Food waste in the food service sector

Quantities, risk factors and reduction strategies

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Abstract

An estimated one-third of all food produced is wasted, meaning that much of the negative environmental impact caused by food production is in vain. Global ambitions to reduce food waste include halving the levels by 2030, while the new EU food strategy views reducing food waste as a key issue in achieving a sustainable food system.

This thesis presents detailed information on the volumes of food waste, where it occurs, why it occurs and what can be done to reduce it. The information originated from 1189 kitchens operating in establishments such as canteens, care homes, hotels, hospitals, preschools, schools and restaurants throughout Sweden, Norway, Finland and Germany. The results indicated that approximately 20% of food served in the catering sector is wasted, although there is large variation, with canteens reporting 50±9.4 g/portion of food waste and restaurants 190±30 g/portion. To identify risk factors and reasons for food waste, a more detailed subset of data on Swedish preschools and schools was analysed. Some of the risk factors identified related to kitchen infrastructure and guest age, which could be difficult or expensive to tackle as a first option. The main risk factor was the amount of food prepared relative to the number of guests attending, an issue that kitchens can tackle by forecasting. This thesis demonstrated the potential of forecasting attendance as a tool in planning catering operations. The current business-as-usual scenario, where food is prepared for all pupils enrolled, results in a mean error of 20-40%, whereas the best forecasting case, using neural network models, resulted in a mean error of 2-3%. However, forecasts can underestimate demand, creating shortages, so some margin must be added in practical use. Providing kitchens with information about roughly how many guests will attend a meal, plus a sufficient margin, and encouraging them to serve food from a backup stock in cases of forecast underestimation would overcome the problems of shortages, reduce food waste and contribute to a sustainable food system.

Keywords: Quantification, risk factors, forecasting models, system optimisation, kitchens, public catering

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Matsvinn i storkök och restauranger

Sammanfattning

Det uppskattas att en tredjedel av all mat som produceras försvinner. Det innebär att en stor del av den negativa miljöpåverkan som livsmedelsproduktionen utgör har ägt rum i onödan. Det finns dock globala ambitioner att matsvinnet ska minska med hälften till år 2030, vilket även speglas i EU:s livsmedelsstrategi där matsvinnet är en av nyckelfrågorna för ett hållbart livsmedelssystem.

Den här avhandlingen undersöker hur stort matsvinnet är, varför det uppstår och vad som kan göras för att minska det i storköks- och restaurangsektorn. Underlaget kommer från 1189 kök som lagar mat till arbetsplatser, förskolor, hotell, sjukhus, skolor, restauranger och äldreboenden med verksamheter spridda i Sverige, Norge, Finland och Tyskland. Det konstaterades att ungefär 20% av all mat som serveras slängs. Det är dock en stor variation där exempelvis arbetsplatser rapporterar svinn kring 50±9.4 g/portion medan restauranger uppmätte 190±30 g/portion. Några av de identifierade riskfaktorerna är kopplade till vilken infrastruktur köken har samt ålder på gästerna. För att undersöka riskfaktorer användes ett mer detaljerat underlag baserat på data från förskolor och skolor i Sverige. Den mest framträdande riskfaktorn är att kök lagar för mycket mat i förhållande till hur många gäster som kommer där överskottet blir svinn. Därför undersöker avhandlingen potentialen i att använda olika prognostiseringsmodeller av närvaro. Idag lagar kök i regel mat till alla inskrivna elever vilket resulterar i ett medelfel på 20-40% av hur många som faktiskt kommer. Det står i kontrast till de bästa prognostiseringsmodellerna, baserade på neurala nätverk, vilka har ett fel på runt 2-3%. Utmaningen är att modellerna ibland underskattar hur många som ska komma, det behövs därför en viss marginal. Lösningen på detta är att ha kunskap om hur många som förväntas komma, hur ofta en prognos har fel och med hur mycket och då ha ett reservalternativ redo att direkt servera. På så sätt finns det potential att minska matsvinnet med hjälp av prognostisering och bidra till ett mer hållbart livsmedelssystem.

Nyckelord: Matsvinn, matsvinnsmätning, riskfaktorer, storkök, restaurang, prognostisering, optimering, offentliga måltider

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Contents

List of publications

This thesis is based on the work contained in the following papers, referred to by Roman numerals 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.

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

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

1. Introduction

Food is essential for human survival, but human societies have come a long way in most parts of the world from traditional ways of obtaining food to today's complex system where food is a globally traded commodity, highly interconnected and rapidly evolving (Puma, 2019). The global food system is also one of the main drivers of climate change, changes in land use, depletion of freshwater resources and pollution of aquatic and terrestrial ecosystems, through excessive nitrogen and phosphorus inputs (Springmann *et al.*, 2018). Current trajectories of population and consumption growth highlight the importance of finding future solutions that meet food demand in a sustainable fashion (Godfray *et al.*, 2010). However, the way to achieve this is intensely debated, with two narratives dominating the discussion (Eyhorn *et al.*, 2019). One narrative seeks to increase crop and livestock yields and associated economic returns per unit time and land, without negative impacts on soil and water resources, an approach referred to as sustainable intensification (Cassman and Grassini, 2020). The other narrative focuses on transformative redesign of farming systems at the local level, based on agroecological principles (Eyhorn *et al.*, 2019; Wezel *et al.*, 2020).

Regardless of path, there is no one-stop solution that will reverse current trends single-handedly. However, one option that is mentioned independently of future viewpoint is that food waste needs to be drastically reduced in all future scenarios. This is also addressed in the United Nations Sustainable Development Goals, which state that food waste should be halved by 2030 (United Nations, 2015). Some claim that this goal is not sufficiently ambitious and that a 75% reduction needs to be in place by 2050, along with implementation of other simultaneous options to keep the planet within the safe planetary boundaries (Campbell *et al.*, 2017; Springmann *et al.*, 2018).

Since food is lost, spoilage or wasted along all parts of the food supply chain (Parfitt *et al.*, 2010), efforts to reduce waste in all steps will be necessary to achieve the reduction targets (FAO, 2019). Although reducing food waste seems like a simple problem, the solution is much more complex than 'just stop throwing food away'. It is therefore a need to understand the scale of the food waste problem and identify where improvements can be made, before establishing countermeasures. This creates a need for methodologies to quantify food waste across the food supply chain in order to obtain primary data, which at the moment are urgently needed in order to understand the problem better (Xue *et al.*, 2017). In a European context, all member states are required to quantify food waste by 2020 onwards and report national food waste 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 to report progress (European Commission, 2018). The vexing issue of food waste is also highlighted within the European Farm to Fork Strategy (European Commission, 2020). This shows that the question is on the political agenda and also aligns with the global overarching Sustainable Development Goals. Establishing quantification practices on national level would provide the potential to gain deeper insights into the magnitude of the problem, provide guidance to achieving established reduction targets and identify the most effective measures.

Previous estimates have shown that European countries are more inclined to waste food at the consumption stage of the food supply chain. This stage involves households, the food service sector and supermarkets (Stenmarck *et al.*, 2016). Wasting food at this stage means loss of more value, in terms of money and resources, since resources are accumulated for every step in the food supply chain (FAO, 2013). Establishments operating in the food service sector face a multitude of challenges in dealing with planning, receiving and preparing food for final consumption by the guests, with all steps in this chain generating waste. The sector itself is also growing, since more and more people are obtaining the financial means to eat out and are willing to pay for food services. Thus potential successful measures implemented in relatively few places could have a large impact. This because the food service sector is dominated by major companies and chains, public catering establishments or small privately-owned businesses, all of which are obliged to follow the same kinds of legislation or directives. Waste quantification in such establishments can provide information about the type of problem that needs to be addressed, but there is also a need to understand the underlying risk factors that generate waste in the first place, and to identify preventive measures that can actually reduce food waste in the food service sector and create a more sustainable food system.

2. Aim, objectives and structure of the thesis

The overall aim of the work in this thesis was to increase knowledge about food waste in the food service sector and provide guidance for food waste reduction efforts. Specific objectives were to:

I. Develop a method to structure, describe and quantify food waste in the food service sector (Paper I).

II. Identify risk factors of food waste generation in school and preschool catering units (Paper II).

III. Develop models to forecast guest attendance in order to optimize catering practices to lower over production in school catering units (Paper III).

The research conducted to fulfil these objectives was structured based on overarching themes of quantities, risk factors and measures to reduce waste. The work presented in Paper I focused on analysing quantities of food waste in the food service sector, to understand the extent of the problem and to find potential hotspots. The quantities were then analysed in Paper II to find causes and risk factors that contribute to waste generation, with the focus on preschool and school catering units. In Paper III, the knowledge gained in Paper II was developed further with the focus on measures to reduce food waste in school catering units, specifically by looking at demand in terms of guest attendance.

3. Background

It is known that food is lost, spoiled or wasted along all parts of the supply chain, but in order to grasp the problem one must reflect upon the following questions: 'When does food waste become food waste?' and, as asked by Shilling (2012) 'Who gets to define what is and what is not food waste?'. This is central to the topic and the foundation for quantification methodologies which seek to answer questions related to scale, or questions such as 'How much?' and 'What?', and a basis for understanding risk factors that generate food waste. However, there is also a need to move beyond these questions and start to address 'Why?'. This chapter of the thesis therefore introduces food waste in general in relation to overarching quantification methodologies, but with the main focus on the issue from a food service sector perspective.

3.1 Definitions of food and food waste

There is a growing body of literature covering food waste from a multitude of angles. According to Bellemare *et al.* (2017), one important limitation is that definitions of food waste differ substantially, which results in wildly differing estimates and, ultimately, different approaches to the problem of food waste. The definition dilemma starts with the fundamental question: 'What is food?' One of the most established meanings of food is 'any substance consumed to provide nutritional support for an organism'. However, this is quite broad. Looking at legal definitions of food narrows this down at least partly, as illustrated by the European Commission's definition in Regulation (EC) No. 178/2002 (European Commission, 2002) on general principles and requirements of food law, where "food" (or "foodstuff") means:

> …any substance or product, whether processed, partially processed or unprocessed, intended to be, or reasonably expected to be ingested by humans. "Food" includes drink, chewing gum and any substance, including water, intentionally incorporated into the food during its manufacture, preparation or treatment. It includes water after the point of compliance…

However, in relation to food waste this creates some problems, as pointed out by Schneider (2013), since cultural norms on what is intended to be ingested by humans differ from country to country and even within countries. In addition, animals which die or are killed before being placed on the market are not defined as food. The same kinds of problems arise for plants.

