numbers of guests per meal and canteen were also recorded, to calculate the relative indicator 'waste per portion'. The number of guests was estimated by counting the number of used plates after the meal serving. The amount of food served was also recorded for some canteens during parts of the quantification period.

To have a robust evaluation procedure, only daily observations that included the indicators "Serving waste", "Plate waste" and "Number of portions" were included. Applying this filter reduced the number of total observations to 3222, of which 187 observations were made during the implementation period. All of the observations were manually validated to have potential errors omitted. The baseline duration is long in order to capture the natural variation in food waste. The yearly average ranged from 66.8 g to 74.2 g per portion. However, behind these averages is a large variation where individual canteens could report between 4.9 and 464 g per portion for daily observations.

2.2. Interventions

Four interventions were selected by the public catering managers in collaboration with the researchers and these interventions were implemented in parallel during summer-autumn 2020, followed by a food waste quantification period to determine the effects of the interventions.

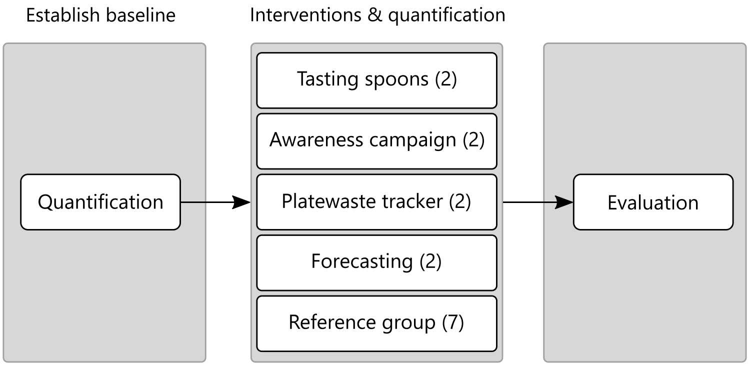

Fig. 1. Different steps of the analysis, ranging from data collection to evaluating the effect of the interventions. Values in brackets show number of school canteensin which each intervention was tested.

During this period the canteens were operating normally and COVID-19 did not impact the dining activities with the exception of queuing systems for keeping distance being in place and that students and staff with symptoms having to stay at home (substitute staff would then be called in). Each of the interventions were introduced in at least two school canteens, while the remaining canteens within the catering organisation acted as a reference group where no intervention took place. Three of the interventions primarily focused on addressing plate waste, whereas one primarily targeted serving waste. The interventions were implemented during a seven-week period, with food waste quantification taking place during the last two of these seven weeks.

The public catering managers selected school canteens to test each intervention, with the remaining canteens forming the reference group. Thus, there was no random selection, but rather selection based on expected willingness to implement new tools or compliance to the will of the kitchen manager. This selection approach represents an implementation strategy that could be applied by other large catering organisations, rather than relying on individual choices by scientists or canteen staff. It is likely that the selection approach favoured test objects with the highest interest and awareness (and least in the food waste problem), rather than those with the greatest potential for introducing the interventions.

2.2.1. *Tasting spoons*

The main idea of providing tasting spoons is to reduce plate waste and this intervention has shown promising results in other schools and establishments (Tocco Cardwell et al., 2019). The spoons allow guests to try a dish before scooping up too much food that may be left uneaten if it does not match the expectations of the guest. Tasting spoons also lower the threshold for guests to discover new types of dishes, as they can try a small piece without the risk of serving themselves too much. However, canteen staff must be made aware that reducing plate waste in this way might just shift the problem to serving waste if guests take less food than expected. This has to be taken into account to fully utilise the intervention of using tasting spoons. During the implementation, several trays of disposable tasting spoons were placed on top of the serving stations during lunchtime in two school canteens (Fig. 2).

Fig. 2. Tray of tasting spoons above one of the options in a school canteen serving line.

2.2.2. Awareness campaign

Running an awareness campaign is a widespread intervention to reduce food waste (Pinto et al., 2018; Visschers et al., 2020). The idea is that if people are aware of food waste issues, they will take action to waste less. Awareness campaigns are often a one-way communication, with posters or table talkers spreading the message to the guests or staff. In this study, the intervention "awareness campaign" was aimed at school children in two schools and targeted plate waste reduction compared with previous years. Table talkers designed by the managers of the public catering organisation were placed on the tables (Fig. 3), and also on top of the serving stations, showing messages such as "Eat as much as you can – but throw away as little as you can". The table talkers also encouraged the school children to start with a smaller portion and then take a second helping, or to taste the dish prior to serving themselves if they were unsure whether they would like it.

2.2.3. Plate waste tracker

To increase interactions with the guests, a plate waste tracker was introduced in two school canteens. The plate waste tracker is a kitchen scale connected to a tablet computer running dedicated software that interacts with the guests. The interface shows the guests how much food they are wasting and the impact of this waste (Fig. 4). The feedback to the guests as regards the impact is displayed as "Today we threw away 7.1 kg of food, which corresponds roughly to 21 portions or 27 cinnamon buns". The tablet computer allows the guests to provide feedback on why they wasted food, with some predefined alternatives: "I did not like it/it was not to my taste", "I took too much food" and "I did not have time to finish my meal". The kitchen also has the ability to set a goal that its guests should not waste more than a certain mass of plate waste per day.

The goal with introducing the plate waste tracker was to reduce plate waste compared with baseline.

