Beyond the Blemishes

Causes and Governance of Food Loss in Upstream Fruit and Vegetable Supply Chains

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Submitted by

Ronja Herzberg

born on the 22nd March 1993 in Blender, Germany

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1st Referee:	Prof. Dr. Martin Banse, Thünen Institute of Market Analysis, Braunschweig
2nd Referee:	Prof. Dr. Stephan von Cramon-Taubadel, Department of Agricultural Economics and Rural Development, Georg-August-Universität Göttingen
3rd Referee:	Prof. Dr. Christoph Dittrich, Institute of Geography, Department of Human Geography, Georg-August-Universität Göttingen

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List of abbreviations

AgrarOLkG	Agrarorganisationen-und-Lieferketten-Gesetz (Agricultural Organisations and Supply Chains Act, Germany)
ANOVA	analysis of variance
BLE	Bundesanstalt für Landwirtschaft und Ernährung (Federal Office for Agriculture and Food, Germany)
BMEL	Bundesministerium für Ernährung und Landwirtschaft (Federal Ministry of Food and Agriculture, Germany)
CAP	Common Agricultural Policy of the European Union
CO_2eq	carbon dioxide equivalent
EU	European Union
FLW	food loss and waste
FAO	Food and Agriculture Organization of the United Nations
FAOSTAT	Food and Agriculture Organization Statistics
FUSIONS	Food Use for Social Innovation by Optimising Waste Prevention Strategies
GHG	greenhouse gas
GLM	generalised linear model
GPN	global production networks
IO	Industrial Organisation
JRC	Joint Research Centre of the European Commission
NGO	non-governmental organisation
PAYT	pay-as-you-throw
PO	producer organisation
RO	research objective
SDG	Sustainable Development Goal
TNC	transnational corporation
UK	United Kingdom
UN	United Nations
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme
US	United States (of America)
UTP	Unfair Trading Practice
SIK	Swedish Institute for Food and Biotechnology
SRS	simple random sample
WWF	World Wide Fund For Nature

Summary

A significant amount of food produced worldwide is lost and wasted along the supply chain. The Food and Agriculture Organization of the United Nations (FAO) estimates that approximately 13 % of food is lost between harvest and retail, while the United Nations Environment Programme (UNEP) states that an additional 17 % is wasted between retail and consumption. In Germany alone, food loss and waste along the value chain amounts to 12 million tonnes per year. Among the food groups, fruit and vegetables suffer the highest levels of loss and waste due to their perishable nature. Particularly, in the primary production of fruit and vegetables, loss is estimated to be many times higher than for other agricultural product groups, although data in this area are particularly limited and controversial.

The existence of high levels of food loss and waste seems paradoxical when one tenth of the world's population suffers from hunger and one third does not have regular access to adequate food. In addition, the environmental challenges associated with food loss and waste make it an urgent problem to address. The production and subsequent wastage of food contributes to climate change, the use and degradation of resources such as water and soil and the eutrophication and acidification of water bodies that could have been avoided. It is estimated that 8 % of global greenhouse gas emissions are caused by food loss and waste.

The causes of food loss and waste encompass various factors, including pests, diseases, weather conditions, market dynamics as well as policy and business frameworks. Particularly, the interactions and power relations among actors in the upstream fruit and vegetable supply chains within increasingly concentrated agricultural markets are suspected to play a significant role. The establishment of private quality standards has recently been identified as a driver of food loss in upstream supply chains, as it leads to the exclusion of theoretically edible but - according to the specific standards - suboptimal fruit and vegetables from the market.

The **overall aim** of this thesis is to examine drivers and courses of action concerning food loss in the pre-retail fruit and vegetable supply chains in European countries. This dissertation aims to unravel the interactions and power relations between value chain actors and the impact of private product requirements as drivers of food loss in these supply chains. Furthermore, it seeks to identify potential actions that can be undertaken by the private sector and policymakers to reduce food loss in these supply chains. This research is unique in that it addresses the interplay of power relations and causes of food loss in agri-food supply chains and seeks to understand them through the use of a wide range of methodological techniques and interdisciplinary perspectives.

This cumulative thesis consists of three scientific articles. The first article identifies inter-stage drivers of food loss in fruit and vegetable supply chains in Germany. It analyses these drivers in the context of power relations between supply chain actors at the interface between primary production and food retailing. The second article examines how specific standards and practices of a large German food retailer influence food loss in the upstream supply chains of selected

fruit and vegetable crops, based on a case study. The third article presents the perspectives and demands of supply chain actors regarding policy and private sector actions to reduce food loss.

The analyses are based on a series of expert interviews conducted with different actors in German fruit and vegetable supply chains, ranging from farmers to producer organisations and other intermediaries to retailers. An online survey of suppliers of the aforementioned retailer in Germany, Italy and Spain forms the second methodological component.

The results demonstrate that retailers possess the ability to govern the supply chain and to transfer the responsibility for and the risk to incur food loss onto upstream suppliers and farmers. This exercise of power is evident in the relationship between retailers and upstream actors, manifested through unreliable contractual clauses and agreements, commercial practices, ordering procedures, modes of communication and product requirements.

The private product requirements established by food retailers are shown to be one such aspect in which power relations become apparent and lead to food loss among suppliers. The case study reveals that, on average, 15 % of the total harvestable production in the field fails to meet the retailer's product specifications. Approximately 6 % of the total production is lost as food due to these requirements. This proportion is used as animal feed and non-food, disposed of as waste or not harvested at all, while the rest is still marketed elsewhere. The main product requirements responsible for food loss are identified as calibre (mass and size) specifications and maximum pesticide residue limits set by retailers. Business practices, such as poorly coordinated promotions, complaints, short-term changes to quantity requirements and inadequate quantity planning and ordering procedures, interact with these product requirements leading to food loss.

To counteract the drivers of food loss in upstream fruit and vegetable supply chains, policy instruments and private sector actions are identified. These efforts should aim to educate consumers, enhance the reliability of quantity and order planning, foster cooperation along the supply chain, facilitate the inclusion of suboptimal and surplus products within the supply chain and strengthen the bargaining position of farmers and suppliers, for example by promoting alternative marketing and processing options.

In summary, the thesis highlights that the structure of business relationships among actors in fruit and vegetable supply chains significantly influences the occurrence of food loss in upstream stages of the supply chain. These relationships between actors in the supply chain are also shaped by power dynamics, which are evident through subtle mechanisms that have the potential to cause food loss. Addressing these inter-stage drivers requires interventions that extend beyond individual stages. The design of such interventions also needs to consider how to incentivise retailers, among other actors, to address food loss resulting from their actions at other stages. The current policy focus in some European countries on voluntary action by supply chain actors may in this regard not be sufficient. Designing effective policies also necessitates considering other concerns within and outside the food system, balancing potentially conflicting objectives and accounting for the rebound-effects of potential policies. Notably, the

indirect effect of many aspects of upstream supply chains on food loss, such as the issue of Unfair Trading Practices (UTP), business conduct, diverse marketing channels and consumer behaviour, underscore the need for a holistic understanding of food loss and waste generation to achieve a more sustainable food system. Some of the findings on drivers of food loss may be applicable to other agricultural products and regions. However, specific and evolving frameworks can easily give rise to the emergence of divergent practices and thus other mechanisms that contribute to food loss in agricultural supply chains.

Further research is required to validate and generalise the findings on drivers and governance of food loss presented in this dissertation. This research should aim to build upon more reliable data on food loss and waste. This in turn requires direct measurement and regular monitoring of food loss in upstream agricultural supply chains, including the pre-harvest level. Future studies should also explore the mechanisms and drivers that span multiple stages of the supply chain as well as the role of power constellations in other product groups, supply chains and regions. Furthermore, the suggested policy and private sector options for action proposed in this dissertation should be quantitatively evaluated in terms of their effectiveness and efficiency.

Zusammenfassung

Ein erheblicher Anteil der weltweit produzierten Lebensmittel wird entlang der Lieferkette zu Lebensmittelabfall. Die Welternährungsorganisation der Vereinten Nationen (FAO) schätzt, dass 13 % der Lebensmittel zwischen Ernte und Einzelhandel verloren gehen, während das Umweltprogramm der Vereinten Nationen (UNEP) angibt, dass weitere 17 % zwischen Einzelhandel und Konsum zu Abfall werden. Allein in Deutschland belaufen sich die Lebensmittelabfälle entlang der Wertschöpfungskette auf 12 Millionen Tonnen pro Jahr. Obst und Gemüse gehören aufgrund ihrer Verderblichkeit zu den Lebensmittelgruppen mit den höchsten Abfallmengen. Insbesondere in der Primärproduktion von Obst und Gemüse sind die Verlustmengen schätzungsweise um ein Vielfaches höher als bei anderen landwirtschaftlichen Produktgruppen, obwohl die Datenlage in diesem Bereich besonders begrenzt und umstritten ist.

Das hohe Ausmaß der Lebensmittelabfälle erscheint paradox, wenn man bedenkt, dass ein Zehntel der Weltbevölkerung an Hunger leidet und ein Drittel keinen regelmäßigen Zugang zu angemessenen Lebensmitteln hat. Darüber hinaus stellen die mit Lebensmittelabfällen verbundenen Umweltprobleme ein drängendes Problem dar, welches es zu lösen gilt. Die Produktion und anschließende Verschwendung von Lebensmitteln trägt zum Klimawandel sowie zu einer Nutzung und Degradation von Ressourcen, wie Wasser und Boden, und zur Eutrophierung und Versauerung von Gewässern bei, die hätte vermieden werden können. Schätzungen zufolge sind 8 % der weltweiten Treibhausgasemissionen auf Lebensmittelabfälle zurückzuführen.

Die Ursachen für Lebensmittelabfälle umfassen verschiedene Faktoren, darunter Schädlingsbefall und Pflanzenkrankheiten, Wetterverhältnisse, Marktdynamiken sowie politische und wirtschaftliche Rahmenbedingungen. Insbesondere die Interaktionen und die Machtbeziehungen zwischen den Akteuren in den vorgelagerten Obst- und Gemüselieferketten innerhalb zunehmend konzentrierter Agrarmärkte spielen vermutlich eine wichtige Rolle. Die Festlegung privater Qualitätsnormen wurde mittlerweile als eine Ursache für Lebensmittelverluste in den vorgelagerten Lieferketten identifiziert, da sie dazu führt, dass theoretisch genießbares, aber - entsprechend spezifischer Standards - suboptimales Obst und Gemüse vom Markt ausgeschlossen wird.

Das **übergeordnete Ziel** dieser Arbeit ist es, die Treiber und Handlungsoptionen im Zusammenhang mit Lebensmittelverlusten in Obst- und Gemüselieferketten vor dem Einzelhandel in europäischen Ländern zu untersuchen. Die Dissertation zielt darauf ab, die Interaktionen und Machtverhältnisse zwischen den Akteuren der Wertschöpfungskette und die Auswirkungen privater Produktanforderungen als Treiber von Lebensmittelverlusten in diesen Lieferketten zu analysieren. Darüber hinaus sollen potenzielle Maßnahmen identifiziert werden, die von der Privatwirtschaft und politischen Entscheidungsträger*innen ergriffen werden können, um Lebensmittelverluste in diesen Lieferketten zu reduzieren. Diese Forschungsarbeit ist insofern einzigartig, als dass sie das Zusammenspiel von

Machtbeziehungen und Ursachen für Lebensmittelverluste in Agrar- und Lebensmittellieferketten adressiert und durch den Einsatz einer breiten Palette von methodischen Techniken und interdisziplinären Perspektiven zu verstehen sucht.

Diese kumulative Arbeit besteht aus drei wissenschaftlichen Artikeln. Der erste Artikel identifiziert die stufenübergreifenden Treiber von Lebensmittelverlusten in den Lieferketten von Obst und Gemüse in Deutschland. Er analysiert diese Treiber im Kontext der Machtverhältnisse zwischen den Akteuren der Lieferkette an der Schnittstelle zwischen Primärproduktion und Lebensmitteleinzelhandel. Der zweite Artikel untersucht anhand einer Fallstudie, wie die spezifischen Standards und Praktiken eines großen deutschen Lebensmitteleinzelhändlers Lebensmittelverluste in den vorgelagerten Lieferketten ausgewählter Obst- und Gemüsekulturen beeinflussen. Der dritte Artikel stellt die Perspektiven und Bedarfe der Akteure der Lieferkette in Bezug auf politische und privatwirtschaftliche Maßnahmen zur Reduzierung von Lebensmittelverlusten dar.

Die Analysen basieren auf einer Reihe von Expert*inneninterviews mit verschiedenen Akteuren der Obst- und Gemüselieferketten in Deutschland, von der Landwirtschaft über Erzeugerorganisationen und andere Zwischenhändler bis hin zum Einzelhandel. Eine Online-Befragung von liefernden Unternehmen des oben genannten Einzelhandelsunternehmens in Deutschland, Italien und Spanien bildet die zweite methodische Komponente.

Die Ergebnisse zeigen, dass Einzelhandelsunternehmen in der Lage sind, die Lieferkette zu steuern und die Verantwortung und das Risiko für Lebensmittelverluste auf vorgelagerte Lieferanten und landwirtschaftliche Betriebe zu übertragen. Die Machtausübung manifestiert sich in der Beziehung zwischen Einzelhandelsunternehmen und vorgelagerten Akteuren in Form eines geringen Maßes an Verlässlichkeit bei Vertragsklauseln und Absprachen sowie in Geschäftspraktiken, Bestellverfahren, Kommunikationsmodi und Produktanforderungen.

Die von Lebensmitteleinzelhandelsunternehmen festgelegten privaten Produktanforderungen erweisen sich als ein wichtiger Aspekt, in dem die Machtverhältnisse deutlich werden und zu Lebensmittelverlusten für die Lieferanten führen. Die Fallstudie zeigt, dass im Durchschnitt 15 % der gesamten erntefähigen Produktion auf dem Feld nicht den Produktspezifikationen des Einzelhändlers entsprechen. Ungefähr 6 % der Gesamtproduktion gehen aufgrund dieser Anforderungen als Lebensmittel verloren. Dieser Anteil wird als Futtermittel und Non-Food verwendet, als Abfall entsorgt oder gar nicht erst geerntet, während der Rest noch anderweitig vermarktet wird. Die relevantesten Produktanforderungen, welche für Lebensmittelverluste verantwortlich sind, sind Spezifikationen des Kalibers (Masse und Größe) sowie Pflanzenschutzmittelrückstandshöchstgehalte. Geschäftspraktiken, wie schlecht koordinierte Werbeaktionen, Reklamationen, kurzfristige Änderungen des Mengenbedarfs und unzureichende Mengenplanungs- und Bestellverfahren, wirken zudem mit diesen Produktanforderungen zusammen und verursachen Lebensmittelverluste.

Um den Ursachen für Lebensmittelverluste in vorgelagerten Obst- und Gemüselieferketten entgegenzuwirken, werden politische Instrumente und Maßnahmen des Privatsektors

herausgearbeitet. Solche Anstrengungen sollten darauf abzielen, Konsument*innen aufzuklären, die Zuverlässigkeit der Mengen- und Bestellplanung zu verbessern, die Zusammenarbeit entlang der Lieferkette zu fördern, den Verbleib von suboptimalen und überschüssigen Produkten innerhalb der Lieferkette zu ermöglichen und die Verhandlungsposition von Landwirt*innen und Lieferanten zu stärken, zum Beispiel durch die Förderung alternativer Vermarktungs- und Verarbeitungsmöglichkeiten.

Insgesamt zeigt die Arbeit, dass die Struktur der Geschäftsbeziehungen zwischen den Akteuren der Obst- und Gemüselieferkette einen erheblichen Einfluss auf Lebensmittelverluste in frühen Stufen der Lieferkette hat. Die Beziehungen zwischen den Akteuren der Lieferkette sind zudem durch Machtbeziehungen geprägt, die in subtilen Mechanismen sichtbar werden und Lebensmittelverluste verursachen. Um diese stufenübergreifenden Faktoren anzugehen, sind Maßnahmen erforderlich, die über die einzelnen Stufen hinausgehen. Bei der Konzeption solcher Maßnahmen muss auch berücksichtigt werden, wie Anreize für Einzelhändler und andere Akteure geschaffen werden können, damit sie sich mit den Lebensmittelverlusten befassen, die durch ihr Handeln auf anderen Stufen entstehen. Der derzeitige Fokus der Politik einiger europäischen Staaten auf freiwillige Maßnahmen der Akteure der Lieferkette ist in dieser Hinsicht möglicherweise nicht ausreichend. Die Gestaltung wirksamer politischer Maßnahmen erfordert weiterhin auch die Berücksichtigung anderer Belange innerhalb und außerhalb des Lebensmittelsystems sowie ein Abwägen potentiell widersprüchlicher Ziele und die Berücksichtigung der Rebound-Effekte potentieller Maßnahmen. Insbesondere die indirekten Auswirkungen vieler Aspekte vorgelagerter Lieferketten auf den Verlust von Lebensmitteln, wie z. B. Unlautere Handelspraktiken (UTP), Geschäftsgebaren, verschiedene Vermarktungswege und Verbraucherverhalten, unterstreichen die Notwendigkeit eines ganzheitlichen Verständnisses von Lebensmittelabfällen, um ein nachhaltigeres Ernährungssystem zu erreichen. Einige der gewonnenen Erkenntnisse über die Ursachen von Lebensmittelverlusten lassen sich möglicherweise auf andere landwirtschaftliche Erzeugnisse und Regionen übertragen. Spezifische und sich ändernde Rahmenbedingungen können jedoch leicht zum Auftreten abweichender Praktiken und damit auch zu anderen Mechanismen für die Entstehung von Lebensmittelverlusten in landwirtschaftlichen Lieferketten führen.

Weitere Forschung ist erforderlich, um die in dieser Dissertation dargelegten Erkenntnisse zu Treibern und zur Reglementierung von Lebensmittelverlusten zu validieren und zu übertragen. Diese sollte darauf abzielen, auf zuverlässigeren Daten zu Lebensmittelabfällen aufzubauen. Dies wiederum erfordert direkte Messungen und ein regelmäßiges Monitoring der Lebensmittelverluste in den vorgelagerten landwirtschaftlichen Lieferketten, auch auf Ebenen vor der Ernte. Darüber hinaus sollten künftige Forschungsarbeiten Mechanismen und Treiber analysieren, die sich über mehrere Stufen der Lieferkette erstrecken sowie die Rolle von Machtkonstellationen in anderen Produktgruppen, Versorgungsketten und Regionen untersuchen. Die in dieser Arbeit vorgeschlagenen politischen und privatwirtschaftlichen Handlungsoptionen sollten zudem quantitativ auf ihre Effektivität und Effizienz hin überprüft werden.

1 Introduction

Food loss and waste (FLW) pose a significant environmental challenge across the entire food system. In 2020, 13 % was estimated to be lost between harvest and retail globally (UN, 2022). Between retail and consumption, a further 17 % of food available at these stages of the supply chain is wasted (UNEP, 2021). For Germany, the annual volume of FLW along the value chain is estimated at 12 million tonnes (Schmidt et al., 2019).

Looking at the different stages of the food supply chain, the highest FLW in high-income countries occurs at the stage of consumption. It is 58 % in North America and Oceania and 42 % in Europe, while only 5 % is wasted at the consumption stage in sub-Saharan Africa (Flanagan et al., 2019b). In the Global South, FLW is highest during handling and storage, with 36 % of total FLW at this stage in sub-Saharan Africa and 32 % in South and Southeast Asia. In primary production, there is little difference in relative FLW between Europe at 33 % and sub-Saharan Africa at 36 % (ibid). However, it is important to treat FLW figures and estimates with caution, as they are often based on small, unrepresentative or unbalanced data (Xue et al., 2017), as described in more detail in section 2.1.

Fruit and vegetables are particularly susceptible to high levels of food loss between post-harvest and distribution, both globally and in the European Union, due to their high perishability (FAO, 2019; Sanchez Lopez et al., 2020). For the EU, Caldeira et al. (2019a) assign the highest absolute food loss levels to vegetables (31.3 million tonnes) and fruit (28.1 million tonnes). This is particularly pronounced in primary production, where the absolute food loss amounts of fruit and vegetables are many times higher than for other product groups (Caldeira et al., 2019a). Sanad Alsbu et al. (2023) support this finding by showing that loss in fruit and vegetables occurs mainly at the harvesting stage.

There are several reasons why FLW needs to be addressed. Despite living in a seemingly abundant world where food is over-consumed and wasted, a tenth of the world's population suffers from hunger and a third does not have regular access to adequate food (UN, 2022). Although this is primarily a problem of lack of access to food and unequal distribution of economic gains rather than a problem of quantity (Runge et al., 2003), it seems paradoxical to invest resources in producing food that is ultimately not consumed by humans.

This unused part of the food supply also poses environmental challenges in terms of climate change and resource depletion. Hanson et al. (2016) estimate that 8 % of global greenhouse gas emissions are attributable to FLW, and globally, an area of land the size of China and a quarter of the water required for agricultural production is used to produce food that ends up as loss and waste. In addition, reducing FLW would go a long way towards keeping the food system within the planetary boundaries for nitrogen and phosphorus use (Springmann et al., 2018).

Food loss at harvest stage is common and yet receives little attention. The carbon footprint of food loss at the farm stage is 2.2 gigatonnes CO_2eq, of which 55 % is attributed to the pre-harvest and harvest stages (WWF, 2021). In addition to the climate-relevant emissions, the

freshwater use, eutrophication and acidification potentials of food loss at the harvest and pre-harvest stages are significant and higher than often assumed: 760 km^3 of freshwater are withdrawn to produce food lost at these stages, equivalent to more than five weeks of water flow from the Amazon River to the Atlantic Ocean (WWF, 2021).

Economic losses in the form of FLW amount to $ 940 billion per year globally (Hanson et al., 2016). Given the economic investment in food production, it is reasonable to ask why FLW persists at all. An answer lies in the many causes of FLW, some of which are largely uncontrollable, such as weather conditions and pest infestations, and some of which are in someone else's hands, such as changes in demand, business practices or standards. This dissertation examines exactly those factors that lie in someone else's hands and contribute to food loss at levels other than their own. In particular, it explores how actors interact and exercise power in their business relationships, and how these relationships are shaped and can lead to food loss. Previous research has highlighted that the design of contracts, commercial practices and business relationships can increase the likelihood of food loss prior to retail (Devin and Richards, 2018; Eriksson et al., 2017; Ghosh and Eriksson, 2019; Rakesh and Belavina, 2020; Skorbiansky and Ellison, 2019). The design of business relationships is of particular interest given the power constellations in increasingly concentrated and vertically integrated agricultural supply chains (Hernandez et al., 2023). The setting and enforcement of quality requirements by retailers is one mechanism through which power relations are manifested and has recently been identified as a relevant driver of food loss in the upstream supply chain (Beausang et al., 2017; de Hooge et al., 2018; Porter et al., 2018). Edible but suboptimal food is thereby not accepted and sorted out before reaching the retailer for fear of being less appealing to consumers. There is a sometimes emotional debate about such sorting of apparently edible food loss, with some arguing that buyers should look *beyond* the blemishes to the inner qualities of the products. This thesis wishes to contribute to the scientific debate on how, why and to what extent such sorting occurs, and what can be done to address it.

The causes of FLW cutting across the different stages of the supply chain require diverse stakeholder and policy interventions. FLW can be seen as a product of lacking incentive compatibility, meaning that private incentives do not lead to socially acceptable outcomes (Koester, 2014). Therefore, policy interventions should be sought when the economic costs of potential side effects of such policies are acceptable (ibid.). Political interventions and private sector measures are already being implemented (see also section 2.3), primarily at the consumer level. This is in line with the Sustainable Development Goal (SDG) 12.3, which aims to halve the level of food waste at the retail and consumption stages and merely reduce food loss at the remaining stages of the supply chain (Flanagan et al., 2019a).

Several research gaps can be identified based on the aforementioned aspects. The literature lacks an assessment of drivers of food loss at early stages of the supply chain, from farm level to retail (Johnson et al., 2019; Soma et al., 2021). In particular, there is a need for in-depth analysis of the interactions between value chain actors and the underlying drivers of FLW at different stages of the supply chain. This necessitates conducting more policy-oriented studies

to identify and evaluate potential tailored interventions targeting the underlying causes (Cattaneo et al., 2020).

These research gaps lead to the following overall research aim and research objectives. The overall aim of this dissertation is to explore the drivers and the options for action regarding the occurrence of food loss in upstream fruit and vegetable supply chains in European countries.

More specifically, the research objectives are

I. to identify mechanisms of food loss creation across early stages of the fruit and vegetable supply chain,
II. to analyse the extent of the specific food loss mechanism of retailer's product requirements,
III. to analyse how power relations between supply chain actors relate to food loss in early fruit and vegetable supply chains and
IV. to assess private sector and public policy options to reduce food loss in upstream supply chains.

This thesis approaches these research objectives in the following manner: chapter 2 provides a detailed thematic background and theoretical embedding relevant to achieve the research objectives. This includes a description of the applied methodological approaches in quantifying FLW. It also encompasses an elaboration on the drivers of FLW generation with a focus on the drivers of product specifications and power relations and an overview of the current state of political and private sector options for reducing FLW. The following chapter 3 presents the scientific methods employed in this thesis, divided into a section on qualitative and one on quantitative methods. The chapter deals with the different understandings of knowledge creation in these research disciplines, describes survey methods and analysis techniques, and provides a rationale for the application of the methods employed in contrast to other potential methods. Chapter 4 contains the three scientific articles selected for this cumulative thesis, dealing with the topics of power constellations, product specifications and options for action regarding food loss. Chapter 5 provides a discussion of the overall findings. This chapter connects the synthesis and background chapter with the three research articles and contextualises the findings within the research objectives. It also explores the potential transferability of the findings to other contexts. The limitations of this thesis in terms of what could not be achieved and should be addressed by future research are also included. Finally, chapter 6 draws overall conclusions from the thesis.

2 Thematic background and theoretical frameworks

Chapter 2 provides a detailed thematic background as well as a theoretical framework relevant for the achievement of the research objectives. First, the applied procedures for quantifying FLW are outlined to give a sense of the overall scale and to illustrate the relevance of primary production within the fruit and vegetable sector in terms of FLW occurrence. The second section highlights the drivers of FLW generation in general, with a focus on the specific drivers of product specifications and power constellations addressed in this thesis. In particular, the study of power constellations requires a deep insight into the sociological understanding of power. The final section is devoted to the current state of policy and private sector options for reducing food loss, as a starting point for the development of further options for action in the context of this thesis.

2.1 Food loss and waste definitions and quantities

Many attempts have been made to quantify the amount of FLW on a global scale and for different regions of the world. These quantification approaches encompass different system boundaries, definitions of FLW and measurement methods. Inconsistency in the definition of FLW is one of the challenges in producing and disseminating reliable statistics. The definitions deal differently with the inclusion of food products used as animal feed or non-food products such as bio-based materials and other industrial products (Table 1). There are also differences in terminology between definitions. The FAO (2019) distinguishes between food loss and food waste, with food loss occurring between primary production and retail, and food waste occurring between the retail and consumption stages. In the European Union, only the term ‘food waste’ is legally defined, while the term ‘food loss’ is not defined at all (European Commission, 2019a). Moreover, neither the European Commission (2019a) nor the FAO (2019) consider food lost before or during harvest as FLW. This is because the definition of ‘food’ implies that the product is already harvested (European Parliament, 2002). However, some authors, such as Baker et al. (2019), Parfitt et al. (2021), Soma et al. (2021) and Stenmarck et al. (2016), argue that pre-harvest loss and fractions used as non-food should not be completely neglected in the assessment of FLW. The FAO (2019), as opposed to the European Parliament (2002), defines crops that are ripe and ready for harvest already as ‘food’. Omitting the pre-harvest stage of production may lead to underestimation of the true extent of loss, associated resource use and underlying drivers (Cattaneo et al., 2020; Delgado et al., 2021). To separate it from the concepts of FLW put forward by the European Commission (2019a) and the FAO (2019), Hartikainen et al. (2018) introduce the term ‘side-flow’ to characterise the part that is lost before harvest and the part that is not further used for human consumption. Based on the above arguments, this thesis applies a broad concept of FLW that includes not only post-harvest, but also pre-harvest loss. Following the definitional framework of the FAO (2019), the term ‘food loss’ is used for loss up to the retail stage (the focus of this thesis) and ‘food waste’ is used for the stages from retail onwards. ‘Food loss and waste (FLW)’ is used as a generic term to describe fractions lost or wasted at all stages of the supply chain.

