DOMINIK LEVERENZ

The use of self-reporting methods to identify food waste reduction potentials at consumer level – a support to achieve SDG 12.3

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The use of self-reporting methods to identify food waste reduction potentials at consumer level – a support to achieve SDG 12.3

Von der Fakultät für Bau- und Umweltingenieurwissenschaften der Universität Stuttgart zur Erlangung der Würde eines Doktor-Ingenieurs (Dr.-Ing.) genehmigte Abhandlung

Vorgelegt von
Dominik Leverenz
aus Göppingen

Hauptberichter: Prof. Dr.-Ing. Martin Kranert
Mitberichterin: Univ. Prof. Dipl.-Ing. Dr. nat. techn. Marion Huber-Humer

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Institut für Siedlungswasserbau, Wassergüte- und Abfallwirtschaft
der Universität Stuttgart

2021

Dedicated to Thaís Santos-Leverenz

Not until the courageous have become smart
and the smart courageous, can we feel what
often has been erroneously declared:
an advancement of human kind.

— Erich Kästner

Foreword

Worldwide, about one third of the food produced is lost or becomes waste. Reducing this amount is necessary for ethical and social reasons, but also for environmental and economic reasons. This situation has also been reflected in the Sustainable Development Goals (SDGs) of the United Nations. On the background of the United Nations SDG 12.3, the European Union has committed to halving food waste at retail and consumer level (households, restaurants and food services) by 2030 and also to reducing food losses along production and supply chains.

In order to monitor the achievement of the set targets, the EU states are obliged to record the amount of food waste and to report annually, starting in 2022 until 2030, to the EU Commission. In order to ensure comparability of the results, it is essential to collect and evaluate the data according to a uniform methodology. For this purpose, the EU Commission has provided different measurement methods for the different activity levels, ranging from direct measurement to questionnaires, comparative coefficients and production statistics to household diaries. Several published studies in recent years show that the amounts of food waste at the consumer level are significantly underestimated. Many results are based on case studies that are not representative, both in terms of households and study periods, and thus not generally valid or transferable. With regard to the effectiveness of measures to reduce food waste and the expected long-term effects, there is a lack of reliable studies.

This is where the dissertation of Dr.-Ing. Dominik Leverenz comes in. Based on extensive measurements of food waste at the consumer level and long-term observations, the aim of his work was to create a reliable data basis on the potential of measures to reduce and avoid food waste. The central element is the investigation of the extent to which self-documentation of food waste not only generates a reliable data basis, but also whether a significant reduction in avoidable food waste can be achieved as a result of raising awareness and a change in behavior.

Dr.-Ing. Dominik Leverenz has generated outstanding new scientific findings through the methodology he applied, which show that the goals of SDG 12.3 are achievable through self-documentation at the private (households) as well as the commercial (hotels and catering) consumer level. This work is an important element on the path to halving avoidable food waste by 2030 at the consumer level. This makes the dissertation a basic scientific work for science and practice, I wish a wide distribution and recognition.

Stuttgart, May 2021 Prof. Dr.-Ing. Martin Kranert

Acknowledgement

There are many colleagues, project partners and friends whom I would like to thank for their contribution and support throughout the data collection, conduction of measurements, software development and the writing of this thesis.

Firstly, I would like to express my gratitude to my advisor Prof. Dr.-Ing. Martin Kranert for the continuous support of my doctoral thesis and related research. Besides my advisor, I would like to thank the co-examiners and members of the committee, in particular Prof. Dipl.-Ing. Dr. nat. techn. Marion Huber-Humer and Prof. Dr.-Ing. habil. Jörn Birkmann. My sincere thanks also go to Dr.-Ing. Gerold Hafner, who offered me an opportunity to join his team. He provided a pleasant and creative work environment that allowed me to develop ideas independently and conduct research without any restraints.

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For the software development I thank Ewgeni Nachbauer, Louis Bergmann and Michael Grotz Grotz †. I gratefully acknowledge the partners from the hotel group Maritim Hotelgesellschaft mbH for participating in this research. In particular, I would like to thank Lutz Niemann, Bernd Witzlack, Rudolf Wachner, Alexander Wolter, and Mirco Ebers, for the collection of data on site and the close cooperation over several years. Also, I thank my colleagues and friends, namely Lea Böhme, Matthias Rapf, Fatah Naji, and Philipp Fuchs, for their feedback and stimulating discussions, and for all the good times we have had in the last years.

Thaís Santos, thank you for sharing your wisdom and strength. You directed and carried me through difficult times, never stopped encouraging me and lifted me up when I was struggling. Sincerely and genuinely, thank you.

Cumulative dissertation

The present dissertation combines three scientific papers published in peer-reviewed journals into one doctoral thesis according to the guideline for cumulative dissertations of Faculty 2 at the University of Stuttgart, adopted on 22 January 2020, and the doctoral regulations of the University of Stuttgart (PromO), adopted on 01 March 2019.

Structure

The cumulative dissertation is divided into five sections:

- **General introduction (section 1)**
- **Publication I (section 2)**

  Leverenz, D., Moussawel, S., Maurer, C., Hafner, G., Schneider, F., Schmidt, T., Kranert, M. (2019). Quantifying the prevention potential of avoidable food waste in households using a self-reporting approach. *Resources, Conservation & Recycling* 150, p. 104417. https://doi.org/10.1016/j.resconrec.2019.104417. License: CC BY-NC-ND 4.0.

- **Publication II (section 3)**

  Leverenz, D., Hafner, G., Moussawel, S., Kranert, M., Goossens, Y., Schmidt, T. (2020). Reducing food waste in hotel kitchens based on self-reported data. *Industrial Marketing Management.* https://doi.org/10.1016/j.indmarman.2020.08.008. License: CC BY 4.0.

- **Publication III (section 4)**

  Leverenz, D., Moussawel, S., Hafner, G., Kranert, M. (2020). What influences buffet leftovers at event caterings? A German case study. *Waste Management* (New York, N.Y.) 116, pp. 100–111. https://doi.org/10.1016/j.wasman.2020.07.029. License: CC BY 4.0.

- **General discussion (section 5)**

Abstract

The European Union is committed to the United Nations target of halving food waste at the retail and consumer level by 2030 and reducing food losses along production and supply chains, including post-harvest losses. According to European legislation, member states are obliged to monitor national food waste levels and report progress to the European Commission at annual intervals between 2022 and 2030. Furthermore, measures will be developed and implemented based on common and Europe-wide harmonized methodology. With reference to the political targets for reducing food waste and the need to find solutions, to date, considerable research has provided a growing body of literature in which food waste and reduction measures were investigated. However, many findings are based on non-representative case studies, which are often associated with short investigation periods and therefore cannot provide any generalizable or transferable results. In particular, there is a lack of evidence concerning the effectiveness of measures to reduce food waste and their performance over longer periods of time.

The main objective of this study is to contribute to filling existing knowledge gaps by performing on-site measurements of food waste at the consumer level. The collected data provide evidence-based results regarding reduction potentials and measures to prevent food waste. The study design uses a self-reporting method to collect food waste data. Measurements were first carried out in households and subsequently extended in a similar form to a gastronomic framework, namely hotels and event caterings such as conferences, business events or graduation ceremonies. Two household panels documented their food waste quantities over a period of 84 days using kitchen diaries. In this context, a quantitative and qualitative comparison between offline-based (Panel 1; 16 households) and online-based self-reporting methods (Panel 2; 37 households) was carried out. For the experimental setup in gastronomic kitchens, a food waste tracking system was developed to ensure an efficient self-reporting procedure. Using this setup, breakfast buffet leftovers were monitored in four hotel kitchens over a period of 336 days. Furthermore, buffet leftovers from 239 individual event caterings were quantified. The results present findings about the influences of four variables, namely event type, season, event size, and menu prices, on buffet leftovers at events.

An essential finding of the study is the evidence that self-reporting interventions contribute to raise consumer awareness, leading to behavioral changes and the autonomous implementation of reduction measures. In households, the amount of avoidable food waste was reduced by approximately 57%, which correlates with a monetary equivalent of about 37 euros per capita

and year. Moreover, by changing their shopping and purchasing habits, households reduced their expenditure on food by an average of approximately 341 Euros per capita and year. Hotel kitchens reduced breakfast buffet leftovers by approximately 64% on average, resulting in monetary savings of more than 9000 Euros per kitchen and year. Buffet leftovers at event caterings, however, were strongly influenced by the size of the event and less by factors such as the type of event, the menu price or the season. For instance, smaller events with less than 100 participants recorded the highest quantities of approximately 280 g of buffet leftovers per guest, and larger events of more than 500 participants recorded the lowest quantities of approximately 74 g per guest.

The results demonstrate that the political reduction targets can be achieved and even exceeded. Behavioral changes in the pilot households improved planning and preparation of meals as well as purchasing habits and food storage. In hotels, reduction measures were related to simple and small changes in daily kitchen routines such as in-time production to refill buffets with demand-orientated food quantities and using smaller serving dishes to present the food. In contrast to hotels, no food waste reduction was observed during the catering of individual events. This can be explained by the fact that the size of the events examined was not sufficiently considered in the menu planning.

The practical viability of reducing food waste incentivizes future research to extend the methodological approach of this thesis, for example, by investigating reduction measures for individual events. The findings of the study contribute to achieving parts of the political goals of halving food waste at consumer level. Therefore, the dissemination of the results is important to reach a wider audience of the target group and motivate households and caterers to measure and consequently reduce their food waste.

Kurzfassung

Die Europäische Union hat sich dem Ziel der Vereinten Nationen verpflichtet, bis 2030 die Lebensmittelverschwendung auf Einzelhandels- und Verbraucherebene zu halbieren und die Lebensmittelverluste entlang der Produktions- und Lieferkette zu verringern. Vor diesem Hintergrund sind die europäischen Mitgliedstaaten daran gebunden, Lebensmittelabfälle auf nationaler Ebene zu erfassen und die Fortschritte der Europäischen Kommission in jährlichen Abständen zwischen 2022 und 2030 zu berichten. Des Weiteren sollen Lösungsansätze auf der Basis einer gemeinsamen und europaweit einheitlichen Methodik erarbeitet werden. In Bezug auf die politischen Ziele und die Notwendigkeit, Lösungen zu finden, sind in den letzten Jahren mehrere Publikationen veröffentlicht worden, in denen das Aufkommen von Lebensmittelabfall dargestellt und Maßnahmen zur Reduzierung untersucht werden. Eine Vielzahl von den bereits gewonnenen Erkenntnissen basiert allerdings auf nicht repräsentativen Fallstudien, die häufig mit verhältnismäßig kurzen Untersuchungszeiträumen verbunden sind und dementsprechend keine allgemeingültigen und übertragbaren Ergebnisse liefern können. Es fehlen insbesondere Erkenntnisse über die Effektivität von Maßnahmen zur Reduzierung von Lebensmittelabfällen und deren Wirksamkeit über längere Zeiträume.

Das vorrangige Ziel dieser Forschungsarbeit ist es, einen Beitrag zur Schließung vorhandener Wissenslücken zu leisten, indem aufkommensseitige Messungen von Lebensmittelabfällen auf Verbraucherebene durchgeführt und wissenschaftlich ausgewertet werden. Im Rahmen der Dissertation wurden belastbare Daten hinsichtlich Reduktionspotenzialen und skalierbaren Lösungsansätzen zur Vermeidung von Lebensmittelabfällen erarbeitet. Die wissenschaftliche Analyse und die daraus abgeleiteten Erkenntnisse basieren auf Daten, die von den Teilnehmern der Studie selbständig dokumentiert wurden. Die Messungen wurden in Haushalten, in Hotels und bei individuellen Veranstaltungen wie zum Beispiel Konferenzen, Firmen- oder Abschlussfeiern durchgeführt. Die teilnehmenden Haushalte dokumentierten das Aufkommen ihrer Lebensmittelabfälle über einen Zeitraum von 84 Tagen mittels Küchentagebüchern. In diesem Kontext erfolgte ein quantitativer und qualitativer Vergleich zwischen offline-basierten (Panel 1; 16 Haushalte) und online-gestützten Erhebungsmethoden (Panel 2; 37 Haushalte). Die Datenerhebung in Gastronomiebetrieben erfolgte unter Verwendung eines digitalen Messinstrumentes, das sich aus einer Software und elektronischen Waage zusammensetzt. In vier Hotelküchen wurden mit dieser Versuchsanordnung die Lebensmittelabfallmengen am Frühstücksbuffet über einen Zeitraum von 336 Tagen gemessen. Zudem wurden die Buffetreste

bei 239 individuellen Veranstaltungen quantifiziert und deren Abhängigkeit von verschiedenen Einflussvariablen (Veranstaltungstyp, Jahreszeit, Veranstaltungsgröße, Menüpreis) untersucht.

Eine elementare Erkenntnis der Untersuchung ist, dass die selbstständige Dokumentation von Lebensmittelabfällen zu einer Steigerung des Problembewusstseins und Verhaltensänderungen der Studienteilnehmer führte. In den Haushalten konnten die vermeidbaren Lebensmittelabfälle um etwa 57% reduziert werden, was mit einem monetären Gegenwert von etwa 37 Euro pro Einwohner und Jahr korreliert. Darüber hinaus änderten die Teilnehmer ihr Einkaufsverhalten und verzeichneten einen Rückgang ihrer Konsumausgaben für Lebensmittel von durchschnittlich etwa 341 Euro pro Einwohner und Jahr. Hotelküchen reduzierten die Lebensmittelabfälle am Frühstücksbuffet im Durchschnitt um etwa 64%, womit finanzielle Einsparungen in Höhe von mehr als 9.000 Euro pro Küche und Jahr verbunden waren. Bei individuellen Veranstaltungen wurde das Aufkommen der Buffetreste insbesondere von der Veranstaltungsgröße beeinflusst und weniger von Faktoren, wie dem Veranstaltungstyp, dem Menüpreis oder der Jahreszeit. So betrug beispielsweise die Menge der Buffetreste etwa 280 g pro Gast bei Veranstaltungen mit weniger als 100 Teilnehmern und etwa 74 g pro Gast bei Veranstaltungen mit mehr als 500 Teilnehmern.

Die Ergebnisse zeigen, dass die politischen Ziele zur Vermeidung von Lebensmittelabfällen erreichbar sind und sogar übertroffen werden können. Die Verhaltensänderungen in den Pilothaushalten führten sowohl zu Verbesserungen bei der Planung und Zubereitung der Mahlzeiten als auch bei den Einkaufsgewohnheiten und der Lagerung von Lebensmitteln. In Hotels waren vor allem einfache und kleine Änderungen in den täglichen Küchenabläufen erfolgreich, wie etwa die bedarfsgerechte Nachfüllung des Buffets und Verwendung kleinerer Servierplatten für die Präsentation der Speisen. Im Gegensatz zu Hotels wurde bei der Bewirtung individueller Veranstaltungen keine Reduzierung der Lebensmittelabfälle erzielt. Dies lässt sich dadurch erklären, dass die Größe der untersuchten Veranstaltungen bei der Menüplanung keine hinreichende Berücksichtigung fand. Die gewonnenen Erkenntnisse bieten jedoch eine gute Ausgangsbasis für zukünftige Forschungsarbeiten und die Entwicklung von Reduktionsmaßnahmen für individuelle Veranstaltungen. Die hier vorgelegte Arbeit kann einen Beitrag zur Erreichung der politischen Ziele im Sinne einer Halbierung der Lebensmittelabfälle auf Verbraucherebene leisten. Dafür ist die Verbreitung der Ergebnisse wichtig, um einen relevanten Teil der Zielgruppe zu erreichen und Haushalte sowie Gastronomiebetriebe zu motivieren, ihre Lebensmittelabfälle zu messen und folglich zu reduzieren.

Table of contents

List of figures

List of tables

List of abbreviations and units

Abbreviation	Description
ANOVA	Analyses of variance
c_i	Relative food waste reduction achieved in hotel i
Eq.	Equation
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FLI	Food Loss Index
FLP	Food Loss Percentage
FWI	Food Waste Index
M	Mean
NACE	Nomenclature générale des Activités économiques dans les Communautés Européennes
UK	United Kingdom
UN	United Nations
UNEP	United Nations Environment Programme
US	United States of America
USB	Universal Serial Bus
SE	Standard error
SDG	Sustainable Development Goal
w	Mean food waste quantities
WRAP	Waste and Resources Action Programme
WWF	World Wide Fund for Nature
μ	Bootstrap estimates of food waste quantities

Quantity	Symbol	Unit
Time	d	day
Currency	EUR	euro
Mass	g	gram
Mass	kg	kilogram
Mass	t	tons
Percentage	%	percentage of mass
Inhabitant	cap	capita
Samples size	n	number
Time	a	year

1 General introduction

1.1 Background

In 2011, the Food and Agriculture Organization of the United Nations (FAO) conducted a study that examined global food waste levels and reported that approximately one-third of the global food production is lost or wasted, corresponding to approximately 1.3 billion tons per year (Gustavsson et al., 2011). The authors of the study emphasized that industrialized nations waste significantly more food than developing countries, particularly at consumer level. For instance, consumers in Europe and North America generate between 95 and 115 kg of food waste per capita and year, and in sub-Saharan Africa and Southeast Asia only between 6 and 11 kg per capita and year. Figure 1-1 illustrates the magnitude of food waste at the consumer level across different regions on a global scale. The quantities at consumer level express the amount of food waste produced in households and the food service sector. Regions with high amounts of food waste are highlighted in dark blue. It has to be considered, however, that Gustavsson et al. (2011) had to make several assumptions because of major research gaps, insufficient input data and statistical uncertainties. Hence, Gustavsson et al. (2013) stated that estimations on food waste quantities must be treated and interpreted with great caution.

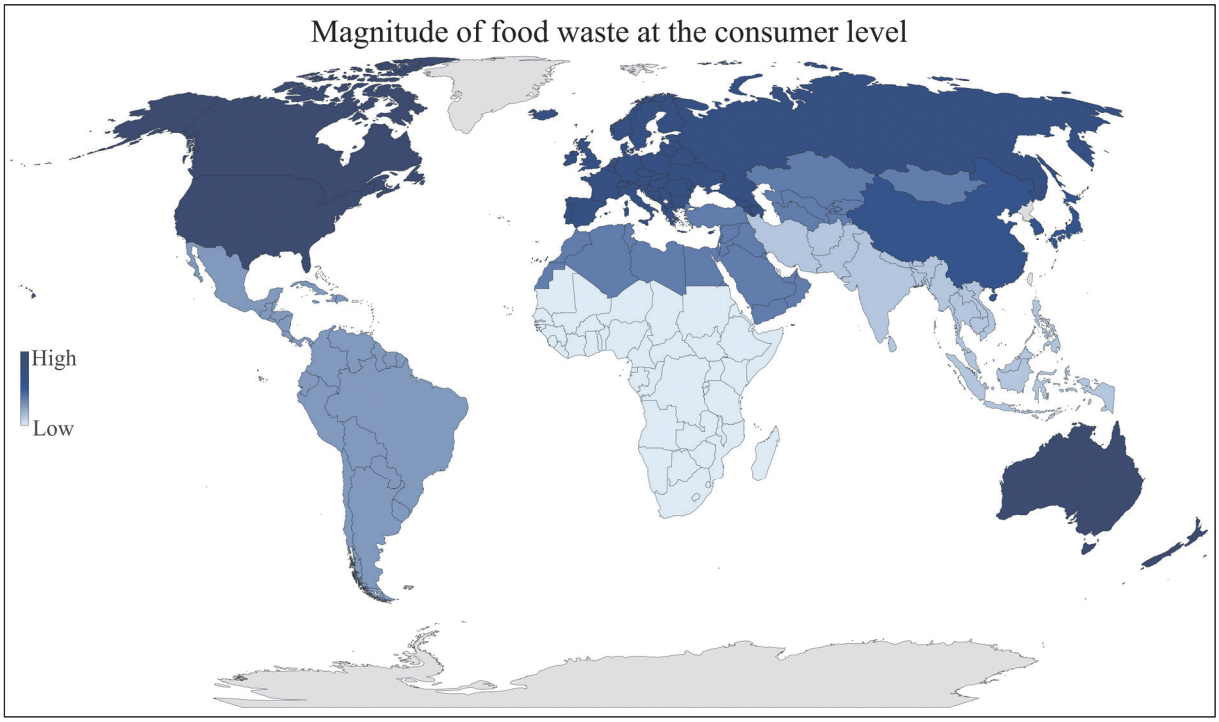

Figure 1-1 Magnitude of food waste at the consumer level on a global scale, based on data from Gustavsson et al. (2011).

Since 2011, food waste has been an issue of growing public concern, which resulted in a steadily increasing scientific interest. To generate knowledge about the problem, research focused on data collection across different sectors of the food supply chain (Hebrok and Boks, 2017). The number of peer-reviewed papers on food waste showed an exponentially growing trend within a few years. The academic output increased from two publications in 2011 to almost 60 food waste-related papers in 2016 (Schanes et al., 2018). Current extrapolations estimate food waste quantities in Europe at approximately 87.6 (± 13.7) million tons per year, which corresponds to approximately 173 (± 27) kg per person and year (Stenmarck et al., 2016). Figure 1-2 compares the proportion of food waste between the consumer level and food supply chain in different global regions based on data from CEC (2017). Accordingly, food waste in medium- and high-income countries is generated to a significant extend at the consumer level, while in low-income countries a higher percentage of food is lost at earlier stages of the food supply chain. These findings are similar to the results of Schmidt et al. (2019), who estimated that approximately 66% of food waste in Germany is generated at the consumer level and approximately 44% during production, processing, distribution and retailing processes.

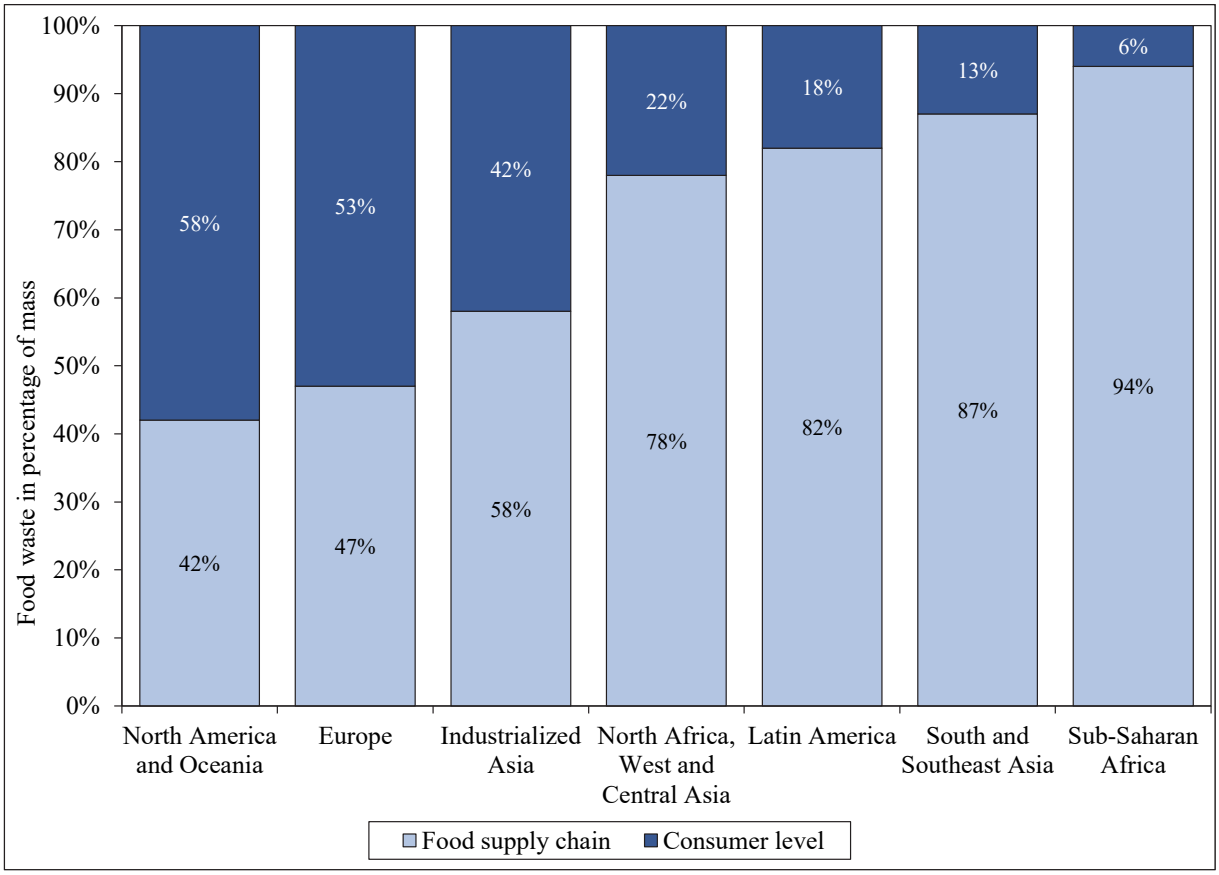

Figure 1-2 Proportion of food waste between the consumer level and the food supply chain in different regions, based on data from CEC (2017).

1.2 United Nations' Sustainable Development Goals

The 2030 Agenda for Sustainable Development adopted by the United Nations' member states is a commitment to achieve sustainable development worldwide by 2030. This global action plan formulates 17 Sustainable Development Goals (SDG) and 169 specific targets based on the three dimensions of sustainable development, namely economy, society, and environment. The objectives include topics such as poverty, health and well-being, equal rights for women and men, access to education, infrastructure, food security, peace, and climate protection. SDG 12 is dedicated to ensuring sustainable consumption and production patterns. The specific target 12.3 refers to reducing food waste and calls for the halving of global food waste at the retail and consumer levels and reducing food losses along production and supply chains, including post-harvest losses (United Nations, 2015). With this formulation of goals, reducing food waste has, on the one hand, gained international relevance, while on the other, the exact meaning of SDG Target 12.3 is somewhat ambiguous. In particular, there is a lack of explicit definitions and explanations, which affects monitoring progress towards 2030 (Hanson, 2017). To overcome the reduction targets' ambiguity, Hanson (2017) prepared a proposal of guidelines for the interpretation of SDG 12.3, including recommendations for system boundaries and non-binding requirements as follows:

- The timeframe for reports on food waste quantities should be 12 months.
- The requirement to halve quantities should be applied to both losses and waste, although SDG 12.3 quantitatively targets food waste only.
- Estimates should consider the edible parts of food and the associated inedible components, wherever possible, and record them separately.
- The recommended indicators report food loss and waste per person and should therefore be expressed in kilograms per person and year.
- The product packaging weight is excluded from the food waste weight.
- The use of food losses as animal feed or for processing into industrial products should not be counted as food losses or waste. The processing of food losses into industrial products means, for example, the production of fibers for packaging material, the production of bioplastics, the traditional use of feathers for upholstery production, or the use of fats and oils for the production of soaps, biodiesel, or cosmetic products.
- All other recovery and disposal routes should be included in the measurement of food losses and waste. Recovery and disposal routes comprise anaerobic digestion,

composting, incineration and thermal recovery, landfilling, sewers, and non-harvesting or plowing of agricultural products.

- Relying on existing indicators and distinguishing between two sub-indicators referring to food losses and food waste is proposed.
- The first sub-indicator comprises the Food Loss Index (FLI), which includes losses in agriculture and food processing. The Food and Agriculture Organization (FAO) has already developed such an index and recently published a report on food losses on a global scale (Fabi and English, 2018).
- The second sub-indicator will be referred to as the Food Waste Index (FWI). This indicator is currently under development (Fabi, 2017).

To support the global implementation of the progress made and to facilitate a harmonized monitoring approach, the Champions 12.3 Committee was formed at the official request of the Dutch government during the 2015 UN General Assembly. Its members are representatives of governments, companies, international organizations, research institutions, agricultural associations, and civil society. Annual reports summarize global progress of SDG 12.3 and show the regions where measures have been implemented or remain lacking. Accordingly, governments that represent 50% of the global population have set specific targets for the prevention of food waste. These include the African Union, the European Union, Australia, Japan, China, and the USA. Approximately two-thirds of the 50 largest global food companies have independently set a reduction target. By the end of 2018, however, only a few countries have quantified or measured food losses and waste, which represent approximately 12% of the global population. Furthermore, the countries and regions that have implemented national or regional strategies to reduce food losses and waste covered approximately 15% of the global population (Flanagan et al., 2019). Hence, some countries are already adopting the reduction targets, but only few are measuring the amount of food waste or developing reduction strategies. However, the responsibility for developing indicators to monitor the achievement of SDG 12.3 has been divided between two authorities within the United Nations. The Food Loss Index (FLI) is administered by the Food and Agriculture Organization (FAO), while the United Nations Environment Program (UNEP) is in charge of the Food Waste Index (FLW). According to Fabi (2019), the Food Loss Index functions as a performance indicator to measure the efficiency of food systems expressed as percentage losses over time. The index is designed to enable policy makers to monitor trends in food losses compared to the baseline year 2015 in order to improve the efficiency of food supply chains. Since agricultural productivity depends on a number of

geographical and socioeconomic parameters (e.g., climate, agricultural technology, farming knowledge, government policies, social factors), performance indicators are applied individually for each country according to its 10 key commodities with the highest production volumes (Fabi and English, 2018). A proposal, however, for the measurement and monitoring of food waste at the retail and consumer level is currently being developed by UNEP. The Food Waste Index (FWI) will focus on the demand end of the supply chain and measure changes in global food waste quantities. The objective is to provide an internationally harmonized standard to monitor trends in food waste (Flanagan et al., 2019). In line with the SDG 12.3, the European Union has proposed a target of food waste reduction in its waste framework directive (Directive 2008/98/EC). In 2020, the European Commission has adopted a new Circular Economy Action Plan, which considers the reduction of food waste as a key action under the forthcoming EU Farm-to-Fork Strategy (COM, 2020). Figure 1-3 illustrates differences and similarities in the definitional framework between the FAO and the EU with regard to SDG 12.3.

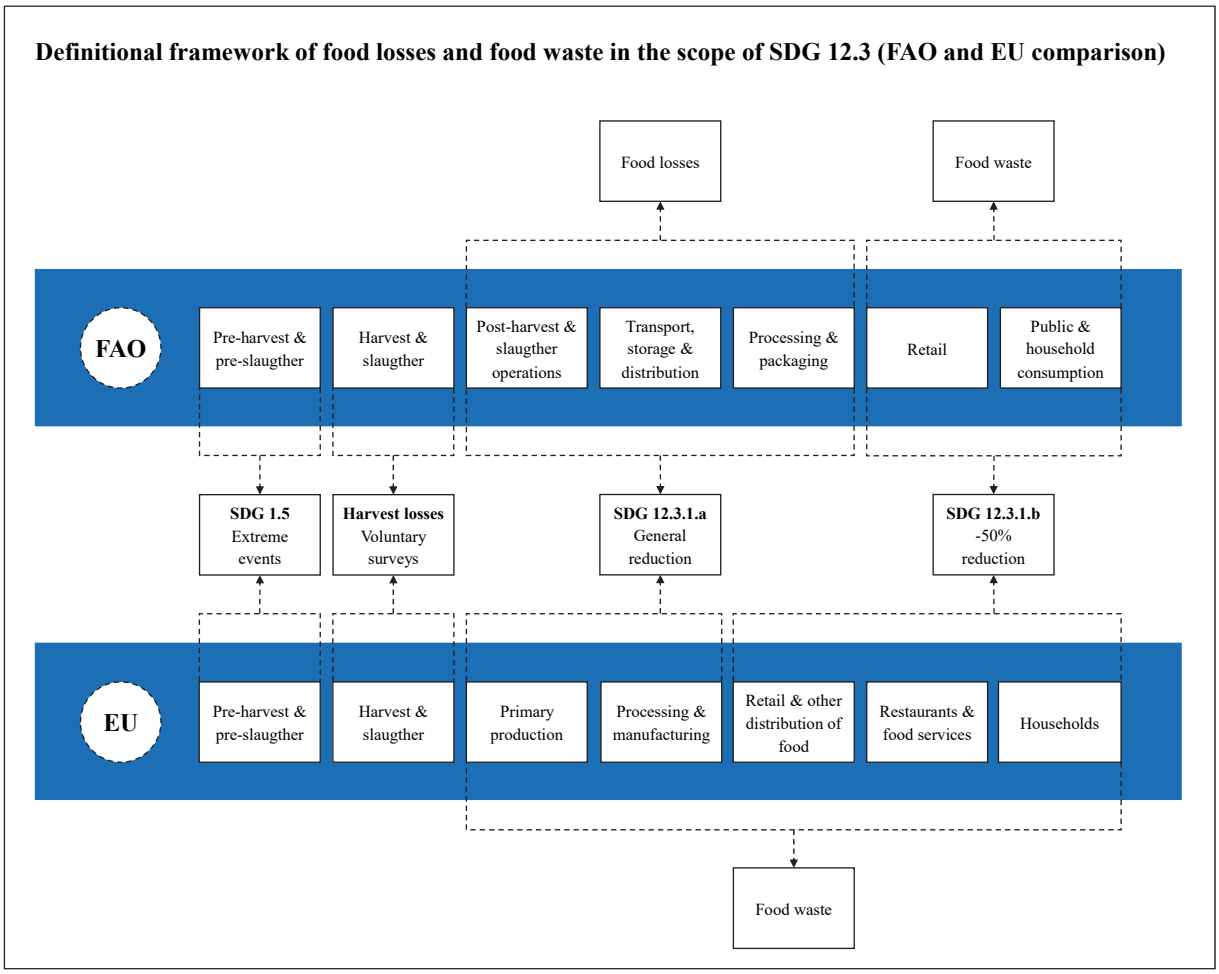

Figure 1-3 SDG 12.3 – Definitional framework of FAO and EU, based on information from FAO (2019) and European Commission (2019a).

In contrast to the United Nations, European legislation does not use the term "food losses" in its definitional framework and consistently defines discarded food as "food waste", regardless of the stage of the food supply chain at which it occurs. However, despite these differences in terminology, the definitional framework of the European Union on food waste can be considered as approximately congruent to the scope of the United Nations. On the other hand, there are some methodological differences in data collection. For instance, the FAO's data collection is based on official statistics such as the food balance sheets, while European member states are committed to conduct in-depth measurements periodically until 2030. Food losses and waste will be monitored along the entire food supply chain. Harvest losses, however, are treated separately and can be reported by member states on a voluntary basis (European Commission, 2019a; Fabi and English, 2018; FAO, 2019).

1.3 Political framework

1.3.1 Food loss and waste accounting and reporting standard

The first approach of global guidance for reporting food loss and waste was published in 2016 by an international group of experts under the title Food Loss and Waste Accounting and Reporting Standard (FLW Standard: Hanson et al., 2016). The guidance sets out some basic requirements for surveys and reporting food waste, such as:

- Food losses and waste should be recorded by mass.
- Pre-harvest losses are addressed by SDG 1.5.
- Surveys and reporting must be guided by the principles of relevance, completeness, consistency, transparency and accuracy.
- The description of the framework has to be clear regarding the time period, material flows (food categories), recovery and disposal routes, and system boundaries (geographical reference area and sectors of the food supply chain considered).
- All mass flows may only contain food or associated inedible components but no product packaging.
- Compliance with scientific standards regarding the methodological description of applied calculation procedures, sampling, and extrapolations.
- Changes in food loss and waste quantities are to be observed over time to monitor progress relative to a baseline year.