Plant products which are not harvested due to low market price or because they do not meet quality standards, such as size or colour, are not counted as wasted food, as they are rejected prior to harvest. The issue of what constitutes the starting point of the food system is also reflected in the various definitions put forward by different actors. The Food and Agriculture Organization of the United Nations (FAO) considers food losses as occurring along the food supply chain from harvest/slaughter/catch and up to, but not including, the retail level. Food waste, in the FAO definition, occurs at the retail and consumption level (FAO, 2019). In contrast, Östergren *et al.* (2014) define food waste as any food, or inedible parts of food, removed from the food supply chain to be recovered or disposed of (including composted plant parts, crops ploughed in/not harvested, anaerobic digestion, bioenergy production, co-generation, incineration, disposal to sewer, landfill or dumped at sea). Their meaning of "removed from the food supply chain" also 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" the chain, regardless of the cause, point in the food supply chain or method by which it is removed.

Further along in the food chain, where the problem is not longer about when food becomes food, the topics more often revolve around what the parts of food that is considered edible or inedible, or avoidable or unavoidable food waste.

3.2 Definition of the food service sector

Food service outlets are facilities that serve meals and snacks for immediate consumption on-site (food away from home). This category includes full-service restaurants, fast food outlets, caterers, cafeterias and other places that prepare, serve and sell food to the general public for a profit, or provide this service with support from the government (Saksena *et al.*, 2018). Another popular term for the food service sector is the eating-out-of-home sector, which may explain slightly more about the kind of establishments that are included and not within this sector. The food service sector is situated in the late phase of the food supply chain, along with households, and both these stages are estimated to produce significant volumes of food waste (FAO, 2011; Stenmarck *et al.*, 2016).

Current population growth and consumption trajectories also point towards a growing urban population and an expanding tourism and food service sector (Knorr *et al.*, 2018; Satterthwaite *et al.*, 2010). This will potentially increase the number of food service outlets and the amount of food waste generated. At present (pre-pandemic), the food service sector employs many people in Europe alone, with roughly 8% of the entire workforce employed in this sector (EUROSTAT, 2018). This makes it important in terms of the economic and social value it creates. It is also reported that one in five meals is eaten within the sector (IRi world wide, 2017).

The Statistical Classification of Economic Activities in the European Community, commonly referred to as NACE (European Commission, 2006), 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). It is important to bear in mind, as with all structural business statistics, that only enterprises for which the provision of accommodation, food or beverages is the principal activity are covered by this definition and category. Enterprises offering food and drink as a complement to their core business are not included, although in some cases meals and beverages may represent a significant secondary activity, such as in sports stadiums, cinemas or recreation parks (if these are not operated by separate enterprises). It can therefore be difficult to pinpoint and get exact numbers from official records to determine the size of this sector. However, it is clear that the food service sector is part of hospitality services, which also include accommodation and meetings (Myung *et al.*, 2012).

The food service sector is generally made up of small to medium-sized enterprises providing food in some form for different kind of meals. Establishments that operate in the food service sector have a multitude of different types of settings due to underlying conditions, such as types of customers targeted, seasonality, whether food is a primary or secondary business, size of the establishment and operating hours, and the type of meals served. A solution to reduce food waste in one establishment may therefore not necessarily be effective for another establishment, and one solution that works to reduce food waste for a lunch meal might not be effective for a breakfast meal in the same establishment.

The most established sites in the food service sector are places such as work canteens, restaurants, hotels, preschools, schools, secondary schools, care homes for the elderly and hospitals. Some of these operate on the free market and some are under the public catering umbrella, which means that their operations are funded partly or totally through taxes, depending on subsidies or government support. In some cases, companies are brought in through the procurement process to operate *e.g.* a hospital kitchen, while in other cases this is taken care of entirely by the public catering organisation. In Sweden and Finland, the majority of public catering is organised by municipal authorities (290 and 310 municipalities, respectively), which are responsible for preschool and school meals, along with meals for the elderly in care homes. The municipalities vary in geographical size and population density, and also in how they are organised. In Sweden, the municipalities fall into one of 21 regions, that with a regional authority that is responsible for healthcare, transport and regional development. The regions share the same kinds of characteristics as the municipalities. Table 1 shows how the food service sector in Sweden is comprised, covering public catering and private actors.

The vast majority of actors are located within the private sector, which according to Statistics Sweden (2019) contains roughly 38 000 registered establishments that at some point provide food within hotels, restaurants, canteens, bars and pubs. It is difficult to get exact data on the number of people that use their services on a daily basis, but according to the Swedish Agency for Economic and Regional Growth (2020) restaurants are responsible for 9.2% of tourist consumption, which represents roughly 0.3% of Swedish gross domestic product (GDP). Both Statistics Sweden and the Swedish Agency for Economic and Regional Growth reported around 39 500 000 nights spent in hotels in the year 2019. The total food sector was reported to have a turnover of around 151 billion SEK in 2013, with the food service sector contributing 85.8 billion SEK excluding VAT (Swedish Competition Authority, 2015).

It is also estimated by Delfi (2015) that 50% of all midday meals are served within the public catering sector. The data for this sector offer better transparency, especially for preschools, schools and secondary schools, as information is available on how many school units exist and the number of enrolled students who participate in education at different levels. This is not necessarily an accurate representation of the number of school kitchens which actually exist, but is the best available guess since all pupils have the right to one free meal each school day according to law (Swedish Parliament, 2010), and they have to eat somewhere. The actual number of units that exist to serve meals to preschool and school pupils is probably lower than that shown in Table 1. The main meal served within schools is lunch, while a majority of preschools also serve breakfast and a snack. Within elderly care, all meals in the day are normally served. In addition to the data presented 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 food box. On top of this, 10 000 elderly people take part in some daily clubs or activities where food can be served.

Sweden has 103 hospitals within its 21 regional authorities (Swedish Association of Local Authorities and Regions, 2020). It is estimated that 25 000 people are served food on a daily basis when they are in contact with healthcare. The vast majority of people who get their meals from the public catering sector are indisputably schoolchildren aged 6-19 years, whereas jails and custody facilities are the smallest segment within the public catering sector. Overall, the Swedish public catering sector purchases food items costing around 8 billion SEK per year, on top of which there are also costs for staff and premises (Swedish National Food Agency, 2019a).

Table 1. Food service situation in Sweden (values rounded off)

Establishment	Units (n)	Guests/day (n)	Age of guests	Sector
Preschools	9800	520 000	1-5	Public[1]
Schools	8500	1 200 000	6-15	Public[1]
Secondary schools	1300	360 000	16-19	Public[1]
Care homes	1700	110 000	65+	Public[2]
Hospitals	103	25 000	0+	Public[2,3]
Jails and custody facilities	45+32	5000+2000	15+	Public[4]
Swedish Armed Forces		22 700+	18-65	Public[5]
Hotels with restaurant	2200			Private[6]
Restaurants, canteens, bars and pubs	35000			Private[6]

3.3 Quantification methodologies and previous studies

Not all kitchens are the same, but they share many characteristics. In order to quantify the amount of food waste generated, it is essential to find common ground and establish what should be quantified, when and for how long. This is important if the goal is to compare different facilities with each other. Quantification of food waste can also be a tool for facilities to get an understanding of their food waste situation and where there are potential problems that they should start to address. Characteristics that all kitchens share is that they have some kind of inflow of food. This can be either in the form of raw food items or ready-made foods from some other actor. The next step is preparation of the food and the last step is serving it to the guests. Waste can occur in all of these steps and there can also be some waste discarded by the guests in the final consumption phase. However, this is quite a simplistic view of all the processes that occur within a kitchen, and a slightly more realistic illustration is provided by Eriksson *et al.* (2018b) (Figure 1).

[1] Swedish National Agency for Education (2019)

[2] Swedish National Board of Health and Welfare (2019

[3] Delfi (2015)

[4] Swedish Prison and Probation Service (2019)

[5] Swedish Armed Forces (2019)

[6] Statistics Sweden (2019) SNI:55101, 56

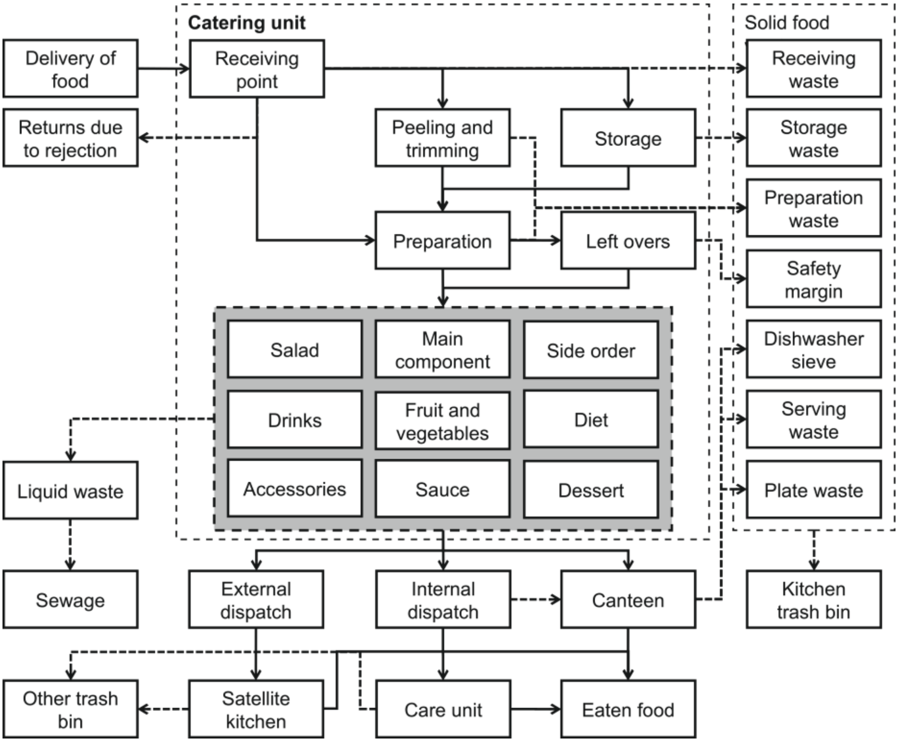

Figure 1. Schematic figure of the mass flow in a catering establishment, illustrating the process-based waste categories. The grey area indicates food prepared in the production (catering) unit, but sent out to be eaten in different places.