Table 1 System boundaries of food loss and food waste definitions proposed by different institutions, based on European Commission (2019a), FAO (2019) and Stenmarck et al. (2016)

	EU definition of food waste	**FAO** definition of food loss and food waste	**FUSIONS** definition of food waste
included	waste treatment (landfill, incineration, biogas, etc.) inedible parts of food	waste treatment (landfill, incineration, biogas, etc.) inedible parts of food	waste treatment (landfill, incineration, biogas, etc.) inedible parts of food not harvested and ploughed back amounts
partly included valorisation and conversion			industrial use, biobased materials animal feed
not included	not harvested and ploughed back amounts industrial use, biobased materials animal feed	not harvested and ploughed back amounts industrial use, biobased materials animal feed	

Source: own elaboration

The following sections provide an insight into food loss quantifications and their underlying definitions. A summary of relevant publications will provide an overview of the estimated amounts in an international and German context.

2.1.1 Food loss and waste definitions and quantities internationally

The most relevant publications on FLW quantification at international level are the FAO report by Gustavsson et al. (2011), the FAO Food Loss Index report (FAO, 2020) and the UNEP Food Waste Index report (UNEP, 2021) and, with a specific focus on primary stages of the food supply chain, the report of the WWF UK (Worldwide Fund for Nature in the United Kingdom) on farm-stage food loss (WWF, 2021). Regarding the European level, the Horizon 2020 FUSIONS project (Stenmarck et al., 2016) and the present developments of a harmonised measurement of FLW across all EU Member States need to be mentioned (Table 2).

The FAO report by Gustavsson et al. (2011) remains one of the most frequently cited references in analyses of FLW (e.g., Anriquez et al., 2021; Corrado and Sala, 2018; Fernandez-Zamudio et al., 2020). The respective figures show that a third of the world's food is lost or wasted along the supply chain, equivalent to 1.3 billion tonnes per year. This estimate does not include inedible fractions of lost and wasted food. Animal feed is also only included if the respective

share was initially intended for human consumption and nonetheless became animal feed ('unplanned' non-food uses) (Gustavsson et al., 2011). In this regard the older FAO report by Gustavsson et al. (2011) differs from the definition by the FAO (2019) that is applied today and includes inedible parts while excluding animal feed (Table 1). In Gustavsson et al. (2011), harvest loss is considered as food loss in agricultural production. The quantification of FLW is based on production volumes and coefficients for each commodity/production branch. Production volumes were gathered from the FAO Statistical Yearbook and FAO Food Balance Sheets. The parts of production intended for human consumption as well as edible fractions were calculated using allocation factors and conversion factors, respectively. FLW coefficients were taken from the existing scarce body of literature and supplemented by estimates of SIK (the Swedish Institute for Food and Biotechnology).

As part of the launch of SDG 12.3 in 2015, the Food Loss Index (SDG 12.3.1) and the Food Waste Index (SDG 12.3.2) were initiated. While the Food Loss Index (FAO, 2020), calculated under the auspices of the FAO, aims to quantify food loss amounts prior to, but not including, the retail stage, the Food Waste Index (UNEP, 2021), led by UNEP, seeks to quantify the amount of food wasted at the retail and consumption stages.

The Food Loss Index detects changes in loss shares for a group of ten major commodities for the respective country compared to a fixed time period (English et al., 2018). The first comparison of food loss data between 2016 and 2020 shows that the relative post-harvest food loss share has remained more or less the same, at around 13 % of the total production (UN, 2022). Looking at geographic regions, sub-Saharan Africa records the highest loss at 21.4 %; East and South East Asia follows with a loss of 15.1 % (especially fruits and vegetables); Latin America and the Caribbean exhibit a share of 12.3 % and Europe and Northern America the lowest loss share at 9.9 % (FAO, 2020). Especially in East and South East Asia fruit and vegetables represent commodities with high loss rates.

The Food Waste Index was created to illustrate trends in food waste at the retail and consumption (household and food service) levels. According to the first Food Waste Index report (UNEP, 2021), 17 % of global food production is wasted within this part of the food value chain. 11 % of the global food production becomes food waste in households, 5 % in the food service sector and 2 % in retail. Contrary to the common claim that food waste arises mostly in high income countries (e.g., FAO, 2013), the recent Food Waste Index report demonstrates that food waste generation is similar across low-, high- and middle-income countries (UNEP, 2021). However, the report points out that data availability is poor and confidence in the database in some cases is low. The database can only be considered reliable for 17 countries, and low-income countries in particular show a lack of data quality and quantity, which means that estimates have to be made for countries that do not yet measure food waste themselves. Only 9 % of the world's population lives in countries with high confidence data on household food waste. High-confidence data are characterised by robust methodology and coverage of a substantial part of the country (UNEP, 2021).

Food loss at the primary stages of the food value chain has been reassessed in a recent report by the WWF (2021) in the UK, the contents of which have also been published by Parfitt et al. (2021). It differs from other quantification approaches in that it considers food loss at the harvest and pre-harvest stages. The focus of the report had been selected because loss at pre-consumption stages is underestimated and often neglected (WWF, 2021). This is a result of the complexity and effort involved in measuring food loss at primary stages, and the fact that many definitions do not include pre-harvest loss as actual food loss (see also section 2.1). A disadvantage of this approach is that loss resulting from market price developments or non-compliance with quality criteria is completely or partially neglected (WWF, 2021). Applying this broader scope, the report estimates that 20 – 25 % of the global production is lost at stages between primary production and up to, but excluding, retail. This can be broken down into 8.3 % loss at the harvest farm-stage and 7.0 % at the post-harvest farm-stage (excluding the post-harvest supply chain beyond the farm-stage). The calculations in the WWF publication are based on a report on FLW compiled by the FAO (2019) and FAOSTAT data. It thereby combines loss factors per commodity and region derived from the literature and the FAO database containing the FAO production data on volume and value per commodity group and region. Although the data are filtered using quality criteria, such as adherence to the Food Loss and Waste Accounting and Reporting Standard (Hanson et al., 2016), most of the examined data points are based on questionnaires rather than actual measurements. However, this is the case in many of the scientific publications on FLW due to the prevalence of significant data gaps (Xue et al., 2017). The WWF (2021) also provides specific figures on fruit and vegetables, estimating losses at 38 % of the total tonnage of lost food.

The focus of this thesis is on European countries and therefore requires a closer look at the levels of FLW within the European Union. The Horizon 2020 project 'FUSIONS' as well as the current developments towards a regular mandatory monitoring of FLW in all European Member States refer to exactly this level.

The FUSIONS project estimated that 88 million tonnes of food were lost and wasted along the supply chain in Europe in 2012, equivalent to 173 kg of FLW per European inhabitant (Stenmarck et al., 2016). Again, the primary production sector was found to be the most difficult to quantify due to insufficient data quantity and quality. Only 15 countries provided any data at all for the FUSIONS estimate, of which only six Member States achieved a sufficient level of data quality with regard to predefined criteria. The project estimated food loss in primary production at 9 million tonnes or 18 kg per person per year. These figures are based on a definition of FLW that also includes pre-harvest loss of products ready for harvest, products intended for human consumption but withdrawn from the food supply chain (animal feed and bio-based materials are therein categorised as valorisation and conversion) and disposal to sewers.

With the renewal of the EU Waste Directive (European Parliament, 2018), regular reporting on the amount of food waste ('food loss' is not defined at EU level) every four years has become mandatory for all EU Member States (see also section 2.3.1). The first reporting period has been

set for 2022, with 2020 as the reference year. The first datasets were published online in October 2022 and the first comparison between measurement periods will be possible in 2024. The measurement methodology was specified by the Commission Delegated Decision (European Commission, 2019a), including direct measurement, waste composition analysis, mass balance approach, questionnaires and interviews, coefficients and production statistics, counting/scanning and FLW diaries. The method to be used depends on the stage of the supply chain, but some countries reported that strict adherence to the measurement guideline was not successful in the first reporting period. The corresponding Eurostat data (Eurostat, 2023) are the first official food waste data across all Member States. Accordingly, total food waste across all stages of the supply chain amounts to almost 60 million tonnes fresh mass in 2020, equivalent to 131 kg FLW per inhabitant. Primary production accounts for 6 million tonnes of food loss (11 %), processing for 12 million tonnes (20 %), retail and distribution for 4 million tonnes of food waste (7 %), restaurants and food service for 4 million tonnes (9 %) and households for 31 million tonnes (53 %). Cyprus, Belgium and Denmark have comparatively high values above 200 kg fresh mass per inhabitant, while Slovenia, Croatia and Slovakia have values below 90 kg per inhabitant. Germany, with 131 kg per inhabitant, is in the middle of the Member States.

2.1.2 Food loss and waste definitions and quantities in Germany

Hafner et al. (2012) made a first attempt to quantify the amount of FLW in Germany. Across the stages from processing to consumption this resulted in a value of 8 million to 15 million tonnes, with a median value of 11 million tonnes of FLW per year. The primary production stage was not included in this study, but was the subject of a parallel study by Peter et al. (2013). According to Hafner et al. (2012), households account for 61 % of FLW, industry for 17 %, retail for 5 % and large-scale consumption for 17 %. At these stages of the supply chain, the quantification is based on small data sets. The authors have supplemented the existing literature with an industry survey, expert interviews at the retail stage, calculations by type of business of large-scale consumers, national and international data and a compositional analysis of household's food waste. Hafner et al. (2012) identify the need to fill existing research gaps, establish consistent measurements and implement regular monitoring of FLW. Peter et al. (2013) focus on primary production by quantifying food loss for three major crops, namely wheat, potatoes, apples and carrots. They report post-harvest loss in Germany of 3.3 % for wheat, 5 % for potatoes, 11 % for apples and 4.2 % for carrots. Obviously, quantifying food loss for such a small selection of products is not sufficient to provide a comprehensive picture of food loss at the primary production stage in Germany.

In 2019, Schmidt et al. (2019) started a new attempt to quantify FLW levels in Germany along the entire supply chain for the reference year 2015, 'Baseline 2015'. Schmidt et al. (2019) estimate FLW at 11.9 million tonnes, of which 6.7 million tonnes are considered theoretically avoidable/edible (Schmidt et al., 2019). In general, the data and methods used were official statistics, databases, primary case data and secondary data. The German FLW figures are based on a small number of non-representative studies and a simplified extrapolation of arithmetic

means. Due to the lack of data and studies, measurement methods were also applied in order to provide better estimates that are not in line with the recommendations of the European Commission Delegated Decision (European Commission, 2019a). For instance, questionnaires and coefficients were used to estimate food waste amounts at retail stage. For the primary production stage, Schmidt et al. (2019) indicate an average amount of 1.4 million tonnes, which represents 12 % of the total FLW that occurs along the supply chain. This estimate is based on a literature review of different product groups and using different methodologies. Food loss in primary production follows the EU definition and therefore neglects the pre-harvest supply chain. The remaining FLW fractions are allocated to processing, with 18 % (2.17 million tonnes), retail with 4 % (0.49 million tonnes), food services with 14 % (1.69 million tonnes) and households with 52 % (6.14 million tonnes).

Overall, it is clear that although figures on FLW exist both internationally and in Germany (Table 2), they are based on very little data. In addition, definitions and methodologies sometimes differ widely, making it difficult to compare figures.

Table 2 Selected reports on food loss and waste figures for different regions and levels

Source	Scope	Figure
Gustavsson et al. (2011)	globally	1.3 billion tonnes 1/3 of global production (edible)
FAO (2020) Food Loss Index	globally, primary production to (excl.) retail	13 % of global production
UNEP (2021) Food Waste Index	globally, retail to consumption	17 % of global production
WWF (2021)	globally, primary production incl. pre-harvest	20 to 25 % of global production
Stenmarck at al. (2016)	Europe	88 million tonnes/year 173 kg/year and inhabitant
Eurostat (2023)	Europe	60 million tonnes/year 131 kg/year and inhabitant
Hafner et al. (2012)	Germany, primary production excluded	8 to 15 million tonnes/year
Schmidt et al. (2019)	Germany	11.9 million tonnes/year

Source: own elaboration

2.2 Drivers of food loss and waste

The causes of FLW can be manifold depending on the specific circumstances and supply chain stage. For example, a household member putting spoiled leftovers in the bin and a farmer tilling field crops are two events of FLW that occur in very different settings, under different circumstances and for different reasons. At the same time, the drivers of FLW may be interrelated, and in many cases a single clear cause of FLW cannot be identified (Canali et al., 2014). For example, a combination of consumer preferences, different quality standards and unfavourable weather conditions can lead to products that do not meet aesthetic requirements and become food loss at the farm stage. In the following sections, the variety of drivers of FLW

and approaches of classifying them with an emphasis on the stages prior to retail are presented. Sections 2.2.2 and 2.2.3 lay a particular focus on the drivers of food loss related to power constellations and product specifications.

2.2.1 Classifications of drivers of food loss and waste along the supply chain

Several studies have sought to identify, categorise and understand different drivers of FLW along the agri-food value chain. Some look at these drivers from a more general macro-perspective, while others identify and analyse very specific drivers from a micro-perspective for particular stages of the supply chain. Thyberg and Tonjes (2016) take a broader view by relating the developments in the FLW at different points. They identify industrialisation, economic growth, urbanisation and globalisation as underlying mechanisms that influence FLW by people being increasingly distanced from food production and preparation, increased food abundance, reduced income spent on food and increased dietary diversification. Cicatiello et al. (2020) and Surucu-Balci and Tuna (2021) take a micro-perspective by focussing on drivers of FLW in supermarkets and their logistics, respectively. In supermarkets, reckless handling, customers' behaviour, volatile purchasing trends, sales management and forecasting were among the identified drivers (Cicatiello et al., 2020). In logistic processes, drivers were categorised as transportation-related, warehousing-related, inventory management-related and packaging-related (Surucu-Balci and Tuna, 2021).

Canali et al. (2014) made an attempt to classify the diversity of current drivers of FLW for all supply chain steps in the frame of the above-mentioned FUSIONS project. Based on a literature review and an expert survey they identified 271 drivers. Three context categories were identified: technological drivers, institutional drivers (subdivided into institutional drivers related to business management and institutional drivers related to legislation and policy) and social drivers (Table 3).

Technological drivers are, for example, an accepted technological collateral effect based on a cost-benefit assessment or suboptimal use and application of technology and supply chain management. Institutional drivers are divided into those related to business management and those related to legislation and policy. Institutional drivers related to business management can, for example, occur at macro level, such as market conditions and unequal bargaining power. Institutional drivers related to legislation and policy comprise legislation derived from agricultural policy and product quality regulations or food safety and health regulations that lead to food loss. Social drivers relate to socio-demographic factors, unconscious preferences for certain food aesthetics or consumer behaviour.

Table 3 Grouping of drivers of food loss and waste according to Canali et al. (2014)

Context Category	Sub-Grouping of Drivers of Food Loss and Waste		
Technological Drivers	inherent in the characteristics of food, production and consumption	technological collateral effect accepted based on cost-benefit assessment	suboptimal use of technology and supply chain management
Institutional Drivers business management	addressed by management solutions on single stages of the agri-food supply chain	addressed at the macro-level	addressed at the business level
Institutional Drivers legislation and policy	related to legislation, such as agricultural policy and product quality regulations	related to legislation concerning food safety and health	related to food waste and tax policy
Social Drivers	socio-demographic factors	unconscious preferences for certain food aesthetics	consumer behaviour modifiable through information and awareness raising

Source: own elaboration

Canali et al. (2014) also identify technological, institutional and social drivers of food loss that are specific to the primary production stage. Harvest damage, climatic conditions and access to modern technologies are potential technological drivers of food loss at this stage. Institutional drivers are cosmetic quality standards for fruit and vegetables, supply and demand forecasting, market conditions and market price, lack of profitability, contracts and agreements, communication within supply chains and government regulations. Consumer preferences are mentioned as the only social driver affecting food loss in the upstream supply chain.

The WWF (2021) suggests a categorisation of drivers of farm-level loss into direct and indirect drivers. Direct drivers encompass technology and infrastructure (e.g., harvest and storage technologies), biological and environmental factors (e.g., pests and diseases and weather) and agronomy (e.g., choice of cultivar). Indirect drivers imply aspects related to market structures and governance (e.g., regulation, investments and access to finance) and human factors (e.g., training and outreach as well as labour aspects).

In primary production, other authors also describe environmental factors, such as weather, pests and diseases and market conditions, such as price, marketing standards and labour availability as relevant drivers of food loss (Spang et al., 2019). In particular, the combination of

unpredictable orders and unpredictable weather conditions affect supply and demand in a very short-term manner, leading to overproduction and food loss (Beausang et al., 2017; Spang et al., 2019). Often unpredictable supply and demand fluctuations coupled with misaligned advertisement campaigns can result even more in short-term overproduction and loss (Beausang et al., 2017; Meyer et al., 2017). This 'crop flush' (short period of surplus supply) and stock piling have also been identified as major causes of food loss in UK fruit and vegetable supply chains, alongside cosmetic quality standards (Rakesh and Belavina, 2020). In the Canadian fruit and vegetable production, in addition to rejected produce due to strict aesthetic criteria, causes of loss include economic and environmental reasons, power imbalances, low market prices that lead farmers to leave produce unharvested, financial risks, market volatility and subsidies that encourage overproduction (Soma et al., 2021). Insufficient market price, product quality and financial risk of rejection were also described as crucial field loss drivers of fruit and vegetables in North-Carolina (Johnson et al., 2019). Furthermore, Johnson et al. (2019) list the availability of a potential buyer as well as other ripe fields under consideration of the labour schedule as important factors in deciding whether or not to harvest a field.

It becomes apparent in the debate about drivers of FLW in general that some drivers seem to be subtler than other ones. For instance, if frost during the flowering period leads to a misshaped apple not being sold and becoming food loss, one could denote the weather as a driver of FLW, but one could also denote the product requirements and societal expectations as the driver. Similarly, either overproduction could be considered as a driver of FLW, or the underlying mechanisms, such as a lack of reliability in orders, insufficient forecasting and the expectations towards producers to remain available for supply at all times. Examples of such drivers inherent to the system are forecasting errors, over-optimistic projections, lack of data sharing, late cancellations, last-minute modifications and rejections of orders, quality specifications and minimum order quantities criteria (Piras et al., 2018). Devin and Richards (2018) add the fact that disposal is often cheaper than reuse in high-income countries, and identify food abundance coupled with consumer attitudes as the underlying drivers of FLW. Burgos et al. (2019) underscore that these systemic drivers of FLW, that are similar to the indirect drivers (WWF, 2021) and institutional drivers (Canali et al., 2014) mentioned above, resonate along the stages of the supply chain. Both Canali et al. (2014) and the WWF (2021) argue that a variety of factors and decisions drive FLW at stages of the supply chain other than where FLW occurs. Therefore, interventions addressing only the, 'biological' and 'environmental' causes are unlikely to be successful (WWF, 2021). Canali et al. (2014) further state that some fractions of FLW seem inherent in industrial production, processing and distribution resulting from markets and mass consumption. These 'root causes' must be identified to design counteracting measures as highlighted by Sanad Alsbu et al. (2023) for fresh fruit and vegetable supply chains.

After this broad overview of the various drivers of FLW, the following sections provide background information on power constellations related to food loss occurrence and the closely related setting of quality standards or product requirements. In line with the system boundaries of the thesis, the focus will be on the primary stages of the food value chain.

2.2.2 Power constellations and Unfair Trading Practices as drivers of food loss

Power relations and power imbalances are recurring themes in agri-food supply chains, which are increasingly characterised by the accumulation of market share and the vertical integration of large players. To give a few examples, the top ten seed companies control almost 50 % of the US global seed market and the top ten pesticide companies control 84 % of the US global pesticide market (Fuchs and Clapp, 2009). At the same time, international retail corporations are expanding not only in the Global North but also in the Global South (Fuchs and Clapp, 2009; Hernandez et al., 2023). In Europe, the retail sector is becoming increasingly concentrated, with the top five food retailers reaching a market share of over 80 % in the 2000s (European Commission, 2014). However, concentration in the retail sector in Europe is lower than in food manufacturing and has not everywhere followed a straight line in recent years (ibid). Whether high levels of concentration are bad per se, whether they lead to the exercise of power and what their effects are, are complex issues that have not yet been sufficiently explored (Hernandez et al., 2023). Issues of power have for example been the subject of scientific research in the agri-food sector with respect to the role of transnational corporations as emerging actors (Clapp, 2021; Fuchs and Clapp, 2009), the role of producer organisations in shaping markets and bargaining power (Sorrentino et al., 2018) and with respect to Unfair Trading Practices (UTPs) in agri-food value chains (Daskalova, 2020; Nový, 2023; Schebesta et al., 2018; Sinclair Taylor et al., 2019).

First, it is important to conceptualise power in general and in the context of agri-food supply chains. For this reason, power is first discussed from the perspectives of applied concepts in (agricultural) economics and sociology without claiming to provide a complete overview of this multifaceted topic. Relevant contributions in terms of power relations in the agri-food system are then presented, setting the stage for the analysis of power constellations and food loss in this thesis.

Conceptualisation of 'power'

The traditional definition of market power in economics emphasises the ability of a selling firm to set and maintain a price above, or of a buying firm to set and maintain a price below the level that would prevail under perfect competition (Khemani and Shapiro, 1993). There is an incentive for the actor with a large market share to restrict trade and produce lower levels of output, which results in that actor capturing large shares of the market surplus and in a deadweight loss in social welfare (Bonanno et al., 2018; Sexton and Zhang, 2001). The research field of Industrial Organisation (IO) deals precisely with these concepts of non-perfect competition and market power theories (Bonanno et al., 2018). Especially in agricultural markets, perfect competition is considered as non-existent due to an ongoing concentration of the food manufacturing and retail sectors (Saitone and Sexton, 2010). Authors in the field of IO have shown that the agri-food sector is increasingly concentrated and vertically coordinated (Sexton, 2013; Sexton and Xia, 2018). Agricultural support policies are significantly affected by the presence of oligopoly and/or oligopsony (Russo et al., 2011) and the product spectrum in modern agricultural markets is increasingly differentiated (Saitone and Sexton, 2010). Based

on economic theory, we are able to measure the consequences of market power and its effects in terms of market shares and price setting. However, Biely et al. (2018) note that this approach to analysing market power neglects other aspects of power and its effects beyond those that can be quantitatively measured. Fuchs and Clapp (2009) argue that purely economic concepts do not take into account the many ways in which firms exercise power to shape the rules that govern markets (see also article 1). Therefore, some key considerations from social sciences about power in general and in markets are outlined below in order to broaden the view on market power.

Foucault and Latour are representatives of social sciences, both of which reject the idea that power is held by a single actor and emphasise the role of relations, subtle mechanisms and actions of the actors involved. A key argument of Foucault (1982) in his essay 'The Subject and Power' is that power is *relational* and therefore characterised by relationships between individuals or between groups, rather than being something that individuals or institutions have and hold. He therefore uses the term 'power relations' rather than 'power' and characterises these relations as constantly being negotiated and contested by individuals and groups. According to Foucault (1982), power operates not only through force or confrontation but rather through government, in the sense that government shapes the ways in which individuals or groups behave. An important point is that 'power exists only when it is put into action' (Foucault, 1982, p. 788). This means that power relations are enacted by the way in which actions modify other actions, acting not directly but through actions upon actions. Examples of such actions upon actions are to induce, to seduce, to make easier or more difficult or even to forbid. On the question of how to analyse power relations, Foucault (1982) raises some points that need to be considered when studying power relations, such as the types of objectives and the means of bringing power relations into being. The types of objectives include, for example, the idea of maintaining privileges or accumulating profits. The means of power relations are explicitly studied in this thesis. They deal with the mechanisms such as communication, control mechanisms and non-explicit rules that bring power relations into being.

Latour (1984) is also concerned with the meaning and effects of power. Similar to Foucault (1982), Latour (1984) argues that there is no possibility of *possessing* power. Instead, there is only an effect through the exercise of power by an actor, which is similar to Foucault's concept of power being manifested through actions that frame the behaviour of other actors. Latour (1984) further argues that the exercise of power does not depend on a powerful actor and his degree of power, but rather on the number of other actors entering into this power relation and potentially acting in terms of the exertion of power. Thus, similar to Foucault (1982), power is manifested in relations. Latour (1984) puts forward two concepts of how power operates in social environments, the diffusion model and the translation model. These illustrate the view of 'power as a consequence, not a cause of collective action' (Latour, 1984, p. 269). According to the diffusion model, power is shared among a network of actors and diffuses via these networks when actors interact and exchange resources and knowledge. Accordingly, a certain token (e.g., technological progress) is diffused within society, being confronted with various degrees of

inertia in the form of other peoples' or groups' reactions and resistance potentially slowing down the process of diffusion. The translation model contends that the process of translating lies in the hands of actions by people or groups while transmitting/translating an initial action through a medium. This translation of claims, orders, artefacts or goods from one context to another, is how power becomes apparent. The translation model, too, supports the idea that power cannot be held by any specific actor or institution but rather arises from the capacity to shape a certain token according to own projects or goals. This token is then diffused across different relationships and networks. The ways of action during translation might be to let the token drop, to modify it, to add onto it, to appropriate it, etc. Hence, while the diffusion principle describes a process of transmission, the translation model is concerned with transformation. Both concepts can provide guidance and a basis for analysing how power relations become apparent in the diffusion and translation of tokens, that might in our context be orders, specifications and norms prevalent in upstream agri-food supply chains (see also section 5.2.).

The empirical analysis of power relations and its interconnection with food loss in article 1 contained in this thesis is guided by the conceptual framework on a social order of markets provided by Beckert (2009). Although Beckert (2009) does not literally refer to power relations, he explains how, in the social order of markets, the exercise of power becomes apparent in the solution of coordination problems in markets, namely the value problem, the cooperation problem and the problem of competition. During the solving of these coordination problems, power relations become apparent in shifting uncertainties and setting implicit rules and norms. The framework by Beckert (2009) is explained in more detail and applied in article 1.

All three conceptual frameworks emphasise the high relevance of relationships and actions between actors when it comes to power. They highlight the fluid nature of power relations, which are constantly being negotiated. Beckert (2009) adds the market and supply chain perspective, implying the shifting of risks between market actors. This is of particular interest for the thesis dealing with mechanisms arising from power relations in specific supply chains, namely upstream fruit and vegetable supply chains.

Empirical application of power concepts in research on agri-food value chains

In addition to the theoretical conceptualisation of power, the following section provides an overview of empirical evidence on power and its manifestations in agri-food value chains, with a particular focus on the creation of FLW. Several scholars from different disciplines have analysed power constellations in agri-food supply chains, only a selection of which can be presented here. Fuchs and Clapp (2009) and Clapp (2021), for example, point out that food systems have become globally integrated over the last half century. Thereby, new actors come into play: transnational corporations (TNCs) stretching horizontally and vertically and being involved in production, processing and distribution activities. Fuchs and Clapp (2009) argue that while a globalised food system brings benefits, such as increased food diversity for consumers and emerging markets for producers, the legitimacy of corporations exercising power as political actors should be reconsidered. Devin and Richards (2018) have evaluated power and corporate social responsibility in agri-food supply chains also with a view to FLW.

They find that transnational retailing companies are able to exert structural power to govern supply chains beyond their own firm-gates. The setting of company-specific marketing standards reflects the structural power exercised (Devin and Richards, 2018).

For example Barathova et al. (2022) and Nový (2023) approach the topic of power in agri-food supply chains from the viewpoint of the adoption of the EU Directive on Unfair Trading Practices (European Parliament, 2019). The EU Directive is based on the idea that power imbalances lead to undesirable practices that are considered unfair and should therefore be curbed. It identifies ten black practices, which need to be regulated through transposition into the national laws of European Member States, and six grey practices, which can be curbed by Member States on a voluntary basis (Table 4). Black practices include, among others, late payments for agricultural products, short-notice cancellations, unilateral contract changes and refusal to provide written confirmations. Examples of grey practices are the return of unsold products and payments by suppliers for listing, promotions, marketing and fitting out premises (European Parliament, 2019).