- Where appropriate, the baseline year should be recalculated if there are changes in the quantification methodology or underlying assumptions for future considerations.

The UK is one of the first countries that retrospectively adapted its previous reporting of food waste to the FLW Standard and published a report in May 2018 revising the amount of food waste from UK households until 2015 (Harris, 2018). Since then, the Food Waste Atlas has been introduced as an online portal that provides an additional source of information on globally available data sets on food waste. This freely accessible online tool enables users to consistently measure and track food loss and waste as well as enabling the reporting of data in accordance with the FLW Standard (WRAP, 2019).

1.3.2 European waste framework directive

The revised European Waste Framework Directive 2008/98/EC was amended by Directive (EU) 2018/851 of the European Parliament and Council on May 30, 2018. An EU-wide target has been adopted to meet SDG 12.3 by 2030, and to achieve a midterm goal of 30% food waste reductions by 2025. Further amendments are related to requirements of measuring, monitoring, and reporting food waste within the European Union as follows:

- Article 3 (4a) defines food waste as all food that has become waste as defined in Article 2 of Regulation (EC) No 178/2002 of the European Parliament and Council[1].
- Article 9 (1g) explicitly commits to SDG 12.3 and calls for the implementation of food waste reduction measures along the entire food value chain.
- Article 9 (1h) encourages member states to promote food donations and other forms of redistribution of food for human consumption to prioritize human use over animal feed and reprocessing into non-food products. Annex IVa (3) further recommends providing fiscal incentives for food donations as a possible economic instrument.
- Member states shall monitor food waste by measuring the levels of food waste based on a common methodology established in the Delegated Decision[2] (Article 9 (5)).

[1] Regulation (EC) No 178/2002 of the European Parliament and Council of January 28, 2002, setting forth the general principles and requirements of food law, establishing the European Food Safety Authority, and proposing food safety procedures.

[2] Commission Delegated Decision (EU) 2019/1597 of May 3, 2019, supplementing Directive 2008/98/EC of the European Parliament and Council regarding a common methodology and minimum quality requirements for the uniform measurement of food waste levels.

- By March 31, 2019, the commission shall adopt the delegated decision that establishes a common methodology and minimum quality requirements for the uniform measurement and reporting of food waste levels (Article 9 (8) and Article 37 (7)).
- Article 29 (2a) requires member states to adopt specific food waste prevention programs within their waste prevention programs.
- Article 37 (3) obliges member states to report annually on their food waste quantities and trends, starting with the reference year 2020.

To achieve the food waste reduction targets and ensure a high level of stakeholder contribution, the European Commission initiated an interdisciplinary platform on food losses and food waste. The platform was established in 2016 and aims to support all actors during measuring, reducing, monitoring, and reporting food waste. Members include key actors that represent both public and private interests such as international organizations, EU institutions, member states, and private sector organizations (European Commission, 2019b). One result of the cooperation was the formulation of recommendations for action in food waste prevention (European Commission, 2019c). Based on the EU legal framework, a preliminary timeline for reporting food waste in Europe can be expected as shown in Figure 1-4.

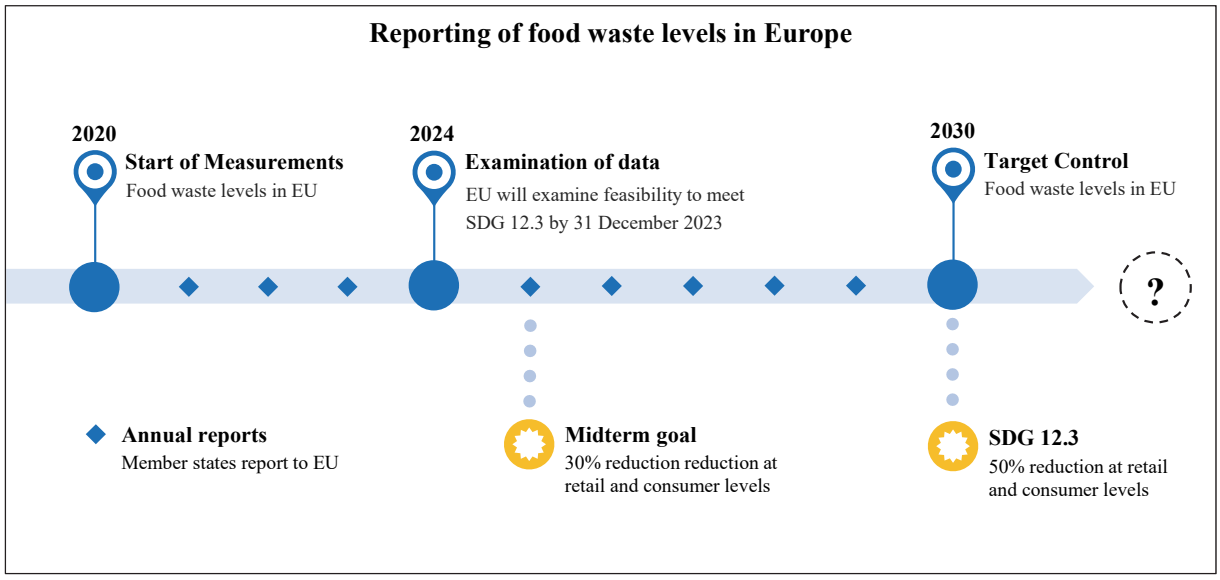

Figure 1-4 Preliminary timeline for reporting food waste levels in Europe until 2030, based on requirements from Directive (EU) 2018/851.

The baseline report of food waste in Europe is expected to be published in 2022 based on in-depth measurements with the reference year 2020. Member states shall provide annual reports on the generation of food waste until 2030 and report them to the European Commission. In-depth measurements are required at four-year intervals, while the annual reports are based on

indicators that are correlated with official statistics on food production in agriculture, fishery and hunting; production of processed food; turnover of food products; employment; population; disposable household income (European Commission, 2019a). The methodology for measuring food waste according to legal reporting requirements in Europe is presented in section 1.3.3.

1.3.3 Legal standard for measuring food waste in Europe

In 2016, the EU research project *FUSIONS*[3] published a manual on the quantification of food waste to harmonize the methodology for measuring, monitoring and reporting food waste in Europe. It was the first approach to develop standards and provide practical guidelines for the quantification of food waste by European member states (Tostivint et al., 2016). Although these recommendations were non-mandatory, they were further used as a scientific basis for the legal implementation of a standardized methodology. The legal framework was adopted in May 2019 by the Commission Delegated Decision (EU) 2019/1597 supplementing Directive 2008/98/EC of the European Parliament and Council regarding a common methodology and minimum quality requirements for the uniform measurement of food waste levels. Furthermore, the Implementing Decision (EU) 2019/2000 regulates the format for reporting data on food waste and submitting quality assessments. The Delegated Decision, however, determines that food waste will be reported separately for five levels of the value chain according to their NACE[4] codes, namely primary production, processing and manufacturing, retail and other distribution of food, restaurants and food services, and households (Article 1). In addition to definitions of food waste, there is also a distinction of what is not considered food waste. Food waste is defined as all food that has become waste, including inedible parts that were not separated from the edible parts when the food was produced, such as bones attached to meat or fruit peels. Hence, food waste may also contain inedible parts that were not intended for consumption. Furthermore, edible plants that have not been harvested or by-products from the production of food that fulfill the criteria of Article 5 (1) of Directive 2008/98/EC are not considered food waste. However, member states shall measure the amount of food waste each year in metric

[3] FUSIONS: Reducing food waste through social innovation. FUSIONS EU project is supported by the European Community's Seventh Framework Programme under Grant Agreement no. 311972.

[4] NACE is derived from the French title Nomenclature Générale des Activités Économiques dans les Communautés Européennes (Statistical Classification of Economic Activities in the European Communities). This acronym has been used to designate the various statistical classifications of economic activities developed in the European Union since 1970. NACE provides the framework for collecting and presenting a large range of statistical data according to economic activity in the fields of economic statistics (e.g., production, employment, and national accounts) and other statistical domains (Eurostat, 2008).

tons of fresh mass. Article 4 of the Delegated Decision (EU) 2019/1597 provides minimum quality requirements to ensure the reliability and accuracy of data. Accordingly, measurements should be based on a representative sample of the population and adequately reflect the variations. In terms of representativeness, the Delegated Decision remains relatively vague and does not more precisely define the meaning and size of a representative sample. ANNEX IV (a) further weakens these requirements by stating that calculations should refer to the best available data when in-depth measurements are not used. Figure 1-5 provides a graphical overview of the common methodology for the in-depth measurements of food waste in Europe. Consequently, the measurement methods used in this dissertation comply with the listed options in ANNEX III of the Commission Delegated Decision. As a result, the findings contribute to recently formulated legal requirements by investigating solutions to quantify and reduce food waste in food services and households.

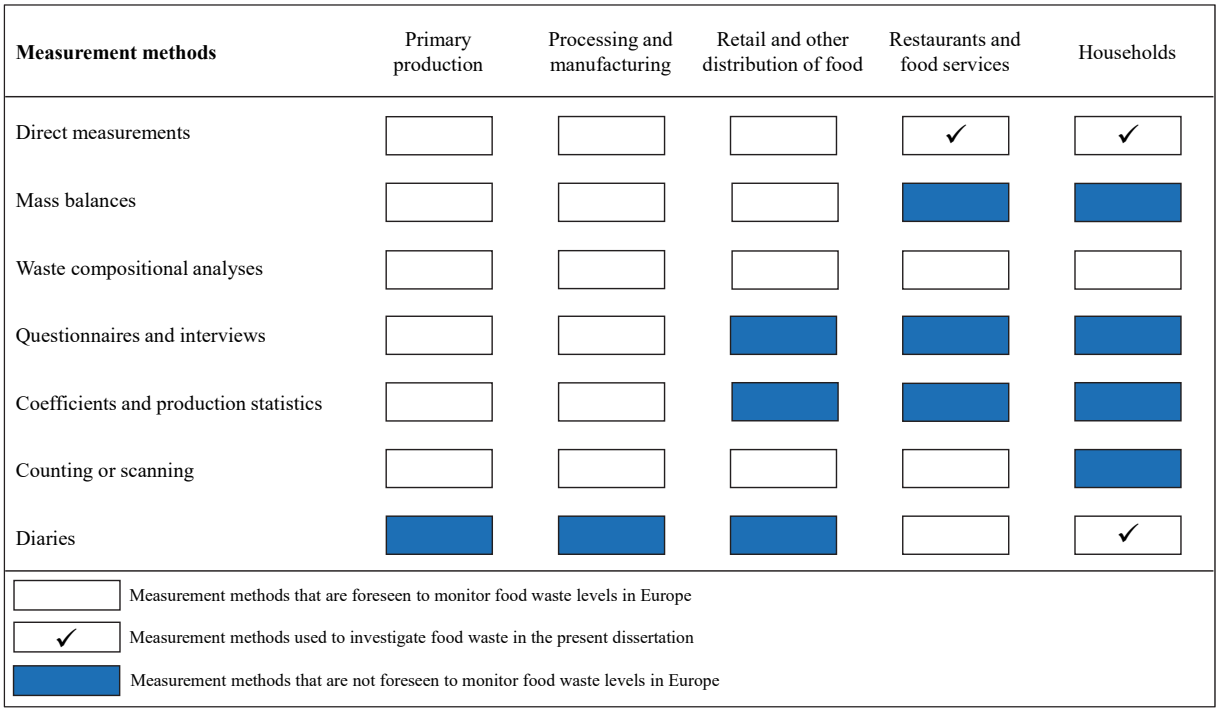

Figure 1-5 Common methodology for the in-depth measurement of food waste in Europe according to ANNEX III of the Commission Delegated Decision, based on requirements from the Commission Delegated Decision (EU) 2019/1597.

1.3.4 National strategy to reduce food waste in Germany

At national level, the "Too Good for the Bin!" initiative was launched in Germany in 2012. The initiative aims to raise awareness among actors and consumers throughout the food supply chain and rewards best practices for effective measures to reduce food waste (BMEL, 2012). The online platform "Appreciate Food"[5] presents initiatives, best practices, and instruments that support stakeholders in reducing food waste, but also calls on other actors to use the platform for the dissemination of their food waste prevention activities. In February 2019, a national strategy for food waste reduction was introduced by the Federal Ministry of Food and Agriculture in Germany (BMEL, 2019). The strategy represents a central element for meeting SDG 12.3 due to interdisciplinary cooperation in four different fields of action (Figure 1-6). The political framework is set by the committee of the federal government in cooperation with the federal states' official authorities at different levels with representatives from industry, science, and society. The members of an inter-ministerial working group on indicator SDG 12.3 are represented by governmental and public institutions such as the Federal Ministry of Food and Agriculture (BMEL), the Thünen Institut (TI), the Federal Ministry for the Environment, Nature Conservation, and Nuclear Safety (BMU), the Federal Environment Office (UBA), and the Federal Statistical Office (DESTATIS). The focus is to develop an indicator that enables the measurement and reporting of food waste according to the legal framework. In September 2019, the National Dialogue Forum was initiated to establish a stakeholder network for all actors from the food supply chain and civil society. An extension was realized within five sector-specific dialogue platforms, in which measures to reduce food waste are developed and voluntary commitments are encouraged. The second field of action is the process optimization in industry, including all stakeholders in the food supply chain that produce, process, handle, or offer food. The aim is to lower costs by reducing food waste to achieve a more sustainable use of resources. Proposed measures that could contribute to providing solutions include, for example, analyzing production processes, food waste monitoring, promotion of innovations that improve processes, cross-sectoral measures, enhancing transparency in the food supply chain, or cooperation between interest groups. The third field of action addresses behavioral changes at the consumer level through awareness-raising initiatives, increased communication via social media, and the education or training of teaching staff. Action field number four focuses on the development of innovative digital solutions and funding research.

[5] https://www.lebensmittelwertschaetzen.de

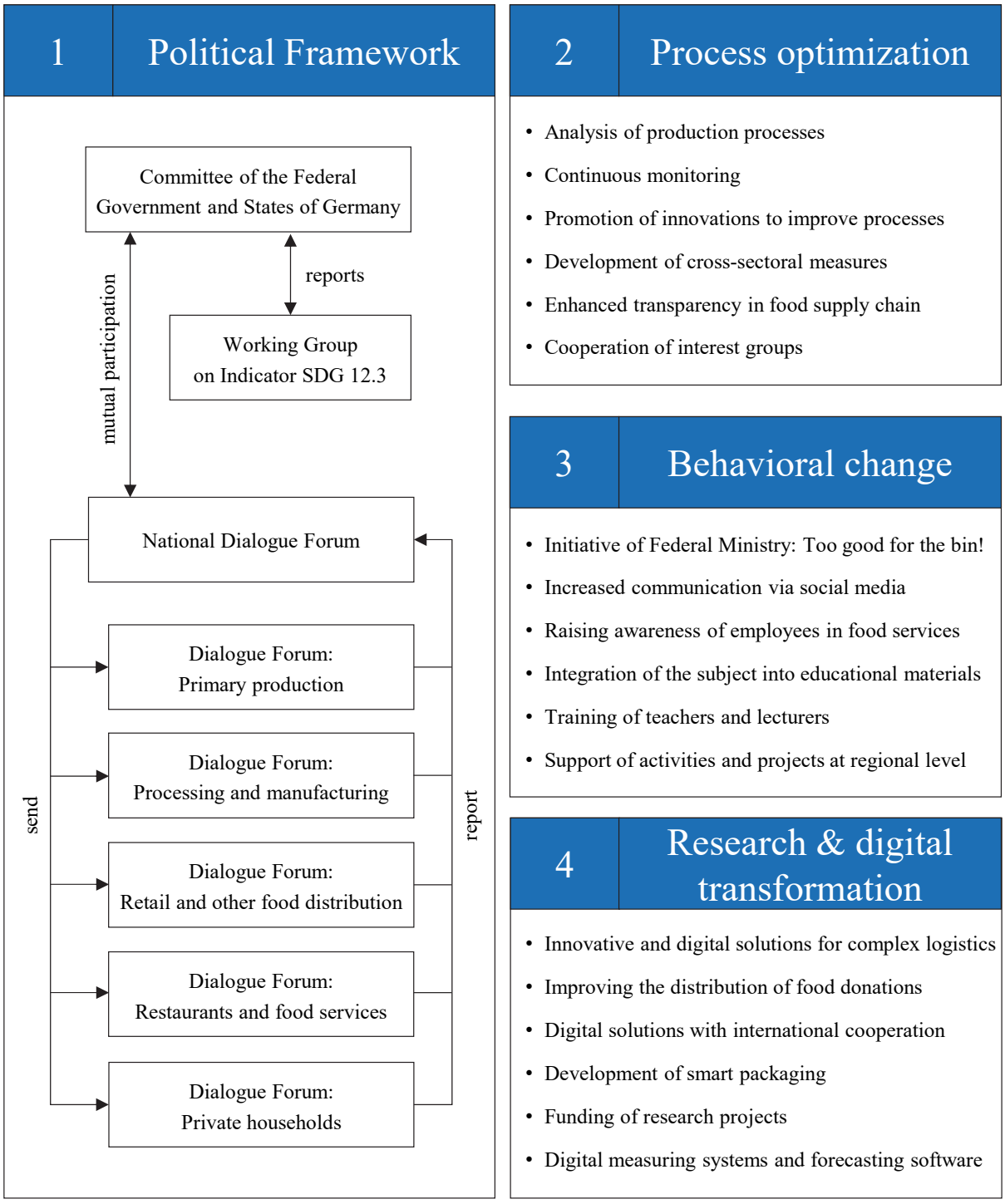

Figure 1-6 Structure for interdisciplinary cooperation between relevant stakeholders in Germany to reduce food waste by 2030, based on information from BMEL (2019).

1.4 International literature review

1.4.1 Food waste in households

Estimations of food waste in households are associated with several uncertainties, since some of it ends up in disposal routes that are difficult or almost impossible to reconstruct, for example, the disposal of liquid food waste through the sewage system or home composting of solid food waste in private gardens. In the literature, these quantities are usually collected through participatory studies in which households keep a diary (Hübsch and Adlwarth, 2017). Participatory studies are associated with relatively high inaccuracies and measurement errors due to missing external control mechanisms, which negatively influence a precise estimation (Delley and Brunner, 2018). However, the amount of food waste that is disposed of through the municipal waste collection system can be determined using information from official statistics that report the quantities of residual and bio-waste from households (DESTATIS, 2015). In December 2016, the Saxony State Office for the Environment, Agriculture, and Geology published guidelines with a common methodology to determine food waste percentages in municipal waste collection systems, amending the waste compositional guidelines at national level (Wagner et al., 2016). This amendment to the waste compositional guideline is a non-binding recommendation for conducting waste compositional analyses and provides an approach for a standardized method in Germany. In accordance with the amended guideline, food waste is divided into avoidable and unavoidable components. For instance, food that was once edible prior to disposal is considered avoidable food waste. Hence, avoidable food waste includes products such as packaged food with an expired best before date or leftovers. Inedible parts of food products such as bones and peels are considered unavoidable food waste. Based on the new waste compositional guideline, the percentage of food waste in the municipal waste collection system can be determined within statistically representative samples, providing robust and comparable results for future investigations. However, the first representative survey on food waste in German households, based exclusively on food waste diaries, was conducted by the market research company GfK SE from July 2016 to June 2017. As part of the GfK study, approximately 7000 households documented their food waste and its disposal routes using waste diaries. Participants had to estimate the type and quantity of food waste and decide whether the waste was avoidable or unavoidable based on their individual and subjective perceptions. The study found that approximately 4.4 million tons of food waste are generated in German households, of which approximately 44% could be avoided. About two-thirds of the total amount ends up in the municipal waste collection system. The participants stated that

approximately 57.6% of the food waste was caused by improper storage and only approximately 5.8% by exceeding the expiration date (Schmidt et al., 2018). Richter and Bokelmann (2018) stated that diaries are suitable for obtaining detailed information about food handling and food waste behavior. However, participants in diary-based studies showed a tendency to document significantly less food waste than actually occurred (Delley and Brunner, 2017; Quested and Johnson, 2009). To overcome this issue and obtain a more accurate approximation of the true food waste quantities in households, a combination of information from waste compositional analyses and household diaries would provide more robust estimates (Quested et al., 2020). For instance, Leverenz et al. (2019) used such a combined approach and reported significantly higher amounts of food waste in German households (approximately 6.96 million tons per year) compared to the diary-based study of the GfK SE (approximately 4.40 million tons per year). Expressed in relation to the population of Germany, food waste in private households corresponds to approximately 85 kg per capita and year (Leverenz et al., 2019).

1.4.2 Determinants and behavioral dissonance

To find solutions to reduce food waste, possible instruments and associated determinants must be identified and understood. Food waste at consumer level is generated during handling, storage, and preparation processes or occurs as leftovers on the plate or at buffets. Accordingly, Hübsch and Adlwarth (2017) recommended to raise consumer awareness regarding appropriate handling, storage, and preparation of food. Visschers et al. (2016) showed that different predictors appeared relevant to the influence of food waste in households. The most important predictors are related to personal attitudes and less to subjective norms such as not throwing away food for ethical reasons (Visschers et al., 2016). There seems to be a certain conflict in consumers' attitudes regarding food disposal and health risks of eating leftovers (Evans, 2011). Accordingly, the motivation of individuals to avoid food waste does not necessarily lead to consequential behavior, which is known as the intention-behavior gap (Sheeran and Webb, 2016). Consumer surveys have demonstrated that there is a tendency among respondents to meet the social norm of not wasting food (Stancu et al., 2016; Stefan et al., 2013). Individuals also demonstrated bias regarding their self-perception, leading to under-reporting with up to tenfold discrepancies when they had to estimate their amount of food waste (Abeliotis et al., 2014; Delley and Brunner, 2018). Consequently, awareness-raising campaigns such as the "Too Good for the Bin!" initiative have to overcome individual biases and intention-behavior gaps to trigger behavioral changes of consumers. According to Moussaoui and Desrichard (2016), further difficulties are related to the significant gap between small individual actions and high-

level goals, such as “halving global food waste”. However, approaches of social influence are able to encourage behavioral changes through communication channels such as social networks or public commitments. The same applies to face-to-face interventions that involve a relatively high number of personnel and financial investment (Abrahamse and Steg, 2013).

1.4.3 Food waste in the food service sector

The amount of biodegradable kitchen and canteen waste from the out-of-home consumption is recorded in official waste statistics under waste code 200108. In Germany, approximately 928 thousand tons of biodegradable kitchen and canteen waste were collected separately from the municipal household waste in 2015 and processed in waste treatment plants (DESTATIS, 2018). Another 829 thousand tons of food waste from out-of-home consumption were collected together with municipal household waste. Resultantly, in 2015 approximately 1.76 million tons of food waste from the out-of-home consumption were disposed of through municipal waste collection systems (Schmidt et al., 2019). Official waste statistics, however, do not provide information regarding the waste quantities of individual facilities or sub-sectors of the food service sector (Leverenz et al., 2019). Therefore, scientific studies investigated the amount of food waste for different areas of the food service sector such as full-service restaurants, event gastronomy, fast-food restaurants, kitchens of the hospitality sector, business canteens or the catering of hospitals, care (nursing) and educational institutions. An overview of literature that provides coefficients about food waste quantities for different food services is presented in Table 1-1. In addition to quantitative findings, some sources provide information about the reduction potentials or the avoidable part of food waste quantities. Differences and variations in the underlying data can be explained, for example, by the great heterogeneity of catering services that work with different preparation methods such as cook and serve, cook and chill, or cook and freeze. Furthermore, the generation of food waste is related to individual influences by administrative and operational processes or by customer expectations (Heikkilä et al., 2016). Consequently, it is difficult to generate statistically representative findings for the food service sector, which complicates food waste monitoring and the identification of reduction potentials. Silvennoinen et al. (2015), for example, estimated that approximately 20% of all food handled and prepared in the Finnish food service sector is wasted. This would mean that every fifth dish prepared in food services is wasted. Due to data gaps, the food waste percentage of food that is handled and prepared in businesses of the German food service sector often remains unknown or is related to strong statistical uncertainties.

Table 1-1 Guest- and portion-specific food waste quantities in facilities of the food service sector.

	Food waste	Avoidable part	Unit	n	Source
Catering industry					
Full-service restaurants	206	105	g/portion	13	Schwarzmayr (2016)
	153	-	g/portion	7	Silvennoinen et al. (2015)
Fast-food restaurants	29	-	g/guest	1490	McDonald (2018)
Hospitality sector	136	109	g/portion	24	von Borstel et al. (2017)
	232	158	g/portion	13	Schwarzmayr (2016)
	323	-	g/portion	70	Eriksson et al. (2019)
	67	-	g/portion	189	Eriksson et al. (2019)
	85	-	g/portion	476	Eriksson et al. (2019)
Educational institutions					
Schools	107	-	g/portion	11	von Borstel et al. (2017)
	136	117	g/pupil	11	Waskow et al. (2016)
	79	-	g/portion	12	Eriksson et al. (2017)
	58	-	g/portion	23	Silvennoinen et al. (2015)
Colleges	280	-	g/portion	1	Ferreira et al. (2013)
	189	-	g/portion	5	Silvennoinen et al. (2015)
	91	-	g/portion	1	Betz et al. (2015)
Childcare facilities	107	-	g/portion	11	von Borstel et al. (2017)
	136	117	g/pupil	11	Waskow et al. (2016)
	51	-	g/portion	12	Eriksson et al. (2017)
Care institutions	152	122	g/portion	64	von Borstel et al. (2017)
	90	-	g/portion	3	Eriksson et al. (2017)
	108	-	g/portion	12	Silvennoinen et al. (2015)
Hospitals	152	122	g/portion	64	von Borstel et al. (2017)
Business canteens	108	78	g/portion	269	von Borstel et al. (2017)
	155	135	g/portion	23	Schwarzmayr (2016)
	86	-	g/portion	1	Betz et al. (2015)
Armed Forces	211	-	g/portion	1	Part (2010)
	160	82	g/portion	1	Müller (1998)
Prisons	226	-	g/portion	1	Kranert et al. (2012)
Cafes	102	-	g/portion	4	Silvennoinen et al. (2015)

Table 1-2, however, presents an estimation of food waste quantities for different sub-sectors of the German food service sector in 2015, based on waste coefficients from literature. Accordingly, the German food service sector produces approximately 1.6 million tons of food waste per year (Leverenz et al., 2019). The quantities in Table 1-2 were used as input data for the baseline calculation of food waste quantities in Germany and provide the reference point for future monitoring and reporting activities (Schmidt et al., 2019).

Table 1-2 Magnitude of food waste quantities in sub-sectors of the German food service sector in 2015 (Leverenz et al., 2019).

2015	Food waste in 1000 t/a			Avoidable food waste in 1000 t/a		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
Catering industry						
Full-service Restaurants	392	414	435	213	225	239
Event gastronomy	268	282	295	145	154	163
Fast-food restaurants	145	145	145	145	145	145
Hospitality sector	59	80	101	48	58	69
Hospitals	64	64	64	52	52	52
Educational sector						
Schools	43	49	55	43	45	47
Colleges	74	74	74	74	74	74
Childcare facilities	60	68	76	60	63	66
Care institutions	135	135	135	108	108	108
Business canteens	244	296	350	176	240	304
German Armed Forces	7	8	9	3	4	4
Prisons	18	18	18	8	9	9
∑ Food waste	1509	1633	1757	1075	1177	1280

According to Leverenz et al. (2019), most of the avoidable food waste in Germany is produced by business canteens (24%), followed by full-service restaurants (19%), catering at educational institutions (15%), event gastronomy (13%), catering of hospitals and care institutions (12%), fast-food restaurants (11%), hospitality sector (5%), and others (Figure 1-7).

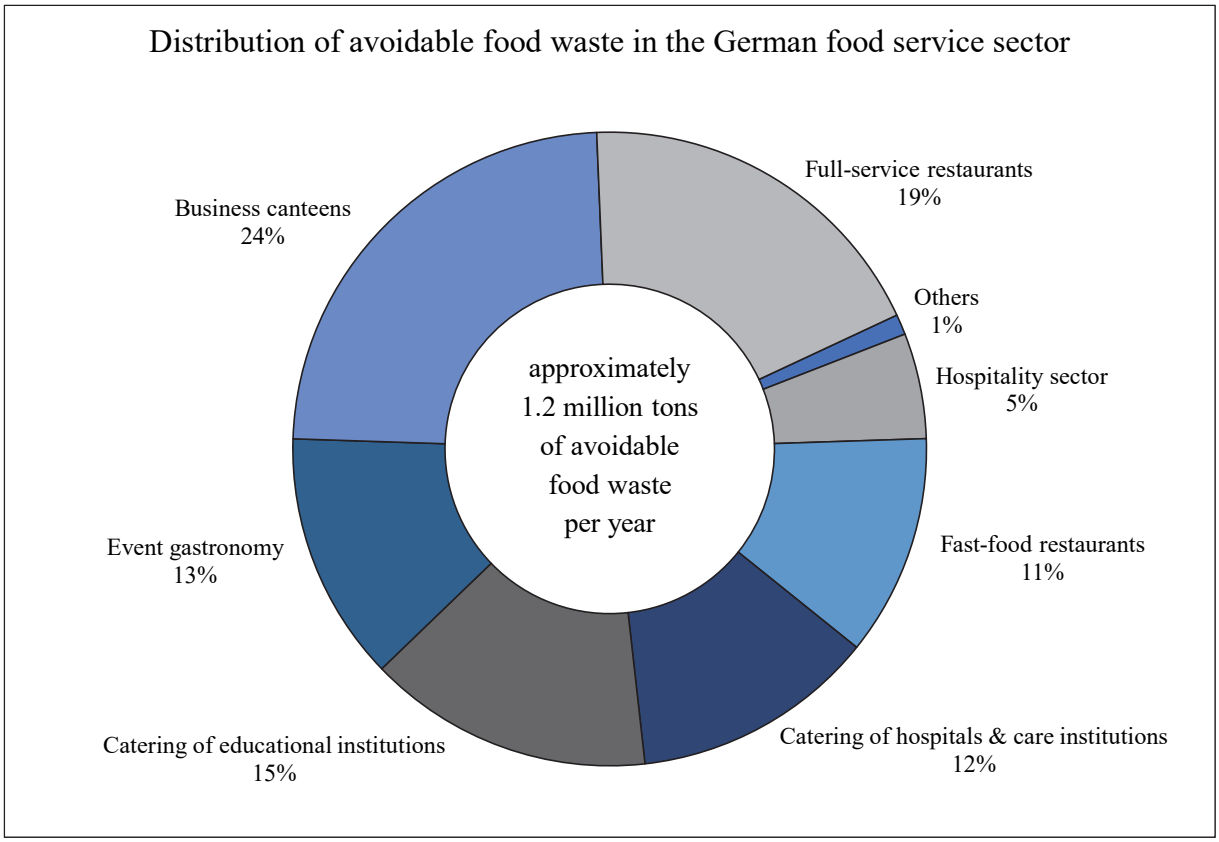

Figure 1-7 Distribution of avoidable food waste in the German food service sector, based on data from Leverenz et al. (2019).

1.4.4 Reduction measures in gastronomic kitchens

In their literature review of food waste at the consumer level, Reynolds et al. (2019) investigated reduction measures with regard to their effectiveness. Most interventions found in the literature were conducted as case studies and their findings were often not generalizable to a large extent because of limitations in the experimental design or due to the individual nature of the applied measures. The reviewed case studies that showed the highest effectiveness are briefly presented in this section. Kallbekken and Sælen (2013), for example, used non-intrusive "nudges" to reduce plate waste in 52 restaurants from a Norwegian hotel chain between June and August 2012. The participating hotel restaurants reduced food waste quantities by approximately 20% by using smaller plate sizes and providing information to guests at buffets based on perceived social norms. Another approach provided handwritten messages with awareness raising information to guests (approximately 540 participants) of a student dining hall during the spring semester of 2011 (six-week study). The guests were encouraged not to overfill their plates, which resulted in a reduction of leftovers by approximately 15% of mass (Whitehair et al., 2013). Wansink and van Ittersum (2013) observed the guest behavior in four Chinese restaurants located in New York and Pennsylvania with all-you can-eat buffets and found that

the larger the plate or serving dish, the more people show a tendency to overfill it. People served themselves 52% more food on larger plates than those who selected smaller plates, consumed 45% more food and generated 135% more plate waste (Wansink and van Ittersum, 2013). Furthermore, two lab and three field studies from the US indicate that people waste more food when they eat on disposable plates compared with permanent plates (Williamson et al., 2016). In 2010, Thiagarajah and Getty (2013) compared food waste quantities in a university dining hall before and after the implementation of a tray-less serving system over a period of five consecutive weekdays for each sample. As a result, solid food waste was reduced by 18.4% and liquid food waste by 6.8%. Between 2012 and 2014, Schwartz et al. (2015) surveyed food consumption and food waste patterns in 12 US middle school schools in an urban, low-income school district. After implementing improved nutritional guidelines in the 2012–2013 school year, less overall plate waste was observed, indicating that reduction strategies can benefit from addressing healthy diets. In 2016, a German field study quantified food waste in 11 school canteens over a sampling period of 10 days. Subsequent improvements in the food management and menu planning resulted to food waste reductions between 14% and 48%. The achieved reductions showed a relatively wide range, which can be explained by individual potentials to reduce waste, but also by statistical uncertainties related to the study design (Waskow et al., 2019). Clowes et al. (2018) analyzed data from 42 hotel sites in 15 countries that documented food waste quantities over a three-year time frame. Accordingly, the hotels were able to reduce the amount of food waste by approximately 21% over a 12-month time frame. Furthermore, Clowes et al. (2019) presented a report of 114 restaurants from 12 countries that reduced food waste by approximately 26% after the first year and by approximately 56% after the third year of investigation. Key strategies to reduce food waste both in hotels and restaurants were measures such as staff training, redesigning buffets, minimizing overproduction, rethink inventory and purchasing practices and donating surplus food (Clowes et al., 2018; Clowes et al., 2019). Furthermore, Eriksson et al. (2017) recommend that each gastronomic kitchen should carry out individual measurements to determine specific potentials and develop measures to reduce food waste accordingly.

1.4.5 Economic and ecological impacts

The generation of food waste is associated with economic losses, whose reduction can result in significant financial savings (Clowes et al., 2019). Schmidt et al. (2018) estimated that avoidable food waste in German households causes monetary losses of approximately 6 billion euros per year. According to the study, a two-person household in Germany could save at least

150 euros every year by reducing food waste, which is equivalent to less than approximately 5% of the annual food expenditures of an average German household. Hence, households can achieve monetary savings by reducing their food waste, although the financial incentives to reduce food waste are relatively low at the individual level. However, the savings that can be achieved by reducing food waste in gastronomy result in higher kitchen-specific monetary potentials, but are subject to significant variations between different catering services. The initiative United Against Waste Germany estimates that between 5 and 70 thousand euros can be saved annually according to the kitchen size (von Borstel et al., 2017). United Against Waste Austria reported that between approximately 14% and 22% of the prepared food in gastronomic kitchens is wasted, which results in an average savings potential of approximately 8 thousand euros per kitchen and year (Hrad et al., 2018; Schwarzmayr, 2016). Hübsch and Adlwarth (2017) found that the monetary savings potential of the average gastronomic kitchen in Germany is approximately 50 times higher than the potential of the average private kitchen in German households.