The diagram shows when the state of food is altered, for instance by adding water in the cooking process. This means that, depending on where the reference point is set, one can end up with various levels of waste. The diagram also shows that there is plenty of room for errors which might lead to food waste, since there are decisions to be taken, often with time constraints, in all of the intermediate steps ranging from planning to serving. Figure 1 takes into account liquid waste and also divides the preparation into different food categories. It shows a production kitchen, one of the two major types of kitchen in the Swedish public catering sector. In a production kitchen, all food prepared on-site. The other type is a satellite kitchen, which prepares some meals, but mainly relies on deliveries from a production kitchen. Since a kitchen is quite complex when it comes to the different places where food waste can be generated, there is a need for a systematic way of quantifying food waste. There are a multitude of different kinds of frameworks available to help facilities with their food waste quantification endeavours (Eriksson *et al.*, 2018b; Hanson *et al.*, 2016; Swedish National Food Agency, 2019b; Tostivint *et al.*, 2016). To achieve transparent food waste quantification, it is necessary to define precisely the waste arising from each kitchen process. The different definitions for the waste-generating processes in kitchens are summarised in Table 2. The waste processes can be broken down further to capture the categories that arise from the different processes, depending on the goal of the quantification and the problem that quantification is intended to solve. For instance, the process of serving waste can be refined to also capture whether food is from the main component or side dishes, as displayed in Figure 1, or even down to food item level.

There is a need to balance the quantification efforts between the level of detail that can be obtained against what is practically possible to achieve during a longer quantification period. One must also consider the kind of method to be used for quantifying waste. Some previous studies have used visual observation (Connors and Rozell, 2004; Hanks *et al.*, 2014), which have a tendency to underestimate the levels of food waste generated (Comstock *et al.*, 1981; Martins *et al.*, 2014). This means that standardised methods must be used for national quantification in order to compare results and to track progress over time, to see if goals on national and global level can be achieved.

Simply quantifying the amount of mass thrown away is seldom sufficient for comparison purposes, since a large kitchen is always likely to report more waste than a small kitchen. To balance this, kitchens would need to use some kind of indicator such as ‘waste per portion’ or ‘waste (%) of served food’, to get relative numbers. The indicators used can also take the form of key economic performance indicators, such as ‘food discarded per Euro’ or other suitable economic indicator. However, actors in the commercial catering sector can be reluctant to share this type of information, while in the public catering sector these numbers might not even be known to those in charge of waste quantification. It is therefore appropriate to adopt a practical approach when quantifying food waste, to make sure that the quantification takes place and is not abandoned because it is too complicated. Table 2 captures most of the waste processes and also other aspects used when performing food waste quantifications. It is common in practice for ‘receiving, storage, preparation and safety margin waste’ to be bundled together and called ‘kitchen waste’

(Swedish National Food Agency, 2019b), as a trade-off to achieve a simpler quantification process.

Table 2. Definitions used in the food waste quantification process

Name	**Definition**
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 inedible parts such as bones and peels.
Waste	Sum of mass from the different food waste processes.
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 kitchen	A kitchen that prepares all meals from raw materials.
Satellite kitchen	Kitchen that can prepare 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 x 1000.
Waste (%) of food served	Waste (kg) divided by food served (kg) x 100.

Previous studies displays some weaknesses in the methodology regarding food waste quantification, where most of the studies are case studies performed by researchers or limited by researchers’ access to data. What unites all the studies within Table 3 is that all used some kind of physical observation to determine levels of food waste. The aims, scope, establishment/s studied and where the studies were performed were different, however, making it difficult to compare the results directly. This is mostly reflected by what was quantified in the different studies and the length of the study. For instance Barton *et al.* (2000) examined plate waste and tray waste in a hospital setting for a 28-day period, whereas Engström & Carlsson-Kanyama (2004) studied two schools and two restaurants and categorised food waste into storage loss, preparation loss, serving losses, plate waste and leftovers, and then divided the losses into food item types over two days.

Betz *et al.* (2015) followed roughly the same approach, but made a distinction between gross and net weight. They defined gross weight as the unprepared food item with the same weight as when delivered, and net weight as food prepared and which has undergone a weight change. Some studies only considered special parts of the kitchen process, for instance Juvan *et al.* (2017) who reported 15.2 g/portion, looked at edible parts discarded from the plate in a hotel setting. Papargyropoulou *et al.* (2016), who reported 1100 g/portion, looked at preparation waste, plate waste and buffet leftover waste and used visual estimation to determine avoidable and unavoidable fractions of the waste from the quantified processes. The results from the two studies were very different, but this is understandable when considering the differences in how the studies were carried out and their duration. Another study focusing solely on plate waste was carried out by Liu *et al.* (2016), but they set their findings in relation to total food served and divided the proportion of food into different food items. Some studies involved an element of quantification but did not display the results from the quantification (Kallbekken and Sælen, 2013). Some researchers (*e.g.* (Jacko *et al.*, 2007)) argue that aggregated methods to measure plate waste are more favourable than weighing each plate/tray separately, as this is less time-consuming and therefore more suitable for long-term data collection performed by kitchen staff, although it would lead to less detailed information being obtained from the quantification.

It is necessary to make a shift from method development for research focused quantification that aims to answer specific research questions to developing a more suitable method for kitchen staff to perform food waste quantification. This would provide kitchens with a tool to reduce their food waste, since kitchen staff would have the ability to reduce their food waste on a daily basis.

Table 3. Aspects covered in previous food waste quantification studies.

Kitchen type	Country	Units (n)	Duration	Waste (%)	Waste/portion (g)	Source
Hospital	UK	1	28 days	>40	-	Barton *et al.* (2000)
Schools & restaurants	Sweden	4	2 days	20	92.5	Engström & Carlsson-Kanyama (2014)
Catering	Egypt	-	-	23-51	126,131,166	El-Mobaidh *et al.* (2006)
Hospital	UK	3	2 days	19-66	-	Sonnino & McWilliam (2011)
University	Portugal	1	4 weeks	24	280	Ferreira *et al.* (2013)
Food service sector	Finland	72	1 day – 1 week	8-27	-	Katajajuuri *et al* (2014)
Preschool	USA	1	5 days	45.3	210	Byker *et al.* (2014)
Schools	Portugal	21	1 month	27.3	49.5	Martins *et al.* (2014)
Hospital	Portugal	1	8 weeks	35	953	Dias-Ferreira *et al.* (2015)
Schools	Italy	3	92+33 days	15.31	-	Falasconi *et al.* (2015)
Schools & restaurants	Switzerland	2	5 days	7.69 & 10.73	86 & 91	Betz *et al.* (2015)
Food service sector	Finland	51	5 days	19-27	58-189	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)
Preschools	Sweden	4	2 weeks	-	145	Hansson (2016)
Schools	China	6	1 day/unit	21	130	Liu *et al.* (2016)
Public sector	Sweden	30	3 months	23 (13-34)	75 (33-131)	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	~50	980, 757	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)

Therefore there needs to be a balance between the level of detail observed and the time required for quantification on the selected level of detail. Very detailed quantification is not likely to be maintained for long periods, while a simple quantification procedure that can be performed indefinitely might not reveal the real problems.

The Swedish National Food Agency has established a national quantification standard that aims to make it easy for kitchens in the public catering sphere to quantify their food waste and get comparable numbers on national level (Swedish National Food Agency, 2019b). This is in line with the ambition to provide national figures to the European Union, to track progress in reducing food waste by half by 2030.

In the national quantification standard, kitchen waste, serving waste and plate waste are recorded, along with information about the number of portions. The quantification can also encompass the amount of food served. From this, key performance indicators such as food waste/portion can be derived and also allocated to the different processes (kitchen waste, serving waste, plate waste), and the total amount of food waste in kilograms (also allocated on the different processes) can be determined. Quantifying the amount of food served also makes it possible to track the amount of food consumed by the guests, which is an important aspect from a national health perspective.

The standard also captures metadata on the kitchen, such as the type of establishment conducting the quantification (preschool, school, secondary school, care home, hospital), the type of kitchen (production or satellite kitchen) and when the quantification took place (date). Some limitations are also addressed, with the aim of making the quantification more practical. Items such as peel, bones and napkins are included in the waste, so that no sorting of these items has to be done. Liquid is not part of the quantification and is excluded. Accessories such as butter for bread are also not included. If liquid components such as soup are served, this is quantified in litres and later converted to kilograms under the assumption that one litre equals one kilogram. If the amount of food served is quantified, it is sufficient to quantify one container of each component (if they are approximately equal) and then multiply the weight by the total number of containers of each component. This standard quantification procedure aligns well with the proposed quantification standard (Tree Structure) suggested by Eriksson *et al.* (2018b). The national standard for quantifying food waste is quite new, but quantification of food waste has already become quite common in the past decade. One survey conducted in 2012 showed that about half of Swedish schools measured food waste at a frequency of one week per semester or higher (School Food Sweden, 2013). A study performed in 2018 showed that 55% of the 290 Swedish municipalities quantify food waste on central level. The most common practice is to quantify plate and serving waste from school lunches during two weeks per year, and to compile waste data in spreadsheets and compare the values against the number of plates used, giving a result in grams per portion served. The Swedish municipality that first started quantifying food waste began doing so in 2000, but only 17 municipalities started food waste quantification before 2010. The start year peak was 2014, when 36 Swedish municipalities began to quantify their food waste (Eriksson *et al.*, 2018a). All this quantification took place with no official guidelines or policy instructing the municipalities to do so. Rather, it was somewhat of a grassroots movement that the Swedish National Food Agency now has the opportunity to build on and develop further. After launching the national quantification standard, the Swedish National Food Agency conducted its own mapping of the food waste situation in Sweden. The results showed that 211 out of 290 municipalities reported food waste data to the Agency in some form. The median value reported from the municipalities for preschools and schools was 60-70 g/portion (excluding drink). The reported food waste was lowest in schools, the establishments for which most data were available. The largest contributor to food waste was care homes for the elderly, but data were most scarce for this part of the sector. The survey concluded that there are large variations in reported food waste between the different municipalities in Sweden (Swedish National Food Agency, 2019a).