Table 4 Unfair Trading Practices (black and grey practices) as listed in the EU Directive on Unfair Trading Practices (European Parliament, 2019)

Black Practices of the UTP Directive	Grey Practices of the UTP Directive
Payments later than 30 days for perishable agricultural and food products	**Return of unsold products**
Payments later than 60 days for other agri-food products	Payment of the supplier for stocking, display and listing
Short-notice cancellations of perishable agri-food products	Payment of the supplier for promotion
Unilateral contract changes by the buyer	Payment of the supplier for marketing
Payments not related to specific transaction	Payment of the supplier for advertising
Refusal of a written confirmation of a supply agreement by the buyer, despite request of supplier	Payment of the supplier for staff of the buyer, fitting out premises
Misuse of trade secrets by the buyer	
Commercial retaliation by the buyer	
Transferring the costs of examining customer complaints to the supplier	

Note: Unfair Trading Practices, which some scientists and institutions link to food loss and waste, are shown in bold/red
Source: own elaboration

Nový (2023) suggests three components of buyer power, namely market power, economic dependence and bargaining power. Market power deals with the structural dimension of the number of buyers and their respective market shares, which is only moderately high in the case of buyers in food supply chains. Economic dependence deals with the potential for switching

to alternative marketing channels, which is particularly important in the case of perishable fruit and vegetables. Bargaining power, and hereby Nový (2023) follows the understanding of Sorrentino et al. (2018) and Deconinck (2021), relates to the power of receiving concessions by intimidating to impose a cost or to withdraw a benefit, e.g., threats of switching suppliers or discontinuation of collaboration. According to Nový (2023), the bargaining power approach better reflects the actual enforcement of power in agri-food supply chains than the concept of market power, to which the above-mentioned directive mainly refers. Barathova et al. (2022) investigate the occurrence of UTPs in fruit (mainly apple) supply chains in Slovakia as part of a cross-country comparison project (Russo, 2020). Barathova et al. (2022) show that apple growers in Slovakia face UTPs mainly in relation to payments and unilateral changes to contracts and orders, but also in relation to short-term order cancellations. Being a member of producer organisations showed to significantly reduce the risk of multiple UTPs compared to direct trade with private traders or retailers. However, a key finding was that UTPs are heterogeneous, country- and context-specific and less relevant in the fruit sector than in other sectors. Furthermore, farmers' perceptions of whether a practice is unfair depend on the context.

Sorrentino et al. (2018) analyse the role of producer organisations in rebalancing power relations in agri-food supply chains. They focus on the assessment of bargaining power, which differs from market power in the sense that bargaining power is exercised by threatening to take a certain action, whereas market power refers to exercising power in the market by actually buying or selling less (Sorrentino et al., 2018). They find that especially larger producer organisations possess the ability to strengthen farmers bargaining through joint selling of produce and horizontal integration.

The potential link between power imbalances as well as Unfair Trading Practices and FLW in agri-food supply chains has been suggested by various authors. Few scholars conducting research in the field of FLW (Devin and Richards, 2018; Eriksson et al., 2017; Ghosh and Eriksson, 2019), scientific reports related to the Horizons 2020 project 'REFRESH' (Piras et al., 2018; Sinclair Taylor et al., 2019) and reports of non-governmental organisations (NGOs) and public authorities (Feedback, 2017; Ungerth, 2018) have addressed this relationship. Accordingly, the practices of short-notice cancellations and take-back agreements included in the UTP Directive are suspected to be responsible for food becoming loss along the supply chain.

Devin and Richards (2018) analyse how retail power results in the application of practices and setting of standards in fresh fruit and vegetable supply chains in Australia. Based on qualitative interviews they argue that power of the highly concentrated retailing sector is used to push the responsibility for FLW and its cost up the supply chain. Eriksson et al. (2017) and Ghosh and Eriksson (2019) analyse the relation of power constellations, mainly in the form of take-back-agreements, and food loss in Sweden. The analysis of bread, milk as well as fresh fruit and vegetable supply chains indicate that take-back-agreements, i.e., the selling back of excess products, is most common for bread (Eriksson et al., 2017). Fresh fruit and vegetables are only returned if the quality is announced to be insufficient (ibid.). In bread supply chains in Sweden,

take-back agreements have been shown to lead to a lacking incentive to manage purchasing according to demand (Ghosh and Eriksson, 2019). As a result, retailers over-order and sell back bakery products, which in turn become food loss for suppliers (ibid.). Within the REFRESH project, a case study comparison between Italy and the UK indicates that trading practices, such as late changes to orders and application of quality requirements to artificially reduce ordered quantities, increase FLW levels (Piras et al., 2018; Sinclair Taylor et al., 2019). Feedback (2017) supports the evidence on imposing strict quality criteria as a means to shift the risk of fluctuating demand onto suppliers. Additionally, they report that retailers' practices lead to food loss, e.g., unfounded rejections and missing liability for quantities and price. On the contrary, Ungerth (2018) reports for Sweden that the increasing demand for Swedish products has improved the bargaining position of farmers and therefore power constellations and UTPs in Swedish fruit and vegetable supply chains are less of an issue.

A comparison of current studies shows that there is a lack of empirical evidence on the relationship between power in general, UTPs in particular and FLW in literature. Existing studies are partly contradictory and analyse very specific regions, product groups and contexts. This thesis aims to fill this gap for selected fruit and vegetable supply chains.

2.2.3 Public and private quality standards or product specifications as drivers of food loss

Agri-food supply chains in general, and fruit and vegetable supply chains in particular, are subject to a number of rules and regulations on product characteristics and attributes. This section relates such standards to food loss occurrence due to non-compliant products being rejected and sorted out and presents available scientific evidence on this relationship. In current food markets, consumers value diverse product traits which makes product differentiation a crucial aspect in these markets (Saitone and Sexton, 2010). Product quality criteria (hereafter also referred to as product specifications or product requirements) focus on the product's appearance, internal qualities, presentation, declaration and grading. They may be set by different stakeholders. These include regulators but also downstream supply chain actors such as retailers and consumers (Porter et al., 2018).

Almost all fruit and vegetables fall under the defined general marketing standards set for the European market (European Commission, 2011). General marketing standards define very basic minimum requirements such as that products are whole, healthy, clean and free of pests. In addition, some fruits and vegetables are subject to specific marketing standards, on the basis of which they can be classified into legal grades. Products with specific marketing standards include apples, pears, strawberries, bell peppers, kiwis, peaches and nectarines, lettuces, grapes, tomatoes and citrus fruits (ibid.). These specific marketing standards allow the differentiation of higher quality produce from products which only comply with minimum quality criteria (Ludwig-Ohm et al., 2019). For instance, Class 2 of a particular fruit or vegetable allows deviations in shape and colouring, size, skin defects, etc., while Class 1 allows only slight deviations. The additional class 'Extra' requires products of the highest quality with almost no skin defects and allows only narrow margins for deviations from the norm. Exceptions to the

compliance with general marketing standards exist for products designated for processing, products sold by producers directly at the producer's premises for the personal use of consumers, sliced products and very specific regional products (European Commission, 2011). General and specific marketing standards are since April 2023 under review, with particular attention being paid to their potential contribution to FLW (European Commission, 2023a).

If no specific marketing standard applies to a product, the international standard of the United Nations Economic Commission for Europe (UNECE) can be used. On the basis of these, fruit and vegetables can nonetheless be legally classified as products of Class 1 or 2 within the European Union (UNECE, 2020). The international UNECE standards can, however, also be applied on a voluntary basis anywhere else in the world. The wording and presentation of these UNECE standards are very similar to the European Commission's specific trade category rules.

With respect to food loss occurrence, private standards or rules set by retailing companies must be mentioned (Devin and Richards, 2018). Beausang et al. (2017), de Hooge et al. (2018), Johnson et al. (2019), Ludwig-Ohm et al. (2019), Meyer et al. (2017) and Porter et al. (2018) suggest that these go beyond European and UNECE standards and are a driver of food loss in terms of sorting out and rejecting fruit and vegetables that do not meet the retailer's private quality criteria. A relationship between product specification and food loss has been observed for certain horticultural products and regions: For example, Willersinn et al. (2015) describe visual standards as a driver of food loss in their detailed analysis of the Swiss potato supply chain. Soma et al. (2021) highlight stringent visual criteria as a driver of food loss in horticultural supply chains in Canada. Qualitatively analysing fruit and vegetable supply chains in North Rhine-Westphalia (Western Germany), Meyer et al. (2017) state that retailers' specifications on quality and uniformity of fruit and vegetables have increased in recent years and indeed are stricter than other marketing standards. Retailers argue that consumers demand near-perfect products, so they have to reject products that are not going to sell (Devin and Richards, 2018). Specific pesticide residue limits set by retailers that exceed legal requirements as a food loss driver have up to now been researched to a lesser extent. In this regard, each company requires its own maximum residues of pesticides within fruit and vegetables and adhering to all of them can be challenging for retailers (Ludwig-Ohm et al., 2019). Meyer et al. (2017) also confirm that retailers set specific norms related to pesticide residue limits. Moreover, a relationship between packaging-related requirements and food loss has been established by Meyer et al. (2017). Failure to comply with any type of standard usually leads to rejection of the products during quality controls within the supply chain (Devin and Richards, 2018; Rakesh and Belavina, 2020) or sorting out during harvesting (Meyer et al., 2017; Soma et al., 2021).

A pressing issue seems to be the vagueness and lack of reliability of retailer's quality standards. Accordingly, quality criteria are undefined and cannot be enforced by contract (Rakesh and Belavina, 2020). It does not appear to be clear on what basis some products are rejected and some are not (Devin and Richards, 2018). The NGO Feedback (2017) reports that suppliers do not always receive a reason of why their products have been rejected or why payment for

products has been refused. Where evidence is provided by retailers, suppliers report that it is unsatisfactory and does not give details of whether the produce actually belongs to the supplier and whether this produce is still being sold on the open market (Feedback, 2017). Reports by NGOs and public bodies have recently taken up and fuelled the public debate on FLW caused by retailer's quality standards (Feedback, 2017; UBA, 2020). Feedback (2017) even describes retailers deliberately using quality standards as a means of rejecting orders they no longer need. In doing so, they transfer the risks of fluctuations in supply and demand to suppliers and producers. However, scientific analyses to what extent this happens and the exact mechanisms and specifications that lead to food loss are not yet well established.

Some scientific studies touch on the topic of product specifications as a driver of food loss, such as the study by Johnson et al. (2018a). They conducted field measurements for six vegetable crops in North Carolina (USA) and concluded that 42 % of the marketed crop volume is left in the field due to poor quality including inedible fractions. The edible but unmarketable share was quantified at 34 % and the most likely marketable share in the field at 24 %. Baker et al. (2019) conducted field measurements for 20 fruit and vegetable crops in California and found that, on average, 33 % of the marketed volume was left in the field. Porter et al. (2018) followed a different approach by using literature and Eurostat-data to estimate fruit and vegetable loss resulting from non-compliance with visual product requirements in the European Economic Area. They found that, on average, 14 % of food is lost due to non-compliance with standards, with a wide variation between crops from 4 % to 37 %. Willersinn et al. (2015) found that quality specifications are responsible for 27 % of potato losses, including not only quality defects related to consumer preferences but also those attributed to storability and health issues. One of the few studies that directly measured persimmon losses in Spain found that 16 % of delivered produce was downgraded at the cooperative warehouse due to quality criteria and not paid to primary producers (Fernandez-Zamudio et al., 2020).

It can be concluded that previous studies have used different methodological approaches, have covered different scopes and geographical regions and have analysed a wider range of quality specifications and other causes of food loss than just retailer product requirements.

2.3 Approaches to reducing food loss and waste

Having provided a broad overview of the drivers of FLW, this section aims to highlight the role of both private sector initiatives and policy interventions in addressing these drivers. While policy interventions play a crucial role in providing a permissive environment and regulatory framework, private sector efforts can focus on optimising supply chains, improving post-harvest technologies and fostering innovation. This section summarises existing policy and private sector interventions to address food loss in upstream supply chains in Europe and high-income countries in general. In their review article, Goossens et al. (2019) found over 200 scientific papers on measures to reduce FLW, which include all stages of the private sector value chain as well as legislation.

2.3.1 Current food loss and waste policies

There are currently several policy efforts at different governance levels to create a more sustainable food system and thus address the issue of FLW (Figure 1). The most important are the Sustainable Development Goals at global level and at European level the Green Deal, the Farm-to-Fork Strategy and the Circular Economy Action Plan. As Reynolds (2023) shows, there is also a wide variety of national policies that address the emergence of FLW in different countries. These range from FLW measurement, investment in infrastructure and production processes, changes in public standards, tackling UTPs, tax incentives and fees, voluntary agreements and behaviour change campaigns (ibid). This section highlights examples of FLW policies in the EU and other high-income countries to set the stage for the empirical analyses located in Germany, Italy and Spain and the potential transferability of the findings in section 5.4. The policies are described in terms of whether they target early stages of the supply chain, the types of policy instruments used (e.g., regulatory, market-based, cooperative or information-based) and whether they focus on prevention rather than recycling and recovery. The prioritisation of prevention (divided into actual prevention and reuse) over recycling, recovery and disposal was suggested by the frequently applied food waste hierarchy of Papargyropoulou et al. (2014).

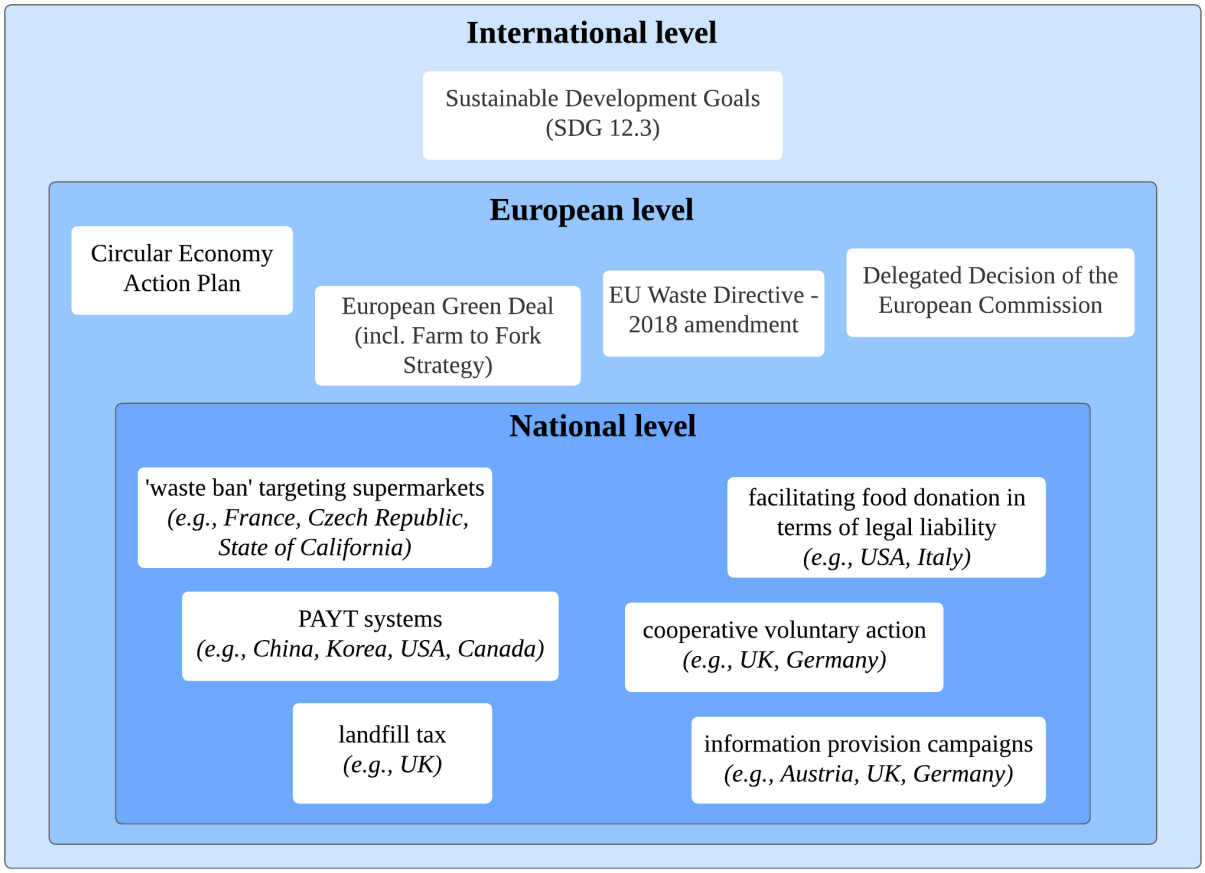

Figure 1 Selected governance approaches and policies addressing food loss and waste on international, European and national levels

Source: own elaboration

In the European Union, FLW plays an increasing role in various policy contexts. The Circular Economy Action Plan primarily seeks to achieve the transition to a regenerative growth model and to keep consumption within the planetary boundaries resulting in a cleaner and more competitive Europe (European Commission, 2020b). Although the Action Plan addresses a wide range of issues, it also puts the subject of FLW on the agenda. It announces concrete actions to be reviewed in 2019 in the context of the European Green Deal and the related Farm to Fork Strategy. The European Green Deal aims to lead the European Union towards the common goal of climate neutrality by 2050 (European Commission, 2019b). The Farm to Fork Strategy forms an integral part of the Green Deal by addressing the challenges of sustainable food systems and building food supply chains for consumers, producers, the climate and the environment (D'Angelo, 2023). Among five other priorities, the Farm to Fork strategy addresses measures to reduce FLW. However, there is a rather narrow focus on date marking, such as 'use by' and 'best before' labels, and a brief mention of quantifying FLW levels and assessing and preventing food loss at the production stage (European Commission, 2020a).

The 2018 amendment of the EU Waste Directive (European Parliament, 2018) requires all Member States to implement measures to reduce FLW within their national waste prevention programmes. Furthermore, EU Member States are obliged to develop regular monitoring with the aim of obtaining reliable figures and series of time spans on FLW within the EU, which has been launched in 2022 (European Parliament, 2018) (see also section 2.1.1). The Delegated Decision of the European Commission (2019a) subsequently specifies details of the underlying definitions and the monitoring methodology. In July 2023, the EU Commission proposed a further amendment to the Waste Directive, requiring to reduce FLW at the processing level by 10 % by 2030. For retail and consumption, the target is proposed to be lowered to 30 % by 2030 (European Commission, 2023b). The current Waste Directive and the Delegated Decision mainly focus on monitoring and data provision. In terms of actual reduction measures, the Waste Directive suggests awareness campaigns and incentives for charitable redistribution of food as potential solutions.

National legislation to combat FLW has also been adopted in several European countries, including France, Italy, Spain, Belgium and the Netherlands (Schanes et al., 2018; Soma et al., 2021). In France, supermarkets with an area of at least 400 square metres are not allowed to dispose of edible food, and since 2016 have been obliged to donate surplus food to charity (FAO, 2019; Porter, 2020). The so-called 'Loi Garot' (Assemblée nationale et le Sénat de la république française, 2016) gained international public and political attention due to its regulatory nature. For instance the Czech Republic and the State of California followed the French example by implementing a similar legislation (Mourad, 2023; Wissenschaftliche Dienste, 2019).

Market-based instruments that address food disposal include pay-as-you-throw (PAYT) systems and landfill and incineration taxes (Chalak et al., 2016). All of these policies aim to incentivise consumers or businesses to waste less by reducing the price of more sustainable prevention or recycling options in relation to the price of disposal. The PAYT approach has

been enacted in several European countries, in Asian countries such as China and Korea and in the United States and Canada (UNEP, 2014). The UK's Landfill Tax Credit scheme is an example of a landfill tax where the revenue is additionally used for environmental projects (UNEP, 2014). This approach is primarily aimed at diverting waste from landfill to recycling opportunities (Chalak et al., 2016), rather than promoting actual prevention. The diversion of biodegradable municipal waste from landfill has also been targeted by a more regulatory approach in the form of the EU Council Directive on the landfill of waste, which provides a phased plan (Council of the European Union, 1999).

Moreover, several countries have focused on the redistribution of surplus unmarketable food by facilitating food donation and enacting legislation to protect charities and other food donors from legal liability (FAO, 2014). The 'Bill Emerson Good Samaritan Food Donation Act' of 1996 and its recent extension, the 'Food Donation Improvement Act' of 2021 in the United States (Senate of the United States, 2021) and the Italian Good Samaritan Law of 2003 (Presidente della Republica, 2016) are common examples of such policies. These allow charities to be declared as end-users, reducing the stringency of legal requirements and controls in the transfer process (Gram-Hanssen, 2016). Donation facilitation is a reduction strategy that mainly addresses downstream stages of the supply chain, as there are several logistical challenges to donating produce at production level (Kinach et al., 2020). Soma et al. (2021) found that a high proportion of FLW interventions in Canada are charity-based and often fail to manage the surplus amount of food, when there is an oversupply in the market.

Cooperative policy instruments in the form of voluntary collective action are strategies for reducing FLW that have been applied in several countries (Burgos et al., 2019). They have become popular following the launch of the Courtauld Commitment in the UK in 2005. The Courtauld Commitment is an agreement between the government and the retail and manufacturing sectors that includes targets for reducing FLW (Porter, 2020; UNEP, 2014). In Germany, the Dialogue Forums at all stages of the food supply chain (as part of the National Strategy for the Reduction of Food Waste) also rely on the voluntary commitment of the respective actors to engage in the reduction of FLW (BMEL, 2019). At retail level, this has led to a voluntary commitment in Germany called the 'Pact against Food Waste' (BMEL, 2023).

In addition to voluntary agreements, there are policy interventions aiming to reduce FLW by providing information. These mainly target later stages of the supply chain, especially consumers (Schanes et al., 2018). Examples of international and national information and education campaigns are 'Think.Eat.Save. Reduce your Foodprint', 'Lebensmittel sind kostbar!' in Austria, 'Love Food Hate Waste' in the UK (ibid.) and 'Zu gut für die Tonne' in Germany (BMEL, 2019). In general, EU Member States use mainly soft instruments to reduce FLW, such as awareness-raising campaigns, round tables and networking activities (Priefer et al., 2016).

Scientific evaluations of national FLW policies remain scarce. A systematic evaluation of US policies has been carried out by ReFED (2016), based on marginal abatement cost curves for FLW reduction and highlighting the net benefits of the policies for businesses, consumers, the

public and private sectors. Cristóbal et al. (2018) have applied a prioritisation approach to potential policies under the assumption of a budget constraint and with the aim of maximising positive environmental impact of the policies. Their results highlight the need to set environmental impact targets, rather than targets related to the mass of FLW.

In general, there is a lack of evaluations regarding the effectiveness and efficiency of FLW policies, and those that do exist are often inaccurate due to insufficient data (see also section 2.1). Policy frameworks at international and EU level increasingly consider the reduction of FLW, and there is a variety of different national approaches. These approaches tend to be voluntary and often address downstream stages of the food supply chain.

2.3.2 Food loss and waste reduction efforts of the private sector

This section provides a summary overview of intervention measures to reduce FLW along the agri-food supply chain, i.e., measures that can be and are implemented by the actors in the value chain themselves. The focus is on the supply chain between primary production and retail, which is the subject of this thesis. The implementation of interventions depends on policy frameworks, so they cannot be fully isolated from their policy environment (see also section 2.3.1.).

There are various private sector interventions aimed at preventing and recycling FLW. A comparatively high density of research in this area can again be found in the field of consumption, as the review articles by Reynolds et al. (2019), Hebrok and Boks (2017) and van Geffen et al. (2020) show. In contrast, scientific evaluations of the effects from pre-harvest stage to the retailer's door are relatively scarce. It should be noted that this includes not only interventions that *take place* at these stages of the supply chain, but also interventions that may take place downstream but still *have an effect* on earlier stages of the supply chain. A family of interventions that is relatively well represented in practice and in scientific publications are those related to marketing standards and suboptimal products. This is an issue that is not only, but mainly, present in fruit and vegetables (see also section 2.2.3). These interventions include attempts to revise the visual requirements for fruit and vegetables, to increase consumer awareness and acceptance of suboptimal products and to develop marketing channels. In practice, there are business cases for marketing fruit and vegetables that do not meet specific visual criteria at retail level. Examples for marketing campaigns of three large German retailing companies are 'Bio-Helden' (organic heroes), 'Die krummen Dinger' (crooked things) and 'Die etwas Anderen' (the slightly different ones) (Aldi Süd, 2023; Kaufland, 2023; Rewe Group, 2023). The marketing of misshapen products in vegetable boxes and in the food service sector is also an existing practice, especially for organic products (Etepetete, 2023; Querfeld, 2023). There is a potential for marketing suboptimal items, as shown by scientific publications in this area (e.g., Louis and Lombart, 2018). In particular, there is potential for consumer acceptance if the shape and size variations are mild (Loebnitz et al., 2015). Combining suboptimal and regular foods in a package or sorting and emphasising their authenticity and naturalness has been shown to be an effective strategy (Hartmann et al., 2021; Qi et al., 2022). Appealing to

customers' value orientation, commitment to environmental sustainability and perceived environmental effectiveness are the basis for developing promising marketing tactics (de Hooge et al., 2017). Price reduction tactics are also effective, although aspects of refinancing such foods, as well as potential image effects of suboptimal products, should be considered (Aschemann-Witzel et al., 2020).

At the pre-retail stage, efforts are also being made to market products that do not meet visual criteria. For example, in Portugal, a non-profit cooperative called 'Fruta Feia' (ugly fruit) was created as a solution to this problem, commercialising the types of goods that farmers cannot sell through traditional channels (Ribeiro et al., 2018). In this case, Ribeiro et al. (2018) also evaluated the intervention using a life cycle assessment that included the economic, environmental and social pillars of sustainability. Another example at an earlier stage in the supply chain is the 'IssSo' label of the German producer organisation 'Landgard', which promotes the marketing of products that deviate from the norm due to unexpected environmental or weather conditions. A sustainability assessment of the initiative was carried out as part of the Dialogue Forum Primary Production (Lehn et al., 2023).

In addition to the marketing of fresh products, the processing of not only suboptimal but also surplus products is an intervention that potentially prevents food loss at producer level. Particularly for perishable products, such as fruit and vegetables, but also bakery and dairy products, it has the advantage of significantly extending shelf-life, thereby buffering mismatches between supply and demand. In recent years, retailers and start-ups have become active in this area. Examples include 'Rettergut' and 'Unverschwendet', which work with retailers in Germany and Austria to process and sell surplus and suboptimal food into chutneys, jams, pestos and other processed products (Rettergut, 2023; Unverschwendet, 2023). Mercadona in Spain has also introduced a concept of buying the whole harvest and processing the surplus into soups, jams and juices. UK retailer Tesco is applying the concept to the up-cycling of bakery products (Leimann and Brauer, 2020).

Another set of interventions involves the integrated management of supply chains and processes. This can be done through improved communication, collaboration and partnership building, as well as supporting technological innovation (Goossens et al., 2019). Optimised and automated forecasting and ordering tools that help predict demand more accurately can be effective in avoiding overproduction (Aramyan et al., 2021). These not only allow for the reduction of food waste in stores, but also prevent rejections and surpluses in production and processing. Platforms that connect surplus production with potential customers are another innovative solution to market surpluses. Leroma is one such start-up that aims to connect producers with industry and make surplus available in the form of a digital 'surplus exchange' (Lehn et al., 2023).

Technological improvements in storage, logistics and cold chain management are also part of an integrated supply chain management. This includes appropriate storage infrastructure, drying facilities, temperature control systems for perishable products and tools to monitor storage and transport conditions (Shafiee-Jood and Cai, 2016). Intelligent climate control

systems to improve storage offer an opportunity to reduce food loss (Aramyan et al., 2021). However, it should be noted that technologies in this regard are already quite advanced in the Global North as compared to the Global South, which limits the potential for improvement in these regions of the world (Shafiee-Jood and Cai, 2016).

Although it is not a business case, donating products directly from the producer or supplier may be an approach to reducing food loss before retail. An advantage of such a practice might be the avoidance of disposal costs. The donation of surplus produce directly from the field, which is then harvested by volunteers, is referred to as 'gleaning' (Johnson et al., 2018a). In Germany, an example is the initiative 'Gelbes Band' (yellow ribbon). The campaign aims to encourage people to mark their own fruit trees with a ribbon to make excess fruit available for collection. One challenge is that the mostly fluctuating amounts of excess produce by far exceed the capacity of gleaning volunteers (Johnson et al., 2018a). In addition, gleaning activities may be limited by persistent negative perceptions (Johnson et al., 2019).

Although by-product valorisation is not an approach to reducing food loss, it can be a means of improving the sustainability of the supply chain. According to the food waste hierarchy (Papargyropoulou et al., 2014), food recycling and recovery are less favourable options compared to prevention. This includes the conversion of edible food and inedible parts of crops into food and non-food products. Whether or not FLW is avoided by definition depends on the valorisation option and the definition used (see also section 2.1). Eriksson et al. (2021) provide an example of the valorisation of inedible broccoli leaves into a powder for soups. By replacing more resource-intensive ingredients in regular soups, the life cycle assessment shows a positive environmental impact of this intervention. To achieve a net positive environmental effect, valorisation should be applied with the aim of producing products that can potentially *replace* goods and services (Eriksson et al., 2015).