Jepsen et al. (2016) investigated the ecological impact of food products throughout the food supply chain and showed that food waste at the consumer level is associated with a significantly higher environmental impact than food waste in agriculture, processing, or retail. According to the results of the study, German households generate approximately 76 kg of food waste per capita and year, which correlates with approximately 345 kg of greenhouse gas emissions, approximately 2 cubic meters of water consumption, and approximately 290 square meters of occupied agricultural area. Furthermore, Jepsen et al. (2016) estimated that the German food service sector generates approximately 24 kg of food waste per capita and year, which correlates with approximately 132 kg of greenhouse gas emissions, approximately 850 liters of water consumption, and approximately 249 square meters of occupied agricultural area. Most parts of the food waste in gastronomic kitchens usually occurs as leftovers from buffets or plates, which is related with resource-intensive preparation processes such as cooling, heating, and cooking (Okumus, 2019; Papargyropoulou et al., 2016). In households, a higher proportion of perishable food is thrown away that has not been cooled, prepared, heated or cooked (Schmidt et al., 2018). Food products that are wasted in gastronomic kitchens often demonstrate higher ecological footprints than those wasted in private kitchens because of higher food waste ratios (Jepsen et al., 2016). Thus, reductions of food waste in the food service sector can lead to relatively higher ecological impacts than the equivalent in households. Nevertheless, literature emphasizes the importance to prevent food waste at all stages of the supply chain and to

thoroughly reduce environmental impacts in order to achieve more sustainable food systems (Kummu et al., 2012; Scherhaufer et al., 2018).

1.4.6 Food waste reduction initiatives and research gap

In 2013, a review of the international literature emphasized a lack of information and findings concerning the implementation and evaluation of food waste prevention measures (Schneider, 2013). Priefer et al. (2016) highlighted that further research is needed to also investigate the impact and efficiency of economic and regulatory instruments, because most reduction measures implemented in Europe are soft instruments such as awareness campaigns, round tables, networks, and information platforms. Stöckli et al. (2018) stated that informational interventions are the most popular type of intervention for reducing household food waste, although they often do not lead to the desired result. There is a lack of evidence in the literature regarding the effectiveness of interventions that focus on reduction measures at the consumer level. With reference to these findings, research needs to investigate other types of interventions that address behavioral changes (Stöckli et al., 2018). According to a recent review paper, the literature meanwhile promotes and recommends initiatives such as cooking classes, fridge cameras, food sharing apps, advertising, and information sharing, but provides little or no robust evidence on their effectiveness (Reynolds et al., 2019). The authors described this situation as worrying, as these recommendations are being proposed as successful approaches. However, except for a few studies, there is no reproducible evidence quantified to ensure credibility. Reynolds et al. (2019) further claimed that more longitudinal and intervention studies are required to substantiate current findings. Consequently, the key finding of their literature review highlighted a significant evidence gap, meaning that it is difficult to make evidence-based decisions to prevent or reduce food waste in a cost-effective manner at the consumer level. Goossens et al. (2019) confirmed that many of the proposed reduction measures are incomplete with regard to their economic, environmental, or social assessments and that efficiency is only rarely calculated. This causes a certain complexity for practitioners and decision-makers when distinguishing measures according to their efficiency and prioritizing them for future implementations (Goossens et al., 2019). The literature referenced in this section thus far provides a chronological overview of review papers that collectively summarizes the most relevant research activities regarding food waste reduction measures. Accordingly, research on food waste has increased significantly in recent years. Nevertheless, most findings from the literature are based on results from case studies with short investigation periods and cannot be generalized to a large extent. In particular, there is a lack of evidence concerning prevention

measures, especially because their effects are rarely studied over long periods of time or their effectiveness is not evaluated at all.

1.5 Objectives and cumulative structure

The main objective of this research is to contribute to filling the described knowledge gap by conducting food waste measurements at the consumer level. The dissertation aims to provide evidence-based results about reduction potentials and measures to reduce food waste. The findings of the research are published in three peer-reviewed papers, which are presented in the remainder of the dissertation in a cumulative structure. This means that the three publications are presented in chronological order, corresponding to the date of their publication, and are called accordingly Publication I, Publication II, and Publication III. Each part analyses food waste quantities and reduction potentials using self-reporting methods in different frameworks. The results of the three publications are summarized, compared against each other and discussed in section 5 ("general discussion").

It is known that self-reporting methods contribute to raising awareness of participants and cause adaptive reactions that may be expressed by behavioral changes (Zimmerman, 2002; Quested and Johnson, 2009; Reid et al., 2009; Lanzini and Thøgersen, 2014). The dissertation therefore addresses a central research question:

"Do self-reporting interventions contribute to raising awareness among participants and thus triggering behavioral changes that lead to food waste reductions?"

Publication I explored the prevention potential of avoidable household food waste using offline- and online-based self-reporting methods, accompanied by additional coaching and awareness-raising measures. Following research questions were investigated:

1.1) What are the reduction potentials of avoidable food waste in households?
1.2) Which product groups are most frequently discarded in households?
1.3) Does the food waste reduction potential depend on household size?
1.4) Do offline and online-based self-reporting methods contribute to raising awareness?
1.5) How effective is an online coaching compared to a face-to-face communication?
1.6) Is it possible to meet SDG 12.3 of halving food waste in households?

Publication II investigated the transferability of self-reporting methods to gastronomic kitchens and conducted experiments in four pilot hotels over a 12-month time frame. Especially for this purpose, a measuring equipment was developed that enabled the participants to weigh and document food waste as an integrated process in the daily kitchen routine. The aim was to realize a time-efficient self-reporting without causing negative effects on operational kitchen processes considering that available human resources such as personnel hours are limited. The investigation addressed the following research questions:

2.1) What are the reduction potentials of breakfast buffet leftovers in hotels?
2.2) Do food waste tracking systems contribute to reduce food waste?
2.3) Which product groups are most frequently discarded during breakfast buffets?
2.4) Which monetary savings potential is associated with breakfast buffet leftovers?
2.5) Which impact has the number of guests on breakfast buffet leftovers?
2.6) Is it possible to meet SDG 12.3 of halving food waste in hotels?

Publication III examined the influence on food waste during 239 individual event caterings and contributed to closing data and knowledge gaps. The collected data set aimed to respond to the following research questions:

3.1) What are the factors that influence buffet leftovers at catered events?
3.2) What are the reduction potentials of buffet leftovers for different event sizes?
3.3) Which product groups are most frequently discarded during events?
3.4) Which monetary savings potential is associated with buffet leftovers?
3.5) Which measures could improve the menu planning for events?
3.6) Is it possible to meet SDG 12.3 of halving food waste at event caterings?

The dissertation also aims to provide a short review about economic efficiencies of food waste reduction measures. Furthermore, the discussion section gives an outlook on the possibilities of upscaling the self-reporting approach to a wider range of households and food services.

1.6 Material and methods

1.6.1 Theoretical framework and sample characteristics

The study design builds on previous investigations that showed positive results during self-reporting studies in households that used waste diaries to collect data (Quested and Johnson, 2009; Reid et al., 2009; Lanzini and Thøgersen, 2014). For the conduction of experiments, a

self-reporting approach was first carried out in households and subsequently extended in a similar form to gastronomic kitchens in order to analyze buffet leftovers during breakfast and event caterings. Table 1-3 provides an overview of the theoretical framework, including sample characteristics such as the panel size, geographical information, time horizon, methodical approach, type of intervention and the object of investigation. Prior to the start of the measurements, participants received instructions regarding the self-reporting procedure and the documentation of data by using kitchen diaries and food waste tracking systems. In each panel, food waste quantities and reduction potentials were investigated within defined time frames. Participants in households reported their food waste quantities over a period of 84 days in 2011 with offline-based kitchen diaries (Panel 1; 16 households) and in 2012 with online-based kitchen diaries (Panel 2; 37 households).

Table 1-3 Theoretical framework and sample characteristics.

	Households (Publication I)	Hotels (Publication II)	Events (Publication III)
Panel size	Panel 1: 16 households Panel 2: 37 households	4 hotels	239 events
State	Baden-Württemberg	Hotel A: Saxony Hotel B: Schleswig-Holstein Hotel C: Bavaria Hotel D: Baden-Württemberg	Saxony
District	Ludwigsburg	Hotel A: Dresden Hotel B: Timmendorfer Strand Hotel C: Munich Hotel D: Stuttgart	Dresden
Start of experiments	Panel 1: 03/2011 (84 days) Panel 2: 03/2012 (84 days)	Hotel A: 06/2014 (336 days) Hotel B: 09/2014 (336 days) Hotel C: 12/2015 (336 days) Hotel D: 07/2015 (336 days)	Period of investigation: - 01/2014 until 12/2017 - 239 events (239 days)
Method	Self-reporting diaries - Panel 1: offline-based - Panel 2: online-based	Self-reporting devices	Self-reporting devices
Interventions	Coaching & interactions - Panel 1: face-to-face - Panel 2: online	Food waste tracking system - Installation in kitchen - Operating instructions	Food waste tracking system - Installation in kitchen - Operating instructions
Quantification of	- Food waste & purchases - Reduction potentials - Monetary equivalents	- Breakfast buffet leftovers - Reduction potentials - Monetary equivalents	- Buffet leftovers - Reduction potentials - Monetary equivalents
Investigated factors	- Household size - Online reporting - Offline reporting	- Product type - Refilling behavior - Size of serving dishes	- Event type - Season - Event size - Menu price

Food waste tracking systems were integrated into the daily work routine of the pilot kitchens and used to monitor breakfast buffet leftovers in 4 hotels and to quantify buffet leftovers during the catering of 239 events. The measurements in hotels were conducted over a period of 336 days between 2014 and 2015. The data collection during events occurred between 2014 and 2017. The results illustrate food waste trends in households and hotels over time and demonstrate the influences of four variables (event type, season, event size, and menu price) on buffet leftovers at events. To describe the distribution parameters of the sample data, confidence intervals were calculated for each sample unit through a random resampling method with replacement (bootstrapping). However, a thorough description of the used material and methods is presented for each publication separately with regard to their definitional framework, study area, experimental design, procedure, data analysis and statistical tests in section 2.3 (Publication I), section 3.3 (Publication II), and section 4.3 (Publication III).

1.6.2 Development of the experimental setup

For the conduction of experiments, a food waste tracking system was developed. Figure 1-8 demonstrates the experimental setup, which is comprised of software (1), a connected electronic scale (2), and serving dishes (3) in which the food is weighed.

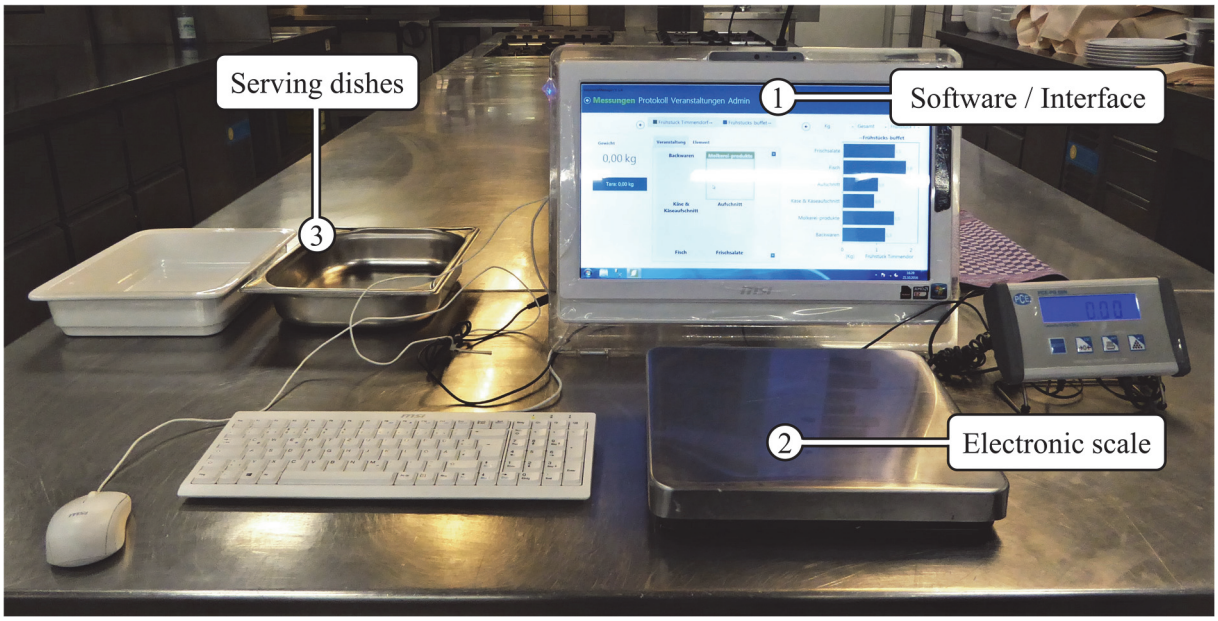

Figure 1-8 Experimental setup, comprised of a software called RESOURCEMANAGER FOOD (1), electronic scale (2) connected to a computer, and serving dishes (3).

The functions of the system were gradually modified, starting with a basic setup in 2013, which connected a computer with an electronic scale that transferred the weighing protocol directly into an Excel spreadsheet. This was later followed by developing an enhanced user interface

(Figure 1-9). Since 2013, the device has been gradually developed in cooperation with and based on feedback from several pilot kitchens. Its functioning is practically oriented, considering case-specific needs and boundary conditions. A part of the system is an electronic scale (PCE-PB 60N[6]) that is cable-connected (Universal Serial Bus – USB) to a 21.5-inch monitor of an All-in-One PC platform (562 mm length, 51 mm width, and 369 mm height). The scale has a weighing range up to a maximum of 60 kilograms, a reading precision of 20 grams, and an accuracy of ± 80 grams. The scale has a weighing plate of 300 mm width, 300 mm length, and 45 mm height. The serving dishes used for the buffet had standardized sizes, and varied in shape, depth, and weight according to their manufacturers. In the catering industry, these serving dishes are usually stainless-steel or polycarbonate trays that are commonly used for displaying, serving, and storing food. For instance, a stainless-steel serving dish of a common size has a dimension of 530 mm length, 325 mm length, and 65 mm height. Hence, the implementation of the system required a little less than one square meter of space in each pilot kitchen (compare Figure 1-8).

1.6.3 *RESOURCEMANAGER FOOD* – user interface

Figure 1-9 presents screenshots to illustrate the software design and related functions of the developed food waste tracking system called *RESOURCEMANAGRER FOOD*. The operator has the option to individually configure the software (Figure 1-9, F-1). Kitchen-specific products can be stored in the product catalogue within the software. The product catalogue in each pilot kitchen, for example, contained slightly more than 130 items. The software further allows evaluation parameters to be included, such as the monetary value associated with each food item. In this way, a direct correlation of food waste quantities and monetary equivalents can be displayed. Event-specific settings such as the type of an event or the number of guests can be entered optionally (Figure 1-9, F-2). Using the export function (Figure 1-9, F-3), the user can transfer the measured data to a spreadsheet file. The protocol function also allows the user to control or delete measurement data. The tare weights of serving dishes are preconfigured in the program (Figure 1-9, F-4). The user is able to measure individual food products that are classified into defined food categories (Figure 1-9, F-5). Once the measurement is completed, the collected data is presented in the form of horizontal bar charts (Figure 1-9, F-6). Photos of

[6] PCE-PB 60N is an multi-purpose industrial platform scale fabricated by PCE Deutschland GmbH (www. pce-instruments.com, accessed 23 February 2020).

individual food products and serving dishes can be integrated, which are displayed during the measurement to simplify the software's usability (Figure 1-9).

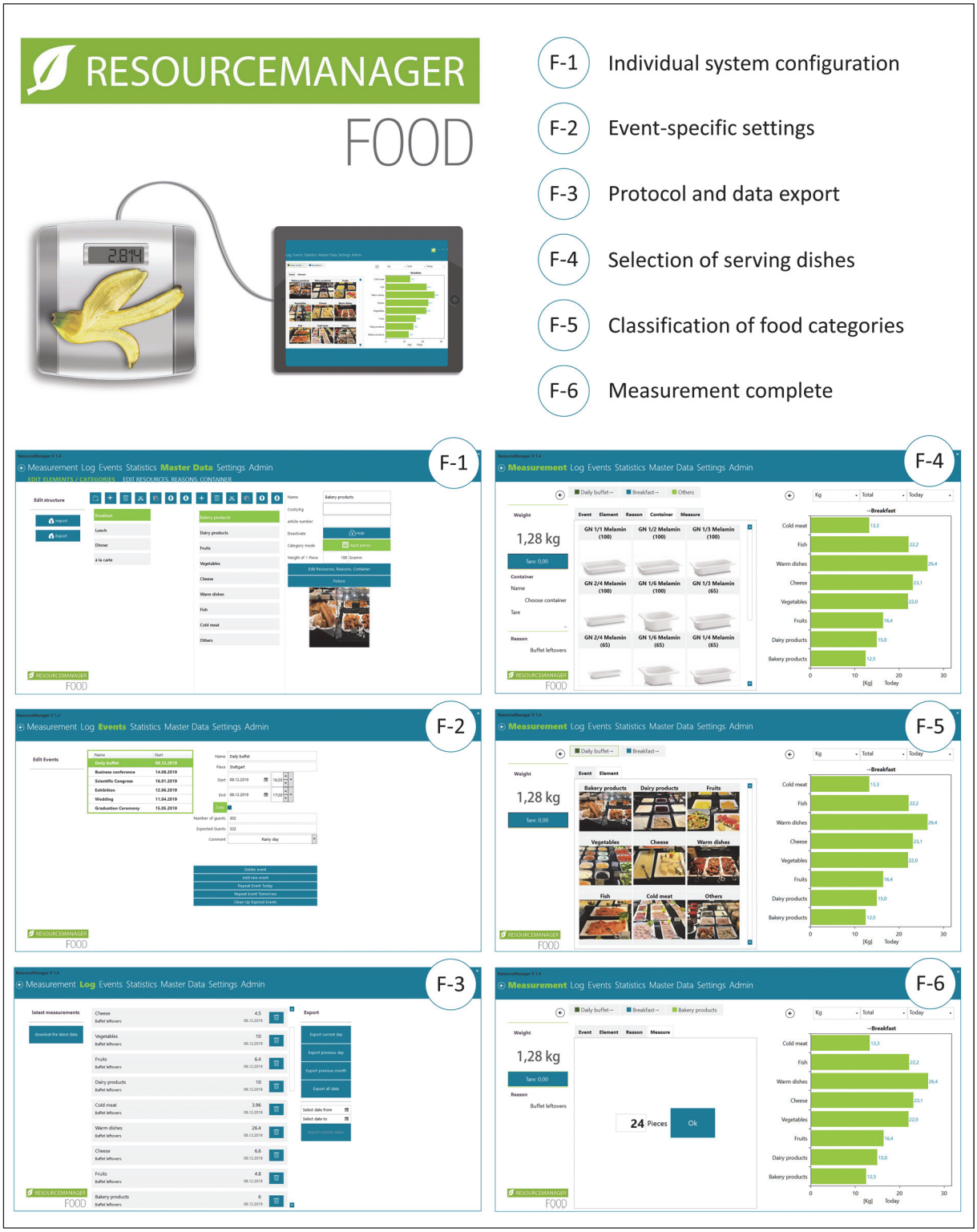

Figure 1-9 RESOURCEMANAGER FOOD: screenshots of the user interface.

1.6.4 Weighing procedure with the developed food waste tracking system

The use of the developed food waste tracking system required a weighing procedure with a defined number of steps to quantify the food waste. First, buffet leftovers were removed from the dining area and then placed on the scale to weigh them. The software directly determined the net weight of the buffet leftovers by subtracting the preconfigured tare weights of the serving dishes from the gross weight, i.e. the total weight of the serving dishes filled with buffet leftover. In the user interface, the operator selected the product category and its associated serving dish and completed the process by clicking on the "weighing button". Once the weight was registered, this process was repeated with the next product, whereby each measurement required three mouse clicks. However, portioned dishes and products whose average weight was known, such as single baked goods, fruits, and antipasti or desserts served in a glass, were documented as a number of pieces.

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2 Publication I: Quantifying the prevention potential of avoidable food waste in households using a self-reporting approach

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2.1 Abstract

The prevention of avoidable food waste at consumer level is an issue of increasing importance, yet persists with no evident solution. Recently the Sustainable Development Goals of the United Nations (SDG) set a new challenge to overcome in sustainable consumption, namely the partial target 12.3 to halve food waste by 2030 at household level. This paper aims to show that this target is indeed possible to achieve using an approach that builds on positive effects of interventions and kitchen diaries. We present an intervention method that is not only beneficial to gather data regarding avoidable food waste in households, but also contributes to reduce it. In this context, we compared the short-term impacts of two different types of self-reporting and coaching methods to reduce avoidable food waste in households. Therefore, we implemented in two separate panels of households in the same area once an offline-system and once a web-based online-system. The study outcomes are based on experimental data collected in these two sets of household panels demonstrating a clear improvement in the participant's behavior regarding food purchase and waste production. The main finding of our study is a reduction of avoidable food waste by more than 50% of fresh mass for both panels, showing that households can achieve the SDG 12.3. Based on the method's effectiveness, we encourage its wider use and further development.

2.2 Introduction

Over the years, food waste has become a pressing issue with annually more than 88 million tons of wasted food in Europe and more than 1.3 billion tons worldwide (Gustavsson et al., 2011; Stenmarck et al., 2016). This correlates with a global loss of about 24% of total freshwater resources used for food crop production, 23% of the total cropland area and 23% of total fertilizer use (Kummu et al., 2012). The avoidable food waste, generated by consumers in Europe, results in a blue water footprint of around 27 liters per capita and day, which corresponds in its magnitude with the total municipal blue water consumption in Europe (Vanham et al., 2015). On the other hand, the global demand for food will rise by up to 60% per capita in the year 2050 according to forecasts of the Food and Agricultural Organization of the United Nations (Alexandratos and Bruinsma, 2012). The target 12.3, under the Sustainable Development Goals (SDG) set by the United Nations (UN), aims to halving food waste at retail and consumer levels by 2030 and reducing food losses along production and supply chains, including post-harvest losses (United Nations, 2015). Thus, it has become a high priority to reduce food waste, especially in industrialized countries due to a relatively high amount of consumer food waste. In order to resolve this issue on a household level, research brought about many studies generating knowledge on the optimal ways to quantify and analyze collected data (Corrado and Sala, 2018; Delley and Brunner, 2018, 2017; Elimelech et al., 2018; Hanssen et al., 2016; Hübsch and Adlwarth, 2017; Jörissen et al., 2015; Ogwueleka, 2013; Schneider, 2016). Some solution-seeking studies use interventional methods to encourage consumers to reduce their avoidable food waste (Shaw et al., 2018; Smith et al., 2014; Young et al., 2017). Successful approaches would contribute to nudge consumers resulting in a food waste prevention without having them to change their attitudes or increasing their efforts drastically (Hebrok and Boks, 2017). Research in the field of behavioral and social science offers important insights on how to nudge people into better decision-making (Thaler and Sunstein, 2009). Amongst other findings, it became apparent that people feel uncomfortable when their behavioral reflection lead to the conclusion that they waste more food than others (Parizeau et al., 2015). The understanding and promoting of pro-environmental behavior can contribute significantly to long-term environmental sustainability, it is therefore important to facilitate a sustainable behavior for individuals (Steg and Vlek, 2009). Another motivator to reduce food waste for consumers, besides the environmental benefit, is the intention to not waste money (Baker et al., 2009; Graham-Rowe et al., 2014). However, triggering consumers by external interventions based on provision of information about environmental impacts and financial

benefits often result in no positive outcome (Shaw et al., 2018; Smith et al., 2014). Consequently, Shaw et al. (2018) recommends actions that are centered on the awareness of the householder's food use and the wasted food type in relation to the product and its life cycle stage. In the community-based approach "Love Food Hate Waste", households received awareness raising sessions on how to better manage their food, with the aim of preventing food waste. The initiators, the Waste and Resources Action Program (WRAP), collaborated with the National Federation of Women's Institutes (NFWI) and arranged personal gatherings for the participants of the study to share their experiences and learn food waste prevention tips from designated representatives. Even though the results were based predominantly on qualitative collected data, they showed highly positive outcomes, noting considerably that the communal nature of the project led to its success. A notable factor mentioned, was that the participants felt empowered to take the lead on resolving the issue on self-developing their food waste knowledge and skills (Falcon et al., 2008). One suggested approach providing gain to essential insights regarding the disposal behavior of consumers to prevent avoidable food waste was found to be the use of kitchen diaries (Richter and Bokelmann, 2017; Young et al., 2017). Richter and Bokelmann (2017) found that the use of kitchen diaries is suitable to get insights to the handling with food in households and showed the existing linkage between food storage, purchase and waste. However, a large number of existing literature generated substantial knowledge regarding the household behavior, analyzing drivers to reduce food waste (Hebrok and Boks, 2017). The realization of a successful concept requires the understanding that awareness is not a one-dimensional concept, but rather a mix of analogue and digital measures allowing the most promising impact when implemented (Gelbmann and Zimek, 2018).

Based on the above-mentioned studies, we used the self-reporting method to analyze the short-term effects within an interventional approach using kitchen diaries accompanied by additional coaching and awareness raising measures. Similar studies also provide the success of this method in a household context (Richter and Bokelmann, 2017; Young et al., 2017). Therefore, the main objective of our paper is to present a possible solution method which contributes to prevent avoidable food waste in households. We introduce the positive impacts of an interventional investigation that ran for three 1-month periods in the District of Ludwigsburg, Germany. We will present the observed short-term effects of using a kitchen diary in which we show trends and possible solutions on how to prevent food waste at the consumer level and discuss the findings considering the UN Sustainable Development Goals Target 12.3 of halving food waste at household level.

2.3 Material and methods

2.3.1 Definitional framework

The definitional framework in our study is consistent to Directive (EU) 2018/851 of the European Parliament and of the Council of 30 May 2018 amending Directive 2008/98/EC on waste, which defines food waste as all food[7] that has become waste. As we focus exclusively on the avoidable part of food waste from households, we refer in our definition of avoidable food waste to existing publications (Hanssen et al., 2016; Katajajuuri et al., 2014; Quested and Johnson, 2009; Visschers et al., 2016). In line with these investigations, avoidable food waste includes all edible parts of the food, which the consumer normally intends to eat when purchasing the food.

2.3.2 Study area

The participating pilot households are located in the administrative district of Ludwigsburg, Baden-Württemberg, Germany. In 2011, about 510491 inhabitants lived in the district of Ludwigsburg in about 228768 households (Statistik-BW, 2018a, 2018b). The average household size of 2.2 persons corresponds to the regional average of the federal state of Baden-Württemberg. In Ludwigsburg, about 136 kg/(cap·a) of residual municipal solid waste is collected via the municipal solid waste collection system, while another 42 kg/(cap·a) of organic household waste is collected separately as well as recyclables. These values are within a similar range compared to the nationwide average (DESTATIS, 2013). We therefore assume that the participating pilot households generate an average amount of avoidable food waste corresponding to the national average between 33.4 and 43.3 kg per capita and year, or between 91.5 g/(cap·d) and 118.6 g/(cap·d) respectively (Hafner et al., 2012).

2.3.3 Experimental design

Within this explorative study, we compared the short-term impacts of two different types of coaching methods to reduce avoidable food waste in households. We conducted two panel studies in the district of Ludwigsburg, both using a method of self-reporting. The first panel (Panel 1) worked with an offline self-reporting system, based on netbooks with an installed spreadsheet software. In addition, we provided paper forms to households that preferred working without the netbooks. We carried out personal communication through face-to-face

[7] Food is defined in Article 2 of Regulation (EC) No 178/2002 of the European Parliament and of the Council.

dialogues within the coaching sessions. The second panel (Panel 2) used a web-based online platform to document and report its data. We used this online platform to communicate and display information within the coaching sessions to the participants without any additional personal meetings. Both panels started the self-reporting process in the first month without receiving any awareness-raising information, thus allowing us to get an insight into their behavior prior to the coaching sessions. In contrast to similar interventional approaches using kitchen diaries (Young et al., 2017), we worked with the terminus *coaching* and not with the terminus *intervention* to describe the disseminated awareness information to the participants, since diary keeping is an intervention itself and is therefore associated with changes in the reported quantities (Delley and Brunner, 2018).

2.3.4 Sample characteristics

In order to recruit households, we called for participation using various media platforms, such as message boards, leaflets and regional newspapers. The households differ in the number of adults and children, as well as in their age and household income. Table 2-1 provides the main characteristics of the sample, the methodical approach and the time horizon. Panel 1 documented their consumer behavior between March and May 2011 while Panel 2 participated between March and May 2012.

Table 2-1 Sample characteristics.

Sample characteristics		Quantity of households	
State	Baden-Württemberg		
District	Ludwigsburg	Panel 1 (n=16)	Panel 2 (n=37)
Household size	single-person household	1	11
	two-person household	6	10
	three-person household	6	2
	four-person household	3	10
	five-person household	0	4
Children	one child	4	3
	two children	6	11
	more than two children	0	4
Methods	Self- reporting	Offline-based	Online-based
	Coaching	Face-to-face interaction	Online interaction
Time horizon	Period 1 (28 days)	03/07/11-04/03/11	03/05/12-04/01/12
	Period 2 (28 days)	04/04/11-05/01/11	04/02/12-04/29/12
	Period 3 (28 days)	05/02/11-05/29/11	04/30/12-05/27/12

The investigation phase lasted in both panels over a period of three months, divided into equal sections of 28 days, named accordingly period 1, period 2 and period 3 (see Table 2-1). In general, the panel does not represent the average German household.

2.3.5 Procedure and coaching

The procedure of the intervention contains three periods of self-reporting including a four-week coaching block with particularly compact information for both panels (see Figure 2-1). In the introductory phase (Period 1), prior to the start of the investigation, participants received basic instructions regarding the procedure of the self-reporting process and the documentation of data by using kitchen diaries. Considering that the panels did not yet receive any coaching, the collected data were taken as initial values, hence useful for determining the status quo.

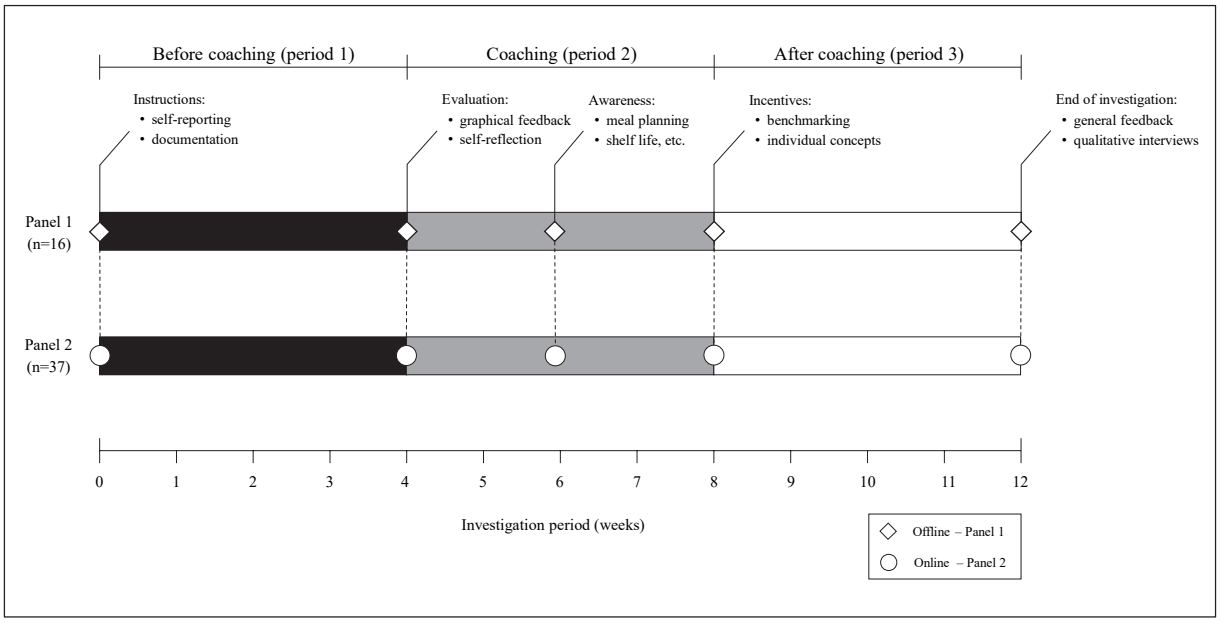

Figure 2-1 Timeline of the self-reporting intervention and its related coaching content.

In the second period (Period 2), both panels received three consecutively coaching sessions with intensified awareness raising information. We disseminated information with participating households from Panel 1 within personal meetings through direct communication accompanied by additional information in printed forms (e.g. flyers, instructional guides, etc.) and objects for demonstration purposes (e.g. fresh and expired food). The online communication with Panel 2 was strongly oriented towards a practical implementation possibility with the intention to reduce efforts of the coaching sessions in terms of personnel and financial resources. The information stream via the internet represents a compromise between the availability of a larger circle of participants and simultaneous depth of information. Content of the coaching sessions included for both panels awareness raising information, which is comparable to similar studies

(Falcon et al., 2008; Shaw et al., 2018; Smith et al., 2014; Young et al., 2017). In the first coaching session, participants received a graphical evaluation of their individual results during the self-reporting in the first month. This type of intervention method aimed to enable a self-reflection of the individual purchasing and disposal behavior with the intention to increase sensitivity towards a more conscious decision-making process when buying and discarding food. The participants of both panels were also required to document their main disposal reasons to enable the derivation of related conclusions by the participants themselves when reflecting their individual disposal behavior. The subsequent coaching session in week 6 contained specific information regarding smart shopping (e.g. using shopping lists), shelf life of perishable and packaged food, adequate storage and handling for different food types, better meal planning and recipes on how to create dishes with food that would have been thrown away otherwise (e.g. old bread to dumplings, cooked potatoes to fries, etc.). To intensify the awareness regarding shelf life of food, participants distinguished on a voluntary base between a fresh and expired yoghurt by visual, olfactory and sensorial tests. The concluding coaching session in week 8 provided further incentives such as a feedback of the so far reduced food waste in form of a benchmarking with other pilot households. In addition, we encouraged households to develop their own ideas and strategies regarding food waste prevention and to implement them on a trial basis in their daily life.

In the third period, households received no additional coaching sessions while maintaining the same kind of self-reporting to collect data and monitor progress, therefore we mark period 3 as the “after coaching” phase. This period presents a short-term observation of the influence of the coaching sessions on the participants’ purchasing and disposal behavior. At the end of the investigation, participants gave a general feedback within qualitative interviews regarding the self-reporting process, related problems and benefits (see Figure 2-1).