One drawback of the Swedish National Food Agency's way of collecting information is that it relies on municipalities to answer a questionnaire and it does not collect any raw data using its own proposed standard approach. This makes analysis of the results somewhat difficult, since the underlying data that make up the results are not available for study. The survey also excludes hospitals and private actors operating in the public sector. The official Swedish food waste data are reported by the Swedish Environmental Protection Agency, which tracks the development of the food waste situation in Sweden every second year. Most recently, it concluded that large-scale catering is responsible for around 75 000 tons of food waste and that the restaurant segment makes a similar contribution, of around 73 000 tons (Swedish Environmental Protection Agency, 2020). However, the methodology used to calculate and analyse the official food waste data needs to be more transparent, since the underlying steps are not displayed.

Inspired by the negotiated agreement made between actors in the food industry in Norway (KuttMatsvinn, 2020), Sweden is now moving in the same direction. The idea is to get actors from the food industry to come together to reduce food waste. Data collection is a vital part of this work and can hopefully provide more insights on the situation (IVL, 2020), especially in the sphere of private actors operating in the food service industry, which is currently a blank spot in the data, at least from a Swedish perspective. This ambition also aligns well with the policy brief published by Strid (2019), which states that establishment of a national centre for data collection regarding food waste is a vital step in ensuring that the actions taken to reduce food waste drive development in the desired direction.

3.4 Causes of food waste and reduction strategies

Previous studies of the public catering sector have concluded that production units have significantly lower waste levels than satellite units, but that there is great variation between kitchens of the same type (Eriksson *et al.*, 2017). A study quantifying food waste in an American primary school based on a quantification period of five days concluded that portion size, noise levels, time available for food consumption and children's age were possible factors determining food waste in schools (Byker *et al.*, 2014). Other attempts to determine and identify the drivers of food waste in the school environment have been made, but they mostly rely on surveys and focus on ensuring nutritional needs via school lunch, instead of on reduction of food waste. Kinasz *et al.* (2015) developed a checklist for the prevention of food waste based on the votes of experts, but concluded that more research is needed to identify waste generation. Their checklist has similarities with the handbook for reduced food waste released by the Swedish National Food Agency (Swedish National Food Agency, 2020b). Both checklists suggest that dining ambiance and knowledge about the diners are factors influencing food waste in public catering, among other factors. Information campaigns are mentioned as a solution to the food waste issue, based on the argument that if all guests and staff are informed, they will stop wasting food. It has been shown in university settings that students who receive information about food waste have the potential to achieve a waste reduction of 15% Whitehair *et al.* (2013). However, only 40% of the students approached agreed to participate in that study and let their tray waste be quantified. Nudging might be a better option for changing the underlying behaviour of guests throwing away food. As an example Kallbekken and Sælen (2013) found that reducing plate size significantly reduced plate waste, while Thiagarajah and Getty (2013) found that removing the trays from a university dining hall reduced food waste.

Kuo and Shih (2016) suggest that gender is the main driver of food waste, and especially plate waste, as they found that female plate waste in universities was significantly higher than male plate waste. Having competing alternatives outside the dining hall increased plate waste for sixth graders in a study by Marlette *et al.* (2005). Other studies suggest that age is an important factor influencing food waste behaviour in schools, with some studies concluding that preschool plate waste is significantly higher than for children in higher school years (Niaki *et al.*, 2017). However, those authors also point out that the younger guests had their lunch break two hours earlier than the older guests, and therefore suggest that differences in lunch break procedures should be examined as a factor coupled to food waste behaviour (Niaki *et al.*, 2017). An earlier study found that children in school years 1 to 3 reduced their food waste by 10% when they had their break before eating lunch (Getlinger *et al.*, 1996).

The UK has a long history of working against food waste and a dedicated organisation, WRAP, has made three intervenetions (improving familiarity and appreciation of school meals, improving the dining experience, children ordering their meals in advance to cooking them) and tested these interventions in 39 schools. The results showed a 4% waste reduction, but the reduction was not statistically significant (WRAP, 2011). Barr *et al.* (2015) theorised that a LEAN philosophy (a systematic method including elimination of waste within manufacturing) could reduce overproduction, and thereby food waste, in school canteens, and tested this approach in Swedish schools. However, they were unable to demonstrate any reduction in food waste due to insufficient waste quantification. This highlights the importance of a systematic approach when evaluating food waste reduction interventions. A more data-driven approach to testing risk factors was taken by Eriksson *et al.* (2016), who tested the effect of six risk factors in a Swedish public catering organisation. Among the risk factors and measures analysed, the use of satellite kitchens and serving more than one lunch option generated the most waste. Informing school pupils about waste quantification and providing a flexible lunch alternative on the menu reduced food waste, but the effect was smaller than that of eliminating the two main risk factors. The claim that larger kitchen units generate more waste was only confirmed for plate waste, while overall waste was reduced slightly as kitchen size increased (Eriksson *et al.*, 2016). The claim that popular dishes result in extra waste was also shown to be untrue, since popular dishes were discarded to a lesser extent than other dishes (Eriksson *et al.*, 2016).

Filimonau and Coteau (2019) argue that from an organisational and stakeholder theory perspective, mitigation of any environmental impact requires understanding of its importance by people who are familiar with the issue and also capable of making decisions on behalf of the business. In the case of food waste, managers are such people, as not only they define what food to order and cook and how to serve it, but are also in charge of decision-making on the floor. Therefore, Filimonau and Coteau (2019) argue that managers need to reflect upon their knowledge and experience of dealing with this issue, both in terms of scale and scope but also the underlying causes of food waste generation. They also argue that the underlying causes are linked to the challenges of effective reduction measures, where for example irresponsible consumer behaviour brings about large food wastage, but managing consumer behaviour can be difficult in the food service sector due to high competition, volatile customer loyalty and limited in-house resources, to name a few factors. The challenges of food waste reduction are costs to businesses that need to be carefully evaluated by managers and staff when deciding on reduction options.

4. Material and Methods

Overall the material used in the different papers are shared. The material for Paper I and II have focus on food waste data, were Paper II contains a subset of the data but with additional collected parameters to be able to identify and model risk factors. The material for Paper III focus on number of guests and metadata around the kitchens such as number of enrolled students to understand the dynamics of demand and methods covering forecasting and inventory theory. Figure 2 shows the links between the material.

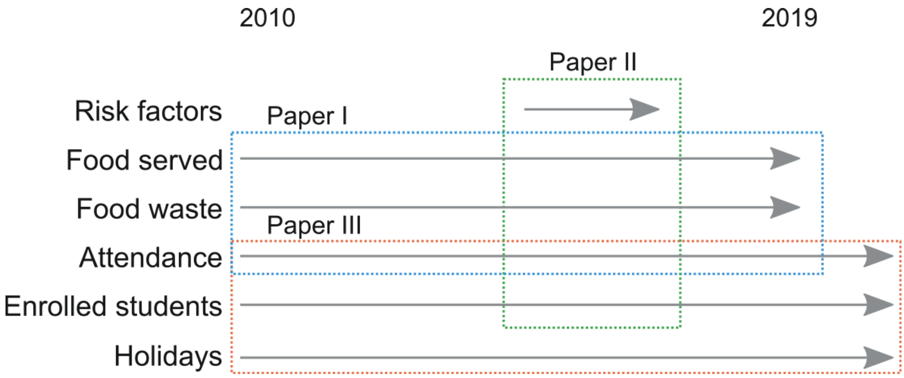

Figure 2. Schematic illustration of the data used in Papers I, II and III and the links between the analyses.

In Paper I, the levels of food waste in 1189 food service outlets in the Nordic region between January 2010 and early 2019 were investigated. The quantification data examined originated from units such as canteens, care homes, hospitals, hotels, preschools, primary schools, secondary schools and restaurants. In Paper II, the material covered 177 kitchens spread across the municipalities of Falun, Malmö, Sala, Uppsala and Örebro. In Paper III, 21 kitchens provided data from 2010 to 2019.

4.1 Quantities of food waste

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

All the food waste quantifications were performed by the organisations themselves, with the focus on weighing waste masses using various kitchen scales. The results of quantification were documented manually on paper or in spreadsheet software, although some kitchens used dedicated food waste quantification online applications provided by different software companies, and some kitchens used a dedicated smart scale for the quantification process. A feature in common for all kitchens participating was that kitchen staff performed the data collection on-site. In some cases, researchers helped with the collection procedure by sorting out and weighing food waste in a few kitchen establishments, which might have influenced the results for those few cases. Additional data, such as number of portions served and, where available, the amount of food served, were collected in order to calculate key performance indicators. Data were summarised on a daily basis per meal for each kitchen unit and most data only covered lunch, although establishments such as care homes, hospitals, hotels and preschools typically serve other meals as well. Figure 3 illustrates the framework used in Paper I and II for quantifying the food waste generated in the establishments studied.

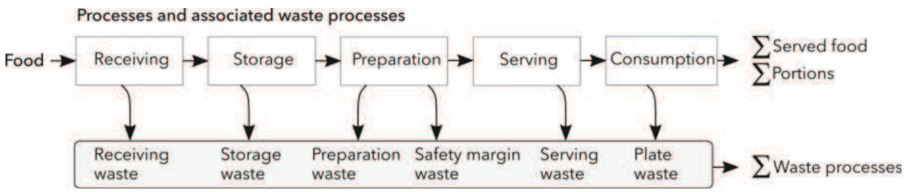

Figure 3. Waste processes captured in the quantification step in different types of catering establishments, together with additional information on food served and number of portions.

The quantification data for the different catering establishments are summarized in Table 4. The majority of the data originated from canteens, hotels and primary schools. Quantification of food served requires more effort than quantifying food waste. Consequently, hotels did not quantify the amount of food served at all, and canteens, hospitals and restaurants rarely made the effort (Table 4). Therefore the data in Table 4 were not subjected to any kind of calculations or derivation of key performance indicators, since this would have given inaccurate answers

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 key performance indicators

Sector	**Days (n)**	**Units (n)**	**Waste (tons)**	**Food served (tons)**	**Portions (10^3)**
Canteens	16 130	288	520	4	9900
Care homes	2155	62	110	19	880
Hotels	12 583	93	570	0	4700
Hospitals	1018	17	110	9	990
Preschools	6462	290	32	61	420
Primary schools	15 183	343	270	740	4600
Restaurants	3453	48	40	2	1100
Secondary schools	1828	48	84	180	1100
Total	58 812	1189	1736	1015	23 690

The data covering canteens represented 288 units, of which 178 were located in Norway, 106 in Germany and four in Finland. Care homes for the elderly were represented by 20 units located in Sweden and 42 in Germany. The data encompassing hotels originated from 43 establishments located in Germany and 50 in Norway. Sixteen of the hospitals from which data were obtained were located in Sweden and one in Germany. Preschool data originated from 256 Swedish units and from 15 preschools located in Finland and 19 in Germany. Of the 343 primary schools, 296 units were within public catering services in Swedish municipalities, 20 units were from Finland and 27 units were located in Germany

Swedish and Finnish primary schools educate children in the ages from around 6 up to 15. From a German perspective, primary schools refer to units educating children in the ages 6 to 10. The restaurant data used in this thesis originated from 48 units, of which 39 were located in Norway and nine in Finland. The secondary school segment is very much like the primary school segment, apart from the fact that the guests are older (age 15-19 in Sweden and Finland, 10-19 in Germany). The material used comprised 48 such kitchen units, of which 39 were in Sweden, six in Finland and three in Germany.