For all of these prevention strategies, it is important to consider that there may be significant potential to reduce FLW, but this must be balanced against the economic losses associated with implementing these measures. An example is provided by Eriksson et al. (2016), who showed that increasing storage temperatures successfully reduced the amount of food waste in stores. In this case, the net economic outcome as well as the net GHG emissions, which include increased energy consumption, depend on the product. According to Caldeira et al. (2019b), it is therefore essential to evaluate FLW prevention activities and not only to assess the associated benefits, but also to identify possible trade-offs. The authors propose a framework for evaluating FLW prevention efforts in the EU based on the key performance indicators of effectiveness, efficiency, relevance, coherence and EU-added-value. Caldeira et al. (2019b) add that detailed data to calculate net economic, environmental and social impacts are often lacking. As a result, scientific evaluations of private sector efforts to reduce FLW in terms of their economic, environmental and social impacts, are often absent or inadequate (Goossens et al., 2019).

Overall, private sector actors are engaged in a variety of activities to reduce FLW at different stages. However, there are barriers to the implementation and financing of such activities.

3 Methodology

This thesis uses qualitative and quantitative methods of empirical social science. 22 qualitative expert interviews with actors (producers, producer organisations and retailers) in fruit and vegetable supply chains in Germany form the first part of the empirics. An additional case study based on five preliminary expert interviews and a survey with 215 suppliers of a retailing company from Germany, Italy and Spain forms the second part. Article 1 is based on the 22 expert interviews mentioned above, article 2 has its empirical basis in the case study and article 3 uses data from both surveys. The actual methodological implementation is described in the scientific articles in sections 4.1, 4.2 and 4.3. This chapter is more concerned with the basic study design, motivations for the choice of methods and the background for the application of the methods. The process of choosing scientific methods for data acquisition and analysis is shown in Figure 2. Chapter 3 is divided into the overall study design, the fieldwork and the analysis of the collected data, with the latter two subdivided into the qualitative and quantitative approach.

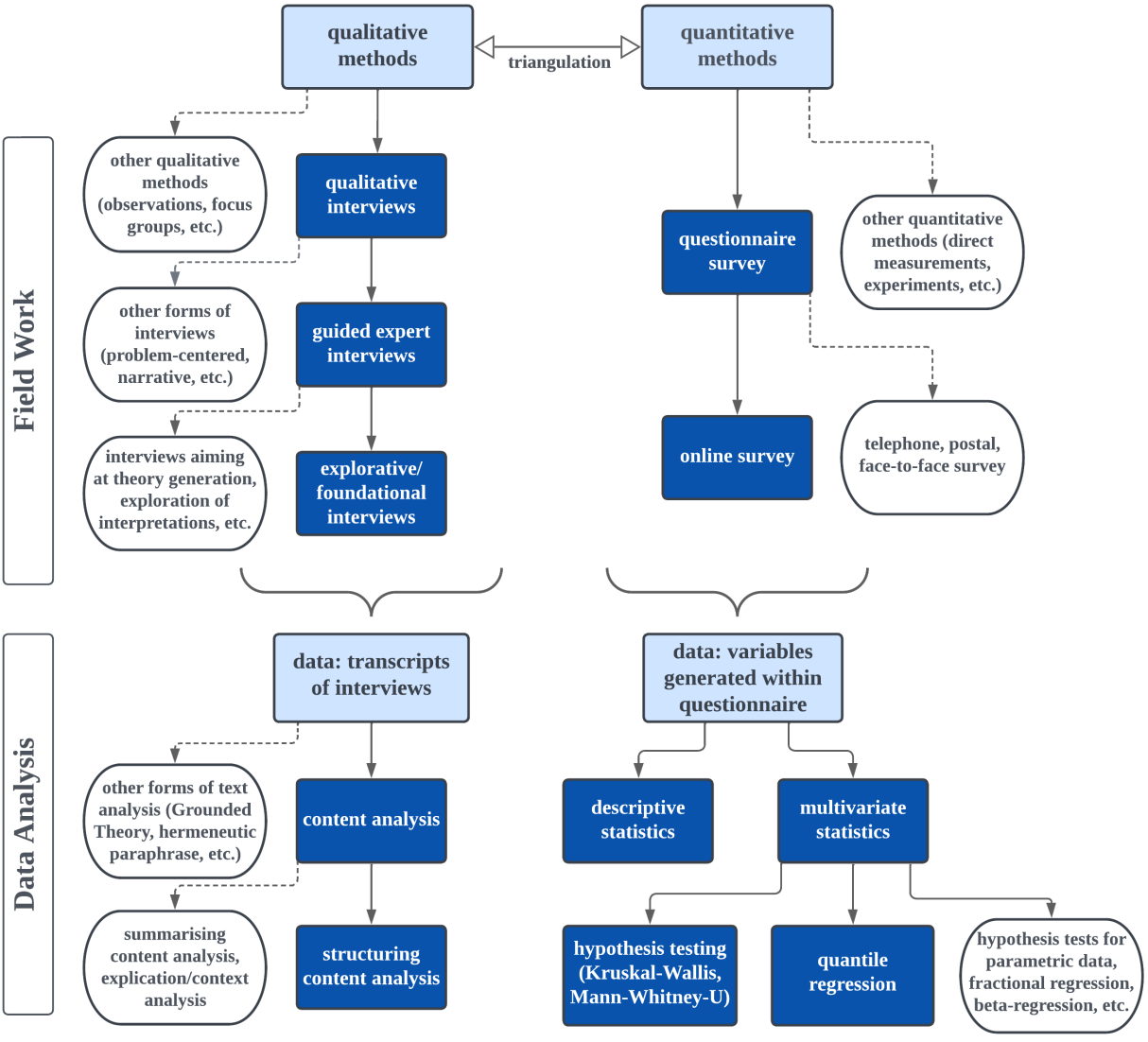

Figure 2 Methods of data collection and analysis chosen for the thesis (blue background) versus other potential methods (white background)

Source: own elaboration

3.1 Overall study design and research strategy

Addressing the research objectives of this thesis requires the study of social dynamics, human behaviour and decision-making processes. It therefore requires an in-depth understanding of the social factors that influence the occurrence of food loss. Through the use of empirical social research methods, namely interviews and questionnaires, this thesis aims to shed light on the underlying dynamics that contribute to its occurrence and potential mitigation strategies. Furthermore, existing primary data on FLW, particularly in the early stages of the supply chain, is scarce, limiting the range of methodological approaches that can be applied. This section briefly introduces qualitative and quantitative research methods, the application of which is based on epistemological and ontological considerations and provides background information on how they can be combined within a study design.

From an epistemological perspective, the question arises as to what is or should be regarded as acceptable knowledge (Bryman, 2016). This thesis follows the research philosophies of critical realism, but also partly positivism. In critical realism, a mainstay is that generative mechanisms constitute phenomena (Bhaskar, 1989). Critical realism aims to identify the mechanisms that generate events, although these mechanisms may not be directly observable and only become apparent through the practical and theoretical work of social science (ibid.). From the standpoint of critical realism, concepts do not directly reflect reality (as is the case in positivist thinking), but are rather a way of knowing that reality (Bryman, 2016). Context is therefore crucial to understanding the conditions that facilitate or hinder these causal mechanisms. The term 'critical' describes the potential to change a certain status quo based on the identification of a generative mechanism (ibid.).

When it comes to quantifying observable outcomes, rather than identifying mechanisms, the thesis also applies a positivist approach that sees social science as closer to the natural sciences. In this philosophy of research, facts are gathered as the basis for laws and theory is used as a means of formulating hypotheses to be tested (ibid.).

From an ontological perspective, which is concerned with the nature of social entities, the thesis aims to combine objectivist and constructivist viewpoints. It moves between the viewpoints that on the one hand social phenomena can be seen as external facts, and on the other hand as continuously produced by social interactions of actors (ibid.).

These onto-epistemological considerations give rise to the qualitative and quantitative fields of research, which are briefly outlined below. The field of qualitative research was inspired by ethnological research and studies of urban sociology and social anthropology (Kelle, 2019). It involves open and non-hypothesis-driven, non-standardised approaches that consider rapidly changing and heterogeneous patterns, structures and social circumstances (ibid). Qualitative research is concerned with concrete human actions that emerge from a particular history and context, are embedded in society and are based on peoples' attributions of meaning and interpretations (Reichertz, 2019).

Qualitative research often follows a constructivist paradigm (Flick, 2009), which assumes that perceptions of the world and knowledge are themselves constructs. Social constructivism is concerned with perception, knowledge and conventions in everyday life and also sees scientific findings as social constructs. This means that research participants produce objects and realities through the meanings they assign to these objects and realities (ibid.).

In qualitative research, texts often form the data basis. These can be seen as representations of reality and reconstructions of social reality. Theories are versions of the world that are developed in an abductive way during the research process (ibid). The process of abduction, which is common in qualitative research, refers to the compilation and discovery of combinations of characteristics during data interpretation for which there is no existing rule or explanation yet, thus generating new insights (Reichertz, 2019).

Unlike qualitative methods, quantitative methods emerged in the 19th century with the aim of explaining macro-phenomena using standardised measuring instruments and samples (Kelle, 2019). It follows the principles that social orders and actions are subject to universal rules which are directly or indirectly observable. In this way of thinking, findings can be measured and tested and theories on them can be developed (Reichertz, 2019). It is about deriving knowledge by testing hypotheses and getting as close to the 'truth' as possible (ibid.). This is close to the positivist paradigm, which assumes that knowledge is confirmed by the senses, that theories generate testable hypotheses and that the collection of facts is the basis of knowledge (Flick, 2009).

In quantitative research, measuring tools are used to obtain numerical data and induction is used to find orders and rules in the data and to generalise them. Quantitative induction refers to the process of extrapolating the characteristics of a sample to the population as a whole (Reichertz, 2019).

Quantitative and qualitative research are seen by some as two distinct research cultures and it should be questioned whether a crossing or blending of these cultures leads to greater data validity and quality, or merely to a greater variety of methods (Reichertz, 2019). One concern is that the qualitative tradition, which calls for openness on the object of research, is difficult to reconcile with the formulation of precise hypotheses and standardised instruments (Kelle, 2019). The concepts of triangulation and mixed-methods help to truly diversify perspectives and improve the quality of research by combining qualitative and quantitative research methods. The fieldwork and surveys of this thesis follow the concept of triangulation (Denzin, 1970). In qualitative research, the classical quality criteria of reliability (identical outcome/stability of results), validity (whether the instrument measures what it is supposed to measure and whether the results are valid outside the sample population) and objectivity (independence from the researcher's perspective) are only partially applicable (Flick, 2019). Triangulation as a means of validating scientific findings was first discussed by Denzin (1970) as more than just a quality check on findings. In this context, the concern is raised that the findings of qualitative and quantitative research at best complement each other, but do not necessarily correspond or contradict each other, which would be a prerequisite for the validation

of findings (Kelle, 2019). Triangulation can therefore be seen as a broad knowledge strategy and a central component of a research project, enabling a deep understanding of the complexity of what is being studied by broadening methodological and theoretical perspectives (Flick, 2019). It also serves to complement perspectives and compensate for the weaknesses of different methodologies (ibid.).

Different forms of triangulation exist: Triangulation of methods, data, researchers and theory. The central concept is triangulation of methods, which aims to approach a research object from different perspectives using different research methods (ibid.). This thesis applies triangulation of data by using qualitative and quantitative methods within the thesis as a whole, but also within the case study itself (article 2). The triangulation of methods in this case leads directly to a triangulation of data, as different data sets are obtained as a result of qualitative interviews and quantitative questionnaires. A triangulation of researchers in carrying out data collection and analysis is applied in the case study (article 2). Triangulation of theories, i.e., approaching the research field from different theoretical perspectives (Flick, 2019), is provided by the integration of classical economic and sociological theories in the frame of article 1. Section 2.2.2 moreover provides further theoretical approaches to the field of research in which the findings on power and food loss are embedded.

Similarly, the concept of 'mixed methods' aims to complement the strengths and weaknesses of methodological approaches (Kelle, 2019). More narrowly defined than triangulation, mixed methods refers to the combination of qualitative and quantitative methods within a research design, which have long been used separately as distinct methodological traditions and schools of thought (ibid.). Flick (2009) argues that the *actual combination* of qualitative and quantitative methods remains a challenge and more often a *linking of results* of these methods within a study takes place.

In summary, depending on the onto-epistemological underpinnings of the research being conducted, a design that combines qualitative and quantitative methods may be appropriate. In this case, the aim is to take advantage of the above-mentioned benefits of both approaches in addressing the research objectives. However, their combination, or triangulation, needs to be approached with caution, contemplating different understandings of knowledge generation and data quality verification.

3.2 Fieldwork and surveys

In terms of the sequence of qualitative and quantitative fieldwork, different sequences can be envisaged, depending on the research objectives. One advantage of qualitative fieldwork followed by a quantitative questionnaire is that the qualitative, in-depth exploration of the field allows more specific hypotheses to be tested in a questionnaire (Flick, 2009; Kelle, 2019). This is the case in this thesis, where the sequence of methodological approaches aims to understand the mechanisms behind the generation of food loss in upstream fruit and vegetable supply chains first. This lays the foundation for a more precise quantitative questionnaire in the context of a case study.

3.2.1 Qualitative survey: expert interviews

In-depth qualitative expert interviews form an integral part of the data collection for this thesis. A number of in-depth interviews with producers, producer organisations and retailers were conducted in the first part of the fieldwork (article 1 and article 3) and preliminary expert interviews were conducted in the case study (article 2). This section explains what constitutes an expert and an expert interview, the types of knowledge gathered in expert interviews, the development of an interview guide and the corresponding sampling strategies.

The decision to conduct systematising expert interviews

Expert interviews are defined on the basis of their subject of interest rather than on the basis of specific methodological procedures. In the frame of expert interviews, experts are less interesting as a person, but rather their skills and knowledge in a certain field are of interest to the researcher (Helfferich, 2019). Experts therefore do not represent an individual case, but a particular group, and it can be assumed that their expertise can be separated from the person and generalised to a certain extent (not to be confused with complete objectivity of the experts) (ibid.). The question of who can be considered an expert is controversial. Przyborski and Wohlrab-Sahr (2019) define experts as people, who have specific role knowledge and claim special competences based on it, while this knowledge is also attributed to them by others. Being an expert is therefore not a personal characteristic, but an attribution and a construct of the researcher and society (Bogner et al., 2014). Expert interviews, therefore, have a specific framing by addressing the expert in a distinct role rather than his or her personal experience (Helfferich, 2019).

The knowledge gathered in the frame of expert interviews has been controversially discussed in the sociology of knowledge (Bogner et al., 2014). This knowledge ranges from insider knowledge of institutional processes, to knowledge of backgrounds and contexts that are difficult to access to tacit or implicit knowledge of organisational cultures (Helfferich, 2019). In the following, we will take a closer look at the different types of knowledge.

The decision to conduct guided expert interviews is based on the described epistemological interest and the pursuit of certain types of knowledge in this thesis, combined with the difficulty of accessing data due to the dual sensitivity of the research topic. The sensitivity lies in the combination of the issues of FLW and market power, which easily trigger negative connotations among participants. This complicates data access in the sense that documents relating to contractual terms, agreements between supply chain actors and FLW figures, even if they exist, are not voluntarily made available to researchers for document analysis or secondary data analysis.

The types of knowledge generated by conducting guided expert interviews are explained below with reference to Bogner et al. (2014). Accordingly, the knowledge generated by expert interviews can be divided into technical knowledge, process knowledge and interpretive knowledge. Technical knowledge describes facts to which experts may have privileged access and the researcher does not. Process knowledge is a form of experiential knowledge rather than

factual knowledge and refers to the understanding of the relationships, organisational structures and activities. In this respect, respondents may have a knowledge advantage by virtue of experience and close personal proximity. Interpretive knowledge is normative and subjective rather than factual, and in this case the expert cannot be considered to have a knowledge advantage. Interpretive knowledge involves individual views, interpretations and explanatory patterns of the expert (Bogner et al., 2014). The expert interviews in the frame of this thesis cover all three kinds of knowledge. When asking an expert about the relationship between food loss and UTPs, technical knowledge about what is written in contracts and agreements may be relevant. At the same time, process knowledge about how the business relationship is conducted in practice may be important, as well as interpretive knowledge about how different actors perceive certain practices. The focus of the expert interviews of this thesis is on technical knowledge and process knowledge. According to Bogner et al. (2014), technical knowledge should only be collected through interviews if there is no other way to obtain the information, which is the case for many confidential aspects related to the research topic. Process knowledge is needed to understand the mechanisms and actions involved in supply chain management and business relationships. Whether the knowledge is technical, process-oriented or interpretive is also determined by the researcher, taking into account the specific interview environment and circumstances (Bogner et al., 2014). For all forms of knowledge, it is important to note that there is no such thing as an idealised authentic response that can be elicited through interviews. Rather, the qualitative interview seeks to understand social systems of meaning and therefore does not require authentic answers, but rather captures personal realities that are true for the interviewee at the time of the narrative (Helfferich, 2019). However, this requires constant reflection on the setting and circumstances in which the interview took place and how this may have influenced the response, of which the interviewers are always co-producers (ibid.).

The interviews that form the basis of this thesis are somewhere in between exploratory and foundational, but rather on the side of foundational. Theories and empirical evidence are already at hand (see also section 2.2.2), which should be thoroughly related to the present research objectives, rather than actually generating new theoretical insights. Therefore, according to Bogner et al. (2014), the method applied in this thesis follows the approach of a *systematising* expert interview. Its purpose is to determine the expert's understanding of the research topic, to obtain information and to gain in-depth analytical knowledge, with the expert acting as an 'advisor'(ibid.).

The interview guide

The degree of structuring of the interview depends on whether meaning structures are to be reconstructed or whether concrete information on specific content is to be gathered (Helfferich, 2019). The interest in expert interviews is often related to the collection of factual or technical knowledge (Bogner et al., 2014). Therefore, on a continuum from highly structured to completely open, the corresponding guide is often more structured through the use of stimuli and factual questions (Helfferich, 2019).

An argument against a high degree of structuring is that certain concepts and terminologies are presupposed, leaving little room for divergent perceptions and interpretations. For example, in the case of this thesis the terminology and definition of FLW is somewhat presupposed. A high degree of structuring is thus in some ways at odds with 'openness' as a key concept in qualitative interviews. Openness in this case means that participants should be able to highlight what they consider important using their own terminology (ibid.).

The advantages of structuring interviews are that the resulting interview material may be more relevant to the research questions and it may be easier to compare interviews (ibid.). Openness may therefore be restricted in the name of research interest and relevance to a particular topic. According to Helfferich (2019), interviews should be as open as possible and at the same time as structured as necessary. In terms of interest in technical and process knowledge, the interview guide in this thesis is quite strongly structured, following the suggestions of Helfferich (2019) and Bogner et al. (2014).

Each thematic block of an interview guide usually contains a main question that serves as a central narrative stimulus. It should also include optional inquiries adapted to the course of the interview and the aspects that have already been mentioned (Bogner et al., 2014). According to Baur and Blasius (2019), different types of questions that aim at attitudes, facts and knowledge, behavioural intentions, social statistical characteristics or issues related to networks may be included. Adjustments to the interview guide may be made even after some interviews have already been conducted, to include information already gathered. Adjustments specific to the interviewee or the expert's function may also be necessary (Bogner et al., 2014). Both types of adjustments to the interview guide were made in the expert interviews of this thesis in order to improve the comprehension of the questions and to reflect the different types of experts involved, namely farmers, producer organisations and retailers. For example, while farmers were asked about their distribution channels, retailers were asked about their procurement channels, in line with the research interest in the pre-retail supply chain. An exemplary interview guide can be found in the supplementary material of article 1.

Sampling strategy

In qualitative research designs, there are several non-probability sampling methods that allow for non-random sample selection based on certain criteria (Akremi, 2019). This thesis uses a combination of criteria-based conscious selection following the principle of quota sampling on the one hand and snowball sampling on the other hand (ibid.). The practical selection of participants is described in more detail in article 1. In general, experts with knowledge of processes in upstream fruit and vegetable supply chains were recruited, i.e., fruit and vegetable farmers, producer organisations and representatives of retail companies. The quota plan (see also Akremi, 2019) provided for a balanced number of participants in the three expert groups, which had different criteria in terms of region, crops, company or size of the organisation and function of the interviewee in the company. In particular, for the diverse and large group of farmers, personal contacts enabled further potential contacts to be recruited through snowball sampling (Rubin, 2021). The number of interviews conducted is based on the principle of

content saturation. This suggests that data collection should stop when content has been raised repeatedly and the researcher is confident that additional data collection will not lead to additional insights (Saunders et al., 2018).

This section has provided background information on expert interviews, the development of an interview guide and sampling strategies. The following section outlines the methodological basis for the quantitative data collection of this thesis, before moving on to the analysis of the interview data in section 3.3.1.

3.2.2 Quantitative survey: Online questionnaire

A quantitative online survey of suppliers to a retail company forms the second part of the data collection. This serves as the exclusive database for article 2 and part of the database for article 3 included in this thesis (sections 4.2 and 4.3). This section explains why this particular method was chosen, the advantages and disadvantages of (online) questionnaires and what had to be and was considered in the process of its application.

In general, the standardised survey can be regarded as a classic instrument of data collection in social and economic sciences. It aims to keep circumstances constant and applies a high degree of standardisation to the wording of the questions, the response options and the order in which the questions are asked (Reinecke, 2019).

The decision to conduct an online-questionnaire survey

A practical argument for using a questionnaire survey in relation to the research interest of this thesis is the lack of existing data and resources to carry out a direct measurement of food loss in the field and the supply chain. Direct measurement of food loss is the more accurate method as compared to quantification using a questionnaire (Xue et al., 2017). For example, Baker et al. (2019) report that actual measured field loss exceeds farmer estimates by 157 %. Nevertheless, questionnaires are able to cover much larger and regionally unbounded samples with the same financial and labour resources, resulting in a trade-off between accuracy and sample size or scope. The questionnaire survey of this thesis covers 30 % of the suppliers of a retailer in three countries (Germany, Italy and Spain) with an average produced/traded volume of 15,820 tonnes/year. The direct measurements of Baker et al. (2019) and Johnson et al. (2018b), for example, were only able to capture 123 in-field surveys in northern and central California and nine farms of eight vegetable crops in North Carolina, respectively.

Another very relevant argument in favour of conducting a questionnaire survey is that it enables not only to quantify food loss (in this case food loss due to a retailer's quality requirements), but also to survey the perceptions, behaviours and attitudes of the participants (Xue et al., 2017).

Online-surveys in particular have a number of advantages and disadvantages compared to telephone, postal and face-to-face surveys. Advantages are their timely and geographically unboundedness, the omission of interviewer-effects, automatic filtering possibilities as well as completeness and plausibility checks (Wagner-Schelewsky and Hering, 2019). They also raise the potential for error prevention and offer less financial as well as work and time

expenditure (ibid.). These advantages suit the rather short but geographically broad study and the questionnaire with complicated filtering. Given the highly sensitive topics of retailer requirements and food loss, it may have been beneficial to conduct the survey without direct communication to reduce potential bias (Reinecke, 2019). The disadvantage of technical barriers, as described by Wagner-Schelewsky and Hering (2019), could be neglected as the target population of direct suppliers can be assumed to be sufficiently internet-savvy to participate in the survey. The potential disadvantage of low exploitation rates was avoided as the retailer and agencies constantly and personally reminded suppliers to complete the questionnaire. However, the problem of social decontextualisation must be taken into account when interpreting the data. It refers to the case where responses are less transferable to everyday social action because personal motives become more important to the respondent than social ones when answering the online survey (Wagner-Schelewsky and Hering, 2019).

Development of the questionnaire

The questionnaire was development based on guiding principles of standardised surveys suggested by Porst (2014) and Lenzner and Menold (2015). According to Reinecke (2019) different forms of questions can be used to collect attitudes and value orientation, knowledge and facts, events, behavioural intentions and actual behaviour, characteristics of the respondents and network information. Accordingly, attitudes can be measured as items on a rating scale (Likert scale), which was used, for instance, to measure attitudes towards options for action. The use of endpoint named Likert scales makes it possible to assume that respondents consider the distances between answer options to be the same. Therefore the resulting variables can be considered to be interval scaled (Porst, 2014). Facts and knowledge can be assessed using two or more response categories (Reinecke, 2019), which was applied, for example, with respect to questions concerning the setting of product specifications.

Network questions aim to obtain information on the relationships of the respondents, in this case on sourcing and supply networks (Reinecke, 2019). These types of questions can be either closed, hybrid or open-ended, depending on how much is known in advance about the universe of possible responses, and depending on practical data analysis considerations (Porst, 2014; Reinecke, 2019). Question types range from dichotomous, over multiple-choice, numerical continuous, categorical and rank-order to matrix table questions, almost all of which were used in the survey of this thesis. When developing questionnaires and items the collection of manifest and latent variables needs to be considered. Manifest variables are directly measurable and describe observable characteristics, whereas latent variables are not directly observable and result from the interrelation of manifest variables (Baur and Blasius, 2019). In the case of the present survey, no operationalisation of latent constructs is required, since the questionnaire mainly targets manifest variables.

Pre-testing of the questionnaire

An essential aspect of ensuring data quality is the pre-testing of the questionnaire, which aims to check the wording of questions and response options, the questionnaire as a whole and its technical implementation (Diekmann, 2007). Questionnaires cannot be adapted after

implementation due to their high degree of standardisation compared to interview guides, which makes their testing an important issue (ibid.). The quality criteria of objectivity, validity and reliability are more straightforward in quantitative research and the respondent's understanding of a questionnaire contributes to the achievement or non-achievement of these quality criteria (ibid.). In the case of this thesis, informal pre-testing took place in discussions with colleagues and experts during the development of the questionnaire, as well as pre-testing in the field with members of the target group as described by Weichbold (2019). In addition, the distribution of responses and potential comprehension difficulties were checked based on the results of pre-testing with members of the target group. However, more advanced pre-testing techniques and several pre-test runs were not feasible due to time constraints and delays within the project.

Sampling strategy

The last aspect that should be mentioned in connection with questionnaire surveys is the sampling strategy. A sample is meant to represent the population in terms of selected characteristics, which enables the researcher to statistically infer results from the sample to the population (Heumann et al., 2017). However, 'representativity' is not a mathematically defined term but rather generally describes how well the population is reflected in the sample (Häder and Häder, 2019). The sample size is based on the required confidence interval (ibid.). Different kinds of random samples exist in which all elements of a population have a probability to become an element of the sample which is larger than zero; strictly spoken only in this particular case can methods aiming at statistical inference be applied (Diekmann, 2007). The simple random sample (SRS) describes a list-based selection including all elements of the target population (Diekmann, 2007; Häder and Häder, 2019). The stratified random sample is interested in certain sub-populations that should be represented within the sample proportional to the population (Häder and Häder, 2019). Self-recruiting, as it is the case in convenience samples, can be a problem as interest and time are constraints for participating in a study that can result in bias and sampling error (ibid.). In the questionnaire part of this thesis, the questionnaire was sent to the total population of the retailer's suppliers, which is relatively small with less than 800 potential respondents (see also supplementary material 13 of article 2). A sampling error due to self-selection cannot be excluded. On receipt, the representativeness of the sample was checked and for certain characteristics, such as country, crop and supplier type, the sample reflects the population relatively well. However, there is no information on other potentially relevant characteristics of the population, such as the size and turnover of the organisations and farms. Therefore, sampling errors cannot be excluded for these characteristics.

The preliminary considerations regarding the use of a questionnaire and its implementation have now been explained. The very different methodological approaches to qualitative and quantitative research described in this section require very different data analysis techniques, which are described in the following section 3.3.

3.3 Data analysis

In the following, the data analysis methods used in the context of the thesis are explained. The section is divided into the evaluation of the expert interviews using content analysis and the descriptive and multivariate statistics for the evaluation of the questionnaire data. The methods actually used are compared with other potential evaluation methods (Figure 2) and their choice is justified on a scientific basis.

3.3.1 Approaches to qualitative content analysis

Content analysis of interview data in the frame of this thesis is mainly based on the guidance by Udo Kuckartz (Kuckartz, 2018; Kuckartz and Rädiker, 2019), which is closely related to the guidance of Philipp Mayring (Mayring, 2015; Mayring and Fenzl, 2019), co-founder of qualitative content analysis. It is a frequently used method of data analysis that can generally be applied to different types of textual data, such as transcripts of interviews and focus groups, open-ended questions in standardised surveys, observation protocols, documents or newspaper and internet articles (Mayring and Fenzl, 2019). Externally, qualitative content analysis must be distinguished from other methods of textual analysis, such as the Grounded Theory research style, objective hermeneutics, social science hermeneutic paraphrase and psychoanalytic text interpretation, which are much more open and interpretive methods, follow different research aims and do not necessarily require a coding system (Mayring and Fenzl, 2019; Strübing, 2019). Internally, content analysis methods can be differentiated into *summarising* content analysis, *explication/context* analysis and *structuring* content analysis (Mayring and Fenzl, 2019). A key aspect of summarising content analysis is the creation of content-based paraphrases and their gradual reduction through summarisation. Context analysis deals with unclear text passages and analyses their context based on pre-defined explanatory material (ibid.).