2.2.4. Attendance forecasting

Forecasting of attendance to gain a better picture of demand is an intervention that can help canteens in determining the number of guests for which they should provide food (Malefors, 2021). Public catering canteens often prepare food for all children enroled in the school, whether they show up or not, resulting in surplus food that is often wasted if not used for another meal. Previous studies have shown that using forecasting can reduce serving waste and help to save money in meal planning (Garre, Ruiz, and Hontoria, 2020; Malefors, Secondi, Marchetti, and Eriksson, 2021a; Ryu and Sanchez 2003; Yurtsever and Tecim 2020).

The two school canteens where the intervention "attendance forecasting" was introduced received a daily forecast of the number of guests that would attend lunch. At the end of the week, the head chef received a forecast for the coming week they could take into consideration in their meal planning and when ordering necessary food ingredients. The forecasting model used was based on a neural network, as described by Malefors et al. (2021b).

The goal of introducing attendance forecasting was to reduce serving waste compared with previous years.

2.3. Reference group

The reference group consisted of seven canteens that had no active measures in place to reduce food waste during the test intervention implementation phase in autumn 2020. The reference was used to examine whether the test interventions actually reduced food waste, or whether reductions were due to other trends and ambitions that would have happened in any case. However, since quantifying food waste can also act as a measure to reduce food waste (Eriksson et al., 2019), the reference group was not completely without active measures. The interventions needed to reduce food waste to a greater extent than in the reference group before any actual effect related to the intervention could be claimed, additional to effects from general awareness, waste quantification etc.

One complicating factor as regards the reference group was that its members had to have the same initial level of food waste, since a high initial level would create easier opportunities for reduction according to Obersteiner, Gollnow, and Eriksson (2021) and Eriksson et al. (2019). The difference in initial food waste level between the test groups and the reference group was quite small, but this variation still posed a potential risk of affecting the accuracy of the results. A greater risk was that many of the school canteens included in the study had low initial waste, at least in comparison with that reported by Obersteiner et al. (2021) and Eriksson et al. (2019), and their potential to reduce food waste is likely to be small. Thus the results are probably underestimates of the potential of the test interventions, and higher reduction potential is likely if the

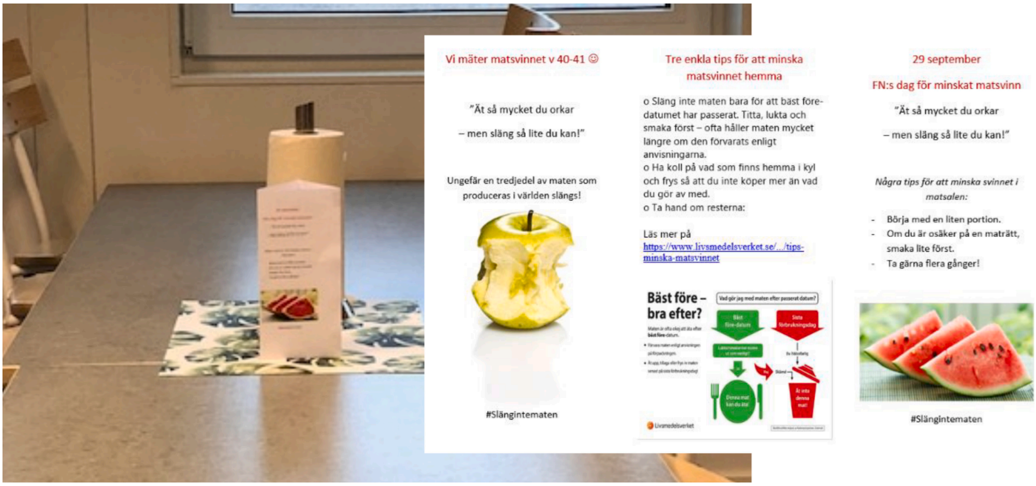

Fig. 3. Table talkers communicating messages on the issue of food waste to school canteen guests, as part of the awareness campaign intervention.