2.3.6 Study approach

Participants of both panels documented and reported their food management in specifically designed kitchen diaries. Panel 1 worked with offline-based kitchen diaries while Panel 2 used an online-based kitchen diary. In order to determine the status quo, the participants recorded every wasted food item by mass and day. The pilot households used a conventional kitchen balance to measure the mass of the avoidable food waste and food purchases by weight and day. The weighing process of the purchased food items within Panel 1 was associated with a disproportional high temporal expenditure in relation to the effort for the measurement process

and the correlated findings regarding the reduction of avoidable food waste. Based on these empirical learnings, we reduced the effort for the proceedings in Panel 2 by asking participants to report their avoidable food waste by weighing, but to report their food purchases in form of summarized monetary values from the purchasing receipts. This should reduce the temporal expenditure and efforts during the reporting period and strengthen the data quality regarding avoidable food waste. For the further evaluation and comparison of purchased food, we transformed the gravimetric values from Panel 1 into monetary values based on harmonized indices of consumer prices from Hafner et al. (2012). Beverages like water, juices, milk and alcoholic drinks were not measured.

2.3.7 Data analysis and presentation of results

We evaluated the reported data by comparing mean values (M) of the food waste quantities in households for both panels. To describe the dispersion of the sample, we calculated the standard error (SE) for each mean value. We analyzed the avoidable food waste of the pilot households and distinguished the examined data into the categories *bakery products*, *meat and fish*, *vegetables*, *dairy products*, *fruits*, *pasta products*, *leftovers* and *others*. The results are presented within vertical bar graphs with the standardized units in mass percentage for avoidable food waste and monetary percentage for purchased food. The corresponding inhabitant specific mass and monetary specifications are also displayed. The graphical presentation of results in mass percent shows the relevance in the context of the 50% prevention target of the United Nations and provides the achieved reductions within the pilot households. In addition, economic aspects of avoiding food waste are derived from the above-mentioned mass data.

Analyzing sample data, the Kolmogorov-Smirnov test showed for both panels normal distribution (α=0.05), so that subsequent statistical analyses are subject to parametric tests. We analyzed differences in food purchases and food waste generation before and after the coaching period, using repeated measures analyses of variance (ANOVA). It indicates the impact of the coaching on the consumer's behavior during the self-reporting periods, showing trends and short-term effects.

2.4 Results

2.4.1 Prevention of food waste through behavioral change

The outcomes are derived from three separate periods of the interventional approach and two separate panels. A major finding of our investigation is that the implemented methods resulted in a significant reduction of avoidable food waste by more than 50 percent of mass. The pilot households documented an average amount of 49.08 g/(cap·d) in Panel 1 and 34.93 g/(cap·d) in Panel 2 during the initial period prior to the coaching sessions. These self-reported quantities of avoidable food waste are significantly lower as the national German average of at least 91.5 g per capita and day (compare (Hafner et al., 2012)). The graph presented in Figure 2-2 shows trends and relations between improvement in food purchase and waste production during the period of investigation. Panel 1 lowered its overall expenditures on food about 15.7% after the coaching period, while Panel 2 spent 25.7% less on food purchases. The food waste trends show a steadily, almost linear decline before, during and after the coaching, both for offline (Panel 1) and online (Panel 2) interaction (compare Figure 2-2, B). Comparatively, we also observe an overall reduction of food purchases after the coaching sessions compared to the status quo, but no consistent reduction trend for Panel 1 (compare Figure 2-2, A).

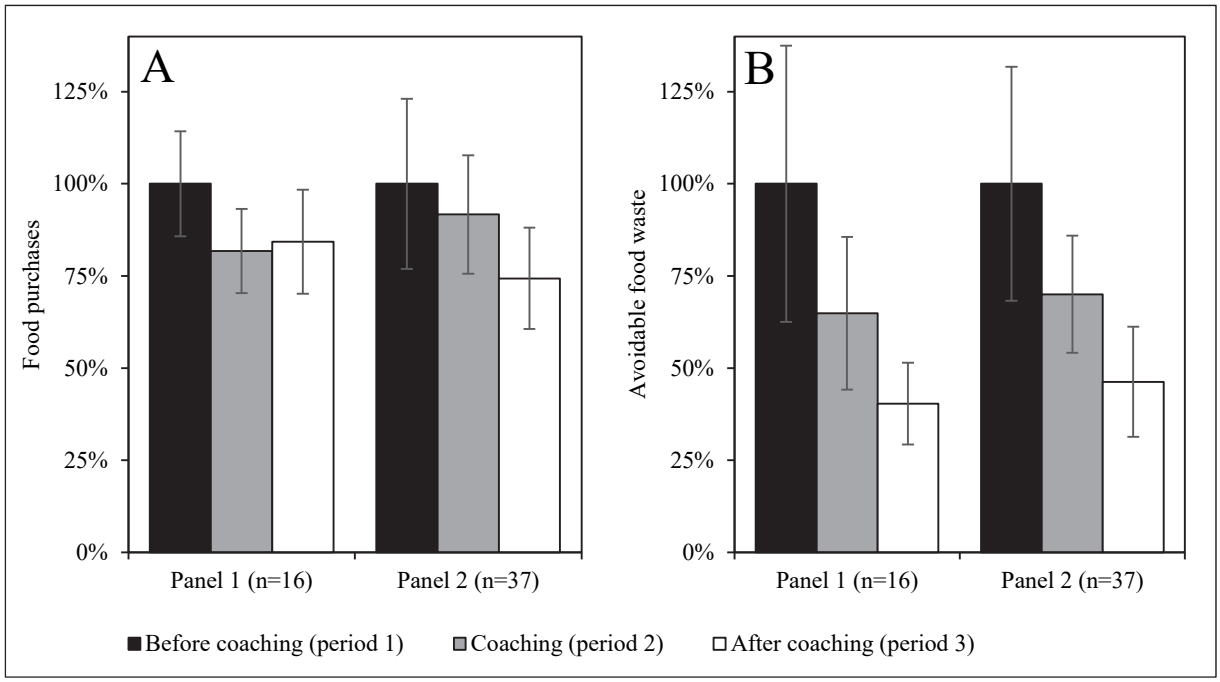

Figure 2-2 Trends in amounts of purchased food (A) and avoidable food waste (B) in total (M ± SE). A: Panel 1 (100% = 5.60 EUR/(cap·d)); Panel 2 (100% = 3.86 EUR/(cap·d)). B: Panel 1 (100% = 49.08 g/(cap·d)); Panel 2 (100% = 34.93 g/(cap·d)).

Table 2-2 presents the mean values (M) and standard error (SE) of avoidable food waste before and after the coaching and shows the resulting changes of mean values. Panel 1 reduced its average avoidable food waste by more than 59.6% of mass during the three months of investigation from 49.08 g/(cap·d) to 19.81 g/(cap·d) within the offline-based approach. A similar improvement of waste reduction occurred within the online-based self-reporting, decreasing avoidable food waste by more than 53.7% of mass from 34.93 g/(cap·d) to 16.16 g/(cap·d). The achieved reduction of food waste correlates with a monetary value in the range of 0.09 and 0.11 EUR per capita and day. According to this, the pilot households could theoretically save between 32.85 and 40.15 EUR per capita and year through the improvement of their food waste management (see Table 2-2).

Table 2-2 Mean values (M) and standard error (SE) of avoidable food waste before and after coaching.

Avoidable food waste	Panel 1 (n=16)				Panel 2 (n=37)			
	M [1]	SE[1]	M[2]	SE[2]	M [1]	SE[1]	M[2]	SE[2]
Before coaching (period 1)	49.08*	18.39	0.21*	0.07	34.93*	11.09	0.15*	0.05
After coaching (period 3)	19.81*	5.45	0.10*	0.03	16.16*	5.22[1]	0.06*	0.02
Changes of mean values (M)	–29.27		–0.11		–18.77		–0.09	
	(–59.6%)		(–52.4%)		(–53.7%)		(–60.0%)	

*Differences of mean values are significant (ANOVA, p <0.05).

[1]g/(cap·d). [2]EUR/(cap·d): Data transformed with values from table 69 in Hafner et al. (2012), p.119.

Table 2-3 presents the monetary mean values and standard errors of purchased food for both panels. Comparing the collected data shown in Table 2-2 and Table 2-3 of purchased and wasted food, we observe that all mean values in the offline-based approach are higher than in the online approach (compare Table 2-2 and Table 2-3). Concerning the expenses of food, our findings also demonstrate a change in the consumer behavior of the pilot-households. After coaching, the participants of Panel 1 spent on average 0.88 EUR/(cap·d) less on grocery shopping than before. Panel 2 showed a similar trend, spending 0.99 EUR/(cap·d) less on food than before (see Table 2-3). According to this, the participants in our study could theoretically save between 321.2 EUR/(cap·a) and 361.4 EUR/(cap·a) by a more conscious purchasing behavior, including overall optimized food management. The repeated measures analyses of variance (ANOVA) assert that differences of the mean values for purchased and wasted food are not random. The test results are statistically significant at a significance level of 5%, which introduces behavioral changes regarding the shopping and disposal behavior. In addition, data is distinctly wider scattered for food waste than for food purchases, which illustrates related uncertainties by

encouraging consumers to change their disposal behavior in terms of food waste prevention (compare Figure 2-2).

Table 2-3 Monetary Mean values (M) and standard error (SE) of purchased food.

Food purchases	Panel 1 (n=16)[1]		Panel 2 (n=37)	
	M[2]	SE[2]	M[2]	SE[2]
Before coaching (period 1)	5.60*	0.80	3.86*	0.89
After coaching (period 3)	4.72*	0.79	2.87*	0.53
Change of mean values (M)	–0.88		–0.99	
	(–15.7%)		(–25.7%)	

*Differences of mean values are significant (ANOVA, $p < 0.05$)

[1]Data transformed with values from table 69 in Hafner et al. (2012), p. 119

[2]EUR/(cap·d)

Furthermore, we observe for the wasted food that the distribution (bandwidth) of the sample values decreases, indicating an increase in conscious behavior of disposing food (compare Figure 2-2, B). Additionally, we found the confidence interval (M ± SE) reduced in total and closer to the mean in the third period. In general, the results show a consistent positive pattern in both panels asserting the two aforementioned targeted behavioral changes of purchasing and wasting food.

2.4.2 Food waste trends related to product groups

Table 2-4 presents detailed information on the avoidable food waste generation at product group level and also provides data about the waste composition for all periods. Initial data from period 1 show that vegetables, fruits, bakery products and leftovers dominate the average composition of the discarded food. These product groups caused in total more than 71.1% (Panel 1) and 74.1% (Panel 2) of the wasted food during period 1 prior to the coaching sessions. Therefore, these four products represent the predominant groups of avoidable food waste within our panels. Furthermore, the results in Table 2-4 demonstrate that participants of both panels reduced their avoidable food waste at product group level for all products except for the group *meat and fish*, where a contradictory effect is seen in Panel 1, increasing in average from 1.97 g/(cap·d) up to 3.66 g/(cap·d).

Table 2-4 Mean values (M), standard error (SE) and percentage distribution of avoidable food waste at product group level.

Avoidable food waste		Panel 1 (n=16)		Panel 2 (n=37)	
		M ± SE g/(cap·d)	M[1] %	M ± SE g/(cap·d)	M[1] %
Before coaching (period 1)	Bakery products	5.57 ± 2.61	11.4	4.75 ± 1.76	13.6
	Meat and fish	1.97 ± 1.83	4.0	1.42 ± 1.41	4.1
	Vegetables	10.75 ± 6.72	21.9	9.03 ± 4.35	25.8
	Dairy products	5.23 ± 2.28	10.7	4.34 ± 2.25	12.4
	Fruits	12.39 ± 10.32	25.2	7.55 ± 5.85	21.6
	Others	2.67 ± 2.69	5.4	2.55 ± 1.42	7.3
	Pasta products	4.32 ± 2.73	8.8	0.73 ± 0.48	2.1
	Leftovers	6.17 ± 2.83	12.6	4.57 ± 2.68	13.1
	Total amount	49.08 ± 18.39	100.0	34.93 ± 11.09	100.0
Coaching (period 2)	Bakery products	6.65 ± 2.95	20.9	2.97 ± 1.24	13.9
	Meat and fish	2.75 ± 1.85	8.6	1.25 ± 0.83	5.8
	Vegetables	11.29 ± 8.08	35.5	4.77 ± 2.08	22.2
	Dairy products	2.36 ± 1.48	7.4	3.22 ± 1.48	15.0
	Fruits	3.64 ± 1.58	11.4	4.09 ± 1.67	19.1
	Others	0.44 ± 0.49	1.4	1.89 ± 1.22	8.8
	Pasta products	0.67 ± 0.50	2.1	0.35 ± 0.32	1.6
	Leftovers	4.03 ± 2.09	12.7	2.92 ± 2.17	13.6
	Total amount	31.84 ± 10.15	100.0	21.46 ± 5.56	100.0
After coaching (period 3)	Bakery products	3.16 ± 1.45	15.9	2.55 ± 1.25	15.8
	Meat and fish	3.66 ± 2.53	18.5	0.50 ± 0.26	3.1
	Vegetables	5.53 ± 2.77	27.9	5.61 ± 3.68	34.7
	Dairy products	1.23 ± 1.08	5.8	1.39 ± 0.66	8.6
	Fruits	2.70 ± 1.99	13.6	3.22 ± 1.57	19.9
	Others	0.33 ± 0.29	1.7	0.93 ± 0.61	5.7
	Pasta products	0.75 ± 0.74	3.8	0.52 ± 0.61	3.2
	Leftovers	2.54 ± 2.11	12.8	1.44 ± 1.01	8.9
	Total amount	19.81 ± 5.45	100.0	16.16 ± 5.22	100.0

[1]percentage distribution of avoidable food waste

Figure 2-3 illustrates data from Table 2-4 for the aforementioned four predominant product groups and shows the respective trends in amounts of avoidable food waste. We observe a steady decline for fruits and leftovers in both panels during the whole period of investigation resulting in a reduction of more than 50% of mass.

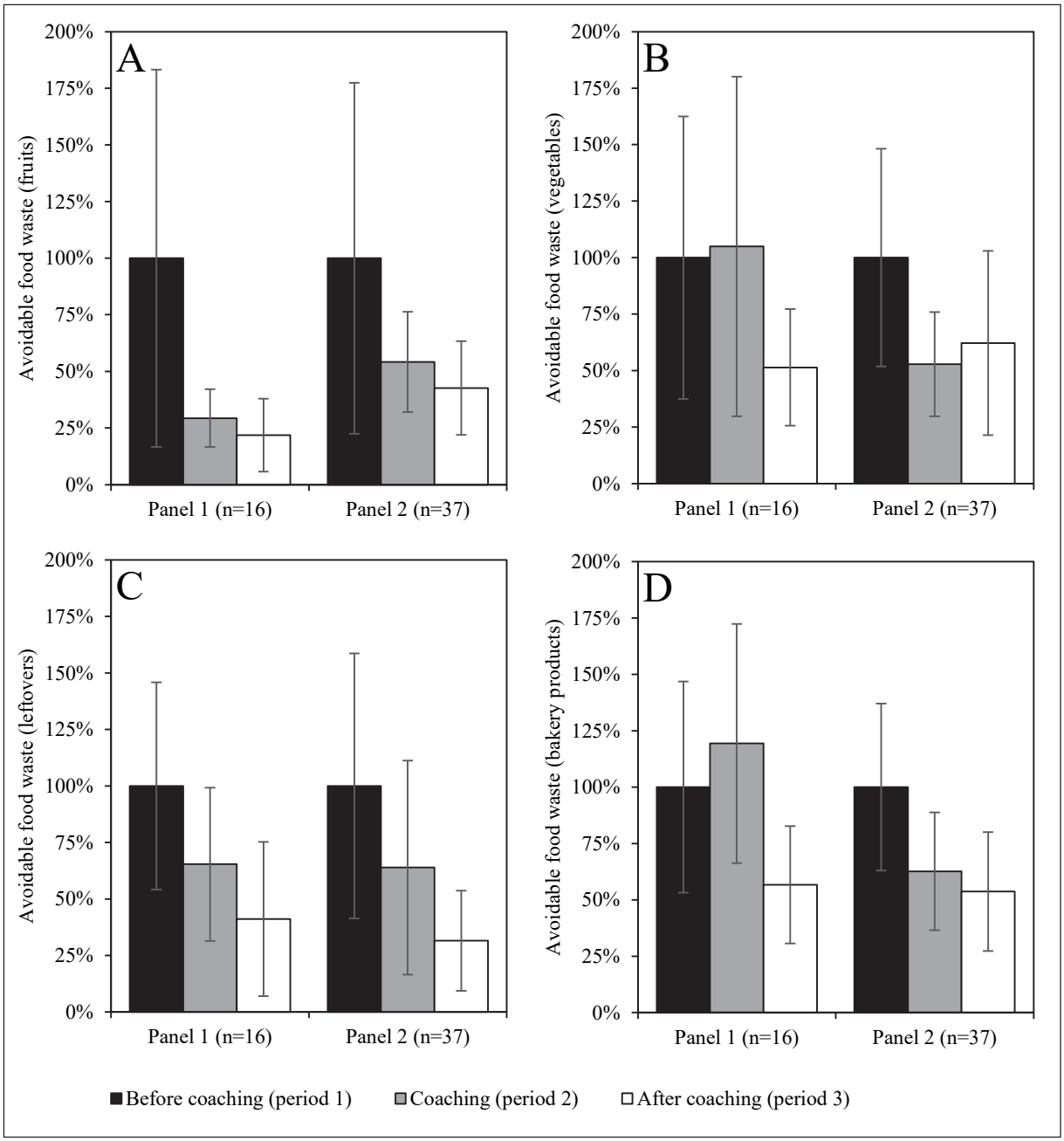

Figure 2-3 Trends in amounts of avoidable food waste (M ± SE) for the predominant product groups: fruits (A), vegetables (B), leftovers (C) and bakery products (D). A: Panel 1 (100% = 12.39 g/(cap·d)); Panel 2 (100% = 7.55 g/(cap·d)). B: Panel 1 (100% = 10.75 g/(cap·d)); Panel 2 (100% = 9.03 g/(cap·d)); C: Panel 1 (100% = 6.17 g/(cap·d)); Panel 2 (100% = 4.57 g/(cap·d)); D: Panel 1 (100% = 5.57 g/(cap·d)); Panel 2 (100% = 4.75 g/(cap·d)).

While vegetables showed in both panels to be one of the highest quantified food waste types within the first month, we found that the time for which each group of participants reduced their avoidable food waste differs in the two panels. Panel 1 reduced its vegetable food waste after the second month, while Panel 2 had a quicker response towards the coaching showing a reduction after the first month, noting however no further improvement in the third month.

Bakery products decreased between 43.3% (Panel 1) and 46.3% (Panel 2) of mass, while Panel 1 generated more food waste during the coaching (period 2) compared to the status quo before the coaching (compare Figure 2-3).

2.4.3 Trends in relation to household size

Figure 2-4 shows trends in amounts of avoidable food waste in the two panels during the three-month study. We observe that all participants living in households of different sizes reduced their avoidable food waste significantly.

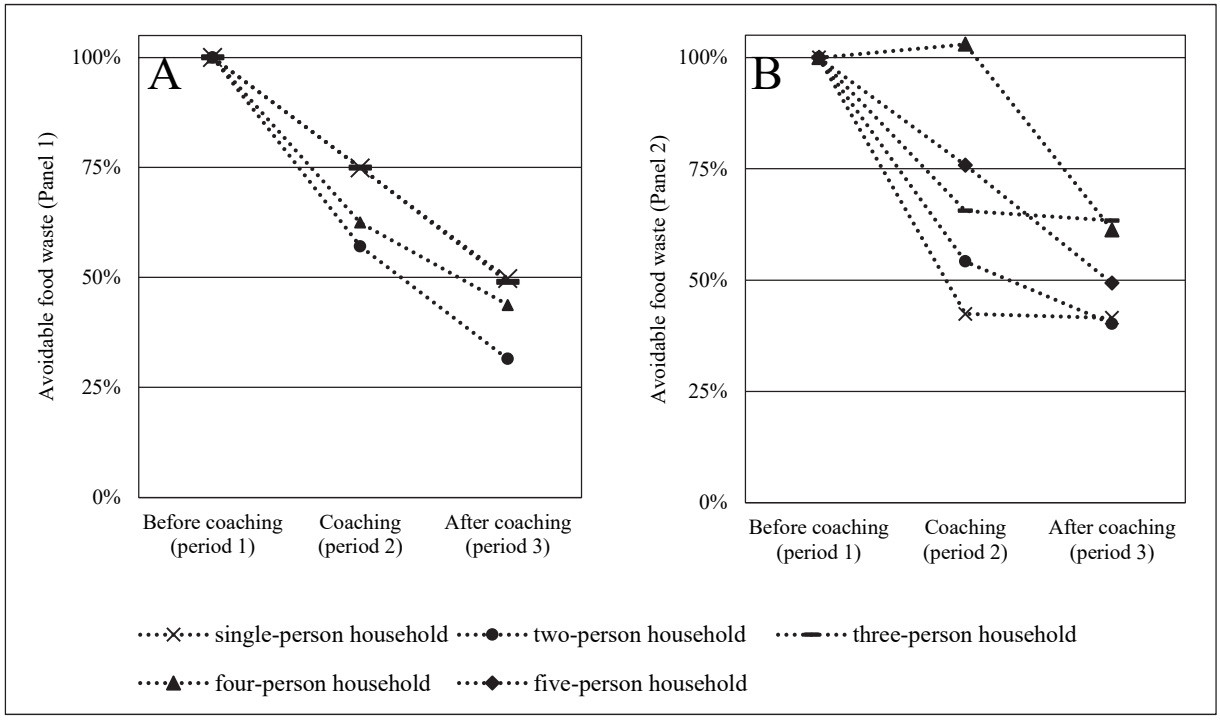

Figure 2-4 Trends in amounts of avoidable food waste (M) for Panel 1 (A) and Panel 2 (B). A: Single-person household (100% = 2.25 g/(cap·d)); Two-person household (100% = 21.65 g/(cap·d)); Three-person household (100% = 16.67 g/(cap·d)); Four-person household (100% = 8.52 g/(cap·d)). B: Single-person household (100% = 13.05 g/(cap·d)); Two-person household (100% = 9.55 g/(cap·d)); Three-person household (100% = 1.81 g/(cap·d)); Four-person household (100% = 5.83 g/(cap·d)); Five-person household (100% = 4.70 g/(cap·d)).

In both panels we notice a steady decrease in the waste quantities, while the four-person households in Panel 2 are an exception, as the amount of avoidable food waste during coaching first increases slightly and then decreases. During the offline-based approach in Panel 1, all households reduced their avoidable food waste by at least 50% of mass. Two-person households achieved the highest prevention with a 69% reduction of mass, while single and three-person households halved their food waste resulting in a similar congruent decline. Within the online-

based approach (Panel 2) single and two-person households achieved a reduction of their avoidable food waste by more than 50% of mass, while five-person households halved their amount. Four-person households reduced their avoidable food waste by 39% of mass and three-person households by 37% of mass, achieving relatively lower reductions compared to other household sizes within the panel (see Figure 2-4).

2.4.4 Reasons for food wastage

We collected qualitative information regarding disposal reasons for both panels. Participants documented the reasons associated to their disposal behavior as an indicator for possible behavioral changes. In general, the most frequently mentioned reasons for food wastage within our panel were attributed to *cooking too much*, *spoiling during storage*, *not using saved leftovers in time*, *expired shelf life*, *mistakes in handling and other reasons* like not having sufficient space in the refrigerator or no more interest in eating a specific food again. The significant decline of avoidable food waste in the participating households is influenced by these mentioned reasons and is related to behavioral changes like better meal planning, adequate storage, higher awareness in using leftovers in time, purchasing planning, preparing the meal and increased awareness on the value of food.

2.5 Discussion

2.5.1 Quantitative and qualitative findings concerning food waste and food purchases

The results of our study provide detailed insights regarding trends and possibility to reduce avoidable food waste in the context of the UN target (SDG 12.3) to halve food waste at the consumer level. The diary method in general is suitable to obtain detailed data regarding consumer behavior and to capture additional information on waste disposal that is not collected by local authorities (Richter and Bokelmann, 2017). The main finding of our research demonstrates an evident food waste reduction in both panels by more than 50% of mass, which would meet the target of halving food waste at household level. Consequently, participants benefited from a direct monetary saving due to changes in their shopping behavior and from an indirect monetary saving due to the prevention of food waste, resulting from food preparation and waste fees. Thus, the presumable reduction of food costs can be an additional driver to motivate people to continue improving their purchasing habits, especially because it is directly related to how well participants engage in food waste reduction practices. This relation of food purchase and wastage was also shown by an explorative study about the analysis of storing,

purchasing and wasting food by using household diaries (Richter and Bokelmann, 2017). Participants also changed their purchasing behavior within our study, resulting in a decrease of purchased food between 15.7% (Panel 1) and 25.7% (Panel 2) after the coaching sessions compared to the initial state. Unlike the food waste trends, food purchases did not decrease linearly, showing a slight increase within households of Panel 1 after the coaching. The observed difference between both panels of their reduced purchasing quantities and related trends are probably caused by the sample characteristics. The larger overall sample size of Panel 2 with a considerably higher number of four- and five-person households lead to a higher reduction of purchases, but to a lower reduction of food waste compared to Panel 1. On one hand, these differences could be caused by a higher flexibility in the purchasing behavior of four- and five-person households due to a larger number of options when buying food with smaller or bigger packaging sizes. On the other hand, a higher number of people living in the household increases the complexity of reducing the food waste due to a related higher inhomogeneity of eating habits within the household. However, the relatively small sample size of both panels did not allow a reliable derivation of a function between household size, purchasing and disposal behavior.

Participating households already actively separated their residual wastes, organic wastes and recyclables within the established separate collection of municipal household waste. We presume according to existing findings that environmentally conscious households generate less food waste (Williams et al., 2012). However, the study showed no association or increased likelihood of participants' interest or initiative to minimize or prevent food waste. The group of people was chosen at random and had to self willingly agree to be part of the project, narrowing the group to mainly interested individuals with distinctive intentions and qualities. We did however benefit from the diversity of the household inhabitants' family characteristics, revealing that all types of households with different sizes achieved a significant reduction of food waste. The majority of the panels' households achieved a reduction of more than a half of their food waste with exception of the three-person households (-37% of mass) and four-person households (-39% of mass) of Panel 2. We did not observe a relation between household size and food waste amounts, as it was found in other studies (Parizeau et al. 2015; Hanssen et al. 2016). The positive response of the participants for all household sizes demonstrates the possibility to encourage households towards a behavioral change and the prevention of avoidable food waste. The first panel however, contained only one single membered household, weakening our generalization that a single person reduces food waste after coaching. In the

second panel, we obtained more conclusive results due to the presence of eleven single-person households. The achieved reduction of (non-preserved) perishables in the food waste, such as fruits and vegetables, and food with a short shelf life, such as bakery and dairy products, indicates better storage and planning habits of the pilot households. Leftovers comprise an evident decreasing trend, which implicates behavioral change in daily habits that may have been affected by the consumer's perception on food and portion size (meal planning). The other food waste types' quantified decline lead to the conclusion of smarter food purchasing habits in relation to portion calculation and management. Consistent to similar studies, the results on food waste composition are predominated by vegetables, fruits, bakery products and leftovers (Hanssen et al., 2016; Hübsch and Adlwarth, 2017; Shaw et al., 2018; Smith et al., 2014). This means that possible recommendations for action to reduce food waste in households should focus in particular on these categories in terms of quantitative avoidance strategies. On the other hand, wasted product groups such as meat, fish or dairy products cause a comparatively higher environmental impact than vegetable and other products such as fruit and bakery products (Vanham et al., 2015). In order to strengthen the effectiveness of a comprehensive avoidance strategy, each measure should consider aspects like its environmental footprint.

The complexity within studies analyzing household behavior including the identification of reasons relating to their disposal behavior was already shown by several studies (Delley and Brunner, 2017; Russell et al., 2017; Visschers et al., 2016; Williams et al., 2012). The reasons considered in our study were grouped into five categories in order to be able to classify associated changes in behavior. We found improvement amongst others in meal planning, food storage and portion sizing due to behavioral changes. These observations support the conclusions regarding food waste trends in our study, but do not allow detailed derivations of recommendations for starting points based on the reasons given.

When tested statistically, we found significant differences between mean values after the coaching. This relates both to food purchases and to food waste and implies a success of the methodical approach, while the standard error is relatively higher for food waste trends compared to food purchasing trends. In overall, we observe a statistically confirmed improvement of shopping and disposal habits.

2.5.2 Limitations of this study

The main limitations of our study are inaccuracies due to influences, which likely occur during self-reporting research. Participants may willingly or unwillingly forget to record items, choose not to record them and change recording in favor of less waste generation. This may lead to underreporting of food waste quantities by the participants and does not allow the determination of any systematic error in the results (Quested and Johnson, 2009). Another study confirms this observation resulting in a tenfold discrepancy comparing data from self-reported quantities with extrapolations from waste compositional analysis (Delley and Brunner, 2017). However, the diary method is suitable to quantify reliable data on food waste in households working with a representative and trained consumer panel as a recent study from Germany shows (Hübsch and Adlwarth, 2017). The results of our study do also express underreporting as compared to the German average (Göbel et al., 2012; Hafner et al., 2012; Hübsch and Adlwarth, 2017), yet this does not conflict with the observed overall decline of participants' food waste and purchase. Whether the participants were underreporting or not, they consistently did so, considering that our interventions did not include any warnings to prevent this issue. However, the qualitative results of the offline and online approach deliver similar outcomes, which are comparable with results from other studies (Hanssen et al., 2016; Hübsch and Adlwarth, 2017; Shaw et al., 2018; Smith et al., 2014). Further, weaknesses arise in the sustainability of the observed reductions due to the fact that the timeline of this investigation was limited to the period of three months. Considering the group of participants themselves in terms of diversity of characteristics and number of pilot households, our panel is not representative for the general population. However, the outcome of our research delivers a high content of information for each sample due to the relatively long and consistent measurement period of three months, which is more extensive than in similar research (Richter and Bokelmann, 2017; Young et al., 2017).

2.5.3 Considerations and recommendations

The results of our study give a good impression on how the numbers of food waste reduced rapidly, considering that pilot households achieved the SDG target of halving food waste on a regional level in such a short term. Young et al. (2017) also observed a food waste reduction during a self-reporting analysis, even for the control group, which did not receive any intervention. In contrast, other literature (Shaw et al., 2018; Smith et al., 2014) shows that external interventions do not lead to food waste reductions, when self-reporting and a communicative exchange with the panel does not take place. For this reason, we suppose the self-reporting effect in combination with the coaching sessions as an important factor within

our study in achieving a significant reduction of food waste. Due to the sample size of the panels, the findings of our study do not claim compliance with the statistical requirements regarding the representativeness of results. Thus, transferring and upscaling these findings to other households in a wider framework, related problems and prospects of success still need to be examined in future research projects. Empirical observations during the implementation of the study showed that the self-reporting procedure, in particular the weighing and documentation process, required a considerable amount of time for the participating households. In addition, the accompanying awareness-raising activities also involved a considerable organizational, personnel and financial expenditure regarding the scientific project management. For this reason, the online-based approach of Panel 2 achieved a practical feasibility allowing the integration of a larger number of participants while simultaneously reducing personnel and financial expenditures for the coaching sessions. In order to determine a sustainable acceptance of the self-reporting approach and related documentation methods, we propose a subsequent investigation in pilot scale before transferring this approach into practice. This essentially includes the conduction of the self-reporting approach within the framework of a statistically representative sample size in order to provide evidence regarding the required upscaling capacities. In this context, we propose the cooperation with organizations that could contribute to the dissemination of information in order to overcome difficulties in reaching a larger number of households. These include public institutions such as schools and administrations, non-governmental organizations or charities. Furthermore, the implementation of the self-reporting method in gastronomic kitchens of the food service sector obtains an even higher specific potential than its use in households. This is due to the fact that the number of portions cooked in a gastronomic kitchen is several times higher than in household kitchens, in which related efforts to reduce food waste are relatively lower with simultaneously higher monetary incentives. In total, our study reveals that the use of kitchen diaries is able to contribute significantly to the reduction of food waste.

2.6 Conclusions

The study outcomes of both sets of household interventions demonstrate a clear improvement in the participants' behavior regarding food purchase and food waste prevention. We are convinced that self-reporting can be a useful precondition to initiate a change in consumer behavior, even if it cannot be separated from the influence of the intervention itself. Providing additional awareness raising information in order to support households and to initiate a self-

reflection of individual purchasing and disposal behavior enable a further reduction of food waste. The implemented measures within our study were not associated with any restrictions in the everyday eating habits of households like constraining their out-of-home eating. The purpose was to offer new information for the participants and confront them with their situation and habits. The measures aimed to support the process of awareness raising actions for households and encourage individual initiatives of the participants on how to reduce their food waste. We also found that the conducted interventions lead to a significant decrease of food waste with the help of food waste diaries in all participating households regardless of their size. The further development of this approach should focus on how to motivate a larger number of households to report or monitor their disposal behavior, respectively to identify instruments and channels to reach and involve them. The cooperation with organizations such as public institutions, non-governmental organizations or charities could give the necessary support to address the target group (consumers) within a wider range. We are convinced that a comprehensive strategy including a self-reporting approach combined with awareness raising actions can lead to significant reduction of avoidable food waste in households.

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Declaration of interests

We have no conflicts of interest to disclose.

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3 Publication II: Reducing food waste in hotel kitchens based on self-reported data

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3.1 Abstract

This study provides insights into the effects of self-reporting on food waste generated in hotel kitchens, and its potential for reducing waste. As a case study, we focus on the generation of breakfast buffet leftovers in four hotels in Germany. To facilitate the self-reporting, we developed a food waste tracking system, which was operated by staff members of the pilot kitchens over 12 months. The self-reporting intervention contributed to improving operational kitchen processes such as refilling the breakfast buffet with less food prepared just-in-time, particularly during the last 30 min of the breakfast time. The self-reported quantities decreased during the first five months of the investigation period and then remained almost constant at a relatively low level. Breakfast buffet leftovers were reduced on average by more than 64.3% of mass, which correlates to annual monetary savings of approximately EUR 9000 per kitchen. The findings of our study demonstrated that breakfast buffet leftovers can be reduced significantly by simple changes and small improvements in daily kitchen routines. However, further research is needed to assess whether self-reporting interventions also contribute to reducing food waste for other types of buffets and food services.

3.2 Introduction

The United Nations formulated food waste reduction targets within the Sustainable Development Goal 12.3, which aims to halve global food waste by 2030 at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses (United Nations, 2015). Current extrapolations of food waste quantities in Europe are estimated at approximately 88 (±14) million tons (Stenmarck et al., 2016). These food waste quantities cause nearly 15–16% of the environmental impact of the food supply chain and correspond to approximately 186 million tons of CO_2 equivalents per year (Scherhaufer et al., 2018). Given that most food waste in Europe is generated at consumer level, reduction measures

in the food service sector can provide an important contribution to achieve parts of the Sustainable Development Goal 12.3 (Beretta and Hellweg, 2019).