The following provides background information on the method of *structuring* content analysis, as this is the method used in this thesis. It is characterised by strict rule-based category formation (ibid) and can be successfully applied to guided interviews (Kuckartz, 2018). The category or code system in structuring content analysis, in which codes can be structured hierarchically, is the basic tool of evaluation (Mayring, 2015). In general, the coding system is used to systematically organise large amounts of text. This can be done either deductively or inductively (Kuckartz, 2018; Mayring, 2015). Deductive coding means that the coding system is derived before working with the textual material. This involves deriving codes from theories, background information, hypotheses and the interview guide before starting to code (Kuckartz, 2018). Inductive coding is a circular and iterative process in which the code system is developed based on the content of the text material itself while coding and working with the material (Kuckartz, 2018; Mayring, 2015). Both approaches have been combined in the context of this thesis in a deductive-inductive approach, as offered as an option by Kuckartz (2018). In both cases, one principle to ensure the greatest possible intersubjective verifiability is the creation of a coding guide, including definitions, anchor examples and coding rules for each code (Mayring, 2015). Another way to improve the quality of the coding system is to assess intra-

and intercoder reliability (ibid.). This involves multiple coding of the textual material by one or more researchers. Due to the extensive text material of 22 hours collected in the context of this thesis, the assessment of intra- and intercoder reliability was not manageable given the limited resources. The actual evaluation of the material using MaxQDA software, which was mainly based on qualitative comparison of cases and groups (Kuckartz and Rädiker, 2019), is described in more detail in articles 1 and 3 (sections 4.1 and 4.3).

3.3.2 Analysis of questionnaire data

The analysis of the survey data has several objectives. One is to derive estimates of the loss of fruit and vegetables caused by the quality standards of a retailing company. It also aims to learn more about the drivers of food loss in general and compared to specific quality standards as a driver of food loss for selected fruit and vegetables. Finally, the analysis aims to determine whether suppliers have high loss rates due to quality standards or not and what the influencing factors might be. This section provides general background information on the statistical analysis of the questionnaire data, while the actual implementation is described in article 2 included in this thesis (section 4.2).

Univariate analysis of the questionnaire data in the frame of this thesis include frequency tables and measures of central tendency and variation (mean, median, range). Graphical representations such as histograms and box plots were used to estimate the distribution of variable values. This was done using measures of the different moments of this distribution, such as the median, interquartile range and range of the data without outliers. Univariate measures are important to get a feel for the data and to provide guidance for further parametric or non-parametric approaches (Stockemer, 2019).

First, the relationship between categorical variables or groups and the outcome variables of interest was analysed. Here, the aim is to compare groups and analyse whether the difference between them deviates significantly from zero (two-sample problems with unpaired data and two-sided hypotheses) (Heumann et al., 2017).

Since the variables of interest are not normally distributed and their transformation is hampered by a relatively high number of natural zeros, non-parametric approaches were used. The non-parametric Mann-Whitney U test and Kruskal-Wallis test were applied for comparison of two and more than two groups respectively. These non-parametric methods compare ranks in skewed distributions (Heumann et al., 2017; Kvam and Vidakovic, 2007). For the Mann-Whitney U-Test of group equality, the null hypothesis states that the probability of a randomly drawn observation from the first population having a value x greater than or less than the value y of a randomly drawn subject from the second population is one half (Heumann et al., 2017). The test compares the entire distribution and checks whether there is a location shift of one distribution to the left or to the right, which would require the null hypothesis of equal groups to be rejected (ibid.).

The Kruskal-Wallis test can be used equivalently to compare more than two samples; it tests the null hypothesis in that the distribution functions of all populations are identical (Kvam and

Vidakovic, 2007). Unlike analysis of variance (ANOVA), the Kruskal-Wallis test places no restrictions on the distribution from which the observations come (Kruskal and Wallis, 1952; Kvam and Vidakovic, 2007).

In addition, correlation analysis was used to test for positive or negative relationships between variables. Correlation analysis can be used to assess bivariate relationships between continuous variables (Stockemer, 2019). The Pearson correlation coefficient only reflects the linear relationship between variables (ibid.).

Regression analysis is more generally able to determine the strength of the relationship between the regressors and the dependent variable, as indicated by the steepness of the slope. In multiple regression, more than one regressor determines partial relationships. Multiple regression allows for the partial relationships between predictors and the dependent variable to be compared. Regression analysis was therefore used to assess the influence of selected supplier characteristics on the proportion of products that do not meet retailer requirements as well as on the proportion of products that become food loss due to retailer requirements (ibid.) (article 2). Such supplier characteristics include the country of origin, the supplier type (farmer, producer organisation or trader) and the crop supplied.

For this purpose, quantile regression was used, an approach introduced by Koenker and Bassett (1978). It allows to focus on certain segments of the conditional distribution analysed, or on upper and lower quantiles, without having to consider strict parametric assumptions (Buhai, 2004). It also allows to determine the effect of covariates on the entire conditional distribution rather than on the conditional mean and is robust to non-normal distributions and outliers (Buhai, 2004; Koenker and Bassett, 1978). This is useful in the case of the data used, which is described in more detail in article 2 and its supplementary material. Whereas classical linear regression methods minimise the sums of squared residuals and estimate conditional mean functions, quantile regression minimises asymmetrically weighted absolute residuals and estimates conditional median functions (Buhai, 2004). Thus, least squares regression is concerned with the dependence of the conditional mean of the dependent variable on the covariates. In contrast, quantile regression looks at each quantile of the conditional distribution and can therefore give a more complete picture of how the conditional distribution of the response variable depends on the predictors (ibid.). Quantile regression captures increasing dispersion or heteroscedasticity and is able to analyse the sources of heterogeneity in the outcome in relation to the covariates (Koenker, 2005).

Other useful regression approaches could have been beta regression (Ferrari and Cribari-Neto, 2004) or fractional regression (Papke and Wooldridge, 1996; Ramalho et al., 2011). These are suitable for situations where the dependent variable is continuous and bounded between zero and one (Ferrari and Cribari-Neto, 2004). This is the case for the present independent variables, which are proportions of one hundred percent. A linear regression approach would not be robust in this case, as it could predict response values that exceed the lower and upper bounds (ibid.). Fractional regression has the advantage of performing well when the response variable takes values at the bounds. This is the case for the two dependent variables, which can indeed take

on the values of zero or one. This indicates that the proportion of fruit and vegetables not meeting the retailer requirements or the proportion of food loss is estimated by the suppliers to be zero or one hundred percent. However, as these models are extensions of generalised linear models (GLM), they do not offer the above-mentioned advantages of quantile regression models with respect to non-Gaussian settings.

The analysis of the questionnaire data, underpinned by methodological principles in this chapter, is presented in more detail in articles 2 and 3, contained in the following sections 4.2 and 4.3.

4 Selected journal articles

This cumulative thesis consists of three scientific articles, which are included as sections of this chapter. The articles have been published or are currently under review in different scientific journals (Table 5). They address different aspects of the issue of fruit and vegetable loss in upstream supply chains.

Table 5 Selected articles of the thesis with journal (incl. status of submission) and authors, as well as other relevant publications of the author not included in this thesis

Article	Title	Journal	Authors
1	Market power and food loss at the producer-retailer interface of fruit and vegetable supply chains in Germany	published in *Sustainability Science* (Herzberg et al., 2022)	Ronja Herzberg Thomas Schmidt Markus Keck
2	Product specifications and business practices as food loss drivers – a case study of a retailer's upstream fruit and vegetable supply chains	published in *Journal of Cleaner Production* (Herzberg et al., 2023b)	Ronja Herzberg Anika Trebbin Felicitas Schneider
3	Policy instruments to reduce food loss prior to retail – perspectives of fruit and vegetable supply chain actors in Europe	under review in *Waste Management* (Herzberg et al., 2023a)	Ronja Herzberg Felicitas Schneider Martin Banse
further publications	Characteristics and determinants of domestic food waste: a representative diary study across Germany	published in *Sustainability* (Herzberg et al., 2020)	Ronja Herzberg Thomas Schmidt Felicitas Schneider
	Lebensmittelverluste bei Obst und Gemüse – die Rolle von Qualitätsanforderungen und Unternehmenspraktiken des Lebensmitteleinzelhandels	published as Thünen Working Paper (Trebbin et al., 2022)	Anika Trebbin Ronja Herzberg Felicitas Schneider
	Quality standards and contractual terms affecting food losses: the perspective of producer organisations in Germany and Italy	published in *Foods* (Pietrangeli et al., 2023)	Roberta Pietrangeli Ronja Herzberg Clara Cicatiello Felicitas Schneider

Note: articles on the subject of FLW which are not part of this cumulative thesis are in grey
Source: own elaboration

The key findings of the three articles are summarised in the following, highlighting how they contribute to the four research objectives (RO) outlined in chapter 1. Figure 3 illustrates how the three selected articles build upon different databases and contribute to the achievement of these research objectives.

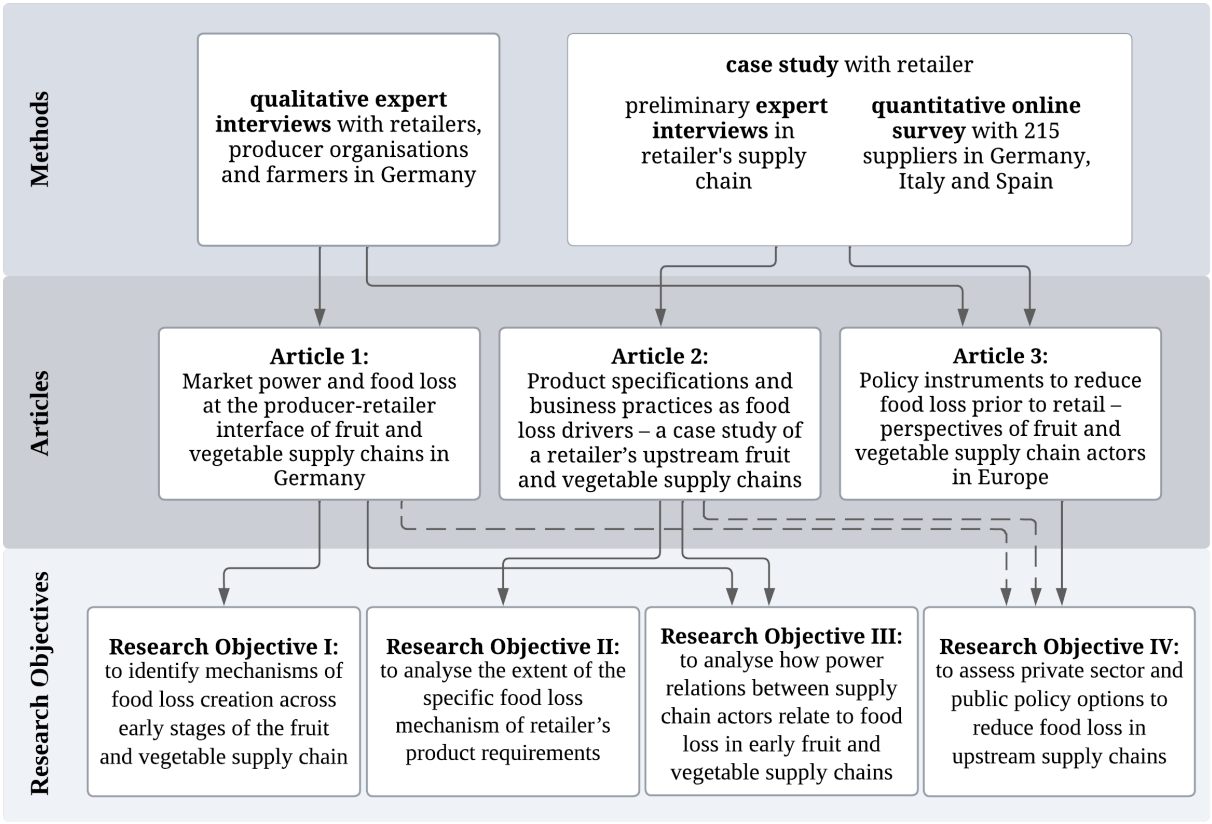

Figure 3 Conceptual embedding of the articles in the methods and objectives of this dissertation
Source: own elaboration

The **first article** identifies key inter-stage drivers of food loss in fresh fruit and vegetable supply chains in Germany. It shows how risk transfer depends on the power relations between actors in upstream fruit and vegetable supply chains and can exacerbate the tendency of producers to incur food loss. The article is based on 22 expert interviews with producers, producer organisations and retailers (Figure 3). It responds to RO I by identifying mechanisms that influence the occurrence of food loss in the pre-retail supply chains for fruit and vegetables. The findings of this article show how retailers are able to largely govern interactions, including contractual clauses, trading practices, ordering procedures, setting of product specifications and communication, which encourage food loss as a side-effect. The conceptualisation of power between supply chain actors and its application to the issue of food loss in upstream supply chains makes RO III one of the main points to be addressed within this article. Moreover, the foundations for proposing options for action in order to reduce FLW have been laid in article 1, which already points in the direction of RO IV. For example, the article highlights potential shortcomings in the European Commission's legislation on UTPs. It also criticises European countries' policies for largely relying on voluntary action by supply chain actors and for thereby neglecting the potential role of power imbalances along the food supply chain.

The **second article** builds on the first by exploring specific issues raised therein, namely retailer quality standards and business practices as drivers of food loss. The article follows the approach of first conducting preliminary expert interviews, followed by an online survey of 215 suppliers of Lidl located in Germany, Italy and Spain (Figure 3). The article focuses on RO II by

answering the question of how and to what extent the upstream supply chains of 12 selected fruit and vegetable crops are affected by the standards and practices set out by the retailer. The results show that, on average, 15 % of all produce does not meet the retailer's product specifications. On average, 6 % of all produce is lost as food as a direct result of these requirements and is either not harvested, used as animal feed or non-food or is wasted. However, the majority of suboptimal produce is marketed elsewhere, for example to other retailers, the processing industry and the food service sector. The second article addresses RO II and III in more detail by identifying the exact product requirements and business practices established by retailers that are most likely to cause fruit and vegetable loss in the upstream supply chain. It shows that the main product standards causing food loss are retailer-specific requirements on calibre (mass and size) and pesticide residue limits, followed by shape and sorting criteria. This is exacerbated by the retailer's business practices, which include poorly coordinated promotions, return deliveries, short-notice call-offs and inadequate quantity planning and ordering procedures. RO IV is partially addressed by the second article, as it provides specific advice to retailers on how to adapt their product specifications and business practices to reduce food loss upstream in the supply chain.

The **third article** focusses entirely on RO IV. It shows the perspectives and demands on policy interventions and private sector measures in terms of food loss reduction of relevant actors in upstream fruit and vegetable supply chains. The analysis is based on the above-mentioned 22 expert interviews in Germany and the 215 questionnaires sent to suppliers of the retailer Lidl from Germany, Spain and Italy (Figure 3). Stakeholders identified policy instruments in the areas of communication and cooperation, subsidies and food prices and regulation and policy frameworks. In terms of private sector interventions, ideas were collected in the areas of innovation and process optimisation, communication and cooperation, reconditioning and repackaging as well as processing, alternative marketing and redistribution. Concrete suggestions regarding RO IV can be drawn from the third article, which proposes interventions in the areas of consumer education and awareness raising, supply chain cooperation and power relations, food prices, marketing standards, alternative marketing and processing and promotion of technologies, infrastructure and agronomic practices. Thus, the article highlights additional leverage points for policy action and argues that stakeholders should be more involved in addressing the underlying mechanisms of the generation of food loss.

The following sections include the selected articles, describing and discussing in detail the methods and findings that contribute to the overall research objectives of the thesis.

4.1 Market power and food loss at the producer-retailer interface of fruit and vegetable supply chains in Germany

Ronja Herzberg, Thomas Schmidt, Markus Keck*

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** corresponding author*

The contributions of the author of this thesis to this article are: Conceptualisation, Methodology, Formal analysis and investigation, Writing—original draft preparation, Writing—review and editing.

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SPECIAL FEATURE: ORIGINAL ARTICLE

Sustainability in Agri-Food Systems: Transformative Trajectories toward the Post-Anthropocene

Market power and food loss at the producer-retailer interface of fruit and vegetable supply chains in Germany

Ronja Herzberg[1] · Thomas Schmidt[1] · Markus Keck[2]

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Abstract
Food loss and waste are associated with an unnecessary consumption of natural resources and avoidable greenhouse gas emissions. The United Nations have thus set the reduction of food loss and waste on the political agenda by means of the Sustainable Development Goal Target 12.3. The German Federal Government committed itself to this goal by implementing the National Strategy for Food Waste Reduction in 2019. However, this policy approach relies heavily on voluntary action by involved actors and neglects the possible role of power imbalances along the food supply chain. While current research on food loss and waste in industrialised countries predominantly focuses on the consumer level, this study puts emphasis on the under-researched early stages of the food supply chain from the field to retailers' warehouses. Based on 22 expert interviews with producers, producer organisations and retailers, this article identifies major inter-stage drivers of food loss in the supply chains for fresh fruit and vegetables in Germany. Its main novelty is to demonstrate how market power imbalances and risk shifting between powerful and subordinate actors can reinforce the tendency of food loss on the part of producers further up the supply chain. Results indicate that prevalent institutional settings, such as contractual terms and conditions, trading practices, ordering processes, product specifications, and communication privilege retailers and encourage food loss. The mechanisms in which these imbalances manifest, go beyond the European Commission's current legislation on Unfair Trading Practices. This study suggests a research agenda that might help to formulate adjusted policy instruments for re-structuring the German fruit and vegetable markets so that less food is wasted.

Keywords Food loss and waste · Agriculture · Horticulture · Retail · Sociology of markets · Primary production

Introduction

Reducing food loss is a global challenge to create more sustainable agri-food systems (Keck 2021): worldwide one third of food is wasted (Gustavsson et al. 2011) representing 4.6 billion metric tonnes in annual carbon dioxide emissions or 9% of global greenhouse gas emissions (Poore and Nemecek 2018). A total of about twelve million tonnes fresh mass was wasted in Germany in 2015 (Schmidt et al. 2019). A political framework to reduce food loss and waste is given by the United Nations, the EU and national regulations: The Sustainable Development Goal (SDG) Target 12.3, the waste directive and its delegated acts regarding food loss and waste at EU level (European Commission 2019; European Parliament 2018), supplemented by the National Strategy for Food Waste Reduction (BMEL 2019a). Within this political framework, food loss prior to retail is addressed less ambitiously (Parfitt et al. 2021; Porter et al. 2018; Soma et al. 2021; Stenmarck et al. 2016). In particular, pre-harvest and harvest loss is not even accounted for within the EU monitoring guidelines (European Parliament 2002) and the SDG 12.3 does not strive for a defined reduction target for supply chain stages prior to retail (Flanagan et al. 2019). Similarly, in research this part of the value chain is often neglected

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✉ Ronja Herzberg
ronja.herzberg@thuenen.de

[1] Thünen Institute of Market Analysis, 38116 Braunschweig, Germany

[2] Chair for Urban Climate Resilience, Center for Climate Resilience, University of Augsburg, 86156 Augsburg, Germany

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as opposed to consumption stages (Herzberg et al. 2020), although it is also associated with resource use and climate-relevant emissions (Porter et al. 2018; Spang et al. 2019).

As in Germany 30% of the overall food loss and waste occurs in primary production and processing (Schmidt et al. 2019) and loss rates prior to harvest are still unknown, this part of the food supply chain deserves further attention by the scientific community. The paper examines drivers of food loss in the early food supply chain at the example of fresh fruit and vegetables in Germany. Although fruit and vegetable production plays a minor role in Germany with a yield of almost five million tonnes per year (BMEL 2019b), food loss of fruit and vegetables in primary production from harvest onwards accounts for 21% of the entire food loss volume in the country (Schmidt et al. 2019).

There have been various studies on the drivers of fruit and vegetable losses both, internationally and in Germany (Baker et al. 2019; Beausang et al. 2017; Gillman et al. 2019; Hooge et al. 2018; Johnson et al. 2019). However, only very few studies deal with the underlying relationship and power constellations between supply chain actors as potential drivers of food loss on other supply chain stages. If they do so, they focus on different product categories or geographic regions (Devin and Richards 2018; Ghosh and Eriksson 2019; Soma et al. 2021).

The relationship and interactions between supply chain actors as well as the underlying power constellations can however be crucial, as food loss often comes along with economic risk and loss. It has been stated that food loss can in many cases be reduced to a minimum for economic considerations (FAO 2019; Koester 2014). However, there is a lacking incentive for buyers to optimise activities if economic decisions result in food loss and accompanying costs shouldered by upstream supply chain actors (Cattaneo et al. 2020). To approach the depicted research gap, this paper combines an analysis of interactions between different supply chain stages and actors on the one hand and its potential facilitation of food loss in the upstream supply chain, on the other hand. In this context, power constellations need to be considered, since it has been shown that the food system is increasingly dominated by large actors, in the case of horticulture particularly on the retailing side (Bundeskartellamt 2014; Wiggerthale 2021). Piras et al. (2018), Feedback (2017) and Eriksson et al. (2017) argue for other countries that Unfair Trading Practices resulting from power imbalances can generate food loss and waste. In the face of a highly competitive market situation and rising consumer claims (Hooge et al. 2017; Loebnitz et al. 2015), retailers can use their superior market position to set standards and terms and conditions, determine business habits and contractual terms, and delegate economic risks and costs onto suppliers (Devin and Richards 2018; Eriksson et al. 2017; Skorbiansky and Ellison 2019).

The European Commission is already paying attention to the topic of market power imbalances and Unfair Trading Practices (UTPs) in agricultural supply chains by issuing a directive to protect suppliers of agricultural produce as defined by their annual sales (European Parliament 2019). The present study discusses whether market power imbalances, trading practices, and the related bearing of risks and costs between supply chain actors have an effect on the occurrence of food loss in the upstream supply chain. To fill the depicted research gap, the paper answers the following questions:

1. Through which mechanisms become structural or market power imbalances apparent in fruit and vegetable supply chains in Germany?
2. How do interactions, shaped by power imbalances, result in food loss?
3. At which stages of the supply chain does this loss occur?

Throughout the paper we use the term “food loss” for losses prior to the retail stage, including harvest and pre-harvest losses, as applied by the Food and Agriculture Organization of the United Nations (FAO 2019). “Food waste”, on the other hand, only occurs at the retail and consumer level.

On the next pages, we embed our research questions into the current debate on circular economies and present a theoretical framework informed by the sociology of markets. Afterwards, we explain the research methods of this study and present the results. Finally, we provide a discussion of our findings and suggest future options for policies and the need for further research.

Theoretical framework

The concept of circular economy (CE) has been proposed as a promising approach to create more sustainable agri-food systems (Koppelmäki et al. 2021). CE is restorative and regenerative by design, and aims to keep products, components, and materials at their highest utility and value at all times, seeking to ultimately decouple global economic development from finite resource consumption. It serves to replace extract-use-dispose systems with an economic and technological model that is based on principles such as reuse, recycling, reducing and recovering (EMF 2015; Kirchherr et al. 2017). In the context of agri-food systems, it has been proposed that CE includes three stages—food production, food consumption and waste management (Jurgilevich et al. 2016). The food waste hierarchy proposed by Papargyropoulou et al. (2014) applies the CE concept to food waste and serves to inform policy makers on transforming current agri-food systems. This hierarchy comprises the

following components, which are ranked from most to least favourable:

1. Prevention;
2. Re-use;
3. Recycling;
4. Recovery;
5. Disposal.

In this study, we put emphasis on the elements of prevention and reuse (1–2).

To analyse how the interrelations between market power imbalances and food loss systematically hamper the development towards a circular agri-food system, we draw on the 'sociology of markets' literature. Interestingly, markets as social spaces that are shaped by particular institutions and power relations were traditionally dealt with by only a minority of economists such as Thorsten Veblen, John Commons and Wesley Mitchell (Hodgson 2006, 1998).

Market power from an economic point of view is traditionally defined on the basis of the price setting ability of actors and its effects on economic welfare (Khemani and Shapiro 1993). Industrial organisation literature studies market power and its effects mainly using quantitative approaches. This scientific discipline describes modern agricultural markets as oligopsonies, characterised by increasing concentration, vertical coordination and product differentiation (Russo et al. 2011; Saitone and Sexton 2010; Sexton 2013; Sexton and Xia 2018). Yet, the economic view on market power may not fully capture the complex manifestation of market power and effects beyond market shares, price setting and mark-up (Biely et al. 2019). Fuchs and Clapp (2009) for instance argue that a broader approach to power reveals how it can be employed to influence food system governance patterns and how it enables corporations to shape its constitutive rules and regulations. Devin and Richards (2018) have applied such a power-related approach in the context of food waste to analyse how business organisations can make use of asymmetries to shift responsibilities.

Against this background, this study looks at the institutional preconditions of markets from a sociological point of view by taking the basic considerations of Jens Beckert (2009) as a starting point. Beckert has raised the question of how it is possible that economic activities can be "coordinated" through markets despite the heterogeneous and partly antagonistic motives and interests of their participants. By coordination he means that actors succeed in aligning their actions in ways that allow market exchange to take place. Such coordination is a precondition to the order of markets. Beckert's (ibid.) point of departure is that markets are highly pre-suppositional arenas of social interaction in which actors are confronted with three fundamental "coordination problems" (ibid.): The problems of (1) cooperation, (2) competition, and (3) value.

1. The cooperation problem arises from the business risks that market actors face because of their incomplete knowledge of the intentions of their exchange partners, the quality of the product they wish to purchase, and incalculable external factors of influence that might hinder the successful order or delivery of the product. The more difficult it is to specify the quality of a product and the less able market actors are to infer each others' actual intentions, the greater these risks are (ibid.).
2. The problem of competition is related to one of the insights of neoclassical theory that while perfect markets are efficient, in market equilibrium no profit can be made. Suppliers therefore have an interest in establishing market structures that shield them from competitors, which allows them to reduce uncertainty with regard to their profit-making possibilities. Firms alleviate some of the uncertainty created by competition by product differentiation, reciprocal agreements, etc. In sum, however, the structure of competition must be seen as a precarious compromise reflecting the inequalities of the power of actors in the market field (ibid.)
3. The value problem refers to the difficulties of market actors to assess the value of commodities given the multiplicity of goods and their complex quality properties. Only if product qualities and values are distinguishable, will uncertainty be reduced and interest in buying and selling arises. While sellers try to create attachment to their goods on part of buyers through marketing strategies, they must simultaneously react to new and often unpredictable emerging trends. In this sense, the assignments of value are subject to a dynamic process of change and uncertainty and can only temporarily be eliminated for market actors (ibid.).

In this study, we will see that all three coordination problems have a bearing when it comes to understanding the prevalent institutions and practices in fruit and vegetable supply chains in Germany.

Material and methods

We chose a qualitative research approach, considering that the mechanisms between power imbalances and food loss have not yet intensively been researched. Therefore, in the first place openly addressing the subjective and social constructs of the involved actors is substantial (Flick et al. 2010). In the course of the empirical data collection, we conducted semi-structured expert interviews, which are

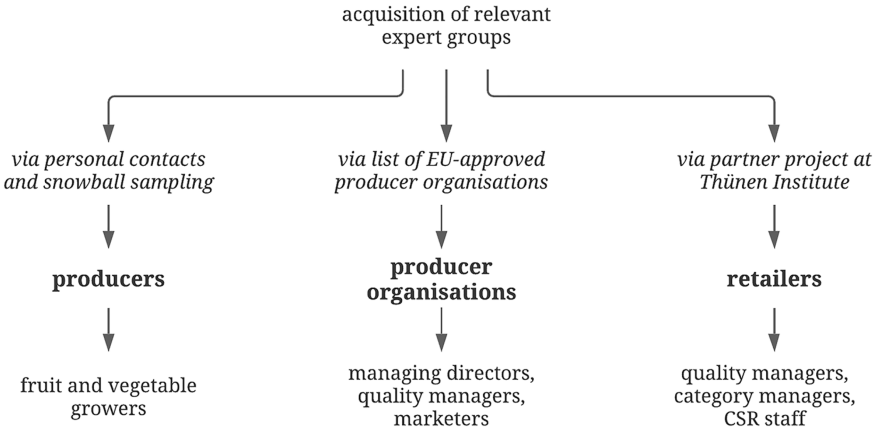

Fig. 1 Expert acquisition procedure (means of selection and acquisition, expert group, and position of interviewees within the enterprise)

particularly advisable when processes are complex and not easily accessible (Bogner et al. 2014). This is the case for processes at the producer-retailer interface, in particular with respect to the highly controversial topics of food loss and power imbalances. The approach of a systematising expert interview thereby aims at gathering technical and process knowledge rather than interpretative knowledge (Bogner et al. 2014), which appears to be an adequate form of knowledge with respect to the research questions.