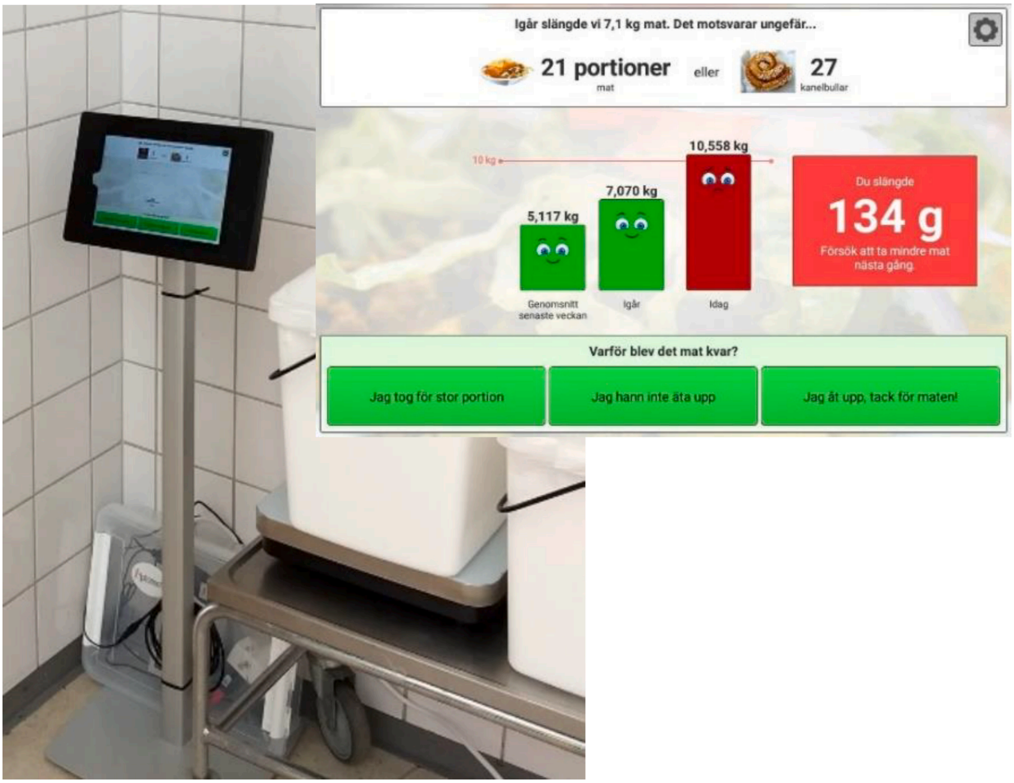

Fig. 4. Plate waste tracker at the point where school canteen guests scrape their plates. The interface communicates the target that the canteen has set and also shows how much plate waste was generated previously. The impact of the waste is shown in indicators that guests can relate to, such as "Yesterday we threw away 7.1 kg, which is roughly the same as 21 portions or 27 cinnamon buns". The interface also allows guests to give feedback on why they wasted food.

interventions are tested in canteens with higher initial waste. To test for differences between the test groups and the reference group with regards to knowledge, a short survey was conducted on the head chefs of the participating canteens. The responses were also used to identify any discrepancies between staff perceptions of their own workplace and actual observations made during the implementation period. The head chefs were asked what sort of food waste (plate waste or serving waste) they have most of, how large portion sizes they serve and how many daily guests they serve on average. The portion sizes were considered correct if they were within 100 g of the true (observed) value and the number of guests was considered correct if it was within +/−10% of the true value.

2.4. Evaluation of interventions

The method for analysing the efficacy of food waste reduction from the interventions was performed in grams per guest for all of the four interventions divided into plate waste, serving waste and total waste

(which also included waste from the kitchen if this was quantified). This was done by calculating the median values for the different waste processes with a median confidence interval of 95% for the levels of food waste before and after the intervention to determine which interventions had a significant reduction of food waste. All of the analyses were performed with the statistical software R.

3. Results

3.1. Result from the interventions test

The findings from the different interventions, divided into total waste, serving waste and plate waste per portion, are presented in Fig. 5.

The awareness campaign targeting guests and plate waste in the school canteens gave a significant reduction in plate waste. The median waste per portion for the plate waste fraction before implementation of the intervention was 37 g per portion (with 134 observations), while after the intervention was implemented it was 24 g per portion (with 15 observations), a 35% reduction. Serving waste and total waste were also reduced in the canteens that implemented the awareness campaign, but not significantly. Providing tasting spoons to allow guests to taste the food before serving themselves to reduce plate waste also resulted in a significant reduction in plate waste. Before implementation, the median plate waste per portion was 27 g (with 218 observations), while after the intervention was implemented it was 21 g per portion (with 14 observations), a reduction of 22%. This intervention also resulted in a reduction in total waste per portion but, due to overlapping uncertainties, no significant difference was seen. However, the median level of serving waste increased after introducing the tasting spoons, from 25 g per portion to 30 g per portion (a 20% increase).

After introducing the plate waste tracker targeting plate waste, both

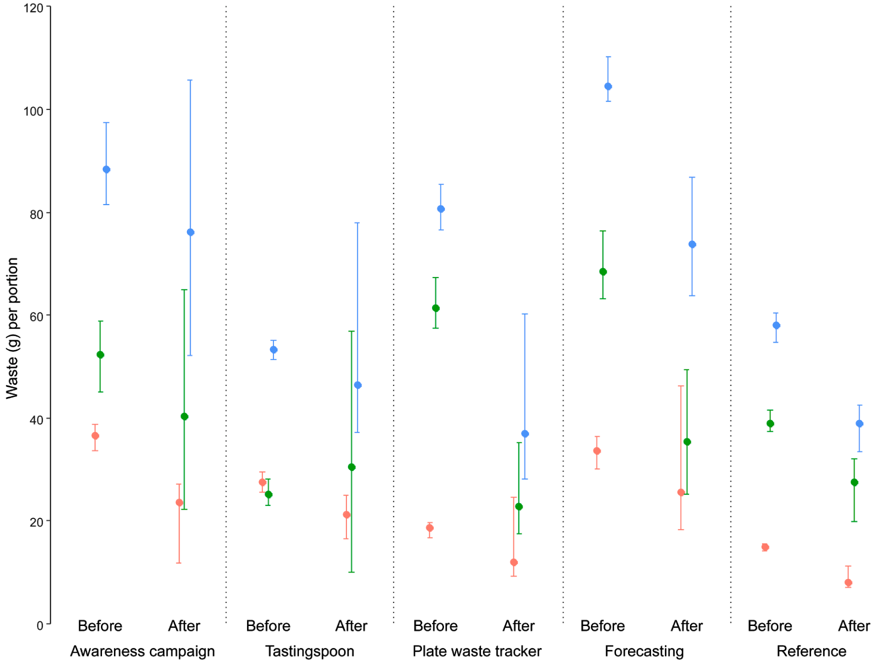

Fig. 5. Waste (g) per portion (median values with uncertainties as 95% confidence intervals) before and after implementation of measures to reduce food waste in school canteens. ● Total waste per portion, ● serving waste per portion, ● plate waste per portion.

total waste and serving waste per portion were significantly reduced. The plate waste tracker gave the largest waste reduction of all interventions (Fig. 6). A reduction from 19 g of plate waste per portion before the tracker was implemented (243 observations) to 12 g per portion after implementation (19 observations) was observed, which corresponded to a reduction of 37% (although not statistically significant). The reduction in serving waste is a possible spill-over effect, with serving waste reduced from 61 g per portion to 23 g per portion (62% reduction) in the canteens where the plate waste tracker was introduced.