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 overarching steps. The first step involved identification of risk factors from previous studies and the second step involved collection of quantitative data that could function as indicators for different potential risk factors, in combination with quantified food waste data. Possible risk factors were identified from the literature in Paper II and are summarised in Table 5. These risk factors did not cover 'soft' parameters such as attitudes and opinions, which were excluded from the study in Paper II due to the difficulties associated with their quantification and generalisation.

Some factors that are difficult to quantify, such as stress, were captured by proxy factors such as time available for eating, and were used as an indicator of how stress was correlated with food waste generation. There are several other factors that could influence the levels of food waste, such as day of the week (Byker *et al.*, 2014; Eriksson *et al.*, 2017), different meal components and their pairings (Painter *et al.*, 2016), popularity of certain dishes (Painter *et al.*, 2016), availability of competing food items (Marlette *et al.*, 2005; Painter *et al.*, 2016) and gender of guests (Kuo and Shih, 2016).

In Paper II, a questionnaire was sent to the public catering managers in the five municipalities studied, to get information about the dining systems in the preschools and schools for the units that supplied the food waste quantification data. The information collected consisted of quantitative data on number of students enrolled, age of students, number of employees working in the kitchen (which was used to calculate the number of employees per student), and the gender distribution of the kitchen staff. Information on the type of dining space (whether students eat in classroom or not) and on the distance between dining space and classroom was also collected, together with information regarding the number of seats available in the dining space, which was used to calculate the number of available seats per student. The variety of meal options and comparable number of dishes were also recorded, along with information regarding number of semesters of food waste quantification. Type of kitchen was divided into whether the kitchen was a production or satellite unit Portion size was calculated from the available quantification data as the amount of food served divided by the number of portions served. To get an understanding of the attendance structure, the standard deviation in the number of guests attending meals was calculated. Some factors, such as number of students enrolled in a school and dining hall capacity, may fluctuate over time, but such fluctuations were assumed to be sufficiently small to allow general trends in the data to be detected

Table 5. Parameters that could have an influence on the amount of food waste generated in educational establishments according to the literature, hypotheses concerning parameters and possibilities to quantify the parameter

Parameter	**Hypotheses according to literature**	**Quantification**
Children's age or differentiation between preschools and 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 of overproduction and to improve management.
Dining ambiance, noise and students physical or emotional condition	A calm ambiance in the dining hall reduces food waste (Byker *et al.*, 2014; Kinasz *et al.*, 2015; Painter *et al.*, 2016; SEPA, 2009)	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 time at which lunch is served	To decrease food waste, children should have enough time to eat during their lunch break (Byker *et al.*, 2014; Getlinger *et al.*, 1996; Niaki *et al.*, 2017; SEPA, 2009)	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 students food intake. Time available for lunch is often restricted by schools' dining hall capacity.
Management factors and guest knowledge	Possible factors influencing food waste (Kinasz *et al*., 2015)	Some management factors and the knowledge of students 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 factors influencing food waste (Painter *et al.*, 2016; Whitehair *et al.*, 2013)	Awareness of food waste can be assessed using education/no education or information about food waste given to the staff members and children as an indicator. This factor is quantifiable given suitable data.
Distance between classroom and dining space	Possible factors influencing food waste (Painter *et al.*, 2016)	The distance could be quantified as different categorical groups.

4.3 Material used for modelling attendance using forecasting and inventory theory

The data used in Paper III consisted of number of guests attending lunch meals in the 21 units studied. The procedure applied for obtaining the data was to count the number of plates after each meal, which was done by the kitchen units themselves. In addition to 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 4 shows the seasonal characteristics of public catering organisations and indicates how the attendance on a daily basis is related to the number of students enrolled. Economic data were also obtained for 17 of the 21 kitchens studied and used to determine portion costs. 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 produce from an economic perspective.

Figure 4. Number of guests over time at school kitchens in a municipality where ● indicates normal day and ● indicates holiday with less activity, where the schools provide 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.

4.4 Ways of determining food waste quantities

In Paper I, the key performance indicators ‘waste per portion’ and ‘waste (%) of food served’ were determined on sector level but also on an individual kitchen basis. Since kitchens and their food waste quantification process are not perfect all the time and since kitchens focus their quantification efforts on different processes, a criterion system was developed to filter the data. The reason for having this filter was to eliminate missing values and to compare data from different kitchens. The most obvious reason for doing this is evident from Table 4, which shows that restaurants and canteens rarely quantified the amount of food served and therefore calculation on the raw data material would render unfair and unrealistic results and not be comparable. The criteria consist of three levels. At the first level (Level 1), which is the strictest, only proceeded if the kitchen had quantified portions and the waste processes ‘plate waste’, ‘serving waste’ for the indicator ‘waste per portion (g)’ and with the additional parameter ‘amount of food served’ for the indicator ‘waste (%) of food served’. When any of these ingoing parameters for calculation of the indicator was missing, the quantification for a given day was excluded. The two remaining levels (Level 2, Level 3) relaxed the above criterion, as explained in Paper I. Waste per portion as an indicator was calculated as:

$$Waste\ per\ portion = \frac{\sum Waste\ from\ the\ waste\ processes}{\sum Number\ of\ portions} \tag{1}$$

Descriptive statistics on ‘waste per portion’ were aggregated on kitchen level. In order to identify which waste process was most dominant in each segment, the waste was divided between the waste processes and displayed as stacked bar plots, which revealed how the waste processes were distributed in each segment. This was done with data aggregated on a quantification day level. Calculations were also performed to get a sense of the development over time, where the ‘waste per portion’ indicator was complemented with a 95% confidence interval and also aggregated on a yearly basis for the Swedish public catering organisations providing data. Results on the error of margin also included a 95% confidence interval based on data from quantification day level.

In Paper I, calculation of the indicator ‘waste (%) of food served’ was performed in a similar matter to calculation of ‘waste per portion’, *i.e.* by dividing the calculations into different strict levels by constraining the input parameters for the calculation by various degrees to compensate for missing input values. Since not all kitchens quantified the amount of food served, the aim was to enable comparisons of kitchens that did quantify this indicator. Waste (%) of food served was calculated as:

$$Waste\ (\%) = \frac{\sum Waste\ from\ the\ waste\ processes}{\sum Mass\ of\ food\ served} \qquad (2)$$

Descriptive statistics for 'waste (%) of food served' were aggregated on kitchen level. When kitchens quantified the amount of food they served, this also made it possible to determine the portion size per guest, which was used as an indicator in Paper II.

4.5 Methods for analyzing risk factors

In Paper II, statistical correlation was used to examine the relationship between the suggested drivers of food waste listed in Table 5 and the amount of food waste generated in preschools and primary schools. Correlations between the parameters 'total waste per portion', 'serving waste per portion' and 'plate waste per portion' were examined and visually inspected manually before each correlation test, to ensure that only monotonic patterns appeared in the sample examined. Paper II used a significance level of $p<0.05$ and examined whether the data samples were normally distributed according to the Shapiro-Wilk test (Royston, 1992).

In order to quantify the impact of influential factors on food waste, three multiple linear regression (MLR) models were developed for each food waste quantity ('plate waste per portion', 'serving waste per portion' and 'total waste per portion'). Backwards elimination was used to choose the best-performing MLR models. The adjusted R^2-value, which considers the number of explanatory variables, was used to determine the best-performing model.

4.6 Models for optimizing the amount of portions

Paper III focused on establishing forecast models and optimising the margin that would be of potential help for kitchens in determining the number of guests for which they should provide food. This was done in two overarching steps. The first step was to try different forecast techniques and determine which approach was the most promising. The second step dealt with how large margin a forecast should have to be of practical use and finding an optimum.

All forecasting with the different models developed was benchmarked against a reference scenario where food was prepared for all students enrolled. 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. 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 ($\alpha = 0 - 10, 15, 20, 25\ and\ 30\%$) 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.

Kitchen staff need to balance the risk of overcatering against the risk of shortages, and find an optimal number of portions (Q*) to produce (Hadley, 1963) in relation to a stochastic demand x. Demand in this case is given by the actual outcome and the forecast value, for which the distribution is known. The balancing in this thesis was done in economic terms and was achieved by the following equation and assumptions (the main idea is further illustrated in Figure 5):

$$\Phi(Q^*) = \frac{p - v + B}{p - g + B} \tag{3}$$

where portions are sold at a price p per portion and at a cost v per portion. The average economic data from kitchens that could provide such data were used, which was in the present case gave p=77 SEK/portion and v=22 SEK/portion. The assumption was that an unlimited amount of portions are kept in a spare stock and 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 represents the cost of avoiding loss of goodwill and preventing shortages occurring, through the use of the spare stock. This was assumed to be 80 SEK per portion. When the spare stock is used, the exact amount of portions required can be served to satisfy customers and no considerable waste occurs. Ordinary planned food that gets wasted 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 & Strid, 2013). In equation (3), this cost is denoted g.

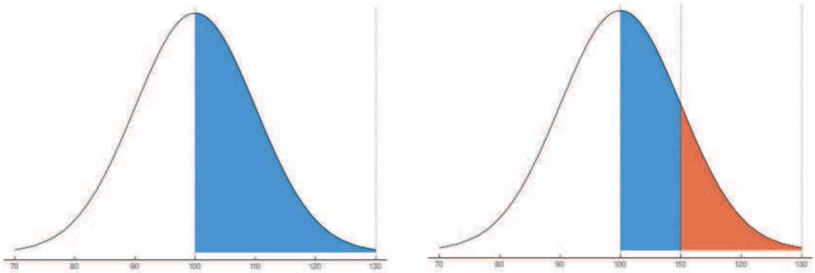

Figure 5. (Left) The current situation in portion provision in school catering establishments, where the line at 100 is the average number of portions and the line at 130 indicates the level of service applied today, where food is served to all students enrolled in the school. In this scenario there is no shortage of portions, and hence the blue 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 red area between 110 and 130, which indicates the probability of such events.