Acquisition of interview participants

We identified three types of experts as relevant to answer the research questions:

1. Producers (fruit and vegetable growers)
2. Producer organisations of fruit and vegetables, and
3. Food retailers.

In consequence of the heterogeneous structure of the producer-retailer interface of fruit and vegetable supply chains, producer organisations represent only one intermediary within the chain. With 43% of the market volume of fruit (Garming et al. 2018) and 30% of the market volume of vegetables (Strohm et al. 2016) in 2014, a considerable share of German produce is marketed via producer organisations. This study does not consider wholesalers, sorters, packers and storage and logistics providers, due to their declining relevance in most supply chains of fruit and vegetables produced and marketed in Germany (Strohm et al. 2016). As producer organisations have been shown to strengthen farmers bargaining position (Sorrentino et al. 2018; Velázquez and Buffaria 2017), we summarise primary producers and producer organisations as "the production side" or "suppliers", while retailers are defined as "buyers". The analysis of power constellations in our case also follows this distinction, although bearing in mind that in some supply chains intermediaries are similarly assumed to exert high levels of market power (Russo et al. 2011).

Experts were acquired by use of personal contacts and snowball sampling techniques, a comprehensive list of EU-approved producer organisations in Germany and a partner project at the Thünen Institute (Fig. 1). The interviewees are active in the fields of fruit and vegetable growing, business management, marketing, quality management, category management and corporate social responsibility (CSR).

Interview guideline and implementation

We subdivided the interview guideline (S1), developed in accordance with Helfferich (2014) into six main thematic blocks, aimed at gaining insights into the relationship between the different actors of the supply chain with special emphasis on the topic of food loss:

1. Structure of value chain and business relationship
2. Perception of food loss
3. Contracts, agreements, orders, and quantities
4. Quality management and quality standards
5. Trading practices and bargaining power
6. Options for action (policy and private sector)

Overall, we conducted 22 expert interviews with one or two interviewees each between September 2020 and February 2021 with an average length per interview of one hour (Table 1). Seven interviews with primary producers, seven interviews with managers or employees of producer organisations and eight interviews with employees of retailing companies were held. Due to the Covid-19 pandemic, only three interviews could be conducted in person, 15 interviews were carried out via an online video conference tool and four via telephone. Audio files of the

Table 1 Characteristics of experts and interviews (region of retailers not shown to preserve anonymity)[a]

Number	Supply chain stage	Date	Region	Produced crops or product range	Type of interview	Length (min)
B12	Primary producer	2020-09-10	Lower Saxony	Carrots and potatoes	In person	45
B16	Primary producer	2021-01-18	Rhineland-Palatinate	Blue berries	Telephone	85
B17	Primary producer	2021-01-20	Baden-Wuerttemberg	Vegetables	Online	38
B18	Primary producer	2021-01-22	Lower Saxony	Blue berries	Online	89
B19	Primary producer	2021-01-22	Baden-Wuerttemberg	Pomaceous fruits	Telephone	59
B20	Primary producer	2021-02-09	North Rhine-Westphalia	Salads and herbs	Online	60
B21	Primary producer	2021-02-10	North Rhine-Westphalia	Vegetables	Online	56
B01	Producer organisation	2020-10-22	Lower Saxony	Onions	In person	61
B10	Producer organisation	2020-11-02	North of Germany	Vegetables	Online	65
B13	Producer organisation	2020-11-03	North of Germany	Vegetables	Online	58
B02	Producer organisation	2020-11-04	Rhenish Hesse	Fruits and asparagus	Online	65
B03	Producer organisation	2020-11-11	Baden-Wuerttemberg	Vegetables	Telephone	49
B04	Producer organisation	2020-11-12	Baden-Wuerttemberg	Pomaceous fruits	Telephone	71
B09	Producer organisation	2020-11-27	North of Germany	Pomaceous fruits	Online	48
B22	Retail	2020-09-16	–	Organic full range	In person	56
B11	Retail	2020-09-22	–	Discounter	Online	44
B08	Retail	2020-11-05	-	Full range	Online	87
B06	Retail	2020-11-09	–	Organic full range	Online	59
B07	Retail	2020-11-09	–	Full range	Online	57
B05	Retail	2020-12-02	–	Discounter	Online	61
B14	Retail	2021-01-06	–	Full range	Online	63
B15	Retail	2021-01-11	–	Organic full range	Online	43

[a]Important cultivation regions, distinct kinds and seasonality of produce, conventional and organic forms of cultivation and a balance between full-range retailers and discounters as well as between large and small companies were considered

interviews were generated and transcribed in accordance with the transcription rules by Dresing and Pehl (2017) followed by a pseudonymisation.

Content analysis

We applied a structuring qualitative content analysis (Kuckartz 2018) with MAXQDA software, which is particularly suitable for analysing technical and process-related knowledge (Bogner et al. 2014). Categories were derived in a hybrid approach combining deductive and inductive logic (Kuckartz 2018). A total of 17 main categories and 29 subcategories were identified of which ten main categories form the empirical basis of the present study (Table 2). We analysed these categories systematically within segment matrices by theme and per expert group (Kuckartz 2018).

Results

Supply chains for fresh fruit and vegetables in Germany are structured very heterogeneously and are subject to an ongoing trend of centralisation, concentration and vertical integration, particularly of the retail side (B04:33; B16:9,75–76).[1] This means that company tasks, such as sourcing and purchasing, are increasingly managed centrally by the firm's headquarters, as companies are growing in terms of annual sales and number of outlets, while the overall number of competitors is declining. As a result, the upstream supply chain is increasingly coordinated by retailers. Within the interview sample two forms of value chains are included: the direct sale from farmers to retailers and the value chain via one or several intermediaries. For most commodities, fresh fruit and vegetable supply chains are strongly linked to processing industries and food services (Fig. 2).

A broad range of food loss causes was mentioned within the interviews, such as extreme weather events, pests and diseases, logistics and storage problems, false declaration, consumer preferences, etc. However, in this paper we place emphasis on the potential of food loss generation initiated through the patterns of interaction between primary producers, producer organisations and retailers. These patterns rest on particular institutional settings and power relations that we address as inter-stage drivers of food loss and analyse

[1] Statements of the results section that are not underlined by a direct quote, are supported by indicating exemplary interview passage(s).

Table 2 Excerpt[a] of the category system developed in content analysis and number of codings

Subordinate category	Codings	Subcategory	Codings
1 General information	23		
2 Relationship between actors	28	2.1 Relationship long-term/on eye level	33
		2.2 Relationship not partner-like/distanced	10
		2.3 Relationship characterised by competition	14
3 Structure of the supply chain	52	3.1 Centralisation/integration	46
		3.2 Supply chain flexibility	45
4 Perception of food loss	31		
5 Orders of retailers	39	5.1 Promotional campaigns	29
6 Quantity estimation and planning	59		
7 Quality standards and specifications	45	7.1 Rejections and complaints	43
		7.2 Packaging specifications	17
		7.3 Pesticide residue limits	20
		7.4 Visual standards/calibre/ripeness	64
		7.5 Legal standards	33
		7.6 Standards set by retailers	43
		7.7 Other standard setters	18
8 Formal contracts	46		
9 Agreements between supply chain actors	58		
10 Trading practices and bargaining power	66		

[a]Only those codes that were considered for this paper and analysed systematically within segment matrices are shown

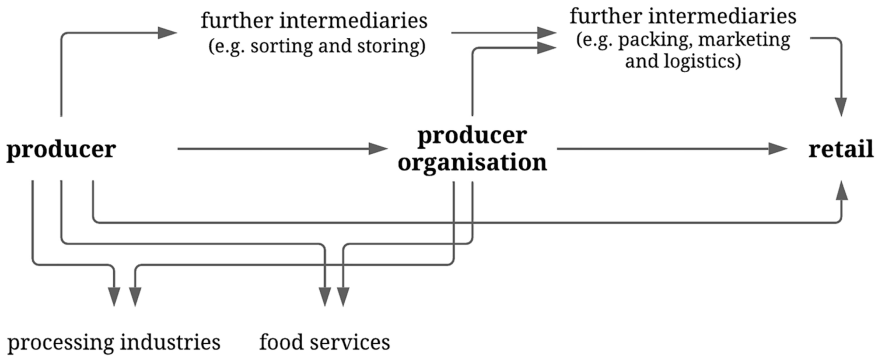

Fig. 2 Common structure of supply chains up to retail stage of fruit and vegetables produced and marketed in Germany as depicted by interviewed experts

within the following chapters. An overview of these mechanisms exacerbating food loss is presented in Table 3.

Contracts and informal arrangements

The interviews show that formal contracts only set the framework conditions in fresh fruit and vegetable supply chains in Germany. These contracts, also referred to as listing agreements or codes of conduct, lay the foundation of business conduct between retailer and supplier. They for instance contain information on reclamations, duration of listing, obligations, terms of payment, compliance to standards or general product specifications (B02:73; B09:45; B14:96). Contracts generally do not include any delivery specific agreements, such as quantities, prices or purchase commitments. One representative of a producer organisation explains:

> "That means, of course, that the framework agreement also regulates the content of the BUSINESS CONDUCT,[2] it says nothing about the actual business, how much [business] we do together, so it doesn't say 'we now need 30,000 tons of apples and we will only buy them from you', such a clause is unfortunately not included" (B09:47).[3]

[2] Capital letters in quotes indicate loud and accentuated pronunciation.

[3] Quotes used within the results section were translated by an English native speaker and grammatical and linguistic errors were corrected to improve understanding and reading flow.

Table 3 Summary of results concerning materialisation of market power within interactions and corresponding mechanisms that potentially enhance the occurrence of food loss

Chapter	Materialisation of power imbalances	Food loss provoking mechanism
4.1	Contracts and informal arrangements	Contracts providing no reliability with respect to actually purchased quantity
		Buyers can spontaneously step back from purchase intention
		Exclusive delivery agreements between buyer and supplier impeding from redirecting sales flows
		Lack of short-term informal communication and increasingly detached collaboration
4.2	Quantity estimation and ordering processes	Short-term nature of orders and reorders
		Assignment of delivery obligation by applying auctioning approach
		Inflexible and prematurely fixed promotions not sufficiently buffering harvest peaks
4.3	Product specifications and requirements	Demanding and specific visual and sensory requirements of different retailing companies
		Campaigns with bulky fruit and vegetables not sufficiently coordinated within supply chain
		Individual packaging and pesticide residue limits of different retailers impeding marketing flexibility
4.4	Business relationship and trading practices between production and retail	Occasionally take-back-agreements or short-notice cancellations
		Uncertain nature of orders inducing unpredictability

Written contracts represent the basis of collaboration that informal verbal arrangements build upon when it comes to purchased quantities, e.g., in the wake of annual consultations. Subsequent to these general contracts and informal consultations, retailers place orders in which final purchased quantities are set short-term and in a rather informal manner (Chapter 4.2).

In contrast to most participants, a producer organisation in a special geographic location is assured a purchase guarantee of a certain amount of vegetables already within the contract (B03:23–25). The interviewee sees the producer organisation in a beneficial position compared to others as the supply from the special location is limited and at the same time increasingly in demand (B3:69). Similar to this exceptional case, contracts assuring guaranteed purchase of a predetermined quantity also seem to be common practice in the processing industry (B21:11).

The statements of some experts regarding contracts and arrangements can be linked to the issue of food loss in the early supply chain. Most contracts provide no reliability with respect to the actual purchase of a certain product quantity (B12:35; B20:63). In some cases, the targeted collaboration between supplier and retailer is put into practice. In other cases, the verbally agreed amount is not being met. In consequence of an unforeseeable event, such as weather events, pest infestations or even the Covid-19 pandemic, the retailer is not liable to actually purchase a certain amount of produce. When buyers step back from their purchase intention, this missing liability is a potential cause of loss early in the supply chain. Moreover, a food loss reinforcing situation can arise, when contracts contain clauses preventing producers from supplying third buyers. In this context a blueberry producer describes the contractual terms of a large bundler outside Germany:

> "As I said, we had signed a contract with a delivery obligation, and had committed to delivering all of our goods to *wholesaler*[4] for five years. We would only have the alternative to apply for an exemption, but that would also have to be approved by *wholesaler*. If they didn't approve it, then we couldn't sell" (B18:59).

If the sole supplied buyer does not accept the entire produce due to certain quality specifications or other hindrances, the producer is hardly able to redirect sales flows – a circumstance, which may result in spontaneous food loss at the producer level.

Additionally, all groups of interviewees highlight the importance of short-term informal arrangements regarding food loss prevention. For instance, photos demonstrating product traits and quality are being spontaneously exchanged (B20:23). Retailers can also be informed about unexpected events during production and resulting differences in product qualities or quantities, which may prevent delivery rejections and subsequent food loss (B01:69). A producer organisation, for instance, sells suboptimal product sizes to a packager using these short-term arrangements:

> "Well, sometimes there is a customer, who gets a 70/90 or a 70 plus[5] it's called sometimes. And then you ask, if it matters if there is something over 90 and if he says, 'no, it doesn't matter', then you put the crate in,

[4] Parts of quotes written in italic were pseudonymised.

[5] Calibre category of onions (diameter in millimetres).

too. In other words, it only happens when the loading is in progress and the colleague comes over and says 'there is still a box, can we also load it?' So it often is very spontaneous" (B01:90).

Particularly those primary producers, who directly deliver seasonal products to retailers, reported a lack of such spontaneous arrangements and indicate a link to food loss. A smaller producer delivering seasonal products to a wholesaler as well as to retailers described the situation:

"And it's a shame that it doesn't meet with understanding. There is absolutely no way I can call my customers, except the wholesaler, who has some room for manoeuvre here […] Others say: 'No, no, we ordered three pallets, so you have to send the three pallets.' Yes, that can lead to a refusal of goods. But there is no understanding for my situation [on part of the buyers]" (B16:59).

Moreover, the producer is concerned that central purchasing and the intensified focus of retailers on internal processes, changing staff in the procurement area and an increasing digitalisation of the collaboration might exacerbate the described communication problem and hence boost further food loss (B16:55–61).

Quantity estimation and ordering processes

The production as well as the retailing side usually carry out an estimation of demanded and supplied fruit and vegetable quantities. Preliminary yield estimation on part of the producers during the flowering period plays a major role for perennial crops, such as stone fruit (B9:51). For annual crops, such as most vegetables, quantities can be adjusted far more flexibly by planting schedules according to the retailers' demand (B13:46). Retailers mainly estimate their preliminary purchase volumes based on the past years' demands using prognosis systems (B6:43). However, particularly in smaller retailing companies, the "gut feeling" of procurement staff still seems to play a significant role as the maintenance of prognosis systems can be costly and time consuming (B15:88). Within annual consultations, retailers and suppliers (e.g., producer organisations) usually agree upon approximate purchase volumes over one season, which however only serve as a benchmark. One to two weeks prior to delivery, these quantities are usually fine-tuned and the actual order or retrieval is placed one day before delivery by use of digital systems, e-mail or telephone (B09:53; B16:83). The consulted experts speak of time spans from 12 to 24 h between order and delivery (B13:16), although a longer time span may be stipulated within the terms of delivery (B16:101). Since the predetermined food quantities specified in the annual consultations are based on estimates, it is not until the actual order is placed that the agreement is binding.

Food loss can occur, if the preliminary estimated and actually ordered volumes do not coincide or if estimated quantities are irregularly retrieved. In these cases, initially planned and planted fruit and vegetable quantities eventually cannot be sold and must be tilled or disposed if no other marketing option arises, as a vegetable producer asserts:

"We have a customer who places an order every day for what he needs tomorrow, but he places his order today at 5 or 6 pm, for example, for what I have to deliver at 7 am tomorrow morning. So, I only have a very narrow window to meet the requirements. And if I have the goods ready for harvest, but the orders are suddenly significantly less, then I am not able to sell the entire volume that is in the field" (B20:11).

Due to this time constraint, producers and producer organisations largely rely on their own predictions and practical knowledge and hence pre-pack produce in advance to be equipped for short-term orders and reorders, as the quality manager of a retailing company states:

"I say, it's THE adjustable screw. Because, we pass this adjustable screw on to our suppliers. […] If we place an order today and need something the day after tomorrow, the packing process no longer works. That means they pack and prepare something which they assume will be ordered" (B14:34).

Moreover, the remaining uncertainties regarding eventually ordered and, in some cases, reordered quantities motivate producers to plant more than initially agreed upon, resulting in food loss due to overproduction (B13:47–50). A further food loss driver is the auctioning approach of which some retailers make use. In this case, every one or two weeks, the delivery obligation of a specific product is redefined (B19:68). Producers repeatedly emphasised that the uncertain nature of such an approach can result in food loss, as suppliers can never be fully sure of the possibility to sell their products:

"They jump from one supplier to another from week to week, I've heard that before about *discounter*. […] There are three suppliers offering the product, but *discounter* decides that only one is allowed to deliver this week, while the other two are not. What are the others doing with their product? It still has to be harvested. No, that is clearly not acceptable" (B21:111).

Experts from all interviewed groups confirm that quantity estimations can become even more challenging during promotion periods, when the retrieval of produce becomes

more volatile. One interviewee from a retailing company describes:

> "We have extremely volatile quantities during promotional activities. Both in one direction and the other. Well, we have advertising, where I need 250,000 raspberries. And then, there is advertising, for which all of a sudden, I only need 100,000 raspberries. That is incredibly difficult for us to estimate" (B08:106).

Accordingly, retailers primarily plan promotions and communicate them to producers or producer organisations mostly two to six weeks before the advertisement period (B09:55). Some experts from the production side depict promotions as becoming increasingly inflexible and prematurely fixed. Hence, they cannot be adjusted spontaneously to harvest peaks. The volatility in orders and the limited flexibility provoke food loss early in the supply chain (B21:55; B20:67).

Product specifications and requirements

Experts identify product specifications and requirements as another major driver of food loss. These specifications include visual and sensory requirements, such as calibre (size and weight), shape, colouring, taste and the level of ripeness as well as inner qualities such as upper limits for pesticide residues. Not only the product itself, but also its packaging and its production processes can be subject to specific requirements and standards. On the one hand, standards may be set by legal entities in the form of trade category regulations of the EU or criteria set by the United Nations Economic Commission for Europe (UNECE) (B08:75; B10:61). On the other hand, independent and label-based standard defining organisations and companies exist, such as QS, GlobalGAP, IFS, organic farming associations, etc. (B10:21). Furthermore, retailers themselves are indicated as standard setters. While producers and producer organisations claim that retailers' standards are stricter than legal ones and evoke food loss due to the sorting out of unsuitable produce early in the supply chain (B01:34–35; B09:66–67), retailers generally do not refer to such a correlation (B08:59). All groups of interviewees underpin the importance of raising consumer awareness regarding products that do not meet visual standards. However, producers and members of producer organisations doubt that product requirements arise from customer requests in the first place, but rather from the competitive situation in which retailers find themselves involved. A producer expresses this doubt:

> "Today, you have to sort within three millimetres in some cases. I always wonder: 'Do the retailers even want that?' […] The consumers can't even see whether the apple is three millimetres larger or three millimetres smaller" (B19:116).

It was frequently pointed out that visual and sensory specifications set by retailers are rather reliable, well known by all participants of the supply chain and usually not used to artificially reject products at delivery (B20:53). However, some interviewees noticed that requirements become stricter in years of abundant produce and are handled permissively in seasons of short supply (B19:30).

Within the debate on visual requirements, representatives of retailing companies also refer to the marketing of misshapen fruit and vegetables. In this regard, interviewees from the production side see a benefit regarding consumer awareness, although such a practice exists only for selected products (B09:97). However, the potential of selling bulky produce for the reduction of food loss is limited, at least for easily processable fruits and vegetables, as a representative of an apple producer organisation explains:

> "[These] apples were already marketed before. Not to retailers, but to processing industries for peeling or juicing. […] In the end you don't get any more money for it, you just get it from someone else" (B02:100–105).

Retailers moreover gave rise to the concern that bulky and over- or undersized products are not readily available in sufficient quantities when asking producers to supply such products (B08:59). In this regard, the production side pointed out that deformed produce is often not even harvested or stored. For the integration of such produce into the supply chain, producers need sufficient assurance that these products will eventually be bought, before adjusting harvesting and sorting processes:

> "So, the pickers always work with measurement rings, because we simply do not store cider apples or industrial fruit in the warehouse. Because, I'll put it this way, those often don't cover the storage costs" (B19:20).

Besides visual requirements set by retailers, the interviewed experts underscore two further subjects concerning product requirements: pesticide residue limits and packaging requirements. Although packaging as a protective layer can prevent food loss, it can simultaneously be a driver of loss by reducing marketing options. Packaging, as an integral part of product differentiation, varies considerably between retailers and may frequently be customised (B10:59). Particularly with increasing supply chain integration and products being packed directly after harvest, suppliers are increasingly restricted to a certain marketing channel, as an interview partner from a producer organisation explains:

"In case I have a food tray, for example apples, six apples on a tray with a plastic sheet, then there are usually […] special trays with the logos of the retailers' own brands, i.e., *full-range retailer*, *full-range retailer*, as they are all called. And I can hardly continue to market them like that. Well, sometimes you would have to repack them" (B04:136).

However, if repacking is too costly, products might rather be disposed of eventually (B14:130).

Similar to packaging, setting individual requirements for pesticide residue limits seems to be common practice of retailers in fruit and vegetable markets in Germany. The interviews suggest that different retailers set individual pesticide residue limits of 100% to 25% of the legally binding maximum value (B20:45; B21:29). Again, the decline in marketing opportunities resulting from these individual pesticide requirements can result in food loss on the part of producers, as an interviewee of an organic retailing company observes:

"Upstream suppliers can only manage this residue requirement in retail if they cultivate the goods specifically for certain commercial channels. […] And the weekly market, which takes the leftovers which no longer come into the food retail for whatever reason, can only absorb to a limited extent" (B14:34).

Business relationship and trading practices between production and retail

All groups of interviewees use heterogeneous attributes to describe the relationship to other actors of the fruit and vegetable supply chain, ranging from "long-term", "stable", "on eye level" and "based on partnership" (B05:47; B6:25) to "acceptable", "dependent on each other" or even as "imbalanced" (B03:21; B10:87).

The existence of so-called Unfair Trading Practices is denied by most retailers:

"Well, I would say that—well, I can only speak for *own fruit and vegetable agency* for now—we have absolutely no fear or points of contact with so-called Unfair Trading Practices. The things that are on the black list[6] will be implemented and we are already implementing them today" (B08:138).

In contrast, some representatives of producer organisations and producers have witnessed or heard of practices that they would refer to as unfair. In this context, mainly topics such as terms of payment, payment of promotion costs and price dumping are named and condemned as inacceptable (B16:95). Nonetheless, they generally do not relate this issue to food loss (B13:82). Yet, one interviewee of a producer organisation describes a case in which the costs of unsold products were returned to the producer:

"I think after eight weeks we got the rating[7] and it was huge and we wondered what was going on and we asked. Well, they packed it and delivered it and then it came back because it was not needed anymore in retail, then it appeared in the rating. Because at that point it was no longer sellable" (B01:183).

However, participants do not refer to return deliveries of unsold products as a systemic problem causing a considerable amount of food loss. Likewise, short-notice cancellations of orders do not appear to happen frequently regarding fruits and vegetables produced and marketed in Germany. In this context, a producer identifies short-term orders as opposed to short-term cancellations of orders as a relevant source of uncertainty, potentially resulting in food loss:

"I might have deliveries of two tons in one day. And the next day zero. Zero. Somehow for me it is of course like a cancellation, but I never got an order" (B16:97).

Interview partners from the production side explicitly identify unequal power relations between the retailing and production side as food loss drivers (B10:87). However, the described mechanisms differ from what the European Commission defines as Unfair Trading Practices. According to the interviews, long-term and balanced business relationships building on a mutual understanding are perceived to effectively prevent food loss along the supply chain.

Discussion

The discussion is divided into two parts: Firstly, our findings will be reflected on the basis of the theoretical framework. Secondly, these findings will be contextualised and compared given insights from other countries with a specific focus on the issue of Unfair Trading Practices and power imbalances.

[6] List of "Unfair Trading Practices" within the directive of the European Commission that must be banned within EU member states, as opposed to "grey list" including practices that may persist if explicitly agreed upon by the involved supply chain actors.

[7] Monetary discount, e.g., due to product shares not fulfilling the required quality.

Food loss from a market sociology perspective

Based on the insights of Jens Beckert (2009) we suggest that market interactions need to be coordinated. By coordination Beckert (ibid.) means that actors need to reduce the fundamental uncertainty inherent in market relations in regard to (1) their incomplete knowledge of the intentions of their exchange partners (cooperation problem), (2) their personal profit expectations (competition problem), and (3) the difficulties of assessing and fixing the value of commodities (value problem) before the exchange of goods can take place. As will be shown, all three mentioned coordination problems have a bearing in current fruit and vegetable supply chains in Germany and help to identify inter-stage drivers of food loss and the interrelation between market power, food loss and waste, and economic loss.

1. The interviews have shown that formal contracts set only the framework conditions for market exchange and form the basis of collaboration. Informal arrangements then serve to place actual short-term orders of specified quantities. Thus, in the supply chains studied, the cooperation problem is solved via a combination of formal and informal modes of governance that are also an expression of underlying power relations. From the producer perspective, most contracts do not provide any reliability with respect to the actual purchase of specified amounts of produce. This lacking liability can cause material and financial loss on the part of producers when retailers step back from their purchase intention—especially when producers are bound by contract clauses to sell their produce to only one defined buyer.
2. The problem of competition becomes important when it comes to quantity estimation and the forecast of demand. Since retailers constantly need to highlight their recognition value in a highly competitive environment, they need to offer their customers the broadest possible variety of high-quality products (Hooge et al. 2018). In this context, retailers estimate the purchase volumes of the next year on the basis of past years' experiences. To be able to source fresh produce on a regular basis and to adapt to short-term changes in demand, retailers make use of short-term orders to avoid economically harmful stock-out (Avlijas et al. 2015). Producers have developed coping strategies such as to pre-pack produce in advance to be equipped for short-term orders or reorders. In case own preparations do not fit with retailers' orders, again, material and financial loss appear while producers have to bear the costs.

   As the interviews show, the described problem of producers to estimate demanded quantities becomes especially difficult in times when retailers run promotion campaigns. As these campaigns are directed against competitors to attract customers and to raise profits, they are seldom communicated to the producers more than six weeks in advance, nor are they adjusted flexibly enough to meet harvest peaks. The unpredictability in combination with the mere size of ordered quantities during promotion periods can result in producers tilling existing crops, if eventually ordered quantities and produce ready for harvest do not coincide. This again can result in material and financial loss to the detriment of the producers.

3. Last but not least, also the value problem can be consulted to explain a food loss fraction that occurs due to quality requirements. This is caused by the fact that the value of a product is nowadays defined by a broad range of specifications laid out in legal standards, independent and label-based standards as well as private standards by retailers. The variety of requirements concerning pesticide loads and packaging by distinct retailers forces producers to either specialise on particular marketing tracks or to fulfil the maximum requirements in the market. As a consequence, producers either have to follow an "all eggs in one basket" strategy or increase production costs to meet the highest standards. None of these strategies goes without the risk of decreasing margins. Apart from that, it is noteworthy that even the sale of deformed produce does not necessarily come without extra costs on part of the producer, since an integration of such produce into the supply chain would involve costs to adjust related harvesting and sorting processes. In this context, the question arises of who bears the costs, if not the producers. From their perspective, however, it seems odd to invest in a production process optimisation to sell their produce at a rate which is not necessarily higher than for regular produce.

In sum, we show that the generation of food loss in current supply chains of fruit and vegetables can arise due to the specific institutional ordering of markets, which are an expression of power relations. Thus, if the aim is to avoid the production of food loss, there is scope to not only focus on technical solutions, but also to transform prevalent market structures and create incentives, policy instruments and alternative marketing options to empower producers and producer organisations to be able to solve their specific coordination problems by negotiating with retailers at eye level. The preceding integration of food loss provoking mechanisms into the theory of coordination problems shows that the question of risk bearing is crucial to understand where

food loss is triggered and where actual loss and its costs occur (Gillman et al. 2019).