The idea of introducing forecasting was that canteens would get a better picture of future demand and plan accordingly, reducing overcatering and serving waste. The serving waste for the canteens implementing this intervention showed a significant reduction, from an initial 69 g per portion (243 observations) to 35 g per portion (20 observations) after the implementation, a reduction of 49%. Serving waste (69 g per portion) and total waste (104 g per portion) were both initially highest for the canteens that implemented forecasting, indicating that these canteens might have the greatest problem to start with and therefore the greatest potential for reduction.

The canteens in the reference group also showed a significant reduction in all waste processes. The number of observations was 805 before the implementation phase and 60 during the autumn quantification period. Total waste per portion (which also included kitchen waste if this was quantified) before the evaluation period was 58 g per portion and this was reduced to 41 g per portion, a reduction of 29%, the serving waste fraction went from 39 to 28 g per portion, a reduction of 28% and plate waste was reduced from 15 to 7 g per portion a reduction of 53%. Since the canteens in the participating public catering organisation generally achieved a reduction in their levels of food waste over the years for which data were available, the interventions implemented had to be better than the general reduction trend observed for the reference group. This concept is illustrated in Fig. 6, which shows the difference in waste reduction per portion for the different waste processes, per measure, before and after the intervention quantification phase. As can be seen, only the awareness campaign (food waste reduction of 13 g per portion) and the canteens that implemented forecasting (reduction of 8 g per portion) achieved a greater reduction for plate waste compared with the reference group. The canteens that implemented the plate waste tracker reduced plate waste to the same extent as the reference group, with both resulting in a plate waste reduction of 7 g per portion compared with the previous quantification periods. Using tasting spoons reduced food waste by 6 g per portion for the plate waste fraction.

The reduction in serving waste achieved by forecasting was 34 g per portion compared with before implementation. However, the canteens that used the plate waste tracker reduced serving waste even more, by 38 g per portion, even though that intervention is not intended to reduce this type of waste. Canteens that implemented the awareness campaign also reduced their serving waste compared with the reference group, but not to the same degree as seen for the forecasting and plate waste tracker interventions.

Further, canteens that implemented the plate waste tracker and forecasting had a larger reduction in their total waste per portion compared with the reference group. Canteens that implemented the awareness campaign and the tasting spoons reduced total waste per portion less than the reference group (see Fig. 6).

3.2. Agreement between kitchen staff perceptions and quantified results

On examining the results from the quantification period in autumn

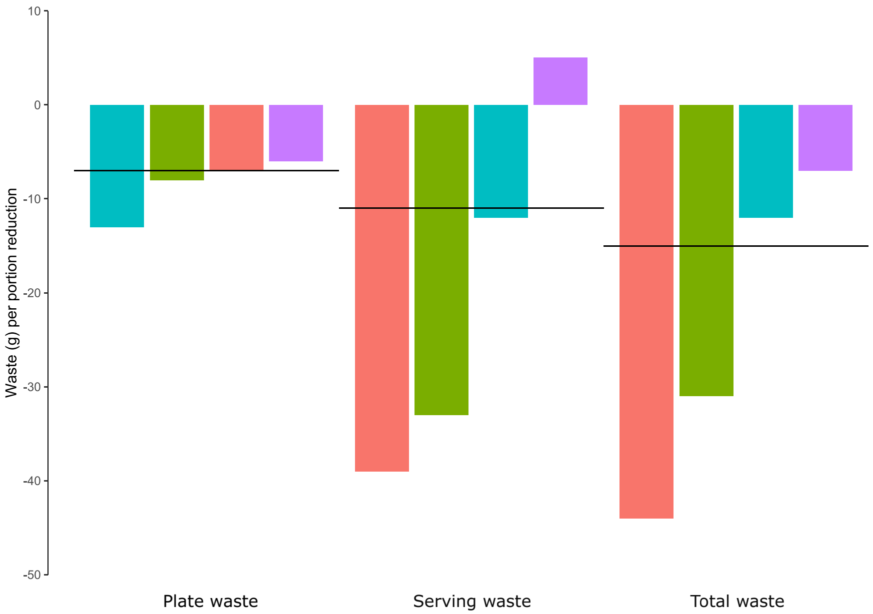

Fig. 6. Median reduction in food waste (g) per portion after implementation of the interventions: ■ Awareness campaign, ■ forecasting, ■ plate waste tracker, ■ tasting spoons, in relation to the reference group ▬, for plate waste, serving waste and total waste per portion. Total waste also included waste from the kitchen if this was quantified.

2020 for the public catering organisation and comparing the results to the perceptions of the head chefs, it emerged that all school canteens except one had a greater problem with serving waste than plate waste (Table 1). Seven out of 12 canteens also had an accurate perception that their main problem was with serving waste. When it came to understanding how many guests on average attended the meals, seven of the canteens (S2, S5, S6, S7, S8, S10 and S12) gave answers that were within 10% of the actual value. The greatest difference was found for canteens S4 and S11, which overestimated the number of guests by 52% and 67%, respectively. Half of the canteens that contributed data had a good understanding of portion sizes. One canteen did not know the portion size and another canteen did not manage to quantify the amount of food served, which is necessary to calculate the portion size. Canteen S9 reported a portion size of less than 100 g, but the quantified results showed that it was actually 288 g. Three canteens were unable to give a response to the questions, due to the ongoing pandemic situation and had to focus on the main operations of the canteen.