3.2.1 Food waste in the hospitality sector

The German food service sector produces approximately 1.69 million tons of food waste per year, of which approximately 1.22 million tons could be avoided. Specifically, the hospitality sector in Germany generates an average quantity of approximately 80000 tons of food waste per year, which corresponds to 136 g of wasted food per meal (Schmidt et al., 2019). Food waste in gastronomy particularly occurs during processes such as food storage, preparation of meals, serving and consumption. Accordingly, the literature has often distinguished food waste into several categories, namely *storage waste*, *preparation waste*, *leftovers* from serving dishes at buffets and *plate waste* (Engström and Carlsson-Kanyama, 2004; Møller et al., 2014; WRAP, 2013). Von Borstel et al. (2017) showed that most food waste in the German hospitality sector is generated by buffet leftovers (45%), followed by plate waste (30%), preparation waste (20%), and storage losses (5%). Recent literature has confirmed that buffet leftovers and overproduction can be avoided to a large extent, resulting in high savings potential (Okumus, 2019; Papargyropoulou et al., 2016; Silvennoinen et al., 2015).

3.2.2 Influences on food waste generation

There are several factors and situation variables that influence the production of food waste in gastronomic kitchens (Göbel, 2018). The literature has named a few of these variables, of which some relate to the internal management of the kitchen, including professional skills and experience of the staff, and others refer to communication structures between the kitchen administration, suppliers, customers and staff members (Heikkilä et al., 2016). However, some variables, such as the number of guests, are external and may therefore be more difficult to control. For instance, food waste increases when a high number of guests unexpectedly miss the event (Gu, 2014; Hennchen, 2019). Menu planning requires not only estimates of the food demand with regard to guest numbers, but also accurate product inventory and a precise organization and arrangement of the ingredients for the food preparation (Silvennoinen et al., 2015). We can deduce that proposed measures to reduce food waste range from changes that require little effort, such as using smaller serving spoons, to more elaborate approaches, such as regular staff training (Marthinsen et al., 2012). There is indeed a certain complexity in identifying and implementing reduction measures due to the variety of influential factors. Recommendations for improvements are therefore often limited to boundary conditions of case

specific studies and can rarely be generalized, emphasizing the need for gastronomic kitchens to conduct individual measuring and self-reporting practices.

3.2.3 Measuring as a food waste reduction measure

According to literature, a fundamental part of an effective intervention is to measure and monitor food waste. In this manner, adequate actions for prevention can be deduced and the performance of prevention measures can be controlled (Heikkilä et al., 2016; Silvennoinen et al., 2015). Eriksson et al. (2017) recommend a detailed waste quantification within each kitchen due to the individuality of reasons for food waste, which can result in different opportunities to reduce it. Waste analytics provide a high content of information because it follows the process of weighing the discarded food directly at the source of origin (Waskow et al., 2016). The data thus collected support further optimization of food management and facilitate the related planning and preparation processes. Food waste tracking systems that support gastronomic kitchens to quantify food waste are offered by enterprises from the United States such as Leanpath or Europe such as Winnow Solutions, Kitro, eSmiley, Matomatic, and Visma (eSmiley, 2020; KITRO, 2019; Leanpath, 2019; Matomatic, 2020; Visma, 2020; Winnow Solutions Limited, 2019). The basic functions of these tracking tools are similar and differ mainly with regard to associated consulting services such as employee training or individualized development of measures. Further differences refer to optional functions, such as visual photo capture and artificial intelligence technology for the automatic identification of the food waste items.

3.2.4 The potential of self-reporting

The implementation of measuring devices in kitchen routines requires an additional self-reporting task because the kitchen staff weighs and documents the wasted quantities. Self-reporting processes, in general, are related to awareness raising and cause adaptive reactions that result in behavioral changes (Zimmerman, 2002). Empirical research in households has already confirmed that substantial reductions of food waste can be achieved within self-reporting processes (Comber and Thieme, 2013; Leverenz et al., 2019; Thieme et al., 2012). The use of the aforementioned digital scales can also be expected to raise awareness amongst kitchen staff because they provide information directly to the operator, which could trigger individual behavioral changes. As described thus far, the literature has generated knowledge on food waste to a considerable extent and showed the benefits of self-reporting interventions. Furthermore, case studies have demonstrated that the reduction potential in the hospitality

sector is high and confirmed the feasibility of reducing food waste in general. By contrast, the literature has rarely examined in-depth measures and practical interventions over long periods of time. Such approaches would generate more complete information on the effectiveness of measures to provide stakeholders with incentives to reduce food waste (Goossens et al., 2019). Our study contributes to fill this research gap by presenting insights from food waste quantification within a self-reporting intervention in hotel kitchens. Thus, our approach follows the recommendation of Stöckli, et al. (2018) in testing measures to prevent food waste in cooperation with practical and academic contributors.

3.2.5 Objectives

With this study, we aimed to quantify breakfast buffet leftovers using a food waste tracking system. The main objective of this paper is to assess whether the self-reporting in hotel kitchens can lead to food waste reductions at the breakfast buffet. To answer this research question, the following hypotheses are tested:

H_0: Self-reporting of breakfast buffet leftovers has no effect on food waste quantities.

H_1: Self-reporting of breakfast buffet leftovers leads to food waste reductions.

To investigate the savings potential, we estimated the monetary effects associated with the generation of breakfast buffet leftovers. Furthermore, we aimed to determine the influence of guest numbers on the breakfast buffet leftovers to gain insights into the relevance of this factor within the self-reporting intervention.

3.3 Material and methods

3.3.1 Methods and study design

This investigation focuses on quantifying and analyzing breakfast buffet leftovers in hotel kitchens. Our case study investigates a self-reporting intervention in four kitchens of the same hotel group, where the kitchen crew weighed and documented the breakfast buffet leftovers. To integrate the self-reporting process into the daily kitchen routine, we developed a food waste tracking system named *RESOURCEMANAGER FOOD.* The tracking system contains software installed on a standalone computer, which is connected through a USB port to an electronic scale. The user interface of the software is similar to a smartphone application and enables quick handling and an easy operation mode. To ensure harmonized reporting for the subsequent analyses, the products were aggregated into the following product categories: *bakery products*,

dairy products, *fruits*, *vegetables*, *cheese*, *warm dishes*, *fish*, *cold meat,* and *others*. Individual photos of the food items and serving dishes were integrated into the software to facilitate the navigation through the user interface (Figure 3-1).

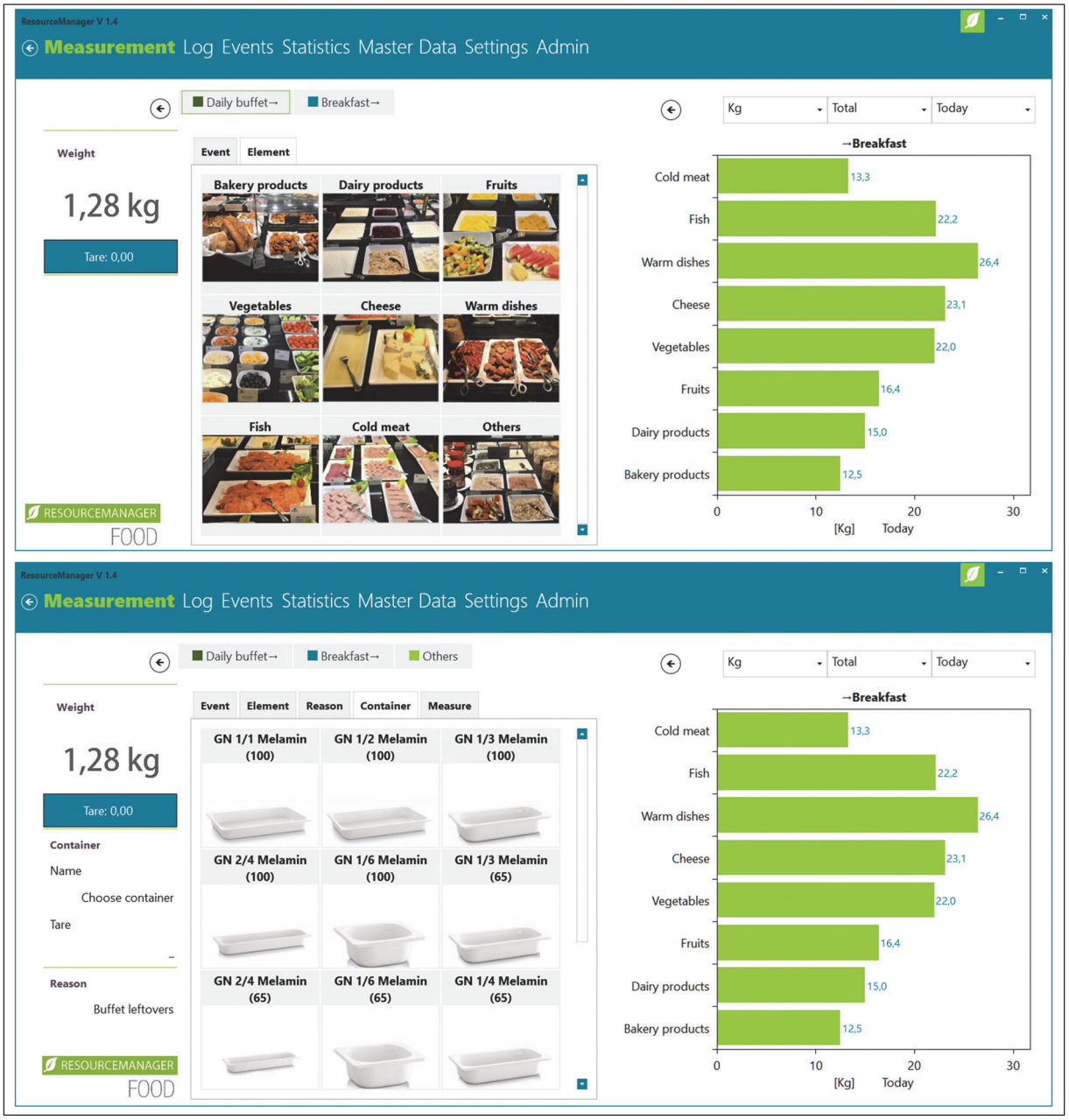

Figure 3-1 Screenshots of the user interface of the food waste tracking system: RESOURCEMANAGER FOOD.

The leftovers were weighed within the same standardized serving dishes in which they have been presented to the guests at the buffet. The tare weight of each serving dish was stored in the program, which means that the net weight of the wasted food was directly measured and saved in the database. The tracking system provided a real-time graphical visualization of the measured data in the form of horizontal bar charts. Thus, the program provided a direct

feedback and immediate information on breakfast buffet leftovers to the operators, namely the kitchen staff. Sample photos of breakfast buffet leftovers and the weighing procedure using the developed food waste tracking system are presented in Figure 3-2.

Figure 3-2 Sample photos of breakfast buffet leftovers and weighing procedure using the food waste tracking system.

3.3.2 Sample characteristics

The pilot kitchens are part of the hotel group *Maritim Hotelgesellschaft mbH*, which is rated with four stars according to the classification of *Hotelstars Union* (Hotelstars Union, 2015). The four hotels are located in different German states and spread across southern, eastern, and northern Germany. The hotels are indexed as Hotels A, B, C, and D in the remainder of this paper. We analyzed the breakfast buffet leftovers based on the daily self-reported quantities. The measurements were conducted over a period of 336 days (12 months) and started at different time horizons for each hotel, in 2014 and 2015 (Table 3-1). The breakfast buffet was accessible from 6.30 a.m. until 10.30 a.m. for hotel guests seven days a week.

Table 3-1 Sample characteristics.

	Hotel A	Hotel B	Hotel C	Hotel D
State	Saxony	Schleswig-Holstein	Bavaria	Baden-Württemberg
City	Dresden	Timmendorfer Strand	Munich	Stuttgart
Number of rooms	328	241	349	555
Guest clientele	Business and tourism	Mainly tourism	Mainly business	Business and tourism
Start of measurement	June 2014	September 2014	December 2015	July 2015

3.3.3 Self-reporting effect

For the presentation of results, we compared the monthly mean values of the daily breakfast buffet leftovers with standardized units in mass percentage for each pilot kitchen. To estimate the confidence intervals of the monthly mean values, we used a random resampling procedure with replacement, namely a non-parametric bootstrapping method. The applied bootstrap method is a simple, robust procedure that allowed us to draw statistical inferences without assuming the distribution of the sample (Haukoos and Lewis, 2005). For the resampling procedure, we applied 1000 repetitions to calculate bootstrap estimates (mean values) for each sample unit. For the computation of the resampling procedure we used XLSTAT, which works as add-on software for Microsoft Excel (Addinsoft, 2019). The bootstrap confidence intervals were calculated for each month at a confidence level of 95% based on sample units of 28 daily mean values. To facilitate the visual presentation of trends, we set the mean value of the first measurement month equal to 100% and indexed all further measurement data against this starting point ($w_{i,1} \approx 100\%$). We calculated differences in quantities of breakfast buffet leftovers over time and expressed them relative to the first month (Eq. 1).

$$c_i = 1 - \frac{w_{i,const}}{w_{i,1}} \quad (1)$$

with

c_i = Differences between the arithmetic mean values of breakfast buffet leftovers from month *n* and the first month in Hotel *i*;

$w_{i,1}$ = Arithmetic mean value of breakfast buffet leftovers during the first month in Hotel *i*;

$w_{i,n}$ = Arithmetic mean value of breakfast buffet leftovers during month *n* in Hotel *i*.

For subsequent statistical tests, we followed the current statements of the American Statistical Association, which recommend a simplified dichotomy between significant and non-significant findings concerning misuses of *p* values. Thus, good statistical practices provide a variety of numerical and graphical summaries of data, while a single index should not be a substitute for scientific reasoning (Wasserstein and Lazar, 2016). Accordingly, graphical summaries of data and the use of confidence intervals increase the validity of results instead of using *p*-values for statistical inference (Matthews, 2018). With reference to these recommendations, we strengthened the significance of our statistical tests by calculating bootstrap quotients based on the sample data in all possible combinations (Eq. 2). By forming bootstrap quotients, we

obtained 1 million observations at a confidence level of 95% and plotted them as relative frequency distributions.

$$c_{ijk} = 1 - \frac{\mu_{ik,n}}{\mu_{ij,1}} \mid j \cup k = \{1; 2; \ldots; 1000\} \quad (2)$$

with

c_{ijk} = Differences between bootstrap estimates of breakfast buffet leftovers from month *n* and first month in Hotel *i*;

$\mu_{ij,1}$ = Bootstrap estimates of breakfast buffet leftovers during the first month in Hotel *i*;

$\mu_{ik,n}$ = Bootstrap estimates of breakfast buffet leftovers during month *n* in Hotel *i*.

The resulting histograms illustrate the distribution limits of the bootstrap quotients at a certainty level of 95% and thus provide information on the strength of the self-reporting effect. According to Cumming and Finch (2005), we used graphical summaries of the results to test Hypotheses H_0 and H_1 based on the principle of inference by eye.

3.3.4 Monetary savings potential

To investigate the monetary savings potential associated with the intervention of self-reporting, we analyzed the breakfast buffet leftovers at the level of product groups. These product groups represent all food products offered at the breakfast buffet in the pilot kitchens. The outcomes are based on the average across the four hotels for each product group. To visualize the product-specific monetary savings potential, we compared the periods with approximately constant mean values ($\overline{w}_{const}$) with the first measurement month ($\overline{w}_1$) under the simplifying assumption that the first measurement month could be considered the status quo. The cost estimation for each product group is based on the weighted arithmetic average values of all food purchases made by the hotel kitchens, excluding the value-added tax.

3.3.5 Influence of guest numbers

The pilot kitchens considered the number of guests who had booked breakfast during their stay in the hotel to plan the breakfast buffet and to estimate the food demand. The pilot kitchens, however, did not have access to real-time information about the number of guests who had already visited or were still planning to visit the breakfast. To develop an understanding of how guest numbers influenced the breakfast buffet leftovers within the self-reporting intervention, we applied a bivariate linear regression.

3.4 Results

3.4.1 Self-reporting effect

Figure 3-3 shows the monthly average of the daily breakfast buffet leftovers. The corresponding bootstrapping intervals and trend lines are displayed over the 12-month investigation period.

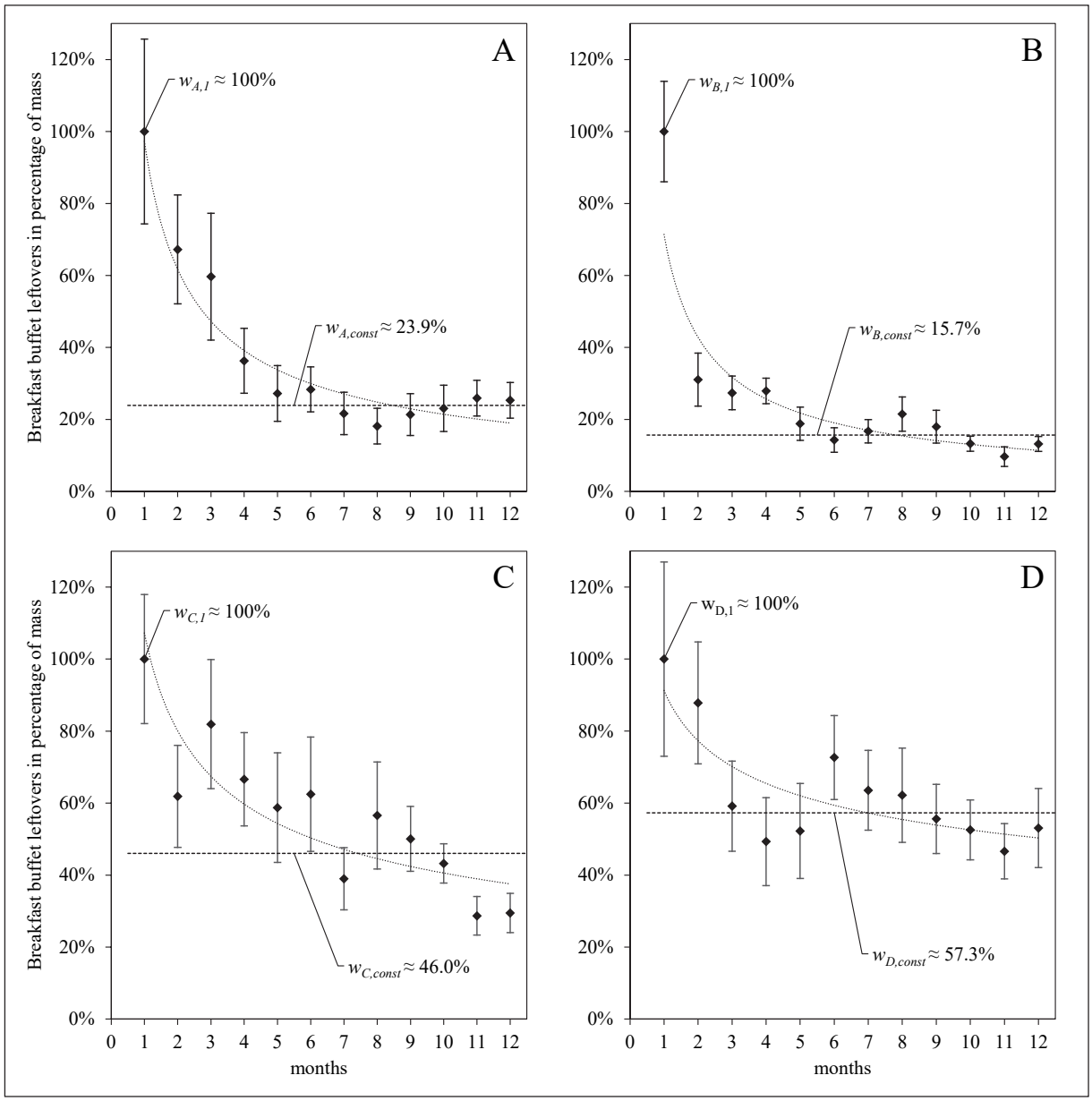

Figure 3-3 Breakfast buffet leftovers in four hotels (Monthly mean ± bootstrap confidence interval). The 100% value represents the monthly mean of the daily breakfast buffet leftovers during the first measurement month. A: Hotel A (100% = 7.78 kg/d); B: Hotel B (100% = 6.94 kg/d); C: Hotel C (100% = 8.48 kg/d); D: Hotel D (100% = 6.69 kg/d); $w_{i,1}$ represents the arithmetic mean value of the first month; $w_{i,const}$ represent the arithmetic mean value of months 5 to 12.

On average, daily quantities of buffet leftovers ranged between 6.69 kg (Hotel D) and 8.48 kg (Hotel C) during the first month, with a corresponding arithmetic mean for all the hotels of 7.47 kg per day. Compared with the first month, breakfast buffet leftovers decreased steadily over the following five months in all four kitchens. The achieved reductions thereby differed amongst the hotels in their order of magnitude. However, after the fifth month, the buffet leftovers stabilized at an almost constantly low level ($w_{i,const}$) in each hotel. Based on this observation, we assumed that the average amount of breakfast buffet leftovers that occurred between month 5 and month 12 can be interpreted as the period that represents the achieved reduction for each pilot kitchen. Consequently, the most striking observation to emerge from the data comparison is the remarkably high degree of reduced breakfast buffet leftovers in each of the hotels. Hotel B achieved the relatively highest savings with a reduction of approximately 84.3%. This resulted in a constant mean value ($w_{B,const}$) of 15.7%, relative to the first month ($w_{B,1}$). Hotel A reduced its breakfast buffet leftovers of approximately 76.1% ($w_{A,const} \approx 23.9\%$), followed by Hotel C with a reduction of approximately 54.0% ($w_{C,const} \approx 46.0\%$). Hotel D achieved the lowest relative savings and reduced breakfast buffet leftovers by approximately 42.7% ($w_{D,const} \approx 57.3\%$). The results provide a satisfactory impression of the existing potential for savings at the breakfast buffet in the pilot kitchens and illustrate the potential for improvements.

To further test the hypotheses presented at the beginning of the article, we calculated the distribution parameters of the relative reductions with a bootstrapping method, namely a random resampling with replacement. The histograms in Figure 3-4 present the relative frequency distribution for the reduced breakfast buffet leftovers and illustrate the strength of the self-reporting effect within the distribution limits at a certainty level of 95%. The histograms show a negative left-skewed distribution in all cases, indicating that days with higher savings were more common than days with lower savings. The effect that breakfast buffet leftovers decreased on a monthly average seems to be strong according to the information presented in the distribution plots. The magnitude of the effect is described within the limits of the distribution boundaries indicated on the abscissas of the histograms in Figure 3-4. Thus, we observed the strongest effect in Hotel B and could confirm that the expected true value is higher than 0.770 and smaller than 0.887. In other words, the achieved reduction of breakfast buffet leftovers ranges between 77.0% and 88.7% for Hotel B. The distribution for the other hotels is more widely spread, indicating that the reductions were subject to greater fluctuations than in Hotel B, which showed an average reduction of 84.3%. We did not observe the same strength

and characteristic of the self-reporting effect in each hotel, but we determined a coherent trend in terms of a reduction over time. On average, buffet leftover in the other pilot kitchens were reduced by 76.1% in Hotel A, 54.0% in Hotel C and 42.7% in Hotel D. The average reduction across all four hotels was thus 64.3%.

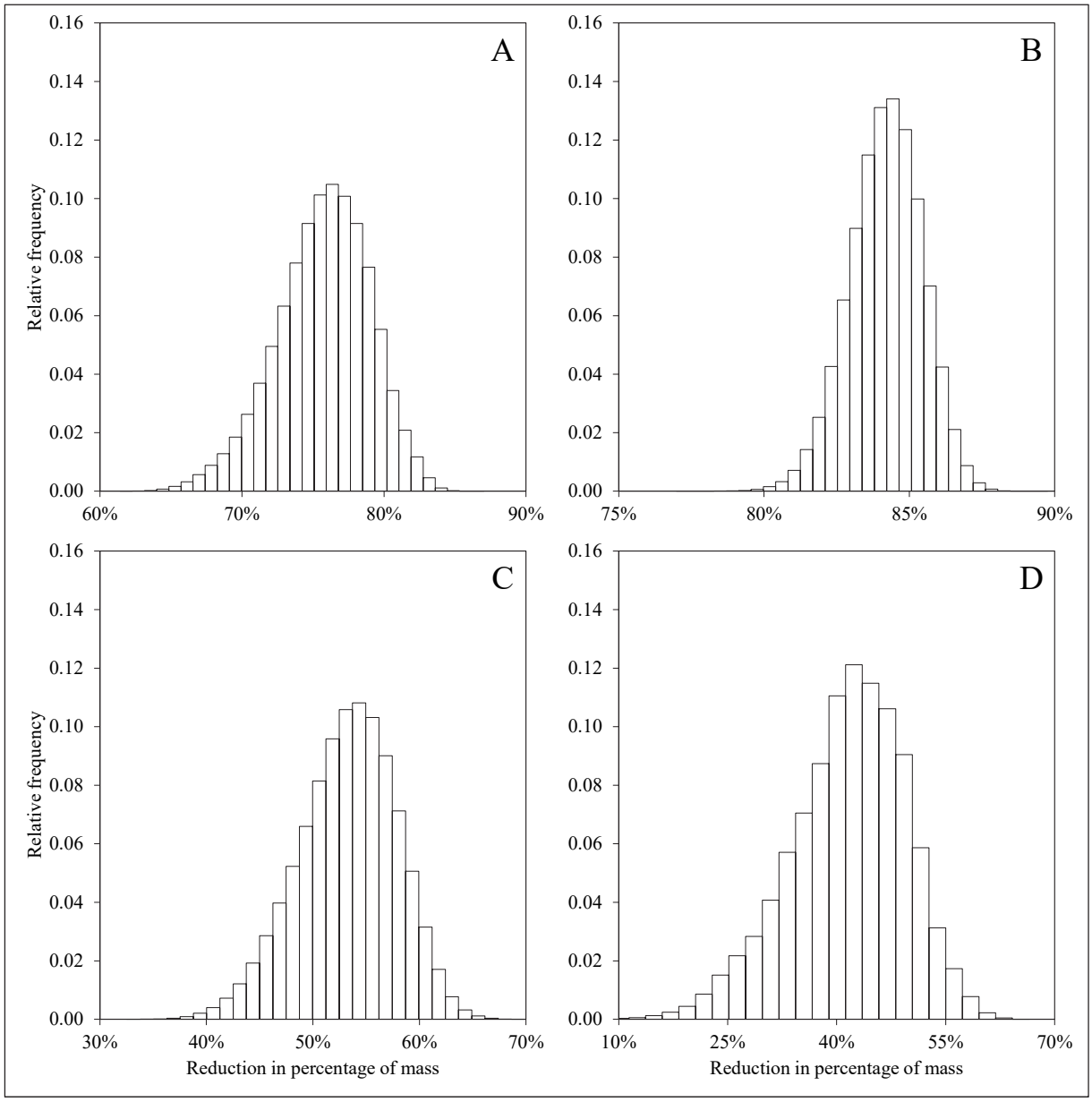

Figure 3-4 Relative frequency distribution of the achieved reductions of breakfast buffet leftovers in percentage of mass for A: Hotel A; B: Hotel B; C: Hotel C; D: Hotel D.

Based on these findings, we can show with a certainty of 95% that there is an effect or exclude that the effect is not present. These results further strengthen our confidence that self-reporting effect leads to reductions of breakfast buffet leftovers. Thus, we conclude that we can reject hypothesis H_0 and accept hypothesis H_1.

3.4.2 Monetary savings

Table 3-2 lists the breakfast buffet leftovers and their monetary equivalents aggregated at the product group level as an average across all four hotels. The first measurement month ($\overline{w}_1$) is displayed in comparison to the period with an approximately constant mean value ($\overline{w}_{const}$) and the overall savings ($\overline{w}_1 - \overline{w}_{const}$). Even though the indicated prices are dynamic and depend on case-specific conditions, they allow us to get a good insight into the magnitude of possible monetary savings associated with the self-reporting intervention.

Table 3-2 Self-reported quantities and monetary equivalents of breakfast buffet leftovers in four hotels at product group level (average values across all four hotels). The first measurement month ($\overline{w}_1$) is displayed in comparison to the period with an approximately constant mean value during month 5 to month 12 ($\overline{w}_{const}$) and the resulting overall savings ($\overline{w}_1 - \overline{w}_{const}$).

	Breakfast buffet leftovers in kg/d			Price[1]	Monetary equivalents in EUR/d		
Category	$\overline{w}_1$	$\overline{w}_{const}$	$\overline{w}_1 - \overline{w}_{const}$	(EUR/kg)	$\overline{w}_1$	$\overline{w}_{const}$	$\overline{w}_1 - \overline{w}_{const}$
Bakery products	2.59	0.87	1.72 (–66.4%)	4.85	12.56	4.22	8.34 (–66.4%)
Warm dishes	2.02	1.05	0.97 (–48.0%)	4.85	9.80	5.09	4.71 (–48.1%)
Fruits	0.80	0.16	0.64 (–80.0%)	3.40	2.72	0.54	2.18 (–80.2%)
Cold meat	0.50	0.21	0.29 (–58.0%)	8.95	4.48	1.88	2.60 (–58.0%)
Dairy products	0.48	0.16	0.32 (–66.7%)	3.72	1.79	0.60	1.19 (–66.5%)
Fish	0.33	0.05	0.28 (–84.9%)	12.26	4.05	0.61	3.44 (–84.9%)
Cheese	0.29	0.05	0.24 (–82.8%)	4.90	1.42	0.25	1.17 (–82.4%)
Others (e.g. jam)	0.29	0.04	0.25 (–86.2%)	5.40	1.57	0.22	1.35 (–86.0%)
Vegetables	0.18	0.08	0.10 (–55.6%)	2.36	0.43	0.19	0.24 (–55.8%)
Total	7.48	2.67	4.81 (–64.3%)		38.82	13.60	25.22 (–65.0%)

[1]Weigthed arithmetic average of all food purchases by the hotel kitchens used for the breakfast, excluding the value added tax.

The product categories that have a high purchasing price per kilogram are *fish*, *cold meat*, *cheese,* and *others*. However, *bakery products* and *warm dishes* have the highest potential for overall monetary savings, which is related to their relatively high amounts of buffet leftovers at the breakfast. Across the four hotels, the total potential for monetary savings during the first month resulted in an average of EUR 38.82 per day. From this amount, an overall saving of approximately EUR 25.22 per day was achieved. The corresponding relative savings for each product group are visualized in Figure 3-5 in the order of increasing savings. *Warm dishes, vegetables,* and *cold meat* showed monetary savings between approximately 48% for *warm dishes* and 58% for *cold meat*. Monetary equivalents of wasted bakery and dairy products were reduced by more than 66%. The highest savings were recorded for *fruits*, *cheese*, *fish,* and *others*, each with a decline of more than 80%.

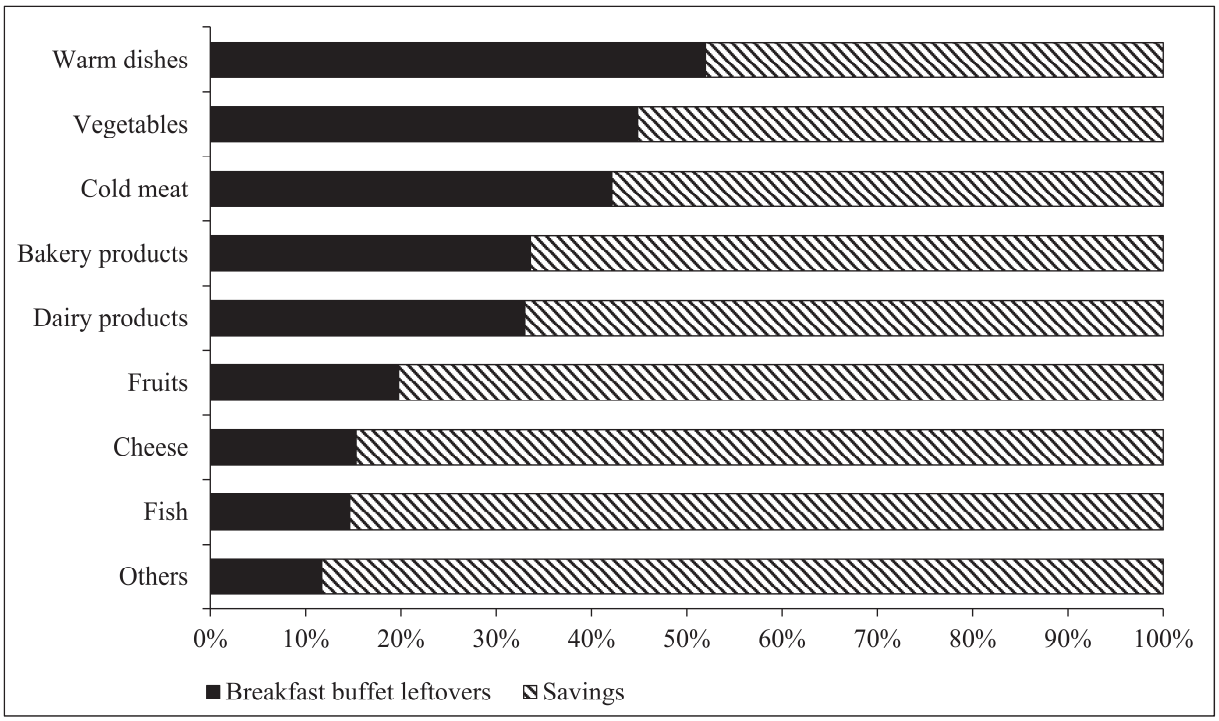

Figure 3-5 Monetary savings of breakfast buffet leftovers for each product group based on the average across all four hotels.

3.4.3 Influence of guest numbers

Table 3-3 presents the summary statistics of the linear regression model, which examined the influence of guest numbers on breakfast buffet leftovers for the period before ($w_{i,1}$) and after ($w_{i,const}$) reduction. The coefficients of determination (R^2) demonstrated that guest numbers explained between 0.3% (Hotel A) and 10.8% (Hotel C) of the variance in buffet leftovers before they were reduced and between 1.0% (Hotel A) and 6.2% (Hotel B) after they were reduced. The correlation coefficients showed both negative and positive values, revealing that there were only weak correlations between the number of guests and buffet leftovers. For instance, Hotel C showed a weak positive correlation ($r = 0.329$) before and a weak negative correlation ($r = –0.176$) after buffet leftovers were reduced. The variables did not consistently provide significant information to the model. The regression models thus indicate that guest numbers had a rather weak or no influence on breakfast buffet leftovers.

Table 3-3 Summary statistics of the bivariate linear regression. The influence of guest numbers on breakfast buffet leftovers is shown for the period before ($w_{i,1}$) and after ($w_{i,const}$) reduction.