Food loss from a comparative, policy-related perspective

The findings of this paper suggest that market power imbalances play a pivotal role in the depicted supply chain interactions inducing food loss. However, the mechanisms through which market power imbalances and risk shifting behaviour result in food loss diverge from the expectations based on the literature and the recent EU directive (European Parliament 2019). Piras et al. (2018), Sinclair Taylor et al. (2019) and Feedback (2017) give rise to the assumption that UTPs represent major drivers of food loss and waste along the supply chain. Accordingly, short-notice cancellations or order changes as well as the artificial reduction of initially ordered quantities by use of inconsistently applied quality criteria are causing major food loss. For the UK, Rakesh and Belavina (2020) describe that the sponatneous alteration of quality requirements is sometimes used as a means to return no longer required produce, a situation previously found by Eriksson et al. (2017), Devin and Richards (2018) and Feedback (2017) as well. The finding that retailers use standards regarding visual and sensory traits, (Beausang et al. 2017; Porter et al. 2018; Richards and Hamilton 2020), pesticide residue limits (Ludwig-Ohm et al. 2019; Meyer et al. 2017), and client-specific packaging (Meyer et al. 2017) to govern the supply chain beyond their own organisation (Devin and Richards 2018; Fulponi 2006), can be supported by the results of this paper. However, an intentionally inconsistent application of quality requirements by retailers to justify rejections could not be found. Similarly, short-term order cancellations, sending back or charging the cost of unsold products in the form of take-back-agreements (Eriksson et al. 2017; Ghosh and Eriksson 2019; Gille 2013) or backward selling contracts (Rakesh and Belavina 2020) were not identified as a systematic problem for fruit and vegetables cultivated and supplied in Germany. In this case, a system is running which makes such practices unnecessary. Due to low liability regarding quantities, missing purchase commitment, and short-term orders and reorders instead of short-term cancellations, the production side of the value chain is burdened with the consequences of potential risks and food loss. In this sense, the practices of take-back-agreements and short-notice cancellations described within the directive on Unfair Trading Practices (European Parliament 2019) are not sufficiently addressing the core problem in this case. As the quantitative assessment of food loss and waste prevention actions is crucial (Goossens et al. 2019), it should be observed whether an imposition of more fixed terms through regulation will actually reduce overall food loss and waste. It might on the other hand reduce flexibility to cope with unexpected changes and thus provoke even more environmentally harmful food loss and waste down the supply chain (Gillman et al. 2019). The horizontal integration of farmers in producer organisations (Porter et al. 2018; Velázquez and Buffaria 2017) as well as the diversification of their distribution channels (Chaboud and Moustier 2021; Devin and Richards 2018) and a reduction of excessive product differentiation and specification (Ludwig-Ohm et al. 2019; Thies et al. 2021) might be more effective mechanisms to enhance producers' bargaining position and counteract food loss.

All in all, to create less waste in more sustainable fruit and vegetable supply chains, it must be recognized that food loss can be the outcome of rational decisions by market actors in consideration of their costs and particularly also risks (Golan et al. 2019; Kuchler and Minor 2019; Rutten 2013). The topic of power imbalances and its arising risk and incentive allocation must thus be considered further. A more balanced risk-sharing along the supply chain may force all actors to optimize activities and prevent a food loss fraction out of economic considerations (Koester 2014). This would be also favourable from a CE and food waste hierarchy (Papargyropoulou et al. 2014) point of view. It should not be neglected that preventing the food loss fraction arising from inter-stage drivers of food loss may incur costs and risk on the part of buyers. Therefore, it must be questioned whether cooperative policy approaches such as voluntary agreements (Burgos et al. 2019) alone will suffice in this particular case or whether further instruments will be required (Garske et al. 2020).

Conclusions

To conclude, inter-stage drivers of food loss play a pivotal role in the context of fruit and vegetable loss in Germany. In this context, powerful retailers use their position to solve the uncertainties arising from 'cooperation problems' within markets to a large extent at the expense of producers. Underlying mechanisms are based on specific institutional frameworks, which vary between countries, products and supply chains. In the case of fruit and vegetables cultivated and supplied in Germany, we have identified the following key inter-stage drivers of food loss:

1. Low liability regarding quantities,
2. Short-term orders and reorders,
3. Missing purchase commitment,
4. Client-specific requirements on appearance, packaging and pesticide residue limits

5. Top-down implementation of orders, promotions and product specification.

We argue that policies restricted to voluntary actions at individual stages of the food supply chain may be insufficient to tackle this particular food loss fraction as the incentive for retailers to shoulder costs and risks resulting in upstream food loss prevention is low. To develop purposeful policy instruments targeting these inter-stage food loss drivers, we suggest for politics and future research to put emphasis on how to:

1. Create more liability within market transactions;
2. Adjust and unify product specifications;
3. Propagate a bearing of costs of process and specification adjustments shared by producers and retailers;
4. Design more flexible promotional campaigns harmonised with producer capacities;
5. Maintain informal modes of governance within supply chains despite further concentration, centralisation and digitalisation; and
6. Limit structural power imbalances and risk bearing in contemporary fruit and vegetable supply chains, e.g. through fostering horizontal integration and alternative marketing channels.

Further research is moreover required on the empirical evidence and quantification of the effects of UTPs in general and with a specific focus on imported products that cannot be ordered just-in-time. A further quantitative evaluation of the effects of food loss drivers identified within this paper, as well as the evaluation of counteracting measures, would be a desirable next step in research. In this context, measures to balance power between producers and retailers would also have to be analysed in consideration of potential rebound effects and should not create new inflexibility or simply shift food loss down the supply chain. We argue that a deeper understanding of the interrelationship of cooperation problems in markets will be helpful to identify and to uncover different facets of power imbalances and the shifting of business risks in food markets. Such an understanding is necessary to refine the current debate on creating CEs and sustainable food systems, which is too often coined by the question on mere technical feasibility, rather than systemically impeding institutions and practices.

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4.2 Product specifications and business practices as food loss drivers – a case study of a retailer's upstream fruit and vegetable supply chains

Ronja Herzberg, Anika Trebbin, Felicitas Schneider*

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** corresponding author*

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Product specifications and business practices as food loss drivers – A case study of a retailer's upstream fruit and vegetable supply chains

Ronja Herzberg *, Anika Trebbin, Felicitas Schneider

Thünen Institute of Market Analysis, Bundesallee 63, Braunschweig, 38116, Germany

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ABSTRACT

The issue of food loss and waste is vital for minimising resource consumption and CO_2 emissions. In particular, reducing fruit and vegetable loss and waste would contribute to keeping the food system within planetary boundaries. At the same time, food loss occurrence from primary production up to the store is underestimated and receives relatively little scientific and political attention. This case study focuses on specific food loss drivers, namely retailers' quality standards and business practices. It provides answers to the questions of how and to which extent standards and practices of the large German retailing company Lidl induce food loss in the upstream supply chain of 12 fruit and vegetable crops. To this end, we conducted qualitative interviews with supply chain actors, followed by an online survey with Lidl suppliers from Germany, Italy, and Spain. Our results indicate that, on average, 15% of the total production in the field ready for harvest does not comply with the retailer's product requirements. While most of it is marketed elsewhere, around 6% of the total production become food loss (non-harvest, animal feed, disposal, non-food items) as a direct consequence of these requirements. Retailer-specific pesticide residue limits and calibre (mass and size) followed by shape and sorting requirements are the most relevant product standards inducing food loss. The retailer's business practices such as insufficiently synchronised advertisement campaigns, return deliveries, short-notice quantity call-offs and improvable quantity planning and ordering processes add onto this. Many suppliers do not view the retailer-specific product requirements and practices as drivers of food loss and report low shares of substandard products. However, methodological constraints must be considered, such as potential selection biases, underreporting in questionnaire surveys and the study focus on suppliers rather than upstream primary producers. From this study, concrete recommendations can be drawn for retailers to adjust and handle their product requirements and business practices in order to prevent food loss at upstream supply chain stages.

1. Introduction

Reducing food loss and waste (FLW) levels can make a significant contribution to the conservation of our natural resources. The United Nations (UN) with Sustainable Development Goal (SDG) 12.3, the Farm-to-Fork Strategy (European Commission, 2020a) as well as the European Circular Economy Action Plan (European Commission, 2020b) prioritise FLW as areas for action towards the goal of obtaining not only a more sustainable food system but also a less resource intensive economic system overall.

Despite this topicality, large data gaps and variations with respect to FLW levels prevail as data generation across all scales and stages remains a challenging task (Parfitt et al., 2021). FAO (2020) and UNEP (2021) present figures on global FLW levels within their Food Loss and Food Waste Indices. These anticipate that 14% of all food becomes food loss at pre-retail stages and 17% gets wasted between retail and consumption. For Europe, it is estimated that food loss in primary production corresponds to about 18 kg per person per year, including edible and inedible parts (Stenmarck et al., 2016).

One of the difficulties in generating and providing reliable data arises from inconsistencies in defining FLW. The FAO (2019) distinguishes 'food loss' from 'food waste', where food loss accumulates between primary production and retail and food waste arises on retail and consumption stages. In the European Union, only the term 'food waste' from production up to and including consumption stages is legally defined, while the term 'food loss' is not defined at all by the European Commission (European Commission, 2019). Loss that occurs before or during the harvesting process, as well as food that is redirected to animal feed or

* Corresponding author.
E-mail addresses: ronja.herzberg@thuenen.de (R. Herzberg), anika.trebbin@thuenen.de (A. Trebbin), felicitas.schneider@thuenen.de (F. Schneider).

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towards the non-food industry is often not considered food loss or waste (European Commission, 2019; FAO, 2019). Some authors however argue that pre-harvest loss and fractions utilised as non-food should be integrated in the definition or at least taken into account in scientific evaluations (Baker et al., 2019; Hartikainen et al., 2018; Parfitt et al., 2021; Soma et al., 2021; Stenmarck et al., 2016). Leaving out this part of production results in underestimating the actual magnitude of loss, the associated resource use and the underlying drivers (Cattaneo et al., 2020; Delgado et al., 2021). This study focusses on the supply chain upstream the retailing stage and uses the term 'food loss', thereby also considering harvest and pre-harvest stages. By analysing fruit and vegetable loss on pre-retail stages, the paper addresses two subject areas that are relevant but under-represented in current research. First, fruit and vegetables are among the product groups with high loss rates (Caldeira et al., 2019; FAO, 2019). Although reducing fruit and vegetable loss and waste would contribute comparatively little to reducing greenhouse gas emissions (WWF, 2021), it would indeed help keep the food system within planetary boundaries of nitrogen and phosphorous application and blue water use (Springmann et al., 2018). Second, food loss at pre-retail stages in industrialised countries is an important issue as its magnitude, especially for fruit and vegetables, is underestimated (Parfitt et al., 2021; WWF, 2021). High- and middle-income countries in Europe, North America and Asia contribute 58% of loss at the harvesting level globally, despite inhabiting a smaller share of the global population. Worldwide, farm stage and food loss prior to retail adds up to 20–25% of total production (WWF, 2021).

There is a growing body of literature dealing with food loss in the retail sector, such as store operations (Teller et al., 2018), in-store food waste drivers (Cicatiello et al., 2020; Moraes et al., 2020) and extending the shelf-life and freshness of products in supermarkets (Broekmeulen and van Donselaar, 2019). Fewer studies have focused on food loss at the supplier-retailer interface by analysing specific trading practices (Brancoli et al., 2019) or by examining the links between resilience and food loss and waste at this interface (Moraes et al., 2019).

This paper addresses this research gap by assessing food loss drivers specific to the production-retail interface: the product specifications and business practices that retailing companies impose on the upstream supply chain. Product specifications or quality requirements refer to visual and inherent characteristics of the crop. The EU has, within their trade category regulation, laid out basic criteria for all horticultural products. More specific criteria apply to ten fruit and vegetable crops (European Commission, 2011), representing 75% of the EU trade value (UBA, 2020). The United Nations Economic Commission for Europe (UNECE) has supplemented these with voluntary criteria for most of the remaining crops, on the basis of which products may be and in practice are grouped into commercial categories (UNECE, 2020). Various authors have shown that company-specific product specifications of retailers go beyond legal requirements, thus resulting in products being sorted out and becoming food loss at early stages of the supply chain (Beausang et al., 2017; de Hooge et al., 2018; Herzberg et al., 2022; Johnson et al., 2019; Ludwig-Ohm et al., 2019; Meyer et al., 2017; Porter et al., 2018; Richards and Hamilton, 2020; UBA, 2020). Reasons for retailers placing specific demands on products include the need to introduce product differentiation (Gereffi et al., 2005), price-discrimination strategies (Richards and Hamilton, 2020), cost-efficient transportation of uniform products (UBA, 2020) and above all the fulfilment of consumers' demands for appealing products (Aschemann-Witzel et al., 2017; de Hooge et al., 2017; Hartmann et al., 2021). However, there is an ongoing 'chicken-and-egg'-debate as to whether consumers impose these so-called product requirements/specifications or quality standards through their demand in the market or whether supermarkets have educated consumers towards these expectations by competing with each other to offer the most appealing assortment (UBA, 2020).

Johnson et al. (2018a) have shown that 42% of the crop volume that is eventually marketed is left in the field due to poor quality (edible as well as inedible) in a case study for North Carolina (USA). Porter et al. (2018) conducted an estimation of loss resulting from non-compliance with visual product requirements for fruit and vegetables in the European Economic Area based on literature and Eurostat-data. They conclude that these losses vary noticeably between 4% and 37% with a mean value of 14%. Conducting direct measurement on the field, Fernandez-Zamudio et al. (2020) calculated that on average, 11.4% of all the persimmon fruit that was potentially suitable for human consumption was directly left in fields due to different flaws.

Closely related to the setting of retailers' product specifications are their business practices applied in fruit and vegetable sourcing. These include the ordering process, communication within the chain, planning of advertisement campaigns, contractual terms and conditions and the handling and passing on of the above mentioned product specifications. Rakesh and Belavina (2020), Eriksson et al. (2017) and Herzberg et al. (2022) indicate that the configuration of such practices can influence food loss levels on earlier stages of fruit and vegetable supply chains.

To date, there is no information on which specific product requirements and practices lead to food loss in which crops, nor on the magnitude of loss induced by specific requirements and practices. It is also still unclear where exactly this loss occurs and what happens to products that do not meet retailers' specific requirements. Therefore, the study pursues the following objectives:

1. To find out how the retailer's product specifications for fruit and vegetables are applied and if they lead to food loss in the upstream supply chain.
2. To find out how business practices, combined with product specifications, work and if they affect food loss in the upstream supply chain.
3. To quantify the proportion of suboptimal fruit and vegetables in the retailer's supply chain and to quantify the fractions that become food loss and those that are marketed alternatively.
4. To identify crops, product specifications and supplier groups that are most likely to fail to meet the retailer's standards.

To answer these questions, we conducted a study in cooperation with the German retailing company Lidl. We involved the retailer's upstream supply chain actors in Germany, Italy and Spain to receive insights into food loss induced by the Lidl standards. The main part of the study is a quantitative questionnaire with suppliers, supplemented by preceding expert interviews.

2. Data and methods

The study applies a mixed methods approach in the frame of a case study with the Lidl Stiftung international. Its corporate social responsibility (CSR) department approached the Thünen Institute in 2020 and expressed an interest in a scientific evaluation of food loss in their fruit and vegetable supply chain, triggered by their own product specifications and related business practices. The authors agreed to collaborate in order to contribute on this scientifically highly relevant topic. The Thünen Institute proposed a study design, while Lidl CSR provided relevant information sources and respondents for the implementation of the qualitative and quantitative survey.

2.1. Scope/focus of the study

The present study considers the Lidl supply chains from Germany, Italy and Spain, its most relevant fruit and vegetable sourcing countries in Europe. Fig. 1 shows the focus of the study indicated in green (suppliers and agencies) as well as the partly included dark grey parts (upstream producers, distribution centres). The remaining parts of the food supply chain (stores, consumers) were not considered within this study. We developed a twofold design by conducting preliminary expert interviews with relevant actors in fruit and vegetable sourcing of Lidl prior

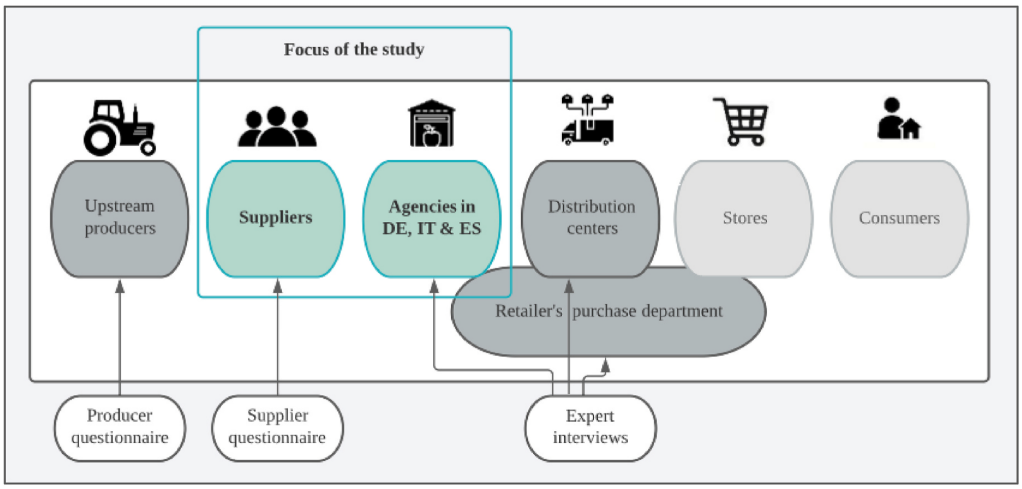

Fig. 1. Supply chain actors covered and methodologies applied in the study; suppliers (producers, producer organisations and private traders/brokers) and agencies (interface between suppliers and Lidl responsible for logistics, commissioning, packaging and quality control) are the core of the study (in green); upstream producers results (dark grey) excluded from this paper due to low response rate; distribution centres and Lidl purchase (dark grey) included in qualitative survey only. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

to the store, followed by a quantitative online survey with suppliers and producers within these value chains (Fig. 1). We included the cooperating distribution centres, agencies, suppliers and upstream producers of Lidl in our study. The distribution centres are responsible for commissioning and final quality control just before the stores. Agencies serve as an interface between the supply side and the retailer by taking responsibility for the logistics, commissioning, packaging and quality as well as pesticide residue limit control for Lidl within their respective country. The agencies, proposed to participate in the study by Lidl, are among the retailer's largest agencies and represent a substantial share of its trade flow within Europe. It therefore makes sense to include them as representatives of this stage of the supply chain.

2.2. Preceding expert interviews

We conducted five expert interviews between December 2021 and February 2022 with

- one purchaser of fruit and vegetables of Lidl
- one representative of a fruit and vegetable distribution centre in Germany
- as well as with the managers of all three so called fruit and vegetable agencies, responsible for German fruit and vegetable sourcing in Germany, Spain and Italy, respectively.

The experts were selected based on the fact that fruit and vegetable purchase, logistics centres and agencies represent the mainstays and points-of-decision concerning the supply chain between suppliers and stores. While the purchasers are employed by Lidl itself, the representatives of the distribution centres and agencies are employees of independent companies, which, however, maintain long-term business relationships with Lidl. The interview partners of all three institutions were selected and acquainted to us by our contact persons from Lidl CSR. The interviews primarily aimed at gaining an understanding of the functioning of supply chains, trade flows, the institutions' roles within the chain as well as of the perceptions of product specifications and food loss. The interview guideline was subdivided into four main thematic blocks, consisting of one to five questions each (Supplementary material 1):

Thematic block 1: Company/institution, position within and functioning of supply chain
Thematic block 2: Trade flows, ordering processes and quantity planning
Thematic block 3: Product specifications and the process of quality management
Thematic block 4: Food loss, drivers and loss points and return deliveries

In all interviews, the interviewee, two authors of this paper as well as representatives of the purchase department and CSR divisions of Lidl were present. Interviews were not recorded but notes were taken and evaluated afterwards.

2.3. Online survey with suppliers

We implemented the online questionnaire within the LimeSurvey setup of the Thünen Institute. Suppliers and upstream primary producers of twelve crops were selected to answer the online questionnaire. We decided to base the survey on suppliers and producers because food loss due to quality criteria is likely to occur during production and early in the supply chain (Beausang et al., 2017; Johnson et al., 2019; Soma et al., 2021). The selection of crops was based on discussions with the agencies, volume traded in the EU and by Lidl, loss rates drawn from the literature and the need to apply EU trade category regulation. We define suppliers as those entities maintaining direct trade relations with the agencies. There are three types of suppliers within the supply chains evaluated: firstly, large farmer suppliers who supply directly to the agencies; secondly, producer associations; and thirdly, private traders or brokers. In contrast to suppliers, upstream primary producers do not have direct trade relations with the agencies. Suppliers and upstream primary producers received distinct versions of the questionnaire. However, due to the limited scope and an unsatisfactory response rate among upstream primary producers, only the results of the supplier questionnaire are presented in this paper. (Supplementary material 2). It addresses the following key points in the form of open-ended, multiple-choice and Likert-scale questions:

1. Quantities and trading partners

2. Product specifications: existence, types and manner of passing on specifications
3. Non-compliance with product specifications: shares and channels of substandard produce
4. Food loss drivers with a focus on product specifications and business practices
5. Crop specific food loss drivers: comparison of Lidl standards with EU and UNECE standards
6. Options for action: suppliers' options, retailer's options, policy options
7. Supplier characteristics: size, fruit and vegetable volumes produced or traded, organisational structure, crop management

We discussed and improved the questionnaires' applicability and comprehensibility with all three agencies in several feedback loops. Additionally, we conducted pre-tests with fruit and vegetable producers, practitioners and scientists in the field. A professional service provider translated the German questionnaire into Spanish and Italian.

Agencies were asked to use their established communications infrastructure (mailing lists, information systems) to recruit their suppliers for the survey. Agencies in Germany and Spain sent the questionnaire link to all suppliers of the selected crops. The agency in Italy preferred to omit suppliers delivering negligible quantities on an irregular basis to Lidl. They argued that very infrequent suppliers would not be able to answer the specific questions of the survey anyway. The total number of suppliers in all three countries is 717 according to the information we received from Lidl (Supplementary material 14). The questionnaires were available online from April 20th to July 14th, 2022.

2.4. Data analysis

Expert interviews were conducted in order to gain insights into value chain functioning that serve as a basis for the quantitative part of the study. Therefore, and since it was not possible to record and transcribe the interviews, we refrained from performing a structuring qualitative content analysis.

The processing of questionnaire data can be divided into data cleansing, descriptive analysis and inductive statistics. Due to the extensiveness of the questionnaire, we included partially completed questionnaires, provided they had got past the initial questions concerning supplier type, crop and volumes traded. Of 430 suppliers who had started filling in the questionnaire, 205 were sorted out initially. Furthermore, ten duplicates were sorted out. In the course of data cleansing, we further erased implausibly high indications of produced and traded quantities in consultation with the respective agency, while keeping the remaining answers provided by these four cases within the data set. The total number of questionnaires included in the analysis was 215, resulting in an average response rate of 30%. However, the rather long and cognitively demanding questionnaire led to suppliers dropping out of the survey along the way, leading to significantly lower response rates for some items (see section 3).

We carried out descriptive analyses of questionnaire data by use of IBM SPSS 23 and Microsoft Excel 2019. We calculated response rates based on indications of the company concerning the number of suppliers in the population. We then depicted relevant characteristics of these respondents per supplier type, crop and country. Respondents' perception of the Lidl product requirements and business practices in general and as a driver of food loss were mainly depicted graphically (e.g. using diverging bar charts) and by use of statistical parameters. We moreover calculated mean shares of products not reaching the product requirements as well as shares of this produce going to alternative marketing channels. Here, we used respondents' total production and traded volume as reference values.

We hypothesised differences and correlations of

A) indicated shares of products not fulfilling requirements and
B) indicated shares of products becoming food loss (disposed, used as animal feed, non-food products or left unharvested),

between/with

a) the country/agency (Germany, Italy, Spain),
b) the supplier type (farmer supplier, broker, producer association),
c) the selected crop,
d) whether or not there are other buyers besides the retailer's agencies,
e) whether or not the supplier produces/trades (among others) organic produce,
f) the total produced or traded volumes of fruit and vegetables,
g) the number of buyers apart from this retailer
h) the duration of the business relationship between the supplier and the respective agency.

In preparation for hypothesis tests we created boxplots (Supplementary materials 3 to 12) to visualise potential differences between groups for the categorical variables. Descriptive statistics of all variables can be found in supplementary material 14. We performed hypothesis testing in RStudio (2022.02.2). For both target variables (A and B) and all categorical variables (a-e) we applied non-parametric Kruskal-Wallis tests in case of more than two groups (a-c) and Mann–Whitney U tests in case of only two groups (d-e). For continuous and discrete variables (f-h) we calculated pearson's correlation coefficient. In the event of significant differences between groups as indicated by Kruskal-Wallis test, we used the Dunn-Bonferroni post-hoc test to detect those groups that differ significantly from each other.

In order to assess the influence of certain predictors and control for interactions between them, we further set up two distinct regression models describing the target variables A and B. We employed a quantile regression approach using the variables a-c and e-h (list above) as regressors. Variable 'd' is omitted as variable 'g' (the number of buyers apart from this retailer) already describes the case where the supplier has several outlets other than Lidl. The models enable describing specific quantiles of the target variable separately and limit the effect of outliers (Koenker, 2009). If the relationship between variables is likely to perform differently at different quantiles, the approach is preferred over ordinary least squares (OLS) regression in practice, as it allows coefficients to vary with quantiles (Opoku and Aluko, 2021; Wang et al., 2019). The models for dependent variables A and B, respectively, are set out as described in formula below.

$$Q_{\tau}\,(y_i) = x_i\,\beta\,(\tau) + \varepsilon_i$$

where y_i represents the dependent variables A and B, respectively,

$Q\tau$ indicates the τth quantile of the dependent variable,
xi denotes the vector of all the independent variables (variables a–c and e–h),
β represents the regression parameter to be estimated
τ denotes the quantile, in our case 0.25, 0.5 and 0.75 and
εi represents the error term.

3. Results

In the following, we present key findings of the expert interviews (Section 3.1). In Sections 3.2 to 3.6 we illustrate the questionnaire findings, divided into the respondents' characteristics, product requirements and food loss, business practices and food loss, marketing channels and factors influencing suboptimal produce shares.

3.1. Functioning of the supply chain and product specifications according to the expert interviews

The interviewees depicted the supply chain functioning related to

their perceptions of food loss and quality standards. Despite noticeable organisational differences between each other, the three agencies supply almost exclusively Lidl and source both domestically and from abroad. Thereby, the goods become the property of Lidl only when they are accepted at the distribution centre in Germany.

Product specifications concerning appearance, packaging and pesticide residue limits are passed on from the retailer to the agencies in the form of a certain specification sheet. Agencies perceive this document as a guideline. The parent purchase department, which is responsible for issuing them, sees them as a flexible means of documenting product characteristics that may be adapted on a weekly basis. According to the purchase department, the only requirements specific to Lidl are to comply with either UNECE standard class I or trade regulation class I as well as with specific pesticide residue limits and corporate design of packaging.

The interviewees draw a diverse picture regarding food loss caused by product requirements. However, interviewees agree that almost no loss occurs at the point of the agencies. Return deliveries at agencies and distribution centres exist but most sorting takes place prior to the agency. Interviewees explain that it is decided on a case-by-case basis and depending on the respective loss point what happens to this fraction of produce. It might be 'made available' to suppliers, utilised for biogas production or marketed elsewhere. In these cases, the supplier pays the costs for food loss. There is no explicit restriction in place by Lidl that hinders produce to be marketed alternatively if rejected by the agency or distribution centres. In case of doubt regarding compliance with quality requirements, agencies consult the Lidl purchase department of Lidl that in turn decides on the acceptability of produce. As described by purchasers, they react flexibly if products do not fully align with the expected quality.

3.2. Characteristics of suppliers within the questionnaire sample

Response rates range from 11% for cucumbers to 75% for carrots (for further response rates see Supplementary material 13). With 72%, the largest share of respondents is situated in Spain, followed by 20% from Italy and 8% from Germany (Fig. 2). The imbalance within the sample roughly reflects the different sizing of the agencies within the three countries, with Spain having the largest number of suppliers, Italy the second largest and Germany the smallest (Supplementary material 13). With respect to supplier types, most suppliers (103) in the sample are farmers themselves. However, this differs depending on the country. The German agency almost exclusively sources from farmer suppliers and also in Spain, the share of farmers among suppliers with 79 out of 154 is quite high. Similarly, the supplier type varies between crops. Lettuce and mandarins are predominantly sourced from farmer suppliers, while tomatoes, apples and bell peppers are largely supplied by producer associations.