5. Results

5.1 Food waste quantities

The results obtained in Paper I indicated that around 20% of all food served was wasted within the food service sector units studied (Table 6), based on the strictest criterion (Level 1) for all years for which data were available. The data underlying the calculations in Table 6 comprised 9061 quantification days. Secondary schools showed the lowest ‘waste (%) of food served’ (18%) according to the findings in Paper I. However, only 35 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 (20%) and provided most data in terms of number of kitchens. The value for care homes was 21%, while preschools reported that 22% of food served was wasted. Canteens and restaurants reported higher waste levels, 26% and 24% of food served, respectively. Hospitals and hotels gave no indication for the strictest criterion, since none met the requirements for Level 1 and, as stated earlier, hotels did not quantify the amount of food served at all. The indicator ‘waste per portion’ gave a complementary picture, with an average of 50 to 190 g per portion wasted within the food service sector. Table 7 displays the findings from Paper I according to the strictest criterion (Level 1) aggregated on kitchen level.

Results from Paper I in terms of the indicator ‘waste per portion’, derived from a total of 38,636 quantification days spread across 954 kitchen units, indicated that canteens had the lowest waste per portion (50±9.4 g). Canteens were the second largest segment in terms of recorded data, with 11,083 quantification days for the 230 units that delivered data meeting the strictest level. Hotels had the second highest value reported for waste per portion

(140±6.4 g), based on 83 kitchens and 7884 quantification days. Care homes for the elderly reported slightly lower waste per portion (130±5.8 g), based on 49 kitchens and 1445 quantification days. Hospitals reported 110±2.7 g waste per portion, with data from 16 kitchens and a total of 909 quantification days. Preschools (4338 quantification days) and secondary schools (1409 quantification days) reported similar waste per portion levels (81±3.2 g and 79±12 g, respectively). Primary schools had the second lowest waste per portion (59±0.8 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 the most waste per portion (190±30 g), based on data from 15 kitchens and 89 quantification days.

Paper I also revealed how the different waste processes were distributed in each segment of the food service sector segments studied, as displayed in Figure 6. ‘Plate waste’ appeared to be the dominant type of waste in canteens, care homes 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 preschools and primary schools. ‘Preparation waste’ was the largest contributor to restaurant food waste. ‘Storage waste’ was quite a small proportion of food waste in all segments and there were no records of ‘receiving waste’ at the strictest criterion for any of the segments studied.

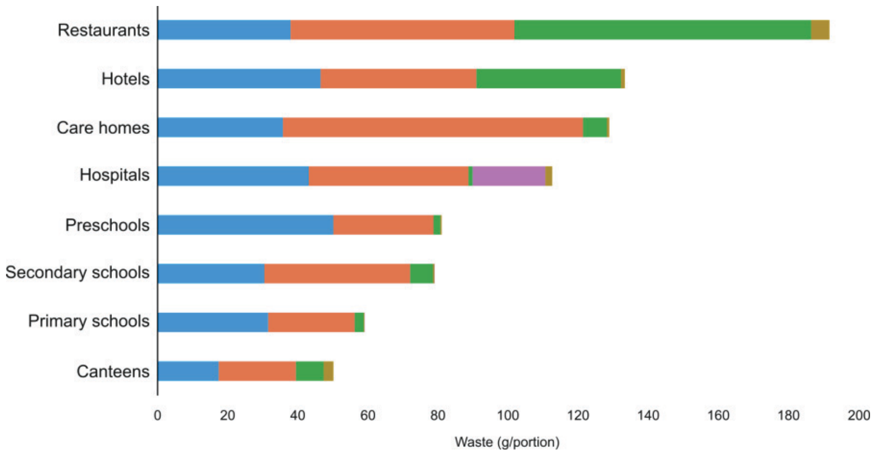

Figure 6. Contribution of different waste generation processes to total waste according to the strictest criterion (Level 1) for the different catering sector segments studied: ■Serving waste, ■Plate waste, ■ Preparation waste, ■Safety margin waste, and ■Storage waste

Table 6. Waste (%) of food served in the different sectors according to the strictest criterion (Level 1), aggregated on kitchen level for all years for which data were available. Results are rounded to 2-digit precision

Sector	Kitchens (n)	Min (%)	Max (%)	Q_1(%)	Median (%)	Q_3(%)	Mean (%)	Std. Dev. (%)	Waste (%)
Canteens	5	23	36	25	29	33	29	5	26
Care homes	8	16	62	18	23	25	26	14	21
Hospitals	-	-	-	-	-	-	-	-	-
Hotels	-	-	-	-	-	-	-	-	-
Preschools	148	7	110	17	24	32	26	13	24
Primary schools	226	7	43	15	18	23	19	6	20
Restaurants	9	15	36	19	24	26	24	6	24
Secondary schools	35	8	39	16	20	23	20	6	18
Total	431	7	110	16	20	26	22	10	20

Table 7. Waste per portion (g) in the different sectors according to the strictest criterion (Level 1), aggregated on kitchen level for all years for which data were available. Results are rounded to 2-digit precision

Sector	Kitchens (n)	Min (g)	Max (g)	Q_1(g)	Median (g)	Q_3(g)	Mean (g)	Std. Dev. (g)	Waste (g)
Canteens	230	3	440	36	62	100	84	74	50
Care homes	49	22	790	94	120	160	150	120	130
Hospitals	16	27	180	94	110	120	110	33	110
Hotels	83	6	410	84	120	200	140	82	140
Preschools	193	21	400	53	87	120	95	56	81
Primary schools	322	15	240	47	60	79	66	29	59
Restaurants	15	120	430	150	210	300	230	94	190
Secondary schools	46	41	180	63	82	100	89	34	79
Total	954	3	790	49	73	100	91	69	75

In Figure 7, ‘waste per portion’ identified in Paper I is plotted over time for the different segments of the food service sector and the units studied. The diagram uses a subset of the data with the focus on units from Swedish public catering. The results show that hospitals and primary schools were the only segments to show a decreasing trend that in later parts, where data were available, did not have overlapping confidence intervals (Figure 7). Another segment showing a decreasing waste per portion were secondary schools, but this segment gave no indication of a strong trend due to overlap of error bars. The same is true for preschools, which appeared to have increasing levels of waste per portion, but overlaps made this finding uncertain. Care home kitchens showed a decreasing trend in food waste, but also with uncertainties

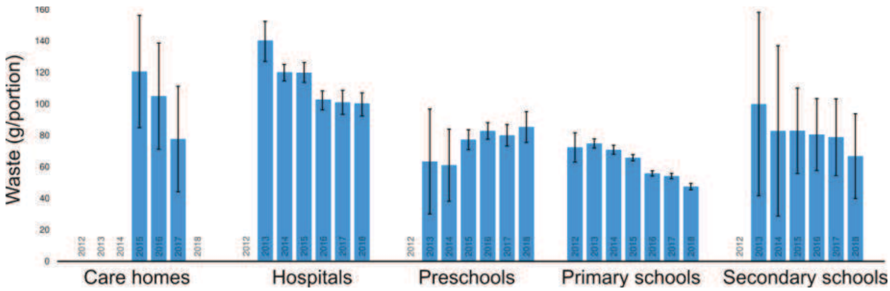

Figure 7. ‘Waste per portion (g)’ with 95% confidence interval for different Swedish public catering units over time according to the strictest criterion (Level 1).

5.2 Risk factors for food waste generation

The findings from the correlation analysis are displayed in Figure 8. The analysis indicated that the factors number of employees, number of seats in dining space, standard deviation (SD) in number of guests and number of guests were strongly correlated. This was expected, since more guests require a larger dining space and more employees to take care of operations. Larger volumes of guests also increase the probability of guests being absent during lunch time, which increases the standard deviation in the number of guests at a facility. Plate waste per portion was significantly positively correlated with comparable age, portion size, number of guests, number of seats in dining space, SD in number of guests, number of employees and gender of staff (male employees). Serving waste per portion was significantly positively correlated with portion size. Satellite kitchens had significantly higher serving waste than production units. Total waste per portion, which is the sum of plate waste and serving waste per portion, was significantly positively correlated with portion size and comparable age. Satellite units had significantly higher waste per portion than primary production kitchens.

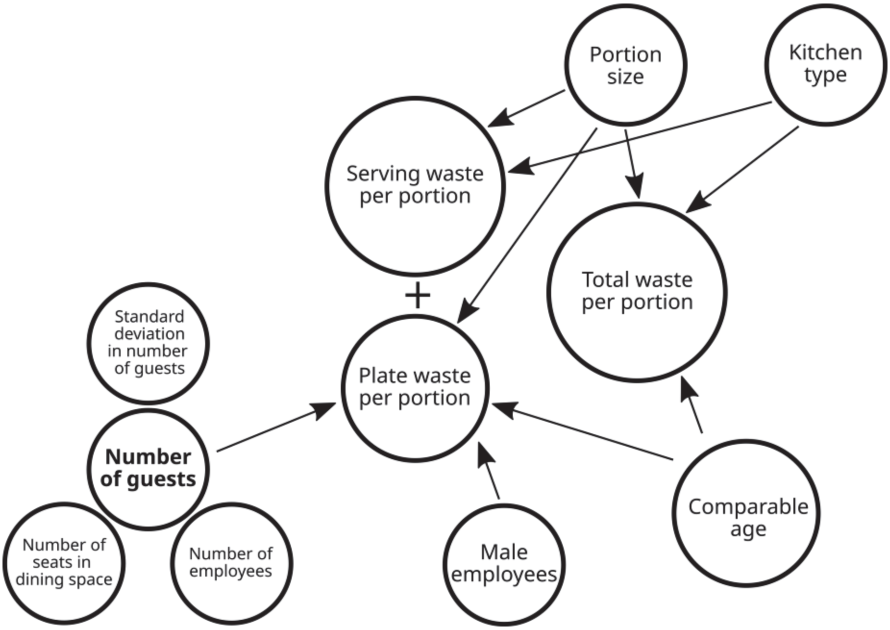

Figure 8. Schematic illustration of the interactions between different factors and their influence on food waste quantities.