When the school canteens were grouped according to the intervention they tested, it was possible to calculate the average number of correct answers within the group (where answers where available). Using this simple compilation, the group with the highest level of knowledge was that using the awareness campaign, with an average of 2.5 correct replies out of 3 possible. This was followed by the users of attendance forecasting (average 2/3), the reference group (average 1.75/3), users of the plate waste tracker (average 1.5/3) and lastly the tasting spoon users (average 1/3). This shows that there was quite wide

Table 1
Responses from canteen head chefs compared with actual quantified data. Canteens S13, S14 and S15 were unable to answer due to the pandemic situation.

Kitchen	Most food waste		How many daily guests		Average portion size	
	Answer	Quantified	Answer	Quantified	Answer	Quantified
S1	Plate waste	Serving waste	170	215	201–300	258
S2	Plate waste	Serving waste	1100	1036	201–300	308
S3	Serving waste	Serving waste	240	214	201–300	218
S4	Serving waste	Serving waste	220	145	301–400	–
S5	Serving waste	Serving waste	130	139	201–300	288
S6	Plate waste	Serving waste	175	168	301–400	332
S7	Plate waste	Plate waste	360	336	100–200	410
S8	Plate waste	Serving waste	224	207	201–300	211
S9	Serving waste	Serving waste	96	85	<100	264
S10	Serving waste	Serving waste	82	81	Don't know	288
S11	Serving waste	Serving waste	135	81	201–300	323
S12	Serving waste	Serving waste	140	128	201–300	294
S13	–	Serving waste	–	141	–	178
S14	–	Serving waste	–	138	–	216
S15	–	Plate waste	–	113	–	297

variation of how well the knowledge of the head chefs was aligned with the quantified data. The reference group was ranked in the middle, indicating that it was comparable to the other test groups. There was no obvious pattern indicating that better knowledge would increase or decrease the potential for waste reduction.

4. Discussion

All interventions tested in this study achieved a reduction in the levels of food waste compared with the baseline quantification, with the magnitude of the reduction ranging from 6 to 44 g/portion. The participating public catering organisation has been active in quantifying its levels of food waste since 2014 and was therefore able to present quite a detailed picture of its current challenges in terms of food waste. Eleven of the 15 canteens studied generated most of their waste in the serving line, which corresponds well with findings in other studies (Eriksson et al., 2017; Getlinger et al., 1996; Silvennoinen et al., 2015).

The interventions evaluated in this study were chosen according to best available technology accepted by users in the catering organisation. Three of the interventions focused on plate waste reduction, which is not the greatest problem for the canteens studied but was still an important educational point. The three interventions that targeted plate waste probably also had a spill-over-effect on the staff in various forms. For instance, the plate waste tracker enabled staff to get an understanding of why meals were wasted on a daily basis, making it possible to adjust their planning, which in the long run might affect serving waste. In this study, the levels of serving waste were strongly reduced (by 62%, a reduction from 61 to 23 g per portion in the canteens that used the plate waste tracker, an intervention primarily designed to target guests and plate waste. The canteens that used the plate waste tracker already had low plate waste to start with (19 g per portion) and a reduction down to 12 g per portion represented a very low level of plate waste. To put this in perspective, Engström and Carlsson-Kanyama (2004) reported plate waste of 33–35 g per portion for two schools in the Stockholm region and the Swedish National Food Agency found the median value of food waste in Swedish school canteens to be 21 g per portion. This indicates that other kitchen units with high initial waste might benefit more from the plate waste tracker, since they have greater potential for reduction. Visschers et al. (2020) examined the effects of an awareness campaign and compared these with the effects of reducing plate size in two university canteens, and concluded that it was the reduced plate size that achieved a reduction in food waste, whereas the awareness campaign alone was not a sufficient measure to reduce food waste. In contrast, in the present study plate waste was actually reduced in the canteens that implemented the awareness campaign (from 37 to 24 g per portion, a 35% reduction). This may indicate that awareness campaigns affect age groups differently depending on how they are designed and whether other or prior measures have previously influenced the guests. However, both 37 and 24 g per portion, as observed in the present study, are normal levels of plate waste in Swedish school canteens according to previous studies (Engström and Carlsson-Kanyama 2004; Swedish National Food Agency, 2019a). Tasting spoons gave a statistically significant reduction from 27 to 21 g/portion, or 22%, in plate waste in the present study, but also created a tendency for a shift towards more serving waste. In a study by Tocco Cardwell et al. (2019), tasting spoons together with clear and consistent portioning instructions reduced the edible food waste fraction significantly. Tasting spoons in conjunction with awareness campaigns might be a cheap tool that canteens can implement rather easily as a starting point.