		Before reduction[1] ($w_{i,1}$)			After reduction[2] ($w_{i,const}$)		
	Variable	Non-standardized	Standardized[3]	SE	Non-standardized	Standardized[3]	SE
Hotel A	Intercept	9.072		4.509	2.161*		0.219
	Guests per day	–0.003	–0.057	0.012	–0.001	–0.100	0.001
	R^2	0.003			0.010		
	F	0.080			2.249		
Hotel B	Intercept	5.291*		1.782	0.517*		0.156
	Guests per day	0.006	0.187	0.006	0.002*	0.249*	0.001
	R^2	0.035			0.062		
	F	0.947			14.687*		
Hotel C	Intercept	5.804*		1.652	5.565*		0.648
	Guests per day	0.016	0.329	0.009	–0.004*	–0.176*	0.002
	R^2	0.108			0.031		
	F	3.156			7.041*		
Hotel D	Intercept	7.261*		1.438	3.770*		0.132
	Guests per day	–0.002	–0.106	0.004	0.001	0.099	0.0001
	R^2	0.011			0.010		
	F	0.297			2.214*		

[1]F (DF = 1; 26);
[2]F (DF = 1; 222);
[3]Standardized coefficients are equal to the linear correlation coefficient (Pearson's r);
*$p < 0.05$

3.4.4 Reduction measures

The qualitative interviews with the managers of the pilot kitchens revealed that self-reporting interventions lead to the autonomous implementation of several measures that required simple operational changes during the serving time. One such measure, for example, was the use of smaller units of serving dishes to present the food at the buffet. The use of smaller serving dishes enabled the pilot kitchens to prepare less volumes of food just-in-time to refill the buffet, particularly during the last 30 min of the breakfast time. Even though estimates on the number of guests were used prior to the breakfast time for the menu planning and preparation of food, the pilot kitchens had no real-time information on the number of guests who had already visited or were still planning to visit the breakfast buffet and therefore did not develop reduction measures accordingly. Hence, the real-time information about the guest numbers was not a prerequisite for the kitchen to make operational changes and to reduce breakfast buffet leftovers.

3.5 Discussion

3.5.1 Self-reporting effect

The main finding of our study is an evident reduction of breakfast buffet leftovers in all pilot kitchens that have implemented a self-reporting intervention. The effect of the self-reporting was of varying intensity within the four pilot kitchens. The hotels reduced between 42.7% (Hotel D) and 84.3% (Hotel B) of their breakfast buffet leftovers. In this context, our study confirms empirical findings in the literature that have demonstrated significant reductions of food waste while using a self-reporting approach in pilot households (Leverenz et al., 2019; Quested and Johnson, 2009). A self-reporting process in general is an aspect of self-awareness and is associated with adaptive reactions that may be expressed by behavioral changes (Zimmerman, 2002). As the hypothesis tests showed, our experimental data demonstrate a strong positive effect caused by the self-reporting, which led to substantial reductions. Thus, the achieved reductions are related to the individually developed reduction measures of each pilot kitchen. Practical and organizational changes included improvements such as the use of smaller serving dishes for the food presentation and refilling the buffet with less quantities during the just-in-time production. However, the self-reporting effect may incorporate other influences that we did not control such as the social desirability aspect or bias (Althubaiti, 2016). This is in line with observations in the literature on the complexity of singling out the effects of one specific measure (Stöckli et al., 2018).

3.5.2 Monetary savings potential

The monetary savings for each kitchen resulted in an average of approximately EUR 25.22 per day. Under the simplifying assumption that the self-reporting effect will remain present, and that the four hotels will continue to save these amounts of waste without additional measurement costs, each kitchen could save approximately EUR 9000 per year. These findings are consistent with non-scientific case studies and success stories. For instance, Clowes et al. (2018) presented data from 86 catering operations that reduced on average 44% of food waste quantities and 56% of the monetary equivalents during a period of three years. However, the monetary savings in our study are based on hotel-specific purchase prices. The working hours for the preparation of the meals and the disposal costs are not included in this estimation. The food waste tracking system was provided to the hotel at no cost, whereas in general, the cost for introducing and leasing such a system would also obtain a better estimate of the associated

monetary savings potential of self-reporting. Considering these factors, the effective monetary savings would probably result in slightly different values.

On average, the pilot kitchens achieved significant monetary savings of breakfast buffet leftovers in all product groups. Product categories with the highest quantitative savings were not always associated with the highest monetary savings because of their comparatively low product price. Scherhaufer et al. (2018) found a similar pattern for food products with regard to their ecological footprint. Meat products, for example, generally have a higher ecological footprint than vegetable products, but often show an inverse pattern for the amount of waste. Therefore, a thorough sustainability assessment would be required to determine the effectiveness of the reduction measures with regard to their economic and environmental impact (Goossens et al., 2019).

3.5.3 Influence of guest numbers

The linear regression models revealed that the variable of guest numbers did not provide sufficient information to explain the generation or reductions of breakfast buffet leftovers. The correlation coefficients ranged from negative to positive values between the pilot kitchens, which indicates that correlations may either depend on the individual food management of each kitchen or that there was no correlation at all between the number of guests and breakfast buffet leftovers. The goodness of fit was relatively low, which means that there could be a non-linear correlation between these two variables. However, although the number of guests did not show significant influences on the breakfast buffet leftovers in our case study, this might not be the case for other types of buffets or food services. For instance, the number of guests showed a strong influence on the generation of buffet leftovers at catered events such as conferences, graduation ceremonies or business events (Leverenz et al., 2020). According to other literature, the precise knowledge of the number of guests enables some kitchens to forecast the food demand and thus to control the amount of food waste (Pirani and Arafat, 2016). As such, although the kitchen administration considered the guest numbers prior to the breakfast for menu planning and the preparation of food, the guest numbers showed only a rather weak influence on how much food returned from the buffet to the kitchen. However, a thorough analysis of how the number of guests influence menu planning, overproduction and buffet leftovers was out of the scope of this paper, which emphasizes the need for further research.

3.5.4 Reduction measures

As several studies have shown, there are many drivers for the generation of food waste and possibilities to reduce it (Betz et al., 2015; Giorgi, 2013; Göbel, 2018; Marthinsen et al., 2012). Heikkilä et al. (2016) showed that it is crucial to attempt to reduce food waste in all aspects, meaning that reduction measures should also be adopted to the concept or philosophy of the business. The results of our case study extend the findings from the literature that have focused on measures to reduce food waste by introducing a self-reporting approach. The effect of the self-reporting intervention apparently resulted in changes of operational routines. The food waste tracking system provided information in real-time, which allowed the implementation of measures within short periods. Improvements were mainly related to the refilling behavior during the last 30 min of the breakfast buffet service and the use of smaller serving dishes for product presentation. The transferability of these positive effects to other kitchens requires the identification of individual reduction potentials (Eriksson et al., 2017). For this purpose, the self-reporting approach was not only suitable for measuring the waste but also provided the necessary information for the development and implementation of individual reduction measures.

Technical assistance to measure food waste exists in the form of different types of digital scales and food waste tracking systems. Some of them are commercially available from several providers, as described in the introduction section. Based on the positive effects of the self-reporting intervention, we conclude that food waste tracking systems deliver relevant information that may result in significant food waste reductions and monetary savings. Eriksson et al. (2019) found that catering units that use tracking systems instead of semi-automated or manual tools record more data and achieve slightly higher reductions in food waste. Hence, systematic monitoring and reporting are essential to evaluate interventions and measures. Other software solutions, such as *Delicious Data*, provide forecast solutions using machine learning to combine historical data from gastronomic kitchens with external factors to predict the future demand for the preparation of meals. These forecasts offer information for kitchen management in terms of procurement, menu planning and daily production (Delicious Data GmbH, 2019). Despite using tracking systems and forecasting tools, gastronomic kitchens might sell their leftovers to environmentally conscious consumers at a discount by using smartphone applications such as *ResQ* or *To Good To Go* (ResQ Club, 2019; Too Good To Go, 2019). Another alternative is cooperating with charity organizations such as those who have food distribution initiatives (FEBA, 2019; Foodsharing, 2019).

3.5.5 Critical remarks and data quality

The findings of our paper have some limitations, which we briefly discuss in this section. As part of our empirical investigation, we analyzed the effect of self-reporting by using the example of breakfast buffet leftovers, which resulted in a restriction of the observational framework. Thus, we were unable to provide a comprehensive overview of the overall savings potential of food waste in these hotels, which could theoretically have been achieved in reducing plate leftovers and wasted food during storage and preparation. In our study, the kitchen staff performed the measurements and operated the food waste tracking system. The quality of the collected data during the self-reporting approach might therefore be influenced by errors during the practical conduction of the measurement. Based on Berthelot et al. (2011), our experimental conditions may have influenced the reported data even before the measurements started because the participants were aware of their involvement in this study. Another possibility is that the pilot kitchens may have consciously reported less waste than was actually produced to improve their self-reporting performance. With this experimental setup, we could not calculate a systematic error in the results. However, this is not in conflict with the main findings of our study because regardless of whether the participants were underreporting or not, they consistently showed the same positive pattern regarding the reduction of buffet leftovers.

3.5.6 Further research

The results of our case study have shown that self-reporting interventions can be very effective to improve operational kitchen routines and reduce buffet leftovers. Although we demonstrated that optimization at the breakfast buffet can be conducted successfully, the transferability to other forms of catering and buffets must be examined. This examination should include lunch and dinner buffets, and the *à la carte* service in hotel restaurants or other types of food services such as the catering of business canteens, school canteens, individual events, or fast food services. In further investigations, it might also be possible to investigate the effectiveness of different prevention strategies and reduction measures. For instance, information on the monetary efficiency of reduction measures could provide important incentives for businesses in the food service sector to develop prevention strategies. However, the possibility of being able to reduce food waste through the application of self-reporting interventions serves as an incentive for further research to build up on the positive findings of our case study and to investigate its potential for different types of buffets and food services.

3.5.7 Final Considerations

The European Union is committed to fulfill Sustainable Development Goal 12.3 of the United Nations, which aims to halve food waste at the consumer level by 2030 (European Commission, 2018). Our study provides information on the feasibility of achieving food waste reductions in the hospitality sector by focusing particularly on buffet leftovers. On average, breakfast buffet leftovers were more than halved and would thus even exceed the political reduction targets. However, it is still necessary to identify to what extent these promising results can be scaled up to other meals throughout the day, to other serving styles (such as *à la carte*), and to a larger number of businesses in the food service sector. We encourage policy makers at regional and national levels to promote the practical implementation of these types of measures. Such initiatives can provide a substantial contribution to achieving parts of the target set by the United Nations.

3.6 Conclusions

Food waste tracking demonstrated a clear improvement in the food management of the pilot kitchens. Breakfast buffet leftovers decreased at the beginning of the investigation and stabilized at a constantly low level after approximately five months. The findings of our study demonstrated that self-reporting interventions can reduce breakfast buffet leftovers in hotels by more than half. The achieved reductions were related to prevention strategies that each pilot kitchen individually developed according to their self-reported data. Simple operational changes such as the use of smaller serving dishes and refilling the breakfast buffet with less quantities of food that was prepared just-in-time seemed to be very effective improvements. The practical viability of reducing buffet leftovers serves as an incentive for further research to improve the methodological approach of our study and validate the concept by, for example, testing whether self-reporting interventions also contribute to reducing food waste for other types of buffets and food services.

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Declaration of interests

We have no conflicts of interest to disclose.

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4 Publication III: What influences food waste at event caterings? A German case study

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4.1 Abstract

In recent years, a growing number of investigations have examined food waste in the food service sector, in which the catering of individual events received little attention. We aimed to contribute to fill this knowledge gap by presenting insights from a case study based on data from 239 event caterings. The case study presents findings about the influences of four variables, namely event type, season, event size, and menu prices, on buffet leftovers. We used a waste tracking system that allowed kitchen staff to quantify buffet leftovers for 4 years: from the beginning of 2014 until the end of 2017. Among the studied variables, the event size demonstrated the strongest influence on the generation of buffet leftovers in the case study. Buffet leftovers showed a trend of decreasing quantities relative to the number of guests for increasing event sizes. For instance, smaller events with less than 100 participants recorded the highest quantities of approximately 280 g of buffet leftovers per guest, and larger events of more than 500 participants recorded the lowest quantities of approximately 74 g per guest. In addition, we found that three food product groups—*meat & poultry*, *finger food,* and *side dishes*—caused approximately 54% of the overall quantity of buffet leftovers and approximately 65% of the corresponding monetary equivalents. Our findings emphasize that further research is necessary on food waste reduction strategies.

4.2 Introduction

The United Nations recently placed the reduction of food waste on its political agenda by setting prevention targets within the framework of Sustainable Development Goals. Sustainable Development Goal number 12.3 aims to halve global food waste at the retail and consumer level by the year 2030 and to reduce food losses along production and supply chains, including post-harvest losses (United Nations, 2015). European countries are committed to fulfilling the UN targets, which is documented in the related European waste legislation. The revision of the

Waste Framework Directive 2008/98/EC, adopted on May 30, 2018, within Directive 2018/851, calls on European Union (EU) member countries to reduce food waste at each stage of the food supply chain, monitor food waste levels, and report progress (European Commission, 2018). In addition, the European Commission defined a common methodology and minimum quality requirements for the uniform measurement of levels of food waste, which requires that member states start collecting data on food waste in 2020 and report national food waste levels for the first time by mid-2022 (European Commission, 2019).

4.2.1 Food waste in the food service sector

Due to the political relevance of food waste and the associated reduction targets, several studies have collected data on food waste in recent years (Stöckli et al., 2018). The current estimate of the amount of food waste in Europe is approximately 88 (±14) million tons, and the majority of the food waste is generated at the consumer level: approximately 46.5 (±1.5) million tons in households and another 10.5 (±1.5) million tons in the food service sector (Stenmarck et al., 2016). According to Scherhaufer et al. (2018), food waste in Europe contributes approximately 15–16% to the environmental impact of the entire food value chain and causes the emission of greenhouse gases: approximately 186 million tons of CO_2 equivalents per year. Because most food waste in Europe is generated at the consumer level, policies and strategies to reduce the food waste of households and food services are necessary (Beretta et al., 2017). Strategies and measures to prevent food waste in the food service sector have been subject to an increasing number of scientific investigations, including case studies in cooperation with food service businesses (Kallbekken and Sælen, 2013; Ofei et al., 2014; Betz et al., 2015; Pirani and Arafat, 2016; Eriksson et al., 2017; Beretta and Hellweg, 2019; Leverenz et al., 2020). For instance, Clowes et al. (2018) presented data from 86 catering operations in facilities (e.g. restaurants, hotels, schools, and universities) that reduced an average of 44% of food waste and 56% of the monetary equivalents over 3 years. Eriksson et al. (2019) analyzed data from 735 hotels, restaurants, and canteens that used a spreadsheet, a dedicated scale, or an internet-based service to track food waste and found that 61% of the catering units reduced their waste. Eriksson et al. (2017) revealed that the savings potential in school catering is subject to strong variations and influenced in particular by the type of catering system. Kitchens that prepare all the meals by themselves showed a waste rate that was on average 42% below the value for facilities supplied with warm food from satellite kitchens (Eriksson et al., 2017). A German case study showed that most of the food waste in schools, hospitals, business canteens, and hotels is related to surplus food such as buffet leftovers or serving waste (von Borstel et al., 2017). The generation

and volume of discarded food depend on internal and external situation-specific variables such as catering processes, kitchen management, operating procedures, preparation methods, technical equipment, and guest characteristics (Göbel, 2018). Food waste in gastronomic kitchens is also influenced by social standards; the development of expertise and experience; product quality; and communication structures with suppliers, customers, and other employees (Heikkilä et al., 2016). During menu planning, decision-making processes often depend on economic requirements, professional ethics, and the need to satisfy the expectations of customers (Hennchen, 2019). Demand-oriented menu planning requires accurate product inventory and reliable information on the number of guests that are expected to attend the event in order to provide a solid basis for the calculation of purchased and prepared food (Silvennoinen et al., 2015). A precise approximation of food demand is challenging because the unexpected absence of guests is difficult to predict and usually has a particularly negative effect on the amount of food waste (Pirani and Arafat, 2016). Waste tracking systems from commercial providers offer support to gastronomic kitchens in quantifying food waste and in developing individual prevention strategies. Among the providers of smart scales are companies from the USA such as *Leanpath*, or companies from Europe, such as *Winnow Solutions*, *Kitro*, *eSmiley, Matomatic*, and *Visma,* which are already contributing to reducing the amount of food waste (KITRO, 2019; Leanpath, 2019; Winnow Solutions Limited, 2019; eSmiley, 2020; Matomatic, 2020; Visma, 2020). The literature has indicated that catering units that use waste tracking systems instead of semi-automated or manual tools record more data and achieve slightly higher reductions in food waste (Eriksson et al., 2019; Leverenz et al., 2020). Beretta and Hellweg (2019) showed that the reduction targets formulated by the UN in terms of halving food waste in the food service sector are realistic and can be exceeded in the long term. Because of the considerable quantities of food waste in the food service sector and the diversity of catering systems across the respective sub-sectors, individual reduction strategies and measures are necessary (Eriksson et al., 2017; Eriksson et al., 2018). As described, many studies have focused on quantifying and avoiding food waste in the food service sector, but the literature has rarely addressed food waste at event caterings, such as individual caterings for private or business events and conferences (Goossens et al., 2019). Catering can be defined as the business of providing food services and it relates to a wide range of business formats and facilities such as hotels, hospitals, full-service restaurants, business canteens, or event venues (Scanlon, 2007). The event caterings examined in this case study were held on the premises of a congress center operated by a hotel and thus formally belonging

to the hospitality sector, which in Germany produces approximately 80 ± 20 thousand tons of food waste per year (Schmidt et al., 2019).

4.2.2 Objectives

With the findings of this research, we aimed to contribute to fill the knowledge gap by presenting insights from a case study based on data from 239 individual events. The main objective was to determine the influences of different variables on the generation of buffet leftovers at the catering of events. To provide a case-specific data base, the study aimed at quantifying the buffet leftovers using a waste tracking system. Furthermore, in order to estimate the savings potential for future reduction strategies, we aimed to determine the monetary effects associated with the generation of buffet leftovers.

4.3 Material and methods

4.3.1 Scope of the case study and definitional framework

We investigated food waste, namely, buffet leftovers, at 239 event caterings over 4 years: from the beginning of 2014 until the end of 2017. For the remainder of this paper, we exclusively use the term *food waste* for buffet leftovers, whereas the legal framework defines food waste as all food[8] that has become waste within the Directive (EU) 2018/851 of the European Parliament and of the Council of May 30, 2018, amending Directive 2008/98/EC on waste. Furthermore, when we discuss the monetary effects, we refer to the monetary equivalents of the wasted food products according to their net product prices.

The catering for the analyzed events was organized by the hotel group *Maritim Hotelgesellschaft mbH* in the city of Dresden, Germany. The events were held in the congress center of the hotel, which has six conference rooms of different sizes with a capacity of up to 6800 individuals. The facilities of the congress center have an integrated kitchen that administrates and operates the catering of the hosted events. The kitchen of the congress center is operated separately from the main kitchen of the hotel and in this article is referred to as the *pilot kitchen*.

[8] Food is defined in Article 2 of Regulation (EC) No 178/2002 of the European Parliament and of the Council.

4.3.2 Quantification procedure and study design

The case study uses a self-reporting approach to conduct the experiments, which means that the staff members of the pilot kitchen reported the quantities of buffet leftovers of the analyzed events. For the quantification process, we worked with the waste tracking system *RESOURCEMANAGER FOOD*, which we developed to collect data in gastronomic facilities and in the pilot kitchen. This computer-based device allows the operator to quantify and self-report the wasted food directly at the source of generation. It comprises an electronic scale connected to a standard or tablet computer, which allows touch-screen navigation through the installed software. Photos of the measuring device and screenshots of its user-interface are published in Leverenz et al. (2020). The measuring device displays the recorded quantities within horizontal bar charts to the operator. The collected data are stored in a spreadsheet software that contains the following information: quantified mass, food products, food categories, date and time, location, event type, guest numbers, and product prices.

The quantification procedure was integrated into the operational routines of the pilot kitchen. First, the kitchen staff collected all the trays from the buffet service after the end of each event and weighed the buffet leftovers by directly placing the serving dishes on the electronic scale. The tare weight of each serving dish is preconfigured in the system, allowing the direct, automatic determination of the specific food weight that remains in the serving dish. Figure 1-4 illustrates the simplified process flow of quantifying buffet leftovers during event caterings. We focus exclusively on the leftovers from the buffet because they are directly linked to menu planning, specifically with the demand estimates for the quantities of prepared food. Plate leftovers were not quantified because they are not subject to the direct influence of operative kitchen processes, because the guests decide the portion size, frequency of buffet visits, and consequently, the remaining plate leftovers.

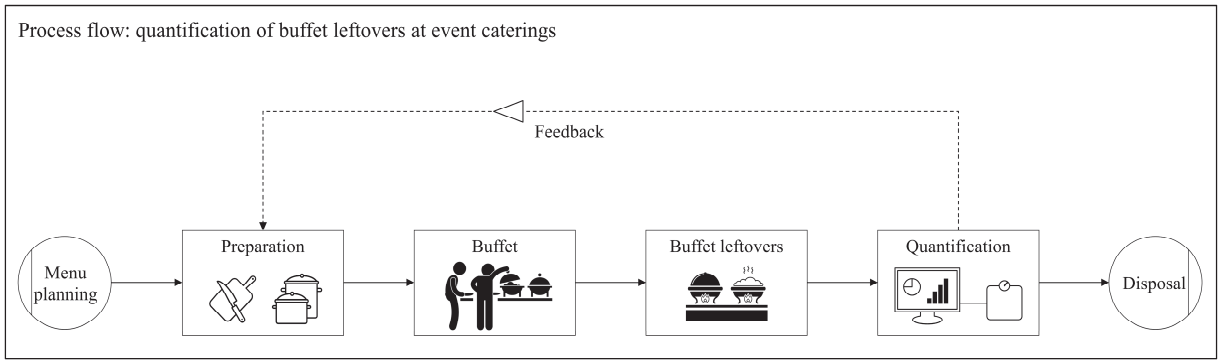

Figure 4-1 Process flow: quantification of buffet leftovers at event caterings.

4.3.3 Sample characteristics

To ensure that the collected data were of high quality, the experiments were conducted over 4 years. For the presentation of results, we examined the collected data by using different groups of variables and divided them into clusters with similar characteristics (Table 4-1). For instance, different event types were distinguished into *graduation ceremonies*; *business events* including business celebrations, meetings, and exhibitions; *conference lunches*; and *conference dinners*. The participants of graduation ceremonies were students from the graduating classes of the same secondary school, their teachers, and close family members such as parents or siblings. Participants of business events, conference lunches, and conference dinners were employees, entrepreneurs, academicians, politicians, and other professionals. We used the four seasons (spring, summer, autumn, and winter) to investigate the seasonal influences. Event sizes were categorized into groups of different guest numbers with a corresponding group size of 100 guests, and the average event demonstrated an arithmetic mean of 302 guests. The smallest event size was a class size of less than 100 guests, and the largest was more than 500 guests. Menu prices ranged from a minimum of 15 EUR to a maximum of 45 EUR per guest and were aggregated into subgroups with a difference of 5 EUR (Table 4-1).

Table 4-1 Variable cluster by groups with similar characteristics: sample size is 239 events (n = 239).

Variables	Cluster	Number of events (n)
Event type	Graduation ceremonies	20
	Business events	16
	Conference lunches	157
	Conference dinners	46
Season	Spring	26
	Summer	98
	Autumn	92
	Winter	23
Event size	<100 guests per event	12
	100–199 guests per event	48
	200–299 guests per event	42
	300–399 guests per event	45
	400–499 guests per event	23
	>500 guests per event	69
Menu price	15–20 EUR per guest per event	18
	21–25 EUR per guest per event	61
	26–30 EUR per guest per event	131
	31–35 EUR per guest per event	15
	36–40 EUR per guest per event	10
	41–45 EUR per guest per event	4

4.3.4 Data analysis and presentation of results

To provide general information on the quantified amounts at all 239 events, we presented the total quantity of buffet leftovers as a sum of all the collected data. Furthermore, we calculated the arithmetic mean values and the corresponding confidence intervals to illustrate the overall quantities of buffet leftovers in kilograms per event and grams per guest. To indicate the temporal expenditure for the quantification process, we present the arithmetic mean value and confidence intervals of the minutes necessary for the weighing procedure. For this purpose, we used the differences in time between the first and last data points of a weighing process, which are stored in the database of the waste tracking system.

4.3.4.1 Influences on buffet leftovers

For the descriptive analysis of the sample, we present the average quantities of buffet leftovers per event for each subgroup of the influencing variables in grams per guest. The results present the arithmetic mean values based on the clustered sample data within vertical bar charts and the corresponding confidence intervals. Given the heterogeneous number of sample data for the different subgroups of the variables, a random resampling method with replacement (bootstrapping) was used to calculate the confidence intervals and the distribution parameters of the sample at a confidence level of 95%. According to DiCiccio and Efron (1996), the resampling method is asymptotically more accurate for the approximation of the true confidence interval than the standard intervals obtained using sample variance and assumptions of normality. Cleophas et al. (2009) recommend constructing at least 1000 resamples (bootstrap estimates) based on the original sample data to derive reliable confidence intervals. We used the XLSTAT[9] bootstrapping routine (Addinsoft, 2019) to repeat the resampling procedure 1000 times and to compute the bootstrap estimates.

Wood (2005) and Lee (2016) demonstrated that confidence intervals are more satisfactory basis for statistical inference than null hypothesis tests and represent an attractive alternative to *p* values. This is in line with statements from the American Statistical Association, which recommend a simplified dichotomy between “significant” and “non-significant” findings concerning misuses of p values (Wasserstein and Lazar, 2016). Matthews (2018) further recommended providing a variety of graphical summaries of data including the presentation of confidence intervals to increase the validity of results instead of using *p* values for statistical

[9] XLSTAT is statistical analysis software that is an add-on for Microsoft Excel.

inference. Cumming and Finch (2005) proposed rules for statistical inference by eye because of the visual comparison of confidence intervals. Accordingly, we identify significant differences between the mean values of the variables within our sample, when the overlap of their 95% confidence intervals is no more than approximately half of the average error margin ($p \leq 0.05$). In addition, two confidence intervals that do not overlap are significantly different at a corresponding p value of ≤ 0.01.

4.3.4.2 Multivariate analysis: random forest model

The literature indicated that drivers of food waste are complex and interrelated (Giordano et al., 2019). Grainger et al. (2018) recommend the analysis of interrelations with statistical models such as random forests to reduce the probability of false-positive results. Accordingly, we conducted a regression through a random forest model to better understand the effects of the analyzed variables and their interrelations. By using the random forest model, we aimed to determine the relative importance of variables such as event type, season, event size, and menu price on the generation of buffet leftovers at the investigated events.

Random forest algorithms use ensemble learning methods for classification and regression by constructing binary decision trees, as proposed by Breiman et al. (1998). The binary decision trees were computed by random sampling with replacement based on the sample data. Oshiro et al. (2012) suggested building between 64 and 128 trees for the random forest to achieve a satisfactory balance between the performance of the model, the processing time, and memory usage. We used the random forest algorithm in XLSTAT (Addinsoft, 2019) to build a forest with a size of 100 trees, and the error rate stabilized at a constant level between 40 and 60 trees. According to Cochran (1977), we randomly selected 70% of the sample values as a training dataset to build the random forest model and used the other 30% to test the model. The importance of each explanatory variable is indicated by the change in prediction accuracy, which is expressed as the increase in mean square error when the observed values of a single variable are randomly permuted in the out-of-bag samples (Addinsoft, 2019). The explanatory variables, namely, event type, season, event size, and menu price, were used to investigate their relative importance for the response variable, namely, the quantities of buffet leftovers.

4.3.4.3 Monetary equivalents of wasted food products

The results provide information on the monetary equivalents of wasted food products for the sum of all the collected data. In addition, we present the arithmetic mean values and bootstrap confidence intervals for different groups of event sizes. For the calculation of the monetary

equivalents, we multiplied the quantities of wasted food products by the corresponding product-specific prices. We estimated the price of each product group based on the weighted arithmetic average of all food purchases, which the kitchen administration made for the catering of the analyzed event (Table 4-2). To provide an impression of the magnitude of the monetary equivalents of buffet leftovers, we reference them against the disposal costs of approximately EUR 0.05 per kilogram of food waste that were given to us by the pilot kitchen (Maritim, Personal communication). Accordingly, we multiplied the specific disposal costs of food waste by the quantified amount of buffet leftovers.

Table 4-2 Product prices for different product categories (menu components). The default planning parameters represent real data used by the pilot kitchen to estimate the food demand and calculate the preparation quantities for event caterings.

Category	Product price [i]			Planning parameters [ii]	Type of food comprised in the category
	min.	average	max.		
Finger food	4.48	7.49	9.75	160 g	Appetizers, snacks, and other small dishes.
Side dishes	0.73	4.35	10.69	120 g	Pasta, rice, potato, sweet potato, corn, oat, cassava, quinoa, and other starch products.
Meat & poultry	7.56	11.67	14.12	150 g	Beef, pork, lamb, goat, chicken, turkey, duck, geese, and other red and white meats.
Vegetables	0.67	1.97	5.46	100 g	Vegetables, legumes, and roots.
Salads	1.18	4.08	12.44	60 g	All types of fresh and prepared salads, including potato, quinoa, and pasta salads.
Baked goods	4.04	6.64	9.92	120 g	Bread, cookies, crackers, cakes, pies, muffins, and other salty and sweet pastries.
Soups & stews	3.01	4.02	6.30	100 g	Prepared hot dishes of mixed ingredients such as soups and stews.
Fish & seafood	4.08	7.71	12.19	50 g	Salmon, tilapia, shrimps, lobster, oysters, and other seafood and fish types.
Desserts	3.19	12.24	17.31	50 g	Jellied desserts, chocolates, puddings, ice-creams, and dairy products.
Cold cuts	4.08	6.94	11.01	70 g	Salami, ham, prosciutto, bacon, sausages, terrines, pâtés, olives, mushrooms, pickles.
Others	1.39	3.28	4.08	100 g	Fruits, eggs, dressings, sauces, seasonings, and others.

[i] Excluding value-added tax in EUR per kg. The column on the left shows the absolute minimum; the column in the middle shows the weighted arithmetic average; the column on the right shows the absolute maximum.

[ii] Default planning parameters used by the pilot kitchen to estimate the food demand and to calculate the preparation quantities for event caterings. The combination of menu components (food categories) for an event catering depends on menu prices and preferences of customers.

Furthermore, we used the Pareto charts to highlight the product groups with the highest quantities of buffet leftovers and those with the highest monetary equivalents. The Pareto charts

display the quantities of buffet leftovers and their monetary equivalents for each product group, within vertical bars and according to their percentage in the total volume within the sum of all 239 events, starting with the highest values of the left bar. The cumulative percentage is represented by a line that proportionally adds the corresponding percentages from each bar.

4.3.4.4 Proportion of demanded and wasted food products

In this section, we provide a brief insight into the quantities of buffet leftovers for the most common food products relative to the demanded amount of food across events with different numbers of guests. The results present the proportion between the demanded and wasted food from buffets, within vertical bar charts, for the six most frequently wasted food products. The outcomes are shown as percentages of buffet leftovers for each product group, according to different groups of event sizes. To facilitate the visual comparison of the results, we defined the different quantities of prepared food as standardized reference values equal to 100% of mass. To estimate the amount of prepared food, we assumed that the planning parameters can be used to express the quantities of prepared food (Table 4-2). Hence, the preparation quantities are rough estimates based on the real planning parameters and reflect the practical experience of the pilot kitchen, but they were not quantified by weighing. In addition, we assumed that the difference between the prepared and wasted food corresponded to the quantity of food that guests serve themselves at the buffet, which can be expressed as the demand for food at an event. Accordingly, the displayed proportions served as performance indicators to illustrate the accuracy of the planning parameters for estimating the food demanded by guests in relation to different event sizes. However, plate leftovers were not included in the empirically collected data within our case study.

4.4 Results

The buffet leftovers across all 239 events resulted in a total quantity of approximately 10 tons (10063 kg), corresponding to approximately 42.1 ± 3.7 kg per event. The average number of guests per event was 302, and the arithmetic mean value of buffet leftovers per event was approximately 139.5 ± 13.7 g per guest. The temporal expenditure to collect these data and quantify the wasted food at buffets was approximately 36.1 ± 5.4 min for each event. In the result sections, the findings are presented according to the factors that influence buffet leftovers at event caterings, and an analysis of the monetary effects on events with different numbers of guests and on different product groups is then conducted.

4.4.1 Influencing variables on buffet leftovers

Figure 4-2 presents the quantities of buffet leftovers for different event types, seasons, event sizes, and menu prices. Graduation ceremonies proved to be the event type with the lowest amount of (approximately 85.5 g) buffet leftovers per guest, followed by business events with an average of 125.0 g per guest (Figure 4-2 A).

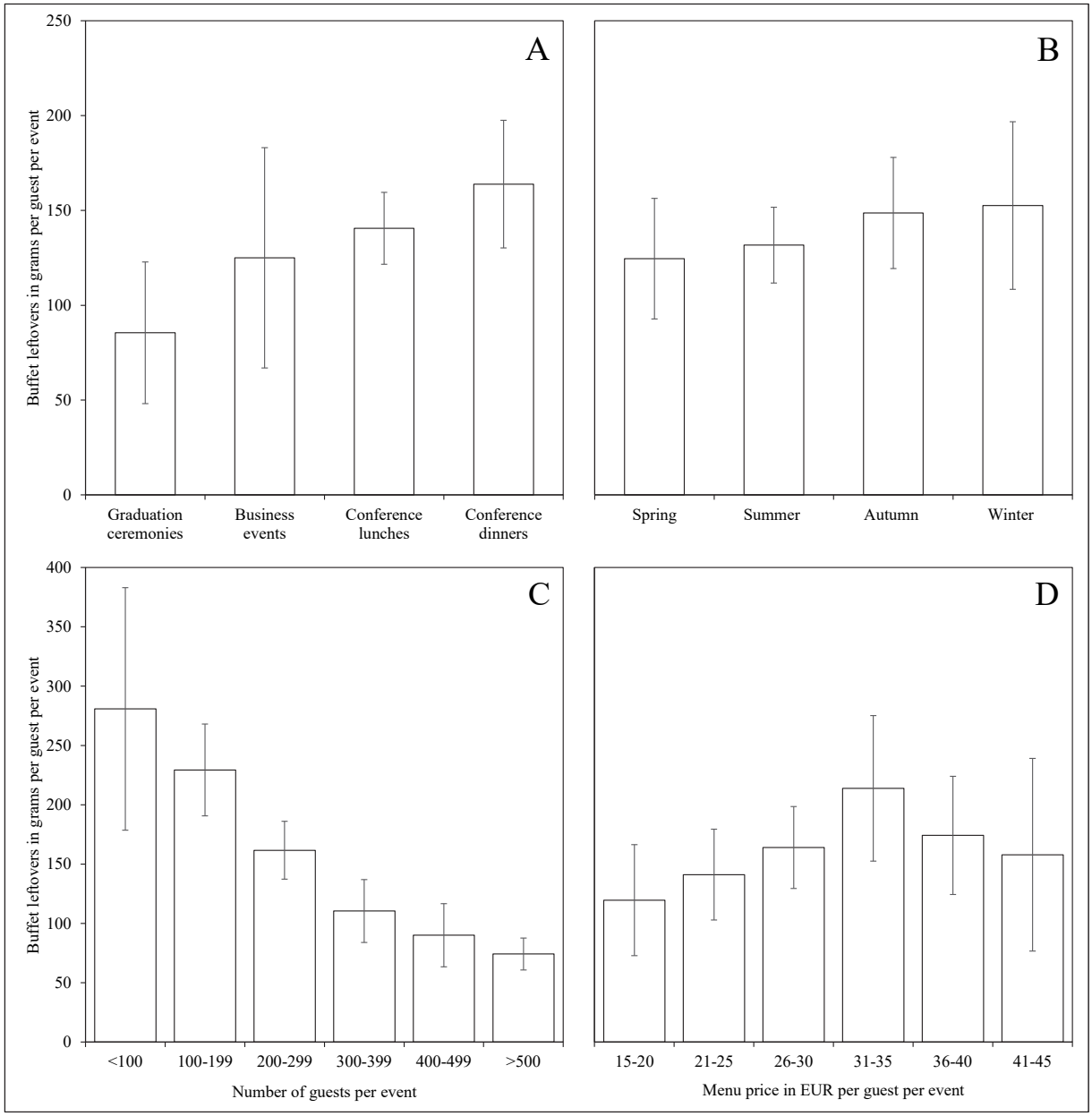

Figure 4-2 Quantities of buffet leftovers at event caterings for different A: event types, B: seasonal influences, C: event sizes, and D: menu prices (Arithmetic mean value ± 95% confidence interval). Vertical bars represent arithmetic mean values (bootstrap estimates) for the subgroups of each variable. The corresponding error bars display the standard bootstrap confidence intervals at α = 5%.