Since a model is always a simplification of reality, the accuracy and robustness of a model decrease with each parameter added. Therefore one needs to balance the amount of parameters to avoid overfitting the model. Among the models tested, the quantity of plate waste per portion was best explained by the MLR model described by equation (4), which included the factors comparable age and portion size. These factors explained 87.1% of the variation in plate waste per portion.

$$Plate\ waste\ per\ portion\ [\text{g}] = 0.952(\pm 0.3176) * Comparable\ age + 0.067(\pm 0.0057) * Portion\ size \pm 10.56\ g \tag{4}$$

Serving waste per portion was best explained by the MLR model described by equation (5), which included portion size and the interaction between portion size and kitchen type. The model explained 85.1% of the variation in serving waste.

$$\begin{aligned} \textit{Serving waste per portion}\ [\mathrm{g}] = 0.018(\pm 0.0086) \\ * \textit{Kitchen type} * \textit{Portion size} \\ +0.101(\pm 0.0050) \\ * \textit{Portion size} \pm 15.04\ g \end{aligned} \quad (5)$$

Total waste per portion was best explained by the MLR model described by equation (6), which included the factors kitchen type and portion size. Together, these factors explained 92.2% of the variation in total waste per portion between the schools used in the analysis.

$$\begin{aligned} \textit{Total waste per portion}\ [\mathrm{g}] = 7.288(\pm 3.516) \\ * \textit{Kitchen type} + 0.180(\pm 0.006) \\ * \textit{Portion size} \pm 18.11\ g \end{aligned} \quad (6)$$

5.3 Forecasting models and optimal portion quantities

Among the different forecasting models tested, the model based on a simple sequential neural network was the best-performing (lowest mean absolute percentage error (MAPE) score) for 11 of the 21 kitchens studied. The moving-average model with a two-day window was the best-performing model for seven kitchens, and the prophet model was the best performing model for three kitchens, according to Paper III. As indicated by the results from Paper III, there was sometimes very little difference between the models. However, 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.

Simply producing a forecast is not sufficient, since for some days the forecast will underestimate the demand, leading to shortages. It is easier to throw away food than to cook new food. Therefore, margins need to be added to the forecast for it to be of more practical use. Table 8 illustrates how often the forecast was an underestimate and, depending on the margin added to the forecast, by how much, in terms of how many portions were missing in the worst case during the period. The first column (0%) shows no margin at all and in the worst case the forecast underestimated actual demand on 105 days out of around 178 school days for kitchen 6, while in the best case it underestimated actual demand on 71 days for kitchen 13.

Table 8. 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 (🔵) and 30+ portions (🟠)

Kitchen	**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 🟠

The first observation where the forecast margin gave zero days of underestimation was for kitchen 14 at 5% margin. At 10% margin, 10 of the kitchens had zero days of underestimation. Even at a 30% margin added on the forecast, five of the kitchens did not have a single day without underestimation. The margin that is sufficient is to some extent a trust issue, but can also be optimised. To find an optimal solution, the amount of portions to produce was optimised from an economic perspective using equation (3) for each kitchen shown in Table 9. The optimal production quantity has margins in place, since $\Phi(Q^*) = 0.86$, which exceeded the average value of 0.5 which means no shortages of food, but the food not eaten became waste. The optimal portion quantity was based on a goodwill cost of 80 SEK/portion. In Paper III, the results were expanded upon with a sensitivity analysis to get an understanding of how the goodwill cost, 'waste penalty cost', affected the optimal quantity that kitchens should produce in each individual case.

Table 9. Optimal portion quantity Q* and sensitivity analysis for goodwill costs and 'waste penalty cost' for the different kitchens in the study in Paper III according to equation (3), 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 $\Phi(Q^*) = 0.86$

	Optimum	**Goodwill (SEK)**			**Waste penalty 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

6. Discussion

The work described in this thesis was carried out in an effort to outline the quantities of food waste in the food service sector. Objectives were to understand the scale of the problem, identify some risk factors for food waste generation in an educational setting and propose solutions to deal with supply and demand in terms of how many portions kitchens should serve. Overall, it is important to recognise that food waste is often a result of a chain of events where other priorities are set higher and therefore propel food waste generation. On a local level, this can be manifested in having strict hygiene protocols in place to protect people from becoming sick, in overstocking and in overpreparing food to satisfy customer demand with the goal of maximising economic profit. All of these aspects are rational from a health and business perspective, but there are few incentives in place to make it difficult to waste food as a resource. It is probably possible to devise and implement prevention measures locally that reduce food waste, but these will probably only scratch the surface of the problem, since the underlying causes are not likely to change without real transformative actions on national and global level. A starting point in achieving this change is to understand the scale of the problem.

6.1 Quantities and quantification of food waste

Overall, this thesis showed that around 20% of the food served in the food service sector is wasted. However, this figure is subject to wide variation, as observed *e.g.* for the 'waste per portion' indicator, which varied from 50±9.4 g/portion for canteens to 190±30 g/portion for restaurants. The variation was expected and was also in line with the results in previous food waste quantification studies (see Table 3). When it comes to kitchens operating mainly in the Swedish public catering sector, the results were in line with the national mapping of food waste in preschools, primary schools and care homes carried out by the Swedish National Food Agency (2019a). It concluded that preschools and primary schools report around 60-70 g per portion of food waste, while the primary schools studied in this thesis reported around 59 g/portion and the preschools 81 g/portion. Swedish National Food Agency (2019a) also concluded that primary schools have lower waste than preschools and that care homes for the elderly report the highest levels of waste. It should be noted that the mapping conducted by the National Food Agency used surveys in which municipalities themselves calculated and reported aggregated kitchen data on an organisational level for preschools, schools and care homes. This probably resulted in higher numbers of kitchens providing data to the National Food Agency, but with the drawback that detailed information may have been lost in the transformation process, since the results are aggregated on a municipality level and not on a daily quantification level. Using fewer kitchens with a more detailed approach and using data captured on a daily basis would have the benefit of displaying the results with more precision. This is of course a matter of the resources that are available for compiling results and the level of ambition applied when mapping food waste on a national level.

For the individual kitchen, food waste quantification can reveal where there are problems. Some kitchens have greater problems with guests that waste more of the food from their plates and some struggle with more serving waste. If kitchens are experiencing problems with plate waste, measures to reduce this type of waste should be given priority. Based on the findings in this thesis, in general such measures would be most applicable to kitchens in canteens, care homes and secondary schools, which had the highest plate waste levels. Measures for reducing serving waste should be given priority in general in kitchens serving food to preschools and primary schools, which were found to have the highest serving waste levels. Hotels and hospitals showed equal levels of serving waste and plate 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 the food preparation processes inside the kitchen, so efforts to reduce waste could focus on this process. However, before kitchens start implementing solutions, it is important that they understand the problems they are facing as individual kitchens. Quantification of food waste will play an important role in bringing this kind of individual awareness to kitchens, so that they can identify the type of waste that should be targeted for reduction measures. Quantification also has the benefit of revealing whether the measure taken was successful or not. In a perfect world, kitchens would first quantify their waste to identify where they have a problem, and then implement a measure and repeat the quantification process, to determine whether the measure was successful or not. Some argue that quantification itself can be a measure to reduce food waste to some extent (Eriksson *et al.*, 2019), since the quantification process may bring awareness of the problem.

For organisations that are about to start food waste reduction work, the question of how often and for how long their kitchens should quantify food waste is a relevant question. According to Swedish National Food Agency (2020b) and Eriksson *et al.* (2018a), a reasonable starting point is to quantify food waste on five days per semester, and then evaluate. It is also reasonable to start with quantification as a pilot project in some kitchens and then extend the efforts to other kitchens over time. This practice is reflected by the results in this thesis that originated from the public catering sector, since most of the quantification took place in primary schools. It also highlights the need to ramp up quantification in other establishments, such as preschools, secondary schools and especially care homes. A feature in common for the organisations participating with their data was that quantification took place sporadically and that quantification efforts differed, which was handled by the standardised quantification framework. It is unknown how the quantification data were used in the different organisations participating or whether the data generated were acted upon by the kitchens. It is crucial that the information gained from the quantification process is acted upon, since otherwise quantification faces the risk of just adding work for kitchen staff and the procedure is just another item to report to managers in a new public management (NPM) fashion. To minimise this risk, lessons from the neighbouring retail sector might act as a compass. The retail sector has had advanced support systems for years to simplify data collection but, more importantly, the information collected is reviewed in weekly meetings, making it possible to act upon the information and reduce waste (Eriksson *et al.*, 2018a). Working according to this systematic approach across kitchen borders in an organisation would also provide opportunities for kitchens experiencing greater problems with waste to learn from the best-performing kitchens, and hopefully perform as well as the best kitchens over time. Since the variability within an organisation can be quite large, as demonstrated by Eriksson *et al.* (2017), this learning transition could have quite a large impact if adopted and implemented successfully on a large scale.

6.2 Use of different indicators and data quality

When making comparisons, it is essential that the indicators used are based on the same kind of input data for calculations on the same premises. For instance, when calculating the 'waste per portion' indicator, the value obtained can be drastically different if the amount of portions is based on the number of students enrolled rather than actual attendance data, such as number of plates used (counted plates). As an example, the number of students enrolled as displayed by Figure 4 would in most cases yield a lower waste per portion value compared with the actual outcome of how many guests that attended a meal. If different kitchens use different approaches to determine how many guests were present for a meal, this can give unfair results that are not comparable.

The indicator 'waste (%) of food served' is associated with more quantification work for kitchens, as indicated by the results in this thesis, as only 431 of the 1189 kitchens studied quantified the data required for this indicator at some point. The benefit that the indicator provides is that it allows kitchens to calculate how much food their guests eat, which is of great importance from a public health perspective and in particular for the public catering sector (Swedish National Food Agency, 2020b)

To ensure data quality when comparing results, a criterion system such as that developed in Paper I might be useful. It would not overcome the problem of using different sources of input for calculation of the indicators, but it does have the potential to equalise the inputs to the indicators by ensuring that the same level of detail is compared. The approach in Paper I used only results obtained using the strictest criterion, and the analysis only proceeded if there were records of 'serving waste', 'plate waste' and 'number of portions' for the indicator 'waste per portion (g)' and with the additional parameter 'amount of food served' for the indicator 'waste % of food served'. However, since far from all establishments operate in the same way during their quantification process, this criterion might be too strict. A possible way forward would be to relax the criterion and use 'total waste' instead of ‘serving waste’ and ‘plate waste’. This would also have the benefit of being easier to explain to kitchens.