A clear limitation in this study was the use of non-randomised canteens when implementing the interventions.. However, it is hard to force canteens to use interventions that they don't believe in. For an organisation to implement tools to reduce food waste there needs to be trust in what the interventions are trying to achieve. Or the interventions need to be redesigned or readapted so they are accepted by the canteens. Therefore, compliance in using the interventions by the canteens might have interfered with the results. It should also be noted that there are always some actions taken to lower food waste in all 15 school canteensstudied, as kitchen staff continually try to keep waste levels low. These efforts may vary in intensity over time, and it is therefore difficult to exclude the possibility of other parameters acting within the organisation and on canteen level. This makes it difficult to evaluate the effects of interventions on food waste, as the reduction observed might not necessarily be attributable to implementation of the intervention alone. For instance, the participating organisation is challenging school children to waste as little as possible and awards the school with lowest plate waste a trophy called the "golden plate". Such gamification and nudging schemes, in conjunction with other types of simultaneous measures against food waste, might have an unexplored interactive effect. Our reference group reported that these interventions that are always running and some have quite a strong reduction effect. Thus the total waste per portion in the reference group before the interventions was 58 g per portion, which aligns well with previous reports of around 60 g per portion for primary schools (Malefors et al., 2019; Swedish National Food Agency, 2019a), and this was reduced to 41 g per portion (a reduction of 29%), to what can be considered a low level of food waste. The plate waste fraction for the reference group went from 15 to 7 g per portion (a reduction of 53%) and the serving waste fraction from 39 to 28 g per portion, a reduction of 28%.This indicates that the systematic work to reduce food waste in the municipality seems to be having an effect and that further interventions should be targeted at specific canteens that have identified potential problems. For instance, canteen S7 has identified that its largest problem is plate waste, so there is high potential for that canteen to target the plate waste fraction. Since problems with food waste are not the same for all canteens, they need to find their own individual solutions to their problems and design interventions accordingly, in this case some of the interventions examined did not perform better than the reference group, which indicates that the tailor made own interventions applied in the reference group are more effective and feasible than the interventions tested.

Since there is a flow of pupils through a school over time, all interventions directed at guests probably need to be of a recurring nature, so that the effects of the intervention are not lost when new pupils arrive and older pupils leave. The same may be true of canteen staff, and it should be noted that engagement, awareness and knowledge can be very individual and therefore change drastically due to staff changes.

For the forecasting intervention, which targeted serving waste, the intervention was overall successful, with a reduction of 49%. This is higher than the reduction of 20–40% anticipated by Malefors et al. (2021b), although it is difficult to isolate cause-effect relations in the type of experimental set-up used in the present study. The forecasting intervention might have been even more efficient if it had been implemented in canteens that actively acknowledge difficulties in planning the number of guests, instead of in canteens where managers decided which intervention they should implement. In future interventions, canteens S4 and S11 would probably be great subjects for a forecasting or ordering system, since they showed large deviations (52% and 67%, respectively) between anticipated number of guests and the real outcome.

The small questionnaire used in this study only asked three questions, but such a simple knowledge test could be used to identify potential problems that could be targeted by certain interventions, thus making the intervention more effective by aiming it at a specific problem. For instance, Filimonau and Coteau (2019) stress the importance of staff and managers reflecting on their role in waste generation, since they can take active decisions to guide the canteen and organisation regarding the food waste issue. Since serving waste is a large problem for some canteens and more efforts are needed to understand how already available tools, such as forecasting and other types of material (e.g. the one promoted by the USEPA (US EPA n.d.)) can be used to reduce this type of waste without shifting the waste to another process. However, plate waste interventions should not cease, as there is plenty of room for multiple types of interventions to co-exist.

According to the survey results (Table 1), half of the participating canteens had a good understanding of a suitable portion size. The actual portion sizes quantified corresponded well with national mapping performed by the Swedish Food Agency (2019a), which reported portion sizes in the range 125–528 g, with a median value of 297 g per portion.

However, there is little knowledge of how much of the school meal is actually consumed, which means that the nutritional value of meals can only be followed up on an average level and makes it possible for individuals to eat very unbalanced meals. Swedish school canteens are making a transition to serving more plant-based options and cooking more food on-site with raw materials, which might generate more food waste in the future, but the waste would then originate from a diet that is more adapted to the planetary boundaries and from less resource-intensive production systems (Willett et al., 2019). Future studies need to assess the direction in which public catering organisations are heading in terms of sustainable diets and how well school children adapt to and accept these changes, since reduced food waste alone is not enough to make the food system sustainable. There is also a risk that increased efforts in food waste quantifications will reveal more food waste, thereby making it look like an increasing problem. In school canteens the food waste issue is two-fold, since the food that is wasted is supposed to provide nutrients to the pupils. However, even if food eaten is a priority, it is also important not to promote overeating, which can contribute to obesity and metabolic food waste (Ellison and Prescott 2021; Sundin, Rosell, Eriksson, Jensen, and Bianchi, 2021). Here pedagogic meals (teachers eating lunch together with pupils) can play an important role, since they are considered a way to build stronger relationships between children and adults, create a healthy attitude to food and generate curiosity about new flavours, foods and textures. This could ultimately increase acceptance of dishes served, increase consumption and even simultaneously reduce waste. Today, the pedagogic meal is still an untapped resource to a large degree, waiting to realise its full potential (Persson Osowski, Göranzon, and Fjellström, 2013; Skolmat Sverige, 2021). Previous studies have shown the effectiveness of presence of positive role models for establishing healthy food choices for children (Eliassen, 2011; Savage, Fisher, and Birch, 2007; Wechsler, Devereaux, Davis, and Collins, 2000), and further studies investigating the teacher role specifically have been suggested (Marty, 2017).