Compared to those, conferences produced slightly higher quantities during lunches, with approximately 140.5 g per guest and during dinners with approximately 163.9 g per guest. Because the confidence intervals of business events, conference lunches, and conference dinners strongly overlap, we cannot confirm evident differences between these groups. However, we can state with 95% certainty that there were significantly less buffet leftovers during graduation ceremonies than during conference lunches and dinners. The amount of buffet leftovers increased slightly through the seasons: starting from spring with approximately 124.6 g per guest until winter with approximately 152.6 g per guest (Figure 4-2, B). In contrast to the event type, we found no significant differences between the seasons, because all corresponding confidence intervals overlap by more than half of the average error margin.

The event size showed the most evident influence on buffet leftovers within our sample. Events with less than 100 guests demonstrated the highest values of buffet leftovers, with an average of approximately 280 g per guest (Figure 4-2, C). Accordingly, we found the lowest specific values, approximately 74 g of buffet leftovers per guest, at events with more than 500 guests. We observed no overlap of confidence intervals for all events with less than 300 guests with those of events with more than 300 guests. Thus, we confirm the presence of significant differences in the mean values between events of this magnitude, with a certainty of 95%. However, we observed fluctuations in the amount of buffet leftovers associated with different menu prices. The buffet leftovers increased with higher menu prices until the price reached a certain price range of 31–35 EUR per guest. After exceeding a menu price of 35 EUR per guest, the amount of buffet leftovers started to decrease again slightly (Figure 4-2, D). Although we observed this tendency in our data, because of the overlapping confidence intervals, we could not detect significant differences between the quantities of buffet leftovers in relation to different ranges of menu prices.

4.4.2 Variable importance

The random forest model showed that the observed variables could explain approximately one third of the generation of buffet leftovers (R^2=0.333) during a series of 239 events. Among the four explanatory variables, event size had the highest value—a 28% increase in mean square error—indicating its importance in explaining the quantities of buffet leftovers at events. Compared to the event size, the other explanatory variables, namely, season, menu price, and event type, demonstrated a relatively low variable importance with an increase in mean square error of approximately 4 to 7% (Figure 4-3).

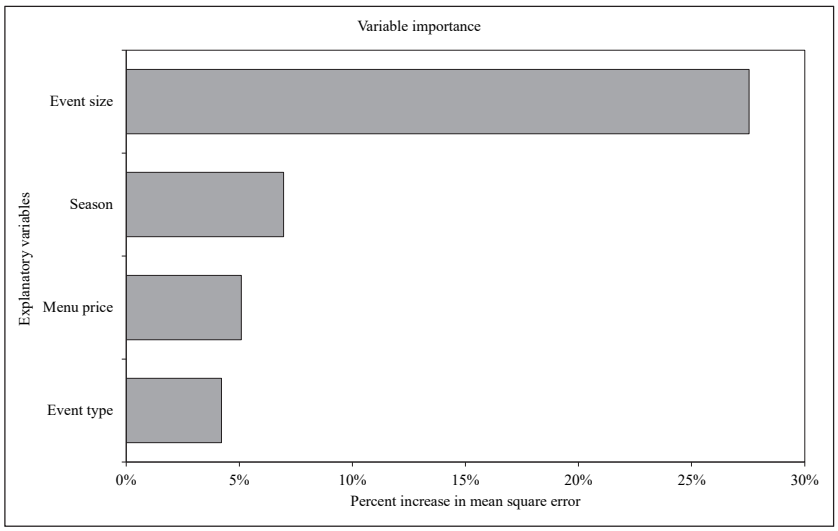

Figure 4-3 Variable importance resulting from a random forest with 100 trees (R^2 = 0.333). The variable importance is expressed by the percent increase in mean square error due to random permutations of the data for single variables. High values of the percent increase in mean square error indicate higher importance of the variable to explain quantities of buffet leftovers at events.

4.4.3 Monetary effects

The monetary equivalents for the overall amount of wasted buffet leftovers across all the examined event caterings was approximately 65000 EUR (i.e., 64769 EUR), and the associated disposal costs were approximately 520 EUR. Because the event size had the strongest influence on buffet leftovers, we present the monetary effects according to the number of guests.

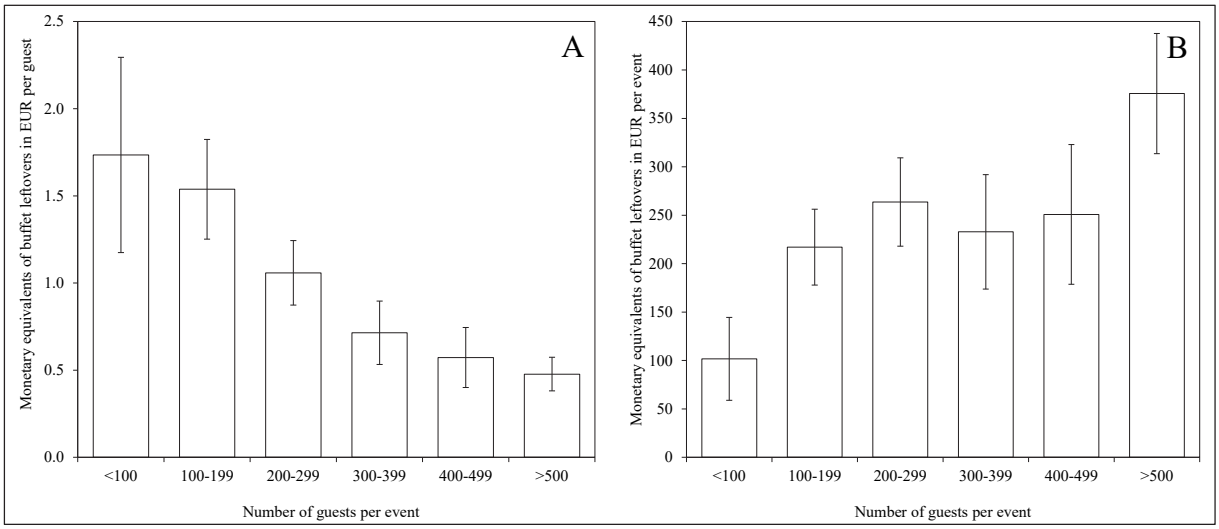

Figure 4-4 Average monetary equivalents of buffet leftovers for different event sizes per guest (A) and per event (B). The markers represent arithmetic mean values (bootstrap estimates) for each group of guest numbers. The corresponding error bars display the standard bootstrap confidence intervals at α = 5%.

Subsequently, we provided the results of the monetary equivalents by product groups. The results revealed a negative trend between the number of guests and the monetary equivalents of buffet leftovers wasted per guest (Figure 4-4, A). This finding means that the monetary equivalents per guest decrease with an increasing number of guests. The highest values, with approximately 1.7 ± 0.6 EUR per guest were documented at events with less than 100 guests, and events with more than 500 guests had buffet leftovers with a monetary equivalent of approximately 0.5 ± 0.1 EUR per guest. Figure 4-4 (B) illustrates the sum of monetary equivalents per event, which ranges from an average of 101.7 ± 42.8 EUR per event (<100 guests) to 374.7 ± 62.1 EUR per event (>500 guests).

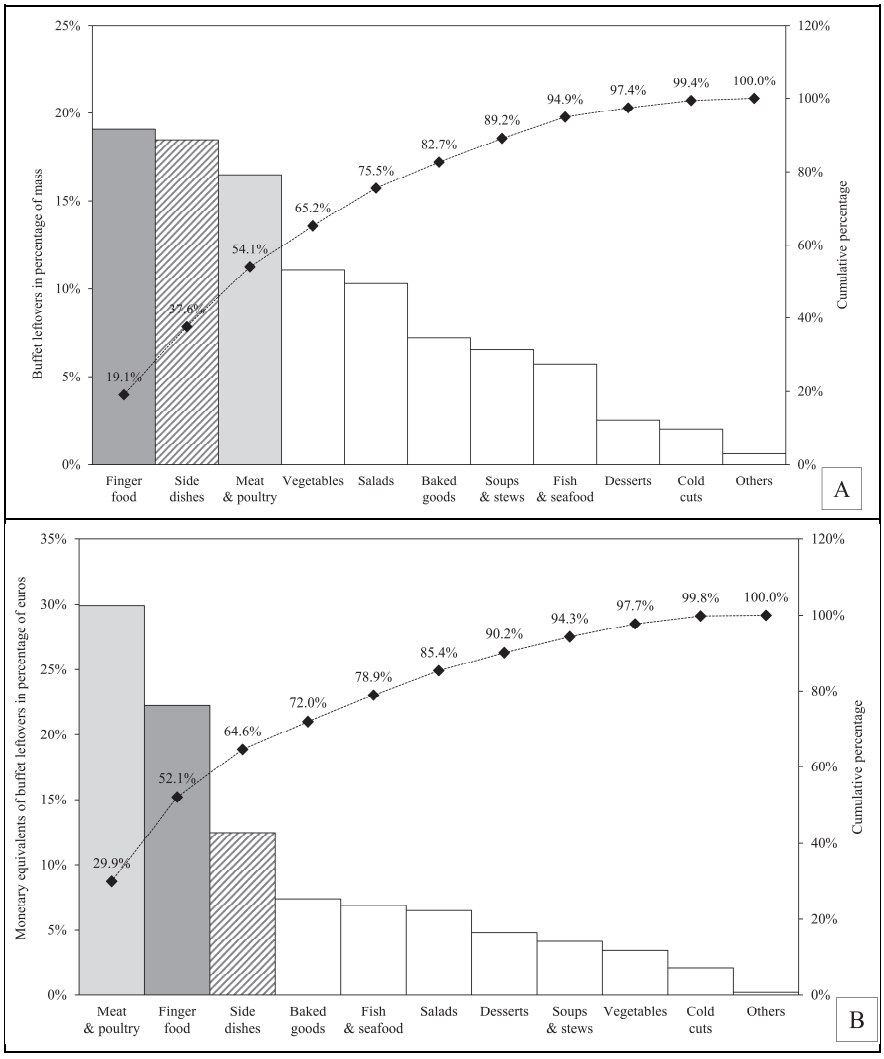

Figure 4-5 Vertical bars in the Pareto charts represent the percentage contribution of each product group to the total volume of buffet leftovers within the sum of all 239 events with A: quantities (100% = 10063 kg) and B: monetary equivalents of buffet leftovers (100% = 64769 EUR). The cumulative line is displayed to proportionally add the corresponding percentages from each bar, starting at the left bar with the highest food waste quantities (A) and monetary equivalents (B).

To highlight the product groups with the highest quantities of buffet leftovers and monetary equivalents, we used Pareto charts. Figure 4-5 (A) demonstrates that more than 80% of the overall quantities of buffet leftovers were caused by 6 of 11 food categories, namely, *finger food*, *side dishes*, *meat & poultry*, *vegetables*, *salads*, and *baked goods*, respectively. Almost the same categories (except for *vegetables*) were also responsible for more than 80% of the corresponding monetary equivalents of wasted food products at the buffet, but with different cumulative percentages (Figure 4-5, B). However, only three of these six product groups produced more than half of the buffet leftovers, which is related to almost two thirds of the monetary effects. The product groups with the highest percentages are highlighted in the Pareto charts with different grayscales to facilitate a visual comparison. Accordingly, *meat & poultry*, *finger food*, and *side dishes* generated approximately 54% of all buffet leftovers and approximately 65% of overall monetary equivalents (Figure 4-5).

4.4.4 Proportion of demanded and wasted food from buffets

As demonstrated in the Pareto charts, six food product groups—*finger food*, *side dishes meat & poultry, vegetables, salads*, and *baked goods*—cause more than 80% of the quantities of buffet leftovers (compare Figure 5). For these groups, we illustrated the proportion of demanded and wasted food in relation to the most important variable: event size (Figure 4-6). At first glance, we observe an overall trend of decreasing percentages of wasted food for increasing event sizes.

The product groups *side dishes* (Figure 4-6, B), *meat & poultry* (Figure 4-6, C), *vegetables* (Figure 4-6, D), and *baked goods* (Figure 4-6, F) showed a similar pattern that follows this trend. In contrast to these product groups, the product groups *finger food* (Figure 4-6, A) and *salads* (Figure 4-6, E) did not follow such a consistent trend and experienced fluctuations throughout the groups of event sizes. One common characteristic of all product groups was the relatively small percentages of wasted food for groups of events with more than 300 guests compared to groups of events with less than 300 guests.

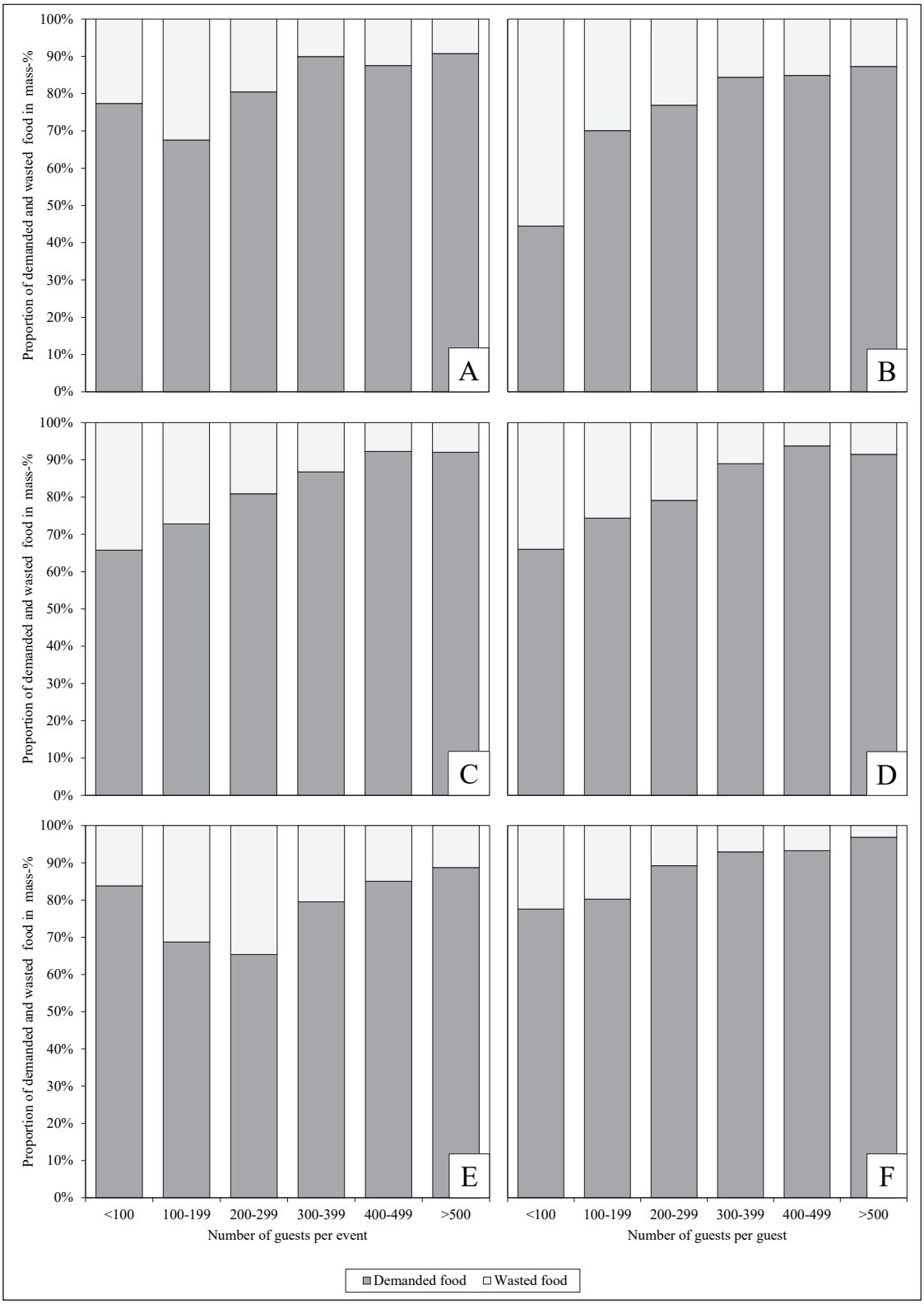

Figure 4-6 Proportion of demanded and wasted food from buffets, clustered into groups of event sizes, with A: finger food (100% = 160 g/(guest·event)); B: side dishes (100% = 120 g/(guest·event)); C: Meat & poultry (100% = 150 g/(guest·event)); D: Vegetables (100% = 100 g/(guest·event)); E: Salads (100% = 60 g/(guest·event)); F: Baked goods (100% = 120 g/(guest·event)). The 100% values represent the estimates of the prepared food quantities for each product group based on real planning parameters.

4.5 Discussion

4.5.1 Influence of different variables on buffet leftovers

We examined the effects of the variables event type, season, event size, and menu price, and we found that the event size was the variable with the highest relevance for buffet leftovers within our case study. In the following subsections, we discuss the observations concerning influence and trends of each variable on the generation of buffet leftovers at catering events.

4.5.1.1 Trends related to event type

Within the examined events, significant differences were found between graduation ceremonies and conferences. For instance, almost twice as many buffet leftovers were produced per guest during conference dinners compared to graduation ceremonies, which indicates that different profiles of guests significantly affect the generation of buffet leftovers. According to Göbel (2018), individual characteristics of the guests probably influence the amount of food waste during catering services, but there is no evidence on the strength of this effect. However, because we did not collect information on the individual characteristics of the guests that attended the investigated events or their eating habits, we could not deduce further conclusions from this. Consequently, further research could improve the understanding of the different types of events and the individual guest profiles while considering sociodemographic parameters, such as gender, age, income, profession, or educational level.

4.5.1.2 Trends related to seasonal influences

Our results revealed that the quantities of buffet leftovers increased slightly from spring to winter, but no evident correlation was determined. Thus, from our results, we could not derive a general conclusion regarding seasonal influences. The relatively broad confidence intervals between the different seasons demonstrate that buffet leftovers are subject to strong fluctuations by season, which is similar to findings in the literature (Koivupuro et al., 2012; Pirani and Arafat, 2016). For instance, Eriksson (2015) observed that food waste had no clear trend among the seasons but had an extreme level of variation in some individual weeks of the year. Hence, there exists a certain complexity to pinpoint or generalize seasonal influences. Machine learning approaches, however, model multiple seasonality (e.g., week, month, year) and were demonstrated the ability to increase the predictive accuracy of demand forecasting in bakeries when the dataset is accurate, of sufficient size, and trustworthy (Huber et al., 2019). This could

serve as an incentive for further research to investigate whether machine learning methods could predict seasonal effects of event caterings to improve menu planning.

4.5.1.3 Trends related to event size

The event size was the parameter with the strongest effect on the generation of buffet leftovers within our case study. In contrast to these observations, no correlation between the number of guests and the buffet leftovers was observed at breakfast buffets in hotel kitchens (Leverenz et al., 2020). Menu planning, however, is challenging when many registered guests cancel their participation on short notice or unexpectedly do not show up, a phenomenon found to be common (Mackenzie et al., 2011; Gu, 2014). The same applies when the number of participating guests unexpectedly exceeds the number of registered guests, thus requiring the kitchen staff to spontaneously produce substantial quantities of food (Pirani and Arafat, 2016). This means that an underestimation of expected guests may also be associated with an increase in food waste due to unplanned last-minute food preparation.

Our results, however, demonstrate that buffet leftovers decreased for increasing guest numbers, showing that the influence of guest numbers on buffet leftovers at catering events is relatively strong for smaller events (<300 guests). These findings indicate the potential for improvements, particularly for smaller event sizes, and provide insights into the possibility to optimize menu planning for individual events by, for example, improving the estimation of expected guest numbers.

4.5.1.4 Trends related to menu prices

Our findings showed that increasing quantities of buffet leftovers were found with rising menu prices. This result can be explained by how the organizer of the event attempts to fulfill the expectations of the customers by introducing and offering a broader variety of products according to higher menu prices; however, for menu prices above 35 EUR per guest, food waste was lower. This result may occur because when menu prices are higher, more high-quality products are used. In our case study, this included expensive products such as fish and seafood, crustaceans (e.g., lobster), which are usually produced in smaller amounts because of their comparatively high product price. As a result, higher menu prices led to less buffet leftovers when a higher product quality was offered. Our findings indicate the observed behavior but provide no evidence for it because of the small sample size within the groups of events with higher menu prices.

4.5.2 Monetary effects

One of the main drivers for businesses to reduce food waste is cost savings. Interviews, for example, with professionals from different catering services, showed that businesses have concerns regarding negative consequences because of their financial situations and the additional expenses of wasted food (Hennchen, 2019). With reference to the Pareto principle (Kim et al., 2017), we did not observe that 80% of the effects (monetary equivalents) were from approximately 20% of the causes (product groups). The presented Pareto charts, however, were beneficial because they enabled us to identify and highlight the product groups with the highest quantities of food waste and those with the highest monetary equivalents. Accordingly, our results revealed that 3 out of 11 product groups caused two thirds of the monetary equivalents and more than half of the quantities of buffet leftovers. The product groups responsible for the highest monetary equivalents of wasted food at the buffet were *meat & poultry, finger food,* and *side dishes*. This finding illustrates that the design and further development of reduction strategies relate to the highest cost-savings potential when it is directed at a few product groups. Similar effects were observed in analyses of the possibilities to optimize reduction strategies (Papargyropoulou et al., 2016; Cristóbal et al., 2018). For instance, Papargyropoulou et al. (2016) recommended prioritizing prevention strategies based on the economic efficiency of food commodities according to product-specific waste levels. Our results, however, are indicative estimates based on extrapolations of monetary equivalents. Compared to the volume of approximately 65000 EUR related to the monetary equivalents of wasted food products, the disposal costs caused less than 1% of the monetary effects and thus do not represent a relevant cost factor. However, the monetary equivalents refer exclusively to the product price and do not consider other preparation-specific costs related to energy consumption during the heating and cooling processes or the invested work hours for the preparation of meals and to conduct the weighing procedure. Accordingly, the true monetary effects are somewhat different than those within our calculations, but the data nevertheless provide one possible depiction of monetary equivalents.

4.5.3 Potential improvements

In this section, we discuss potential improvements that refer to individual specifications of the pilot kitchen. The findings are limited to the framework of our case study and therefore represent an indication of how the individual quantification of buffet leftovers can be directed to building a decision base for the development of individual reduction strategies. For instance, we found that larger event sizes (>300 guests) demonstrated relatively lower levels of buffet

leftovers than smaller event sizes (<300 guests). This trend was observed for most of the product groups, which indicates the potential for improvement, particularly for smaller events, because the groups of larger events demonstrated lower levels of buffet leftovers. However, some food products showed fluctuating percentages of wasted food among groups of smaller event sizes, emphasizing it might be difficult to derive general recommendations in accordance to the event size (compare Figure 4-6, A and E). This implies that reduction strategies must address the influence of event sizes on each product group. To further explain a possible practical implementation, we illustrate a potential improvement strategy by giving a product-specific example based on the results presented in Figure 4-6. For instance, the product group of *side dishes* showed the highest percentages of buffet leftovers among all product groups. For smaller events with less than 100 guests, more than half of the prepared food was wasted because of buffet leftovers (compare Figure 4-6, B). In other words, the planning parameter of 120 g per guest seems to overestimate the food demand by more than 50%. A possible improvement would be to adjust the planning parameter through an iterative procedure from event to event by, for example, reducing the initial planning parameter by 5- or 10-g steps. Accordingly, it would be possible to empirically test the influence of the planning parameter on the generation of buffet leftovers for specific product groups. As part of ongoing research that builds on the findings of our case study, we are testing the proposed procedure in cooperation with the pilot kitchen to investigate its practical feasibility and reproducibility.

4.5.4 Critical remarks and data quality

The findings of our case study are subject to limitations, which we briefly discuss in this section. We acknowledge that the method of data collection relies on self-reported data, which might influence data quality. Studies that investigated household food waste by using self-reporting methods have demonstrated that individuals tend to report less data than what occurred (Quested and Johnson, 2009; Delley and Brunner, 2017; Leverenz et al., 2019). Inaccuracies and errors within self-reporting studies can be reduced by instructing the participants well and thoroughly explaining the quantification procedure (Hübsch and Adlwarth, 2017). However, due to the aforementioned limitations of self-reporting methods, deriving a systematic error with regard to the quality of the collected data is hardly possible. Because the case study had no control group, we could only compare data between individual events of the same clusters. Thus, according to our review of the literature, because no study has examined food waste or buffet leftovers from individual event caterings, it is difficult to verify our findings and data quality against other literature. Considering that the underlying data of the case study were

obtained from 2014 until 2017, changes in recent years are not reflected in the results. The collected data, nevertheless, represent a knowledge base for developing and testing potential improvement closely linked to ongoing research in cooperation with the pilot kitchen.

4.6 Conclusions

In our case study, we found that event size had a strong influence on the generation of buffet leftovers, and other variables such as the event type, season, or menu prices had a comparatively weaker relevance. However, the observed variables provided a partial explanation that approximates the influences on buffet leftovers at event caterings. We observed significant differences between groups of smaller and larger event sizes. For instance, buffet leftovers for events with more than 500 guests amounted to approximately 74 g per guest, corresponding to a monetary equivalent of 1.7 ± 0.6 EUR per guest. Events with less than 100 guests recorded 280 g per guest of buffet leftovers, with a monetary equivalent of approximately 0.5 ± 0.1 EUR per guest. From these results, we deduce that there exists a certain potential for improvement, especially for events with smaller numbers of guests. Furthermore, we found that only three product groups, namely, *meat & poultry*, *finger food*, and *side dishes,* generated approximately 54% of the overall quantity of buffet leftovers and approximately 65% of the corresponding monetary equivalents. Accordingly, the findings are an incentive to further investigate potential improvements in relation to event sizes and for specific food products. Finally, the results of our case study emphasized that further research is necessary to thoroughly understand the problem and test the practical viability of reducing buffet leftovers at event caterings.

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Declaration of interests

We have no conflicts of interest to disclose.

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5 General discussion

The research questions posed at the beginning of this dissertation refer to the effects of self-reporting interventions and the identification of key factors that influence the generation of food waste and its prevention. To investigate the research questions, experiments were conducted in different contexts, namely in households (Panel 1: 16 households; Panel 2: 37 households), in four hotel kitchens, and during the catering of 239 individual events. For the performance of the self-reporting, semi-automated food waste tracking systems were installed in private and gastronomic kitchens. Evidence-based results were obtained for each object of investigation, which contribute to filling existing knowledge gaps regarding food waste quantities, reduction potentials and development of reduction measures. The research was published in three peer-reviewed papers and the main findings were thoroughly discussed in each paper to present a clear and concise interpretation of the results. The following sections summarize the results of the dissertation and discuss the economic efficiency of reduction measures, the scalability of food waste tracking systems and the relationship to the political targets.

5.1 Summary of main findings

The central result of the dissertation was the evidence that self-reporting interventions can raise consumer awareness, which consequently leads to a behavioral change resulting in significant reductions of food waste. Both the avoidable food waste in households and the breakfast buffet leftovers in hotel kitchens were reduced by more than half. Table 5-1 summarizes the three parts of the examination to provide a concise overview of the main findings and facilitate their comparison. Accordingly, the examination of self-reporting interventions in households led to an average reduction in food waste of approximately 57%. The quantities that the participants in the pilot households reported were of varying magnitude between offline- and online-based documentation methods but resulted in similar reductions in both cases. Behavioral changes referred to the food purchasing behavior and waste management. Based on these positive findings, the self-reporting approach was subsequently extended to gastronomic kitchens, where behavioral changes were also experienced, for example, in food management. There was a significant impact on self-awareness that resulted in the autonomous implementation of prevention measures. As a result, the pilot kitchens reduced their breakfast buffet leftovers by an average of approximately 64% due to improvements in operational kitchen processes. The four pilot kitchens showed similar trends over a period of 12 measurement months, indicating

a similar pattern of behavioral changes caused by the effect of self-reporting. To visualize the status quo antes, Figure 5-1 shows photos of typical dishes that were presented at breakfast buffets and resulting leftovers before the reduction strategies were implemented. The quantities of breakfast buffet leftovers were apparently very high, which indicates that the demand for food was overestimated or the buffet was overloaded with food for presentation reasons.

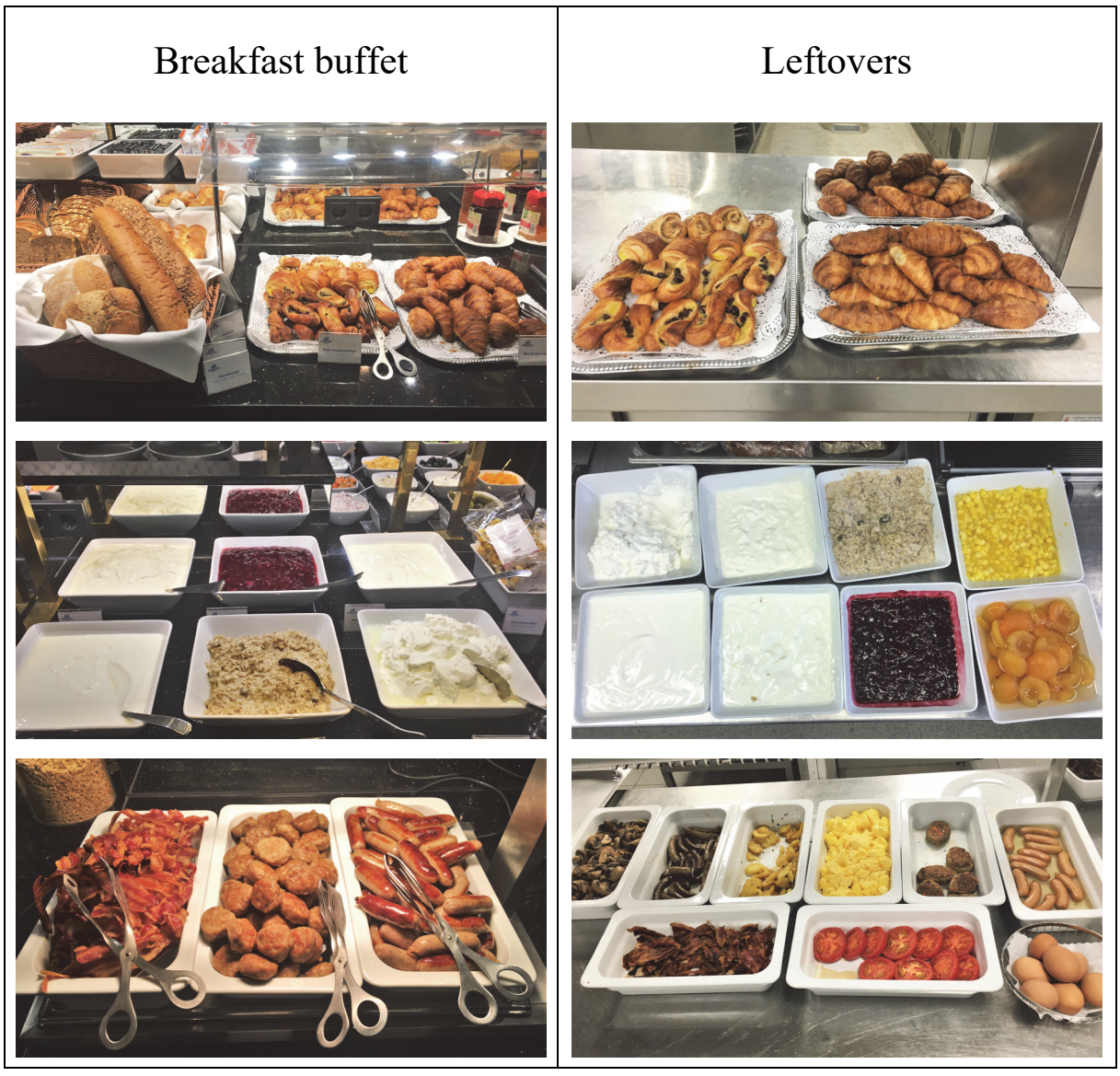

Figure 5-1 Status quo: sample photos of food presented at breakfast buffets (left) and leftovers (right).

The applied reduction measures comprised simple changes such as improving the just-in-time production for refilling the buffet with demand-orientated quantities, especially at the end of the buffet. For this purpose, using smaller serving dishes to present the food was effective. Hence, the efforts to improve daily kitchen routines or operational procedures were relatively small. These results are promising, however, they cannot be transferred to other segments in the food service sector without limitations, as the investigation of event caterings has revealed.

To illustrate a typical situation at individually catered events, Figure 5-2 presents sample photos of a randomly selected event.

Figure 5-2 Event caterings: sample photos of a buffet at an individual event and resulting leftovers.

As opposed to the breakfast buffet, the kitchen staff that catered the events did not experience any kind of behavioral change. Although the amount of food waste generated during the investigated events (42.1 kg/event) was on average almost six times higher than at breakfast

buffets (7.47 kg/d), no reduction in food waste could be achieved at these events (Table 5-1). According to literature, menu planning requires information about several external variables in advance to precisely forecast the food demand (Gu, 2014; Göbel, 2018). Information on external variables, however, is either difficult to determine because it is not provided to the kitchen administration or is not available at all, which leads to relatively high uncertainties in forecasting food demand.