6.3 Risk factors of food waste generation

Most of the risk factors found in Paper II that are drivers of food waste are tricky to address, since some of them relate to aspects that kitchens cannot change easily, *e.g*. infrastructure or the age of the guests. For instance, it can be expensive to convert kitchens from satellite kitchens to production units. It can also be problematic to add/remove seats from a dining hall which might already be full, as removing seats might mean that guests have to eat their lunch outside standard hours for the lunch meal. To further expand upon and capture risk factors, one way forward could be to capture noise level as a direct indicator of stress and to assess how actual noise levels and food waste are linked to each other. Another option could be to include the menu with food waste data, to see how different dishes interact with levels of food waste. For this to provide additional value, the quantification of food waste would need to be expanded to capture food waste on a category level, or even down to single food items. This would be a suitable step to perform when kitchens have quantified their food waste for some time. Another factor that might be of interest is distance to an alternative food outlet. In some cases, especially for older pupils, a school cafeteria that sells snacks to pupils might compete with the free lunch alternatives provided by the school kitchen, as found by Marlette *et al.* (2005) and Painter *et al.* (2016). Lastly, it might also be of interest to examine the types of staff working in the kitchen and how they affect the levels of food waste, since some previous studies have found that food waste levels can be drastically reduced upon changing personnel (Malefors *et al.*, 2017). Providing staff training and courses in food waste can be an important step, since staff and managers have the power to alter their own behaviour (Filimonau and Coteau, 2019). However, the models developed to date already explain a large share of the variation in the amount of food waste generated, and in the first instance the focus should be on implementing and evaluating measures to reduce food waste. One of measures with potential for good improvement is to better match the amount of food served to the number of guests, which reduces the risk of having a portion provision that is not in line with actual demand. This is something that kitchens have the potential to control. Forecasting can play an important role, especially if the forecast is backed up with information regarding how often the forecast is wrong and whether kitchens are ready with a sufficient instant backup option.

6.4 Forecasting as food waste reduction measure

Balancing the supply and demand for food is one obvious measure to take when addressing food waste, since the surplus food often goes straight into the bin. Other ways of preventing waste can be measures related to infrastructure. In this regard, kitchens and organisations would need to balance the costs of implementing measures against the benefits these measures might provide. It is unrealistic for organisations to convert all of their satellite kitchens to production kitchens. What could be done as an intermediate step is to supply satellite kitchens with equipment to handle surplus food, such as cooling and heating equipment. This infrastructure-related change, together with using forecasting, could be a promising approach and a first step for kitchens to match portion provision to the actual number of guests.

Paper III showed that by using simple forecasting techniques, it was possible to predict quite accurately the number of guests that would attend a certain meal. However, as indicated by Table 8, the forecasts underestimated demand quite often if they had no margin applied, leading to shortages of food. Shortages of food are not desirable and therefore adequate margins are required, along with a system to serve food from a backup source. Since larger kitchens displayed greater variation in the amount of guests, with a 10% margin they still needed to have 30+ portions ready for 22-43 days of the school year. However, smaller kitchens with a 10% margin to their forecast had zero days of underestimation. It is possible to have an optimal margin in place, *e.g*. Table 9 illustrates a margin optimised from an economic perspective. 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 students enrolled at the school, 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 to the expected portion quantity average. At the moment, there is a very low cost associated with throwing away food.

Combining forecasting with a backup stock approach has the potential to address food waste. Today, kitchens do not seek to identify the optimal number of portions to produce and the system is optimised to produce for all students enrolled, due to fear of shortages. By step-wise adjusting the portion quota 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 and hopefully lead to less food waste. This approach has considerable potential and needs to be explored in terms of the food waste reduction achieved in reality. Since the key in this reasoning relies on a backup stock of food that is available when there is a shortage, one solution might be to meet this shortage with food from the contingency plan that is being established across strategic public catering establishments (Swedish National Food Agency, 2020a). This stock of food is intended for emergency situations but could be refilled instantly after being used to cover a shortage in the normal day-to-day business. This would serve two purposes, by reducing food waste in daily operations and ensuring that the emergency stock is fresh and ready for use.

6.5 Uncertainties and generalization

All of the kitchens studied in this thesis provided data and collaborated freely. Thus poses the risk that only kitchens that are very interested in the topic were included in the analysis, so the results might not give a representative view of the situation. Thus there might be hidden statistics on food waste quantities and risk factors that were not observed or analysed in this thesis. A promising development is that more and more actors in the food service sector are now acknowledging food waste as an vexing issue and are willing to take measures against it. Another promising development is that there are now quantification standards (Swedish National Food Agency, 2019b) which organisations can use, lowering the threshold for participation. The results provided in this thesis also focused on a Swedish or Nordic perspective, and there is a need to assess how well the results can be used as a proxy for establishments in other parts of the sector and in other countries around the world. Regarding risk factors for food waste, the results regarding the issue of infrastructure and rate of overproduction, and the need to have an optimal production margin in place, are probably generally applicable outside the Swedish public catering sector domain. The benefit of working with kitchens operating in the Swedish public sector is that the data generated are publicly available and not subject to any kind of business restrictions that can arise when dealing with company data. On the other hand, economic optimisation of the margin during forecasting would probably be greatly improved if done in a setting where point-of-sales data were available, which is the normal case outside the public catering sector.

One way of increasing knowledge of food waste is to push kitchens to quantify their amount of waste for longer periods and to expand studies on risk factors to incorporate establishments operating in the private domain. However, longer periods of quantification might risk reducing the level of detail. National guidelines or even implementation of food waste quantification into standard kitchen protocols such as HACCP (Hazard Analysis and Critical Control Points) or similar might be a way forward to make food waste quantification a natural part of kitchen operation and enhance comparability. However, uncertainties will always be present in any kind of system that is based on self-reporting.

6.6 What is an acceptable level of food waste

Each segment of the food service sector has its own challenges in reaching the Agenda 2030 target of halving food waste. According to the results in this thesis, a level of around 10% of the food served would be required for the sector to reach the target. Some argue that this is not enough and that further reduction (to 75%) needs to be in place by 2050, which would imply that only 5% of food served should eventually become waste, on average. This would mean that school kitchens should have around 30 g/portion of food waste by 2030 and 15 g/portion by 2050. To put this in perspective, the lowest level observed in Paper I was 15 g/portion and the first quartile was 47 g/portion, which indicates that it would require great efforts from kitchens to reduce the level further, but that this reduction is achievable. However, it might be easier for establishments in other parts of the food service sector to reduce their food waste, since they have larger problems to start with and might be able to solve their problems by implementing fairly easy solutions. Quantification and follow-up is essential to track progress on this. The change over time, as illustrated by Figure 7 indicated that hospitals and primary school kitchens are moving in the desired direction but that more efforts are needed in other parts of the public catering sector. It is reasonable to assume that food waste reduction is subject to the law of diminishing returns, where reductions might be quite easy initially but where it becomes increasingly difficult to achieve the last part of stated goals. Primary school kitchens, which have already devoted a lot of resources and efforts to food waste reduction, could act as a learning platform for kitchens operating in other parts of the sector. Learning can be a good starting point, but if the infrastructure or incentives to reduce food waste are lacking, progress will be slow. National policies that focus on prevention of waste and make it undesirable to generate waste might drive development forward. It is worth investing in policy tools in order for the sector to reach the reduction targets and to make the transition to a more sustainable food service sector with less food waste.

7. Conclusions

This thesis showed that establishments in the food service sector waste around 20% of the food they serve, although with large variations between different units and over time. Food waste levels ranging from 50±9.4 g/portion in canteens to 190±30 g/portion in restaurants, with serving waste being the main contributor in establishments such as preschool and primary school kitchens. Plate waste was on average the main contributor to food waste in canteens, care homes and secondary schools. Hospitals and hotels had equal proportions of plate waste and serving waste, while in restaurants the largest contributor was waste created during kitchen processes. Primary school kitchens and hospitals were found to be the only segments of the Swedish public catering sector displaying a significant decreasing trend in food waste during the past decade, which suggests that more efforts are needed to quantify food waste in other segments of the sector.

The main risk factors influencing the levels of food waste identified in this thesis were portion size, age of the guests, type of kitchen and other issues related to kitchen infrastructure. Combined models of these factors explained 87.1%, 85.1% and 92.2% of the variation in plate waste, serving waste and total waste per portion, respectively. One factor that kitchens can address is to better match the number of portions prepared to the actual guest demand, in order to reduce the risk of overcatering. Kitchens could tackle this problem by using different forecasting approaches. In the best case in this thesis, guest demand in school catering establishments was predicted with 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, yields an error of 20-40%. Overall, forecasting models for guest demand based on neural network modelling were found to be the best option for most of the kitchens studied, but even simple forecasting methods provided the potential to better understand guest demand and, if used, can address food waste. For a forecast to be of practical use for kitchens, they would need to have some acceptable margins to the forecast in place 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 students enrolled at the school, whether they show up or not. Forecasts, therefore, have the potential to guide kitchens in their operations and contribute to a more sustainable food system

8. Future research

Food waste in the food service sector is attracting increasing attention, but research in this area is still in its infancy and must be extended. This thesis only touched upon the questions of how much, why and what can be done to prevent waste. Other topics that need to be further investigated are as follows:

- From a public catering perspective, the food waste quantification work that is ongoing should continue, but should also encompass establishments where quantification has not yet been a priority, such as care home kitchens. Food waste quantification should also be expanded to cover a more diverse range of actors in the private sector.
- Measures aimed at reducing food waste should be investigated and practically tested and evaluated in real situations. This work should include the costs of performing the measure in relation to the potential waste reduction benefit it provides. A prerequisite for this is to have a robust food waste quantification process in place. If measures to reduce food waste are tested without sufficient quantification, monitoring of progress will be impossible and it would be unclear whether the measure achieved the desired effect.
- Studies are needed to determine how much food waste reduction is practically achievable and whether this is a suitable level over time.
- Studies are needed to identify policy instruments that would provide kitchens with the incentive to introduce measures to avoid food waste.

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