It should further be pointed out that, even though the interventions tested in the present study should be seen as the best available technology, all interventions were of a fairly simple nature, so they could be implemented and used for long or recurring periods by school canteens. As this study (and literature) shows, tools with the potential to reduce food waste are available, however, what is missing, is the large-scale use of these tools. What is needed is therefore policies that enforce reductions in food waste or, even better, reduced negative impact from the food system, where reduced food waste is one of many components. For efficient implementation, such policies need to be supplemented with sufficient means to reduce food waste, but also sufficient incentives for staff and organisations, to increase motivation. Our recommendation from the present study is that all Swedish public catering organisations should have access to a toolbox of interventions that could be used in individual canteens to solve individual problems, so that efforts are targeted where they can make the largest impact. There should also be checks to ensure that the tools are actually used. However, interventions need to deal with the complex problem of fostering good eating habits while also lowering food waste levels, since only by addressing both these problems simultaneously can sustainable development be achieved.

5. Conclusions

All four interventions tested (awareness campaign, forecasting, tasting spoons, plate waste tracker) reduced food waste, by 6 to 44 g per portion. However, the reference group also reduced its levels of food waste during the study period, indicating a general trend for reduced food waste in the participating canteens. For plate waste, the awareness campaign was the only intervention that reduced this fraction of food waste by more than in the reference group (by 13 g per portion compared with 7 g per portion). For serving waste, forecasting and the plate waste tracker resulted in a significant reduction, of 34 and 38 g per portion respectively, while the reference group achieved a reduction of 11 g per portion. For total waste per portion, the plate waste tracker and forecasting achieved greater reductions (44 and 34 g of per portion respectively) than the reference group (17 g per portion). The best interventions were therefore the plate waste tracker and the forecasting procedure, followed by awareness campaign and finally tasting spoons. Tasting spoons had a tendency to shift waste from the plate waste fraction to the serving waste fraction. This highlights that an intervention can have an expected effect on certain waste fractions but that there are spill-over effects to other fractions and therefore all fractions should be included in the evaluation to fully capture the overall performance. The interventions tested proved to be successful in the experimental setting (Swedish school canteens), but there is no guarantee that they would provide similar results elsewhere, and they might perform better if tailored to the needs of specific canteens. It is therefore a need to test the feasibility and implementation integrity of food waste interventions. Organisations need to have a toolbox of interventions that canteens with the largest scope for improvement can implement to solve a problem, thereby reducing food waste. With systematic and continuous use of food waste interventions, catering organisations have good potential to reduce their food waste and help create a sustainable food system.

CRediT authorship contribution statement

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

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: The authors Christopher Malefors and Mattias Eriksson developed the interventions ‘plate waste tracker’ and ‘guest attendance forecasting’, and own the rights to these innovations through the company Matomatic AB. There is a potential conflict of interest as those authors have a financial interest in the two innovations.

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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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A B S T R A C T

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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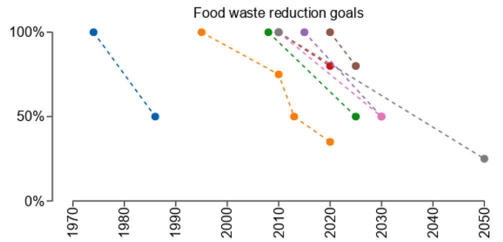

Fig. 1. Targets and achievement deadlines set for some previous food loss and waste reduction goals. ● FAO 1974 goal of reducing post-harvest losses, ● DEFRA, Ev 47, ● Lundqvist et al. (2008), ● Swedish Environmental Protection Agency (2013), ● SDG 12.3, ● Swedish Environmental Objective Goal ● Springmann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

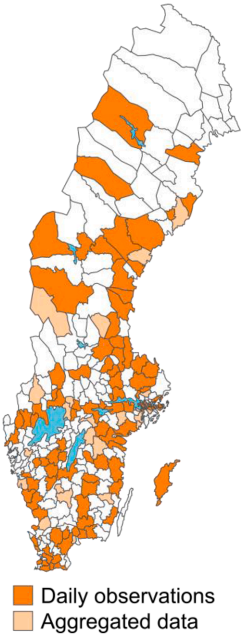

Fig. 2. Geographical plot of the municipalities that shared their food waste quantification data.

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

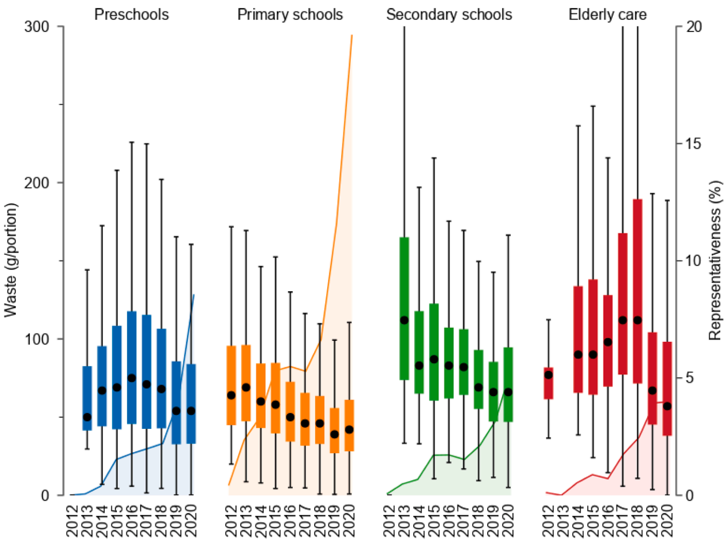

Fig. 3. Boxplot of changes over time (2012–2020) in food waste in different parts of the Swedish public catering sector. ● shows the median waste level (g/portion); box limits indicate the 25th and 75th percentiles; whiskers illustrate the minimum and maximum values, and outliers are omitted. The representativeness (%), 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