However, the generation of food waste is related to monetary losses, which were examined for each sample. In addition to the food waste reductions in households, participants achieved monetary savings resulting from a change in shopping habits, which were up to tenfold higher than the savings related to the reduction in food waste. Members of the pilot households became more conscious about their shopping behavior and reduced their expenditures on food by an average of approximately 20%. These findings, however, need to be interpreted with caution, because there may be an underlying bias as the shopping behavior was not observed in relation to the food stock in the pilot households. Furthermore, the participants' eating habits were not monitored, which means that the savings on food purchases could have been compensated by a higher frequency of eating out of home. Nevertheless, expenditures on food purchases could have been reduced because the households developed better inventory management over short time. Investigating this issue was not part of this study's scope and therefore could not be examined in more detail. Future research is needed to investigate the described relationship and elucidate how improved shopping behaviors and food management affect food expenditures.

In hotel kitchens, annual monetary savings due to the reduction of food waste amounted to more than 9000 euros per kitchen, which illustrates that significant financial benefits can be achieved with relatively little effort. The feasibility to achieve monetary savings should provide incentives, especially for kitchen managers, to develop strategies and use existing potentials to save money and reduce food waste. At catered events, the monetary losses differed according to the event's size and ranged on average between 101.7 ± 42.8 EUR per event (<100 guests) and 374.7 ± 62.1 EUR per event (>500 guests). Consequently, buffet leftovers at events with less than 100 guests resulted to monetary losses of approximately 1.7 ± 0.6 EUR per guest, and at events with more than 500 guests to approximately 0.5 ± 0.1 EUR per guest. The total monetary savings potential was approximately 77000 euros across all 239 events, however, no savings were achieved during the study period. The findings revealed that reducing only approximately one-third of the food waste quantity, specifically caused by a few expensive product groups, could potentially halve monetary losses. This correlation can be advantageous

for developing strategies and measures, since an effective reduction can be aimed at only a few product groups at the beginning and thereby reduce most costs.

Table 5-1 Summary and comparison of the main findings.

	Households (Publication I)	Hotels (Publication II)	Events (Publication III)
Sample	- 16 households (offline) - 37 households (online)	- 4 hotels	- 239 events
Method	- Self-reporting diaries	- Self-reporting devices	- Self-reporting devices
Quantification of	- Food waste - Food purchases	- Breakfast buffet leftovers	- Buffet leftovers
Food waste generation	- Offline: 49.08 g/(cap·d) - Online: 34.93 g/(cap·d)	- First month: 7.47 kg/d	- Per event: 42.1 kg/event - Per guest: 139.5 g/guest
Reductions	- approx. 57% of mass	- approx. 64% of mass	- No significant reductions
Financial factors	Savings: - Waste: 36.5 EUR/(cap·a) - Purchase: 341.3 EUR/(cap·a)	Savings: - approx. 25 EUR/d - approx. 9000 EUR/a	Potential: - 0.6 to 2.1 EUR/guest - 121 to 442 EUR/event
Qualitative results	- Coaching and awareness-raising measures were effective and successful - Feasibility of halving food waste in households	- Autonomous implementation of avoidance measures - Adjustment to reduce size of the serving dishes - Refilling the buffet with less food in the last 30 minutes	- Monetary losses can be halved by reducing only approximately one-third of the food waste quantity - Six food categories cause more than 80% of food waste
Influential factors	- Household size - Online reporting - Offline reporting	- Refilling behavior - Size of serving dishes - Operational processes	- Number of guests - Menu price - Type of the event - Seasons
Improvements in	- Food purchasing - Planning - Storage	- Food management - Refilling the buffet - Food presentation	- No changes documented
Challenges	- Motivating households - Measurement efforts - Underreporting	- Transferring findings to a wider audience - Measurement efforts	- Complexity of menu planning - Forecast of guests - Measurement efforts
Future applications	- Web application - Initiatives and campaigns - Regional collaborations	- Smartphone application - Staff training	- Smartphone application - Forecasting systems
Relation to SDG	- SDG 12.3 exceeded	- SDG 12.3 exceeded	- SDG 12.3 not achieved

The number of guests had almost no effect on the amount of food waste at the breakfast buffet. Although kitchen managers considered the expected numbers of guests for menu planning, this variable did not affect how much food returned uneaten from the buffet. In contrast to breakfast buffets, a clear correlation was found between the number of guests and the generation of food waste during events. For instance, approximately 280 g/guest of food waste was generated on average at events with less than 100 guests, which is approximately four times higher than at events with more than 500 guests. According to the literature, organizing and catering an event requires a high degree of flexibility when a large number of guests unexpectedly do not show up (Mackenzie et al., 2011). If the opposite happens, then the kitchen has to produce a large amount of food in a relatively short time, which can also lead to last-minute overproduction (Pirani and Arafat, 2016). With reference to the examined influence of guest numbers at events and according to findings from literature, the production of food waste is more likely to increase with fluctuating guest numbers, which has an even higher impact for smaller events. Further influences were identified depending on the type of event. The highest food waste levels were found at event dinners (approx. 164 g/guest), followed by event lunches (approx. 141 g/guest), business events (approx. 125 g/guest), and graduation ceremonies (approx. 86 g/guest). Food waste increased with higher menu prices until reaching a certain price range. After exceeding a menu price higher than EUR 35 per guest, food waste slightly decreased again, which can be justified by the increased use of high-quality products. For instance, crustaceans such as lobsters are usually produced in smaller amounts due to their relatively high product price and are thus wasted less frequently.

5.2 Economic efficiency and pareto optimization

According to the model of Campoy-Muñoz et al. (2017), the generation of avoidable food waste in the German food service sector corresponds to significant economic losses of approximately 1.6 billion euros per year. To increase the ecologic and economic efficiency of food waste reduction measures, the literature recommends that gastronomic kitchens prioritize their prevention strategies (Goossens et al., 2019). Investments of time and money are required to achieve economic and environmental gains by reducing food waste. For businesses, it is therefore particularly important that the benefits from implementing measures to reduce food waste exceed the associated costs (Parry et al., 2015). Huppes and Ishikawa (2005) presented an analytical framework that introduced the principle of economic efficiency as an instrument to assess sustainability and to indicate an empirical relationship in economic activities between

environmental costs and environmental impact. For this purpose, combining life-cycle assessment (LCA) with life-cycle costing (LCC) delivers suitable information for businesses (Gabriel and Braune, 2005). This method is also used in environmental research on a macroeconomic level to assess the economic impact of food waste for entire countries.

Another approach is to prioritize reduction strategies based on the concept of multi-objective optimization. Cristóbal et al. (2018) presented this model and used the principle of Pareto optimization to identify prevention measures with the highest environmental impact. One important output of their model is a Pareto graph that combines different scenarios of reduction measures to maximize the environmental benefits according to individual budgets. Resultantly, some measures are considered "quick wins", which contribute to reduce high environmental impact at low cost. To achieve quick wins, the authors suggest the use of self-reporting methods and the implementation of food waste tracking systems, which is in line with the results of the present dissertation. In addition, a few other approaches to efficiently reduce food waste are proposed, such as consumer education campaigns, waste analytics, tray-less dining, spoilage prevention packaging, improved inventory, and cold chain management. Cristóbal et al. (2018) concluded that decision makers should prioritize strategies and reduction targets that primarily address the level of environmental impact instead of reductions in mass. However, the weakness of the presented multi-objective optimization is inherent in its theoretical nature, as it does not provide concrete guidance for implementing measures in practice, but instead emphasizes the environmental relevance in decision-making processes. Furthermore, the implementation of measures to reduce food waste is often in conflict with common kitchen practices. To meet customer expectations, professionals that work in restaurants often calculate rather large portion sizes to ensure that customers leave their table satisfied. Hennchen (2019) conducted 17 semi-structured interviews with restaurant owners, chefs, kitchen managers and representatives from the local authority, revealing that hungry customers were seen as the "worst case scenario", which seemed to be an important driver for practitioners to consciously plan oversized portions. With reference to these insights, it can be assumed that awareness raising actions should not only focus on the consumers, but should also involve the entire professional staff of a restaurant. However, the main tasks in daily kitchen operations are related to a workflow of planning, purchasing, storage, preparing, cooking, and serving food. For a business to be successful, it is fundamental that these processes are carried out as efficiently and profitably as possible. Environmental objectives can therefore be inferior to economic performance from a business perspective. Thus, it can be expected that the implementation of measures is both successful

and sustainable if the business is compensated for the additional time investment through monetary savings related to food waste reductions (HLPE, 2014). Parry et al. (2015) shed light on another aspect and noted that the size of the business plays an important role for the development of strategies. Hence, larger food businesses can undoubtedly make a significant impact, but small businesses need different types of support, which must be made accessible in a manner that is suitable for them. For instance, smaller businesses could use self-reporting methods to document their food waste, but are often limited by a lack of professionals that could perform the measurements and waste analytics.

Papargyropoulou et al. (2016) present a different and strongly practical oriented concept of economic efficiency that expresses the relationship between the economic value of food waste and its quantity. The authors calculated economic efficiency ratios by matching the product prices of selected food products to their amount of food waste. The method proposed by Papargyropoulou et al. (2016) could help businesses to evaluate processes in their food management and develop prioritized food waste reduction strategies. For illustration purposes, the data are plotted in a chart that shows the food costs on the ordinate and the food waste quantities on the abscissa. Figure 5-3 provides an example of an economic efficiency analysis based on data from a randomly selected event of this dissertation. The plot is divided into four quarters representing a defined priority according to the economic efficiencies. Food products with high product prices and high amounts of food waste have a low economic efficiency. Consequently, food products with low product prices and relatively small amounts of food waste have a high economic efficiency. For instance, products located in the top right quarter of the chart have the highest priority to be reduced because of their low economic efficiency (Figure 5-3). Hence, the wasted food products in the given example should be reduced in a hierarchical sequence, starting with meat and poultry and finger food (priority 1), followed by side dishes and vegetables (priority 2), fish and seafood, baked goods and desserts (priority 3), salads, hot dishes, and others (priority 4). The proposed example from Figure 5-3 led to a similar prioritization as the Pareto chart in Figure 4-5 (section 4.4.3). Thus, monetary losses could be halved by reducing only approximately one-third of the food waste quantities. It can be concluded that individual reduction strategies should first target the three to four products or product groups that are most commonly found in food waste, as these are also the products that cause the highest monetary losses in many cases.

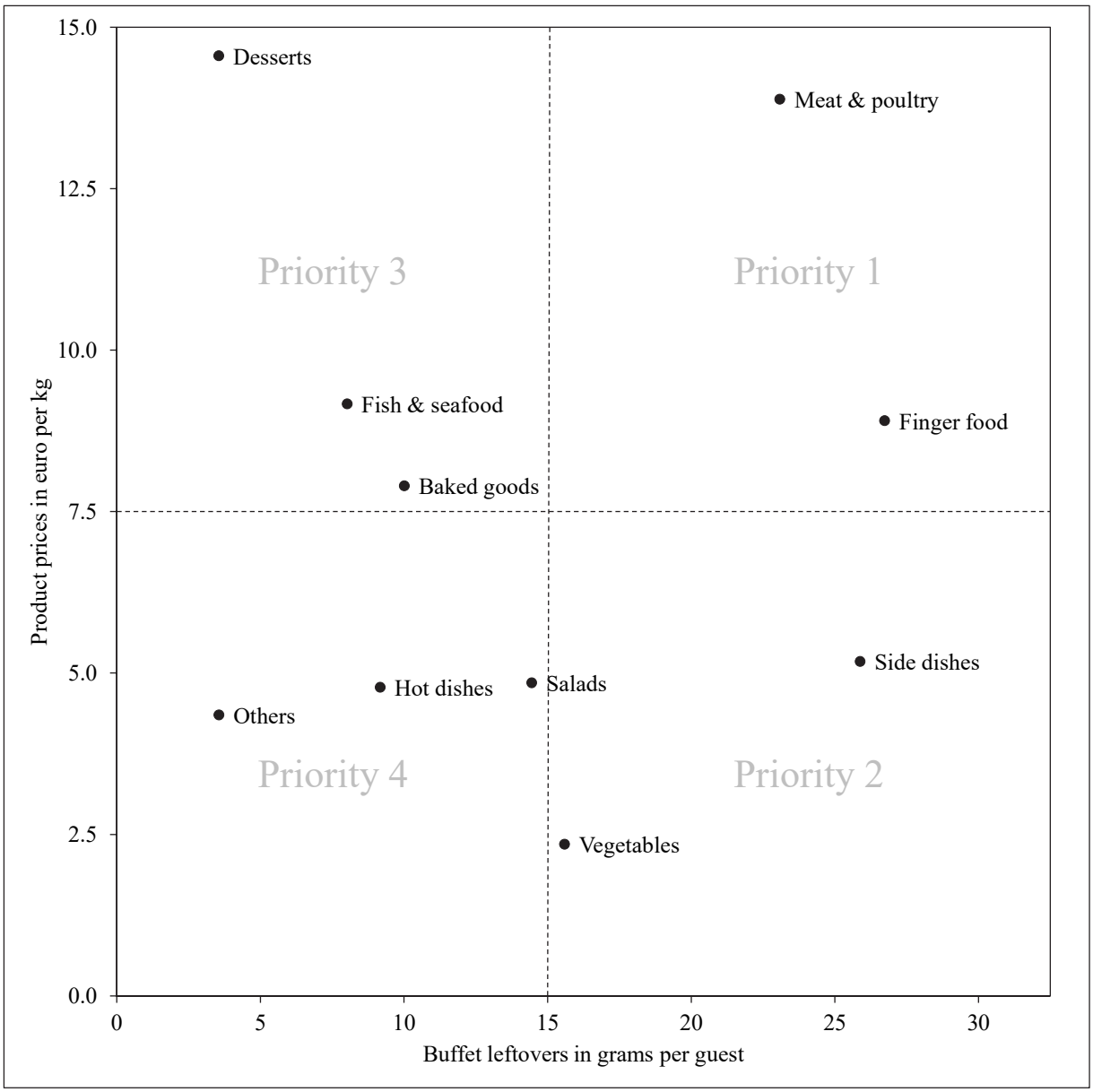

Figure 5-3 Economic-efficiency plot: product prices are presented in relation to their quantity of buffet leftovers to prioritize products according to their economic efficiency, based on the approach presented by Papargyropoulou et al. (2016).

To identify the reduction potentials with the lowest effort, it is necessary to record or weigh the food waste, which does not require any further prioritization using mathematical models to derive strategies. The weighing process can be carried out with manual tools or with the support of advanced technical devices such as semi-automated tools or food waste tracking systems. The technical solutions developed within the framework of this doctoral thesis, namely different applications of food waste tracking systems, are briefly described in the following sections.

5.3 Scale-up

5.3.1 Web application

The *RESOURCEMANAGER FOOD* has proven to be suitable for measuring and tracking food waste in different types of private and gastronomic kitchens. The collected data enabled the pilot kitchens to develop individual prevention strategies and measures that significantly reduced food waste. The associated monetary savings proved to be much higher for gastronomic kitchens than for private kitchens. Furthermore, the investments in food waste tracking systems can be compensated within a short time due to the related savings potential, which could serve as a financial incentive (Clowes et al., 2018a, 2018b, 2019). In terms of practical scale-up viability, a web application called *RESCUE MY FOOD* was developed and launched in February 2020. This web application requires neither a software installation nor additional hardware and can be used free of charge by a broad audience. Figure 5-4 provides screenshots of the web application's user interface. Users can perform trial measurements by clicking on the "trial" button on the landing page[10] (Figure 5-4, W-1). During the registration process, kitchen-specific data are requested that allow categorization according to the kitchen size indicated by daily guest numbers and the type of kitchen (private or commercial). Twelve product categories are predefined in the measurement interface (Figure 5-4, W-2). Hence, measurements are carried out according to a uniform procedure generating comparable information and benchmarks. To record a measurement, five specifications are reported: the product weight, product category, mealtime, point of origin, and reason for disposal. First, the user enters the weight of the food waste in kilograms and specifies the corresponding product category. Second, the mealtime is selected, whereby a dropdown list provides a choice between breakfast, lunch, dinner, catering, and others. Then the waste's origin is defined by distinguishing between buffet leftovers, plate leftovers, overproduction, preparation leftovers, storage losses, or others. Subsequently, the reasons for disposal are selected, whereby a distinction is made between damage and spoilage, improper planning, expiry of the best-before date, portion size, product quality, and others. The protocol function lists measuring points, including the product category, type of waste, reasons for disposal, and date and time of the recorded measurement (Figure 5-4, W-3). Furthermore, measurements and incorrect entries can

[10] https://www.rmfood.de

be corrected or deleted. The reported data are displayed within horizontal bar charts in mass, monetary values, or CO_2 equivalents (Figure 5-4, W-4).

Figure 5-4 Screenshots of the web application called RESCUE MY FOOD.

5.3.2 Smartphone application

The web application described in the previous section offers private and gastronomic kitchens a quick and straightforward method of documenting their food waste and comparing it with other consumers or kitchens. Users can easily become familiar with the measurement process and its documentation without any financial investment, receiving immediate feedback on the extent of their produced amounts of food waste. This is a first step towards spreading the self-reporting approach to a wider audience by giving consumers the opportunity to monitor and benchmark their food waste with a simple web application. The web application is currently being improved by developing a smartphone application, whose range of functions will include additional management options allowing businesses to configure the software for case-specific needs. For the weighing process, an electronic scale will be connected to the software via Bluetooth, enabling wireless data transmission (Figure 5-5). This type of combination between the electronic scale and the software enables quick and easy installation in the kitchen using

either a tablet or smartphone. The smartphone application is available for download as a beta version in the Google Play Store since September 2020. The collected measurement data is stored in the cloud and can be managed individually by each user in the administration interface. The management options will enable businesses such as hotel chains to operate the system in several kitchens and different locations at the same time and centrally manage and monitor the measured values via the cloud. The smartphone application will provide a broad range of options to document, report, and analyze data that are relevant for process optimization, including information such as the product weight, mealtime, point of origin, reason for disposal, product costs, monetary losses, climate impact (CO_2-equivalents), benchmarks, and progress reports. The technical progress and ongoing system development are important factors that represent a good basis for the subsequent scale-up.

The smartphone application's programming and software engineering is being developed within the framework of a research project called Efficient Lowering of Food Waste in the Out-of-home Sector (ELOFOS). The project has a three-year duration, ending in May 2021, and is funded by the German Federal Ministry of Agriculture and Food. In the ELOFOS project, the smartphone application will be tested and customized for different types of food services such as hotel kitchens or hospital catering and health care facilities.

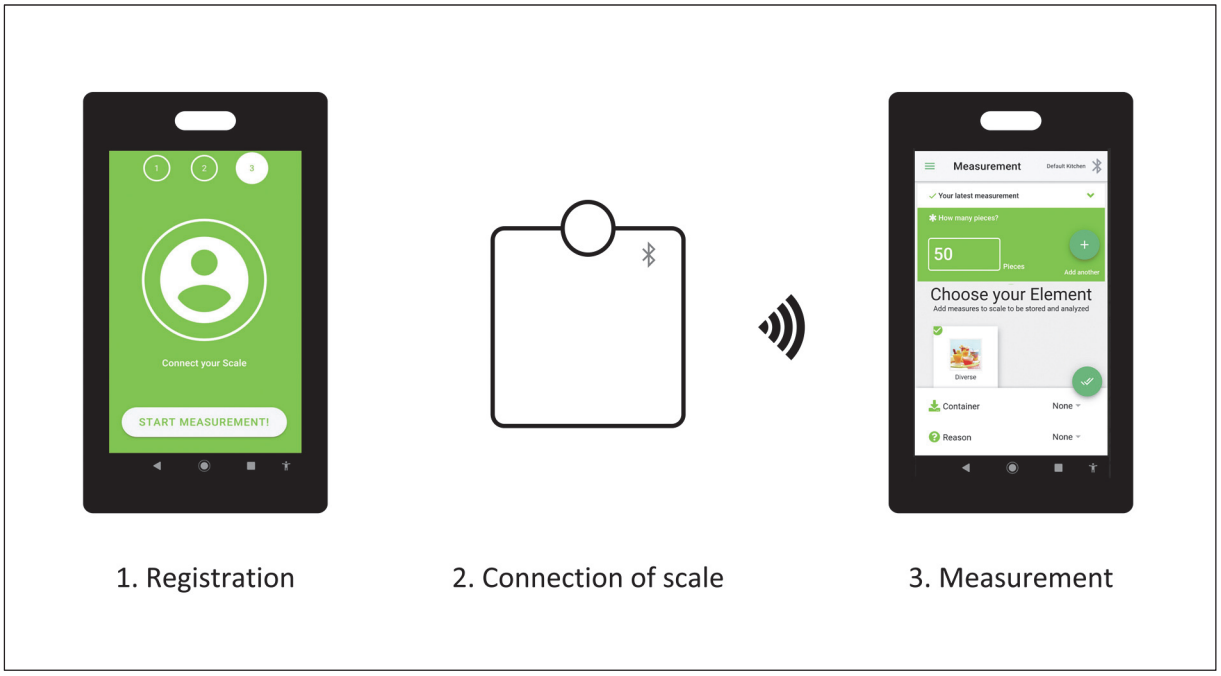

Figure 5-5 RESOURCEMANAGER FOOD (beta version): Smartphone application connected to an electronic scale via Bluetooth.

5.4 Dissemination and possible implementations

Given that the European legislative framework obliges member states to monitor and reduce food waste, it is important to find possibilities and technical solutions that contribute to halving consumer level food waste by 2030. The dissemination of the findings that emerged from this dissertation and the technical solutions developed will enable households and gastronomic kitchens to measure and reduce their food waste. As already described in the introduction, the Federal Ministry of Food and Agriculture in Germany has developed a national strategy for preventing food waste that is intended to be a central element for achieving prevention targets at the national level. One part of this strategy is establishing a dialogue forum for the food service and catering sector to initiate a sectorial commitment to formulate specific targets to reduce food waste and define measures that are evaluated at regular intervals in terms of their effectiveness. The dialogue forum for the food service sector has been functioning as a communication and dissemination platform since February 2019 and is coordinated by the World Wide Fund for Nature (WWF) Germany (BMEL, 2019). Approximately 60 representatives from food services, politics, research, civil society, and education will meet twice a year, discuss progress, and present best practices. To accompany this progress, WWF Germany has produced information materials that present best practices in order to create incentives and motivate companies to develop reduction strategies (Dräger de Teran et al., 2019; Weber et al., 2019). Table 5-2 provides an overview of some instruments and tracking devices that can be used to monitor food waste in gastronomic kitchens. Accordingly, technical equipment that supports the measurement of food waste is commercially provided by companies from different countries such as *eSmiley, Kitro, Leanpath*, *Matomatic*, *United Against Waste*, and *Winnow Solutions* (KITRO, 2019; Leanpath, 2019; Winnow Solutions Limited, 2019; eSmiley, 2020; Matomatic, 2020; United Against Waste, 2020). Tracking systems like the *RESOURCEMANAGER FOOD, RESCUE MY FOOD* or the *Küchenmonitor* are free of charge and predominantly used to collect data for scientific purposes within the framework of research and scientific activities (Küchenmonitor, 2020). However, the food waste tracking systems are very similar regarding their functions and operation modes, while some of them have optional or enhanced features, such as visual photo capture and artificial intelligence technology (see Table 5-2). Food management systems such as *Delicious Data* and *Mitakus* also provide forecasting models to better plan and calculate food demand. These software programs produce sales forecasts for menu and meal planning based on historical data (Delicious Data GmbH, 2019; Mitakus, 2019).

Table 5-2 Food waste tracking systems: advantages and disadvantages of different applications.

Tracking systems	Applications	Advantages	Disadvantages
Delicious Data (forecasting software)	Food services (Germany)	+ Sales forecasting (food demand) + Improved menu planning + Artificial intelligence technology	- Algorithms need to be trained - Data mining methods require comprehensive historical data
eSmiley (scale & software)	Food services (Europe)	+ Tailored measurement design + Individual reports & measures + Improved food management	- Semi-automated tool - Data quality depends on user
Kitro (scale, camera & software)	Food services (Switzerland)	+ Fully automated device + Individual reports & measures + Visual photo capture + Artificial intelligence technology	- Algorithms need to be trained frequently with data from individual measurements
Küchenmonitor (web application)	School canteens (Germany)	+ Free of charge + Individual reports & measures + Tailored tool for school canteens	- Manual data entry - Data quality depends on user
Leanpath (scale, camera & software)	Food services (worldwide)	+ Fully automated device + Visual photo capture + Online portal for users + Individual reports & measures + Artificial intelligence technology	- Algorithms need to be trained frequently with data from individual measurements
Matomatic (scale & software)	Food services (Sweden)	+ Tailored measurement design + Individual reports & measures + Better food management	- Semi-automated tool - Data quality depends on user
Mitakus (forecasting software)	Food services (Germany)	+ Sales forecasting (food demand) + Improved menu planning + Artificial intelligence technology	- Algorithms need to be trained - Data mining methods require comprehensive historical data
RESCUE MY FOOD (web application)	Research, households & food services (Germany)	+ Free of charge + Suitable for private and gastronomic kitchens + Free trials without registration	- Manual data entry - Data quality depends on user
RESOURCEMANAGER FOOD (scale & smartphone-application)	Research & food services (Germany)	+ Free of charge + Worldwide deployable through download in AppStore + Individual reports & benchmarks	- Semi-automated system - Data quality depends on user
Waste Analytical Tool (scale & web application)	Food services (Germany)	+ Online portal for users + Case studies online available + Individual reports & measures	- Semi-automated system - Data quality depends on user
Winnow Waste Monitor (scale, camera & software)	Food services (worldwide)	+ Fully automated device + Individual reports & measures + Case studies online available + Artificial intelligence technology	- Algorithms need to be trained frequently with data from individual measurements

In addition to these instruments and initiatives, dissemination and knowledge transfer also takes place in the field of education. In 2016, Bavaria launched an alliance called "We Save Food", in which alliance partners from agriculture, processing, retail, food service, and consumer organizations develop prevention strategies (StMELF, 2016). This alliance initiated several measures to prevent food waste. One is called "food saver coaching" that educates kitchen employees and managers in the food service sector by providing knowledge and methods to reduce food waste. The coaching approach includes several knowledge transfer ideas and is disseminated through professional training courses, seminars, and conferences that are organized by public institutions throughout Bavaria. The Bavarian Competence Center for Nutrition (KErn) organizes the dissemination of knowledge and prepares information that is disseminated by 47 Bavarian offices for nutrition, agriculture, and forestry as well as eight centers for nutrition and catering services throughout Bavarian administrative districts (KErn 2020). These structures were established throughout the entire state of Bavaria in order to enable widespread education and professional training for businesses in the food service sector. Food waste tracking systems are an integral part of these coaching concepts, in particular *RESOURCEMANAGER FOOD* and the *RESCUE MY FOOD* web application. The latter was funded by the Bavarian State Ministry for Nutrition, Agriculture and Forestry (StMELF) to provide a free-of-charge tool to support food services and households in Bavaria to conduct measurements (StMELF, 2016).

In addition to the political support, the measurement of food waste in gastronomic kitchens is driven by opportunities to reduce its amount and to achieve monetary savings. The results of this research showed that households could save considerably less money than gastronomic kitchens by reducing their amount of food waste. Hence, the measurement effort is significantly higher in private kitchens than in gastronomic kitchens. Consequently, the question raises whether it is possible to motivate households to measure their food waste or if other methods and measures are needed to provide incentives for consumers to change their behavior. This question is discussed briefly in the following chapter.

5.5 Triggering behavioral changes in households

The conducted self-reporting interventions in households were suitable to motivate individuals to reflect on their disposal behavior and to reduce their food waste. These observations are in line with investigations in the literature that examined environmental behavior based on self-reported data (Falcon et al., 2008; Reid et al., 2009; Lanzini and Thøgersen, 2014). The main

shortcomings of this dissertation are related to limitations that are inherent in participatory studies (Quested and Johnson, 2009; Hübsch and Adlwarth, 2017; Delley and Brunner, 2018). However, it is important to better understand the self-perception of individuals, which can be achieved, for example, through representative consumer surveys, such as those recently conducted by the Society for Social Research and Statistical Analysis (Forsa) in Germany. Forsa interviewed 1230 randomly selected individuals who were older than 14 years. In this consumer survey, 7% of the respondents stated that they threw away food several times a week. Every fifth person threw away food once a week (19%), several times a month (19%), or once a month (18%). Younger respondents threw away food significantly more often than older respondents. Nine out of ten individuals (91%) said that they had recently received information about this topic in the media. Among the respondents who had recently heard something about food waste in Germany through the media, 18% stated that they threw away significantly less food since learning about this topic (Forsa, 2019). However, the perception of individuals to dispose of less is probably biased, because current estimations show that the amount of food waste in German households has not decreased since 2012 (Schmidt et al., 2019). Furthermore, awareness-raising information disseminated in the form of leaflets does not directly affect the disposal behavior of consumers (Smith et al., 2014; Shaw et al., 2018). Awareness-raising campaigns often fail to consider individual characteristics of their targeted audience when designing informative materials or interventions (Schmidt, 2016). As a consequence, recipients may feel overwhelmed or less motivated to manage such information, especially if most of it is not relevant to them. Schmidt (2016) therefore recommended that initiatives should personalize their information, for example, by disseminating information through channels such as social media or e-newsletters targeting specific groups. Although social media interventions can significantly reduce food waste, they cannot replicate the effect of face-to-face interventions (Young et al., 2017). To benefit from the positive outcomes of self-reporting interventions, community-based approaches seem to be powerful instruments for raising awareness and triggering behavioral changes in consumer behavior. Personal gatherings enable individuals to share their experiences and mutually learn from each other how to prevent food waste (Falcon et al., 2008). Implementing community-based approaches could be supported by organizations with direct access to private households, including public institutions such as schools and administrations, non-governmental organizations, or charities. Waste management companies that collect and treat municipal waste have direct access to households and could provide awareness-raising information using community-based approaches as well.

5.6 Relationship to Sustainable Development Goal 12.3

Verma et al. (2020) stated that consumers discard far more food than widely believed, since some of the most cited scientific publications significantly underestimate the amount of food waste at consumer level. Flanagan et al. (2019) further highlighted that more governments and businesses urgently need to set reduction targets aligned with the Sustainable Development Goals to measure food waste and, in particular, to act boldly to reduce it. On a political level, food waste reduction initiatives from the UK can serve as a role model. The UK succeeded in reducing the amount of household food waste by approximately 1.44 million tons in 2018 compared to 2007. Accordingly, food waste from private households decreased from 132 kg per capita and year to approximately 100 kg per capita and year (Parry et al., 2020). The starting point for this positive development was set in 2000, when the Waste and Resources Action Program (WRAP) was established to support sustainable waste management and increase recycling in the UK. To follow up their recycling initiatives and to promote food waste issues to the general public, WRAP launched a campaign called Love Food Hate Waste in 2007. The objective was to encourage consumers to reduce food waste through awareness-raising information (Falcon et al., 2008). The campaign was one of the first of its kind worldwide and raised awareness not only among the general public, but also among stakeholders from industry, politics, and science. In the following years, numerous initiatives to reduce food waste in all parts of the food supply chain were implemented throughout the UK and several other countries. Based on these developments, the UK has assumed a pioneering role in avoiding food waste, and other countries benefitted from their experience. The Courtauld Commitments, a series of voluntary agreements, seemed to be powerful vehicles for change and improvements in the food supply chain. The first Courtauld Commitment was launched in 2005 for a four-year period, addressing solutions and technologies that contribute to reducing food waste and primary packaging waste (WRAP, 2020b). Supported by the Love Food Hate Waste campaign, local authorities and charity partners, approximately 670 thousand tons of food waste and 520 thousand tons of packaging waste were reduced in the UK over this period. Targets for 2025 are a further 20% reduction in food and beverage waste and also a 20% reduction in greenhouse gas emissions associated with the production and consumption of food and beverages (WRAP, 2020a). No other country can present a similarly positive trend in reducing food waste. Nevertheless, WRAP claims that even more measures are needed to ensure that most people and organizations get involved and make the necessary changes to achieve political targets.

In contrast to the UK, Germany has not achieved any statistically relevant reduction in food waste to date. In 2012, household food waste in Germany amounted to approximately 82 kg per capita and has remained at the same level until 2019 (Leverenz et al., 2019). It has to be noted, however, that British households still discard significantly more food waste than German consumers, although they have reduced their amount by approximately 24% since 2007. Considering these facts, the question arises whether awareness-raising campaigns and initiatives in Germany would have a similarly positive effect as the ones in the UK. Reducing food waste in German households could therefore be more difficult, because the quantities are already at a comparatively low level. The potential impact of consumer-related measures in Germany therefore still needs to be investigated, particularly regarding the feasibility of achieving the political targets.

5.7 Conclusion

The overall findings of this research provided insights about the effects of self-reporting interventions, revealing clear improvements in the participants' behavior regarding their food and kitchen management. There was a significant impact on self-awareness that resulted in the autonomous implementation of prevention measures in households and hotel kitchens. The participants reduced their food waste by more than 50%, exceeding SDG 12.3 aimed at halving food waste at consumer level. The observations during the experiments in gastronomic kitchens indicated that behavioral changes in the context of self-reporting interventions are particularly effective if their implementation is related to small efforts such as reducing the size of serving dishes to present food in smaller units or to refill buffets with demand-oriented quantities. The number of guests, for example, had no influence on the amount of breakfast buffet leftovers, but showed a clear correlation with the generation of buffet leftovers at events. The savings potential is therefore particularly dependent on the size of an event. Hence, strategies to reduce food waste at events should be aimed at improving administrative processes prior to operational routines. For instance, accurate information on the number of guests in advance of an event would help to improve the forecasting of food demand and the number of meals that need to be prepared. However, the results of the study demonstrated that there are considerable savings potentials in different food services that can be exploited. If future research successfully uses information from food waste measurements to improve administrative processes such as menu planning, then it is not only expected that food waste can be reduced effectively, but also that an even higher number of scalable reduction measures can be elaborated.

5.8 Outlook

To conduct experiments and to facilitate the self-reporting process within this doctoral thesis, a food waste tracking system was developed, which functions as an automated tool for the quantification, monitoring and reduction of food waste. For the scale-up of the food waste tracking system, however, several tasks for future applications arise. To reduce food waste in households and hotels, the challenge is to adapt and transfer the findings from the model into practice. Catering services are faced with the complexity of menu planning and the difficulty of accurately forecasting food demand. Future research is required that contributes to develop methods and scalable applications in order to provide adaptable solutions for a wider audience. As part of ongoing research, the software of the developed food waste tracking system will be transferred to a cloud and be available as an application for smartphone and tablet devices. In 2021, intensive practical tests will be carried out and system improvements will be implemented based on user feedback. The developed tools can be used by households and facilities of the food service sector, supporting individuals and businesses to reduce their food waste and to achieve monetary savings. For practical implementations in a larger scale, a conceptual framework needs to be elaborated which helps to reach and motivate a higher number of private and gastronomic kitchens to measure their food waste and develop prevention strategies.

Moreover, the food supply and the consumption of food are facing new challenges due to the global pandemic situation in 2020. For instance, established processes and procedures need to be adopted to the requirements of stricter hygiene concepts. Accordingly, the transferability of already implemented measures and achieved food waste reductions need to be investigated in the light of new hygiene concepts and changed consumer habits. In view of ongoing dynamic changes in catering systems, research is facing several challenges and tasks that must be addressed in future studies. Further research, for example, is needed to quantify and evaluate the effects of the global pandemic on food waste across the entire food supply chain.

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