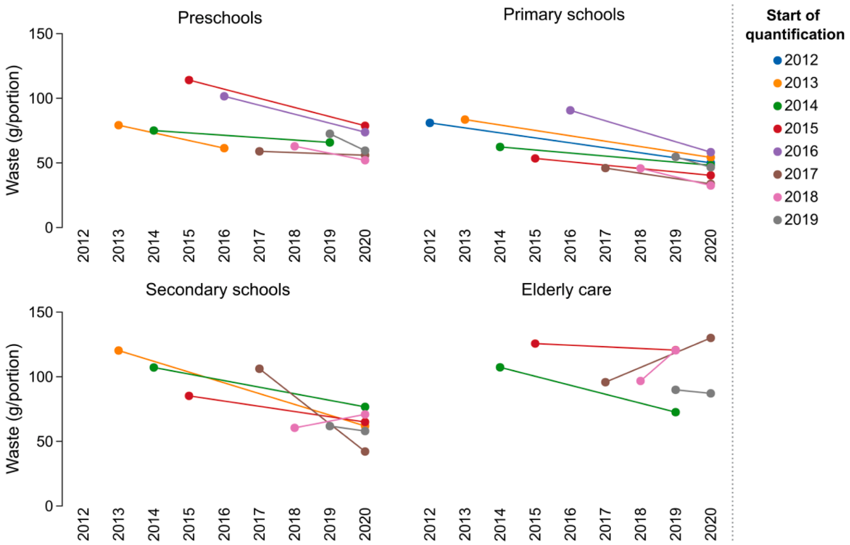

Fig. 4. Linear trends in food waste amounts for canteens in different parts of the public catering sector in Sweden. Canteens are grouped and tracked by the year in which they started to quantify food waste, e.g., school canteens that started to quantify food waste in 2012 and their levels of food waste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

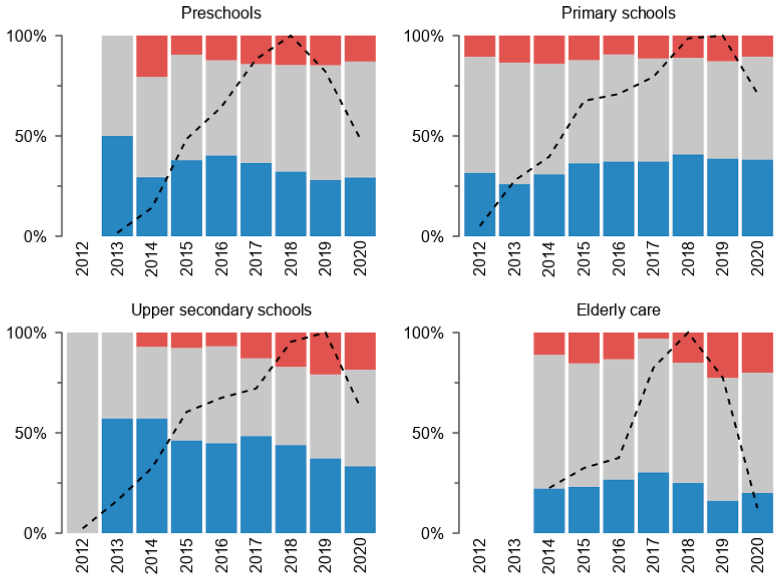

Fig. 5. Proportion plot illustrating the percentage of Swedish public catering canteens with significantly increasing (■) or decreasing (■) trends in food waste per portion (■ indicates no significant increase or decrease). A dashed line indicates the percentage of canteens observed for a specific year.

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

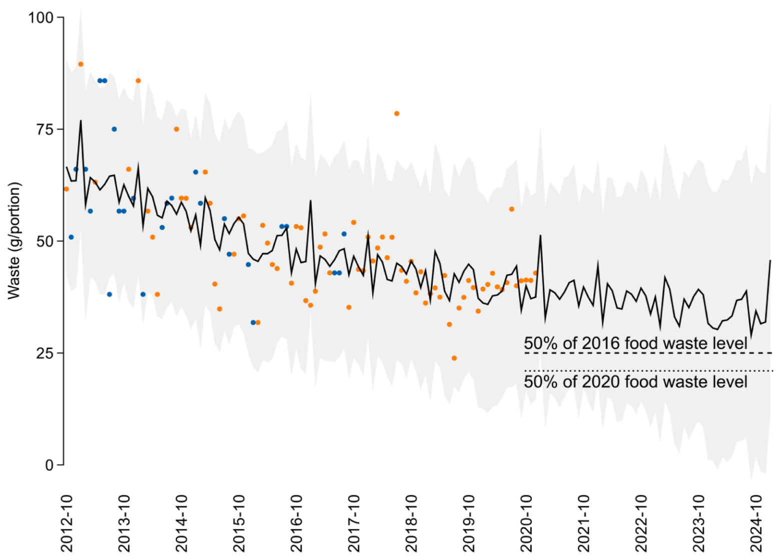

Fig. 6. Monthly median food waste in g per portion over time for Swedish primary school canteens. ● indicates monthly aggregated level of food waste between October 2012 and December 2020, ● indicates imputed monthly values. **–** indicates the model fitted to data, with the shaded area illustrating 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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Food waste is an urgent problem that needs to be addressed. Studies show that 18% of food served within the catering service sector is wasted. Improved forecasting and direct feedback on food waste quantities are effective measures to reduce food waste. Food waste in the Swedish public catering sector was reduced by 25% between 2016 and 2020. Systematic work on food waste quantification that leads to waste reduction is necessary for a more sustainable food system.

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