When looking at supplier sizes, indicated by cropping area, produced and traded volumes and number of members or upstream vendors, the variety within the sample becomes apparent. Cropping areas range from less than one to 15,000 ha. Farmers in Germany are the smallest, Spanish farmer suppliers the largest. The average farmer supplier hereby grows 11,000 tons of the chosen crop per year; the average farmer of a producer association grows 34,500 tons. The smallest grower in the sample cultivates 5 tons of apples and the largest 56,000 tons of cucumbers per year. With respect to volumes traded, producer associations trade a mean of 25,100 tons and brokers 8,900 tons. Producer associations in the sample on average comprise of 211 members with a maximum of 1,300 members for Italian apple producer associations. Private brokers in the sample purchase fruit and vegetables from an average of 20 producers.

Both cultivation methods, organic and conventional are represented in the sample. The majority cultivates or trades fruit and vegetables in a conventional manner, while 7% grow/trade exclusively organic products and 26% cultivate or trade both.

Only 17% of the sample suppliy their entire production to the agency that in turn supplies Lidl. The remaining share of the sample supplies an average of 25% of the traded volume to the respective agency. Regarding further marketing channels, export, other retailers and wholesale make up the largest shares of volumes traded by the suppliers.

3.3. Product requirements and food loss

The aim of the survey was to find out which requirements lead most to food loss in the Lidl upstream supply chain. Firstly, it seeks to answer the question of whether Lidl sets product requirements at all. Secondly, it contrasts these requirements as drivers of food loss with other drivers and with each other. 98% of respondents report that Lidl demands some kind of company-specific product characteristics. Suppliers indicate that all potential product requirements provided are existent within the supply chain. Among these, requirements concerning pesticide residue limits (PRL) as percentage of legal requirements and as maximum number of substances as well as requirements on calibre are mentioned most frequently (Fig. 3).

The notion whether certain company-specific requirements exist differs between crops. For instance, all participating suppliers of grapes assure the existence of standards of the retailer concerning pesticide residue limits as percentage of legal requirements. On the contrary, none of the cucumber and avocado suppliers indicate to be given

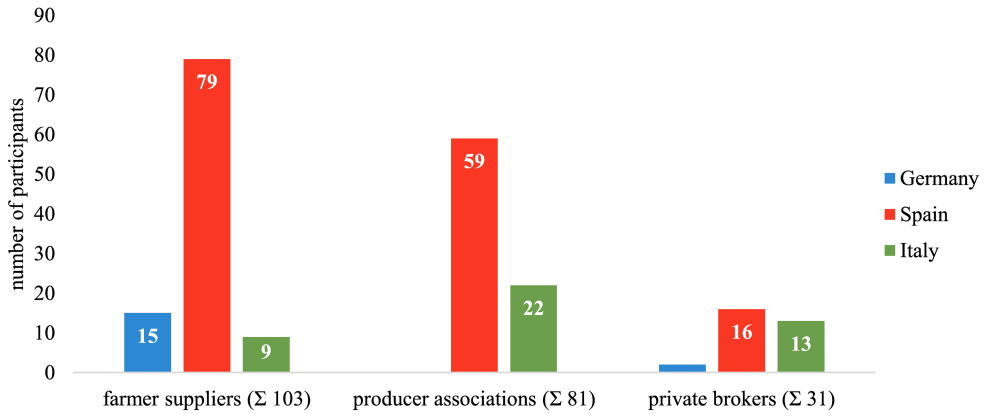

Fig. 2. Number of participants in supplier survey by supplier type and country (n = 215).

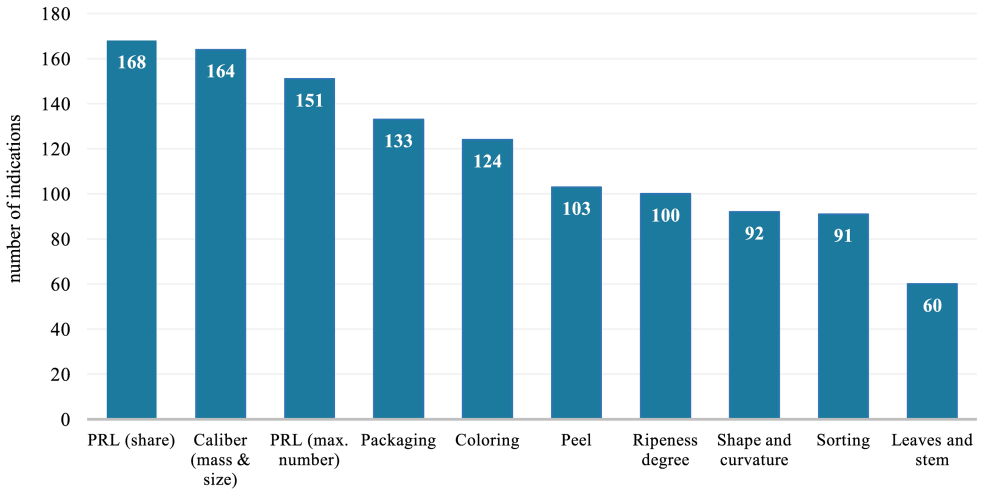

Fig. 3. Number of indications regarding which product requirements the retailer imposes on the respective crop, across all crops (multiple choice allowed, n = 178).

requirements on leaves and stem by the retailer.

With respect to overarching food loss drivers from the field to the retailer's warehouse, 21% of suppliers identify product requirements as cause of food loss. Only natural causes, such as weather events and pest infestations, are regarded as food loss driver by more respondents (35%). When looking at specific quality requirements (Fig. 4), many suppliers feel that pesticide residue limits and calibre requirements enhance food loss, followed by shape and curvature, sorting and peel specifications (red bars). All in all, the majority of suppliers does not perceive the requirements specific to Lidl which were available for selection as food loss drivers (green bars).

Whether or not participants regard a certain requirement as inducing food loss seems to depend on the selected crop. Table 1 depicts the averages of the Likert-scaled item on whether a specific quality standard leads to the occurrence of food loss (same items as Fig. 4). Accordingly, product requirements in general appear to have a greater influence on some crops (e.g. mandarins, carrots and tomatoes) than on others (e.g. avocados, cauliflower and cucumbers) and therefore food loss due to requirements are more likely in these crops. Some requirements play a more significant role for loss in certain crops, e.g. calibre and sorting

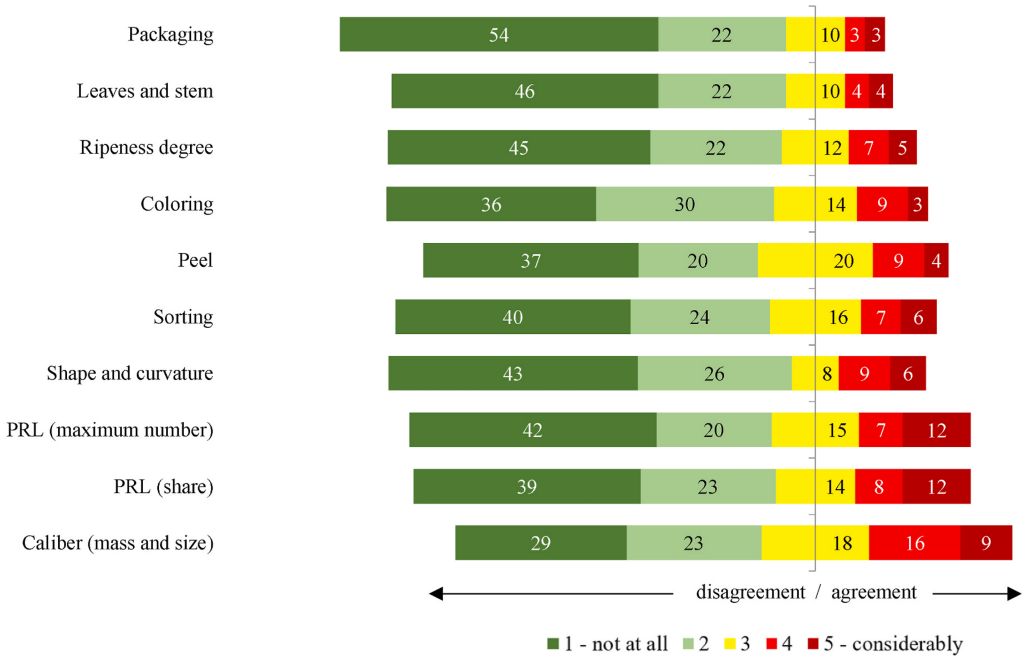

Fig. 4. Suppliers' assessment of the extent to which different retailer-specific product requirements lead to food loss on a Likert-scale as percentages of respondents (n = 147 to 148, depending on item; percentages do not sum up to 100% due to omitting NAs).

Table 1
Mean values of Likert-items regarding the question of whether certain requirements or practices lead to the food loss in the respective crop.

	Apples	Avocados	Cauliflower	Iceberg lettuce	Strawberries	Cucumbers	Mandarins	Carrots	Bell peppers	Peaches/ Nectarines	Tomatoes	Grapes
Shape and curvature	1.7	1.3	1.8	1.7	1.8	1.5	2.1	2.9	2.1	1.9	2.9	1.1
Colouring	1.9	1.5	1.9	1.6	1.8	1.8	2.6	1.9	2.3	1.5	2.9	1.6
Calibre (mass and size)	2.1	1.5	2.3	2.3	1.8	1.5	2.9	3.5	2.5	2.1	3.4	1.5
Peel	1.9	1.8	1.0	1.7	2.0	1.5	3.0	2.2	2.4	2.1	2.5	1.5
Leaves and stem	1.8	1.3	1.3	2.0	1.5	1.5	2.4	1.6	2.1	1.2	2.4	1.3
Ripeness degree	2.0	2.0	1.0	1.4	2.2	1.5	2.4	1.3	2.1	1.3	2.7	2.1
Pesticide residue limit (share)	2.3	1.3	1.4	1.9	2.3	1.8	3.4	1.9	2.6	1.5	2.3	2.4
Pesticide residue limit (max. number)	2.3	1.3	1.5	1.9	2.3	1.8	3.2	2.0	2.9	1.5	2.3	2.4
Packaging	2.3	1.5	1.0	1.6	1.5	1.5	2.0	1.2	1.9	1.3	2.2	1.5
Sorting	2.0	1.3	1.8	2.1	1.9	1.5	2.4	3.3	1.9	1.4	2.4	1.8
Restrictions in alternative marketing channels	1.7	1.3	1.9	2.0	2.1	2.0	2.8	2.5	2.3	1.4	2.4	1.6
Short notice of the actual quantities to be delivered	2.0	1.0	1.5	2.1	2.0	2.5	2.7	2.2	2.2	1.6	3.1	1.4
Short-term changes in product requirements on the part of the retailer	1.7	1.5	1.3	1.5	2.1	2.5	2.3	2.0	1.9	1.3	2.3	1.4
Inconsistencies in calculation between annual planning and called quantities	2.0	1.5	2.0	2.2	2.0	2.8	2.4	2.8	1.9	1.7	3.0	1.5
Return of goods as a result of a complaint	2.0	2.0	2.0	2.1	2.7	2.8	3.1	1.9	2.5	1.7	2.4	2.4
Promotions insufficiently coordinated with production peaks	1.7	1.3	2.8	2.5	2.1	2.8	2.9	2.9	2.7	1.8	2.9	1.8
Insufficient communication between supply chain actors	1.7	1.0	1.8	1.8	1.9	2.8	2.7	2.6	2.3	1.3	2.6	1.4

Note: on an end-point Likert scale ranging from 1/green (not at all) to 5/orange (considerably): higher mean values (highlighted in orange) indicate higher estimated extent to which requirement/practice induces food loss, number of indications (n) ranges between 5 and 34 depending on crop (row) and item (line)

requirements in carrots and pesticide residue limits in mandarins.

The manner of transferring requirements along the supply chain is a major issue. The survey reveals that the agencies usually pass requirements on to suppliers in written form, e.g. via e-mail (86%), or specify them in the contract (56%), while 17% of respondents receive them in an informal verbal way only. The informal verbal transmission becomes more important for suppliers in turn passing on requirements to their upstream producers. In this case, 40% pass them on verbally, 39% specify them in their contracts with upstream producers and still the majority of 72% communicate them in a written manner.

3.4. Business practices and food loss

We surveyed views on the existence and manifestation of potential business practices in general that may be associated with food loss (Fig. 5). Suppliers perceive the Lidl product specifications to be clear, potential adjustments to be well communicated and standards to be generally reliable. The large majority of suppliers moreover states that the retailer provides justifications for return deliveries. 53% of respondents generally comprehend these justifications. According to the suppliers, there is still room for manoeuvre with regards to the flexible handling of product requirements and the timing as well as coherence of advertisement campaigns. The results further highlight a disagreement as to whether short-term call-offs of fruit and vegetable quantities are subject to fluctuations and whether they align well with annual volume planning. The majority states to produce buffer quantities in order to be able to deliver if demanded quantities increase short-notice. For most, but not all of the suppliers, quantities to be delivered are clear no later than 24 hours prior to the actual delivery. Moreover, communication between supply chain actors is regarded as sufficient and alternative marketing of class II as well as class I products is legitimate in most cases.

We also asked participants to assess to which extent business practices contribute to the creation of food loss between primary production and retail. 8% of all respondents indicate that business practices are a food loss driver, while 14% are unsure and the majority does not perceive them as a driver. The participating suppliers perceive natural causes (35% of respondents), product specifications (21% of respondents) and market environment (19% of respondents) as major food loss driver. Only technological drivers (3% of respondents) are perceived as less relevant.

When looking at certain business practices in detail (Fig. 6), again many suppliers do not see a relationship between the practices available for selection and food loss occurrence (green bars). Nonetheless, 15–25% believe that insufficiently synchronised advertisement campaigns, return deliveries, short-notice quantity call-offs and inconsistencies in planning and ordering of volumes by Lidl strongly or very strongly contribute to fruit and vegetables becoming food loss along the upstream supply chain.

Similarly to the product requirements, the extent to which business practices are perceived as contributing to food loss appears to vary by crop. (Table 2). For cucumbers, mandarins, carrots and tomatoes, the suppliers view business practices in general as a stronger food loss driver than for other crops.

3.5. Food and non-food channels of substandard produce

From the supplier questionnaire, we calculated a self-assessed average share of 15% of the total production ready for harvest not meeting the Lidl specifications. Fruit and vegetables not fulfilling the requirements do not necessarily end up as food loss. We therefore asked follow-up questions on what happens to these products (Fig. 7). 32% of suppliers indicate not to harvest (farmer suppliers) or purchase (producer associations and brokers) them. This sums up to 3.4% of total production/traded volume that is not harvested/purchased due to the specific quality requirements of Lidl. The remaining percentage of

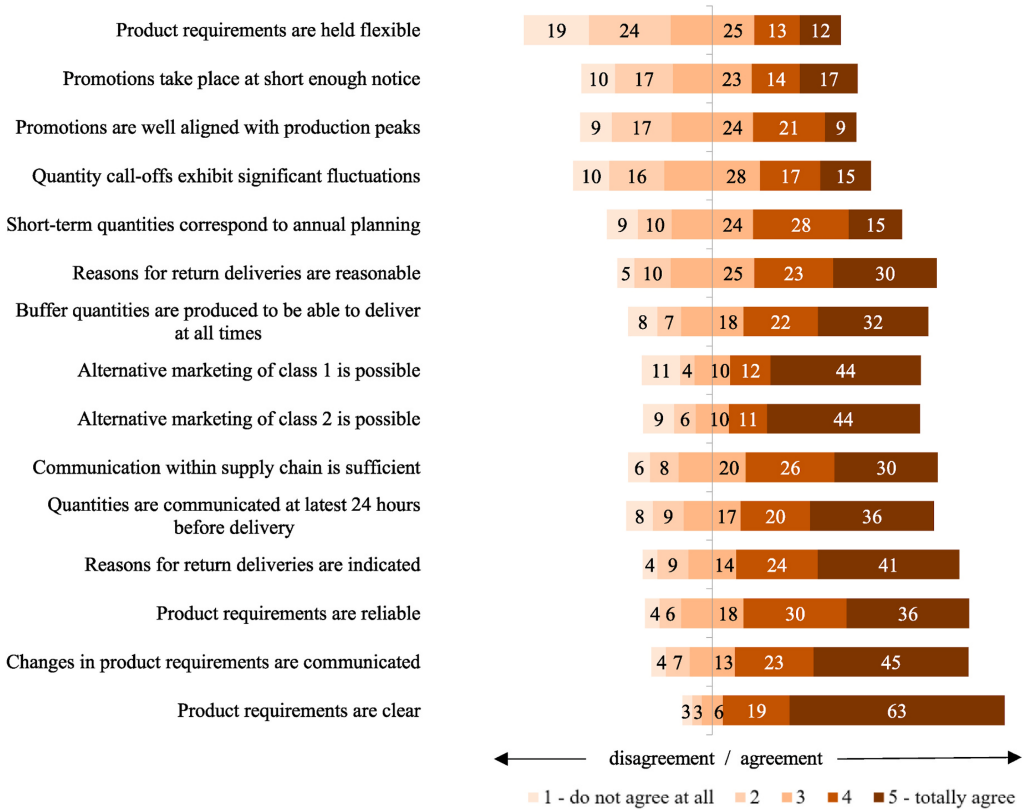

Fig. 5. Suppliers' assessment of statements regarding business practices within the supply chain on a Likert scale as percentages of respondents (n = 169; percentages do not sum up to 100% due to omitting NAs).

suppliers nonetheless harvest or purchase the substandard produce or decide on a case-by-case basis whether to harvest/purchase or not. In this case, the fruit and vegetables take other food and non-food channels. Due to the Lidl quality standards, an average of 0.9% of total production/traded volume is being disposed, including biogas, compost and other disposal routes. 1.7% becomes animal feed and only 0.04% is converted into non-food articles. Including the share which is not harvested or purchased, an average amount of 6% of the total production/traded volume or 41% of the substandard produce is lost for human consumption due to the retailer's requirements. The remaining part not complying with the requirements is mainly marketed to wholesalers and other retailers, followed by the food industry. Only a small share is sold via farmer-to-consumer direct marketing.

3.6. Factors influencing the amount of substandard produce

We applied Kruskal-Wallis tests and Mann-Whitney-U tests to detect group differences in the following two variables:

A) indicated shares of products not fulfilling requirements,
B) indicated shares of products becoming food loss (disposed, used as animal feed, non-food products or left unharvested),

The categorical variables and their characteristic values representing the groups between which differences are hypothesised are presented in the first column of Table 2. Descriptive statistics of the variables are presented in supplementary material 14.

Both variables (A and B) show significant differences between countries/agencies, via which the produce is traded. The German agency exhibits a significantly higher share of substandard produce compared to the Spanish and the Italian agency. Moreover, its loss share due to product requirements is significantly higher than the one of the Spanish agency. The Kruskal-Wallis test revealed significant differences between crops in the share of products becoming food loss. Namely, the share of substandard produce in carrots is significantly higher than the one of peaches/nectarines and tomatoes. For all other variables, no significant differences were found.

The correlation coefficients calculated for the continuous and discrete variables did not exceed |0.3|. Weak negative correlations were found between the total produced or traded volume as well as the share of the crop produced in the open field and the shares of products not fulfilling the requirements. The two mentioned variables also weakly correlate with the share of products becoming food loss.

Table 3 presents the results of quantile regression models for both dependent variables A and B. It can be inferred from model 1 that for the 0.25-quantile (representing the share of the sample that exhibits rather low shares of substandard produce), the share of produce not fulfilling the requirements is significantly lower in Spain as compared to Germany. For the 0.5-quantile, this share is significantly lower in Spain as well as in Italy. Regarding the supplier type, no significant influence was detected. However, the coefficients for producer associations are positive and for brokers negative compared to farmer suppliers in all quantiles.

The 0.75-quantile on the other hand shows significantly lower shares of substandard products for certain crops as compared to the base variable 'apples'. Lower shares can be found in cauliflower, iceberg lettuce,

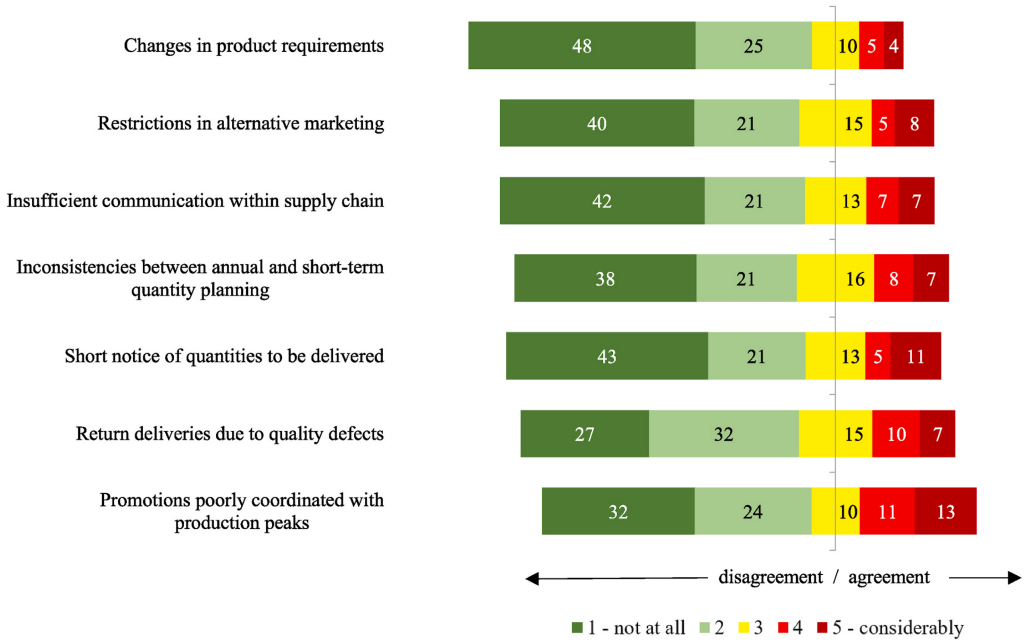

Fig. 6. Suppliers' assessment of the extent to which different business practices lead to food loss on a Likert scale as percentages of respondents (n = 149; percentages do not sum up to 100% due to omitting NAs).

carrots, peppers, peaches/nectarines, grapes and, based on a 90% confidence interval, also tomatoes. The total produced/traded volume as an indicator of the supplier size has a significantly positive effect on the share of substandard produce within the 0.75-quantile, although its effect size is small.

In model 2, which estimates the share of products becoming food loss, less influence of explanatory variables was found. With respect to the supplier type, again, the coefficients for producer associations are insignificantly positive and for brokers negative as compared to farmer suppliers in all quantiles. Looking at the crop type, interestingly, the coefficients of the variables 'carrots' and 'peppers' are significantly positive in the 0.75-quantile, although these crops' shares of substandard produce are significantly lower as compared to the base (see model 1).

4. Discussion

We interpret our findings by consecutively addressing our four research aims (Section 1), followed by suggesting options for action and discussing the study's limitations.

We addressed the question of how the interplay of a retailing company's product requirements and business practices affects food loss levels in the upstream supply chain of fruit and vegetables. Our findings support previous evidence that retailing companies impose requirements regarding certain characteristics of produce onto suppliers and producers. This in turn leads to sorting out of non-compliant products along the supply chain. Beausang et al. (2017) found that farmers perceive cosmetic specifications as a key cause of food loss. However, companies' product requirements cannot be viewed as strictly established criteria but rather as implicit knowledge. This uncertainty about the very existence, differing perceptions and handling of retailer product requirements, makes the issue of product requirements as a driver of food loss very elusive. We can derive from the suppliers' survey that a combination of product requirements primarily aiming at pesticide residue limits, calibre and other product traits, coupled with a lack of flexibility of these requirements, insufficient timing of promotion periods and inadequate quantity planning increase the risk of food loss within the evaluated Lidl supply chain. Our findings appear to be somewhat transferable: retail fruit and vegetable supply chains in Brazil face similar problems, such as a lack of coordination and information sharing, as well as demand forecasting and control in ordering (Moraes et al., 2022). Devin and Richards (2018), Rakesh and Belavina (2020) and Feedback (2017) describe lacking reliability of requirements and elaborate that retailers neither clearly define standards, nor provide sufficient evidence on the non-compliance of produce in case of a quality-related rejection. Suppliers in our study however describe requirements as rather reliable and are generally aware of the required standards and reasons for rejection, similar to Herzberg et al. (2022). It is not clear whether German retailers are actually more transparent on these issues, or whether this can be explained by the limitations mentioned at the end of this section.

We further aimed at estimating the share of fruit and vegetables not complying with the product requirements set by Lidl. The supplier survey reveals that a mean share of 15% of the total production does not meet the specific standards of the retailer. There is a lack of comparable figures in literature related to grading out of products not fulfilling retailers' specifications. Meyer et al. (2017) report producer estimates of general fruit and vegetable loss between production and store shelf of 20–30%. Baker et al. (2019) conclude that an average of 34% of the marketed volume is left in the field for various reasons in their quantification of fruit and vegetable loss during the production process for California. These estimates, in contrast to the present study, include all kinds of food loss drivers and do not distinguish food loss induced by requirements of the retail sector. Johnson et al. (2018a) show that poor quality (edible as well as non-edible) results in 42% of marketed crop volume being left in the field within their measurements in North Carolina (USA). Porter et al. (2018) estimate that retailers' quality requirements cause food loss rates between 4 and 37% within the European Economic Area. One reason for the low proportion of suboptimal products in Lidl supply chains may be better practices and

Table 2
Results of Kruskal-Wallis tests including Dunn-Bonferroni post-hoc tests for categorical variables with more than two characteristic values, Mann-Whitney-U tests for categorical variables with only two characteristic values and Pearson's correlation coefficients for continuous and discrete variables.

Variables	Share of products not fulfilling requirements (variable A)		Share of products becoming food loss (variable B)	
	Results of Kruskal-Wallis tests			
	Median	Mean ± SD	Median	Mean ± SD
Country/agency	p-value = 0.039*		p-value = 0.009**	
DE	17[a]	20.9 ± 12.8	15[a]	17.2 ± 113.8
ES	10[b]	13.8 ± 17.1	5[b]	8.75 ± 116.6
IT	10[b]	15.1 ± 18.4	9.5[ab]	12.6 ± 111.8
Supplier type	p-value = 0.338		p-value = 0.720	
Farmer supplier	10	15.6 ± 16.4	5	10.9 ± 13.7
Producer association	7.5	15.5 ± 19.8	5	11.8 ± 20.4
Broker	5	9.17 ± 8.79	10	9.64 ± 6.23
Selected crop	p-value = 0.329		p-value = 0.003*	
Apples	20	26.7 ± 26.6	1[ab]	1
Avocados	10	18.2 ± 20.0	3[ab]	3 ± 2.83
Cauliflower	5	8.78 ± 10.3	3[ab]	6.8 ± 8.35
Iceberg lettuce	10	9.25 ± 7.64	10[ab]	8.62 ± 8.08
Strawberries	5	16.3 ± 27.6	10[ab]	38.3 ± 53.5
Cucumbers	8	11.8 ± 13.8	8[ab]	8 ± 9.90
Mandarins	15	19.8 ± 18.1	5[ab]	8.44 ± 8.80
Carrots	20	20.0 ± 13.5	20[a]	24.5 ± 14.4
Peppers	10	10.7 ± 11.4	3[ab]	7 ± 7.42
Peaches/Nectarines	5	13.1 ± 17.3	1[b]	1.4 ± 2.07
Tomatoes	7.5	16.2 ± 20.5	5[b]	5.33 ± 5.98
Grapes	4.5	7.5 ± 8.54	4[ab]	3.67 ± 1.53
	Results of Mann-Whitney U-Tests			
	Median	**Mean ± SD**	**Median**	**Mean ± SD**
Exclusively supplying this retailer	p-value = 0.095.		p-value = 0.224	
Yes	12.5	18.7 ± 20.4	10	17.6 ± 24.6
No	10	13.9 ± 16.3	5	8.86 ± 10.5
Organic produce	p-value = 0.783		p-value = 0.723	
Yes	10	13.7 ± 14.2	5	10.8 ± 12.2
No	10	15.1 ± 18.2	5	11.1 ± 16.8
	Pearson correlation coefficients			
Total produced or traded volume [t/year]	−0.113		−0.154	
Number of buyers apart from this retailer	0.048		−0.06	
Duration of the business relationship [years]	0.049		0.088	

Note: SD = Standard deviation; Kruskal-Wallis test and Mann-Whitney-U test were applied to test H0: There are no differences between groups; . indicates p-value <0.1; * indicates p-value <0.05; ** indicates p-value <0.001; values with the same accompanying letter are not significantly different at the 10 %-significance level according to Dunn-Bonferroni test. For Pearson's correlation no p-values are reported due to not normally distributed variables.

handling of product specifications. However, this cannot be unequivocally inferred as other influencing factors might be the more precise method of direct field measurement in other studies, natural variations in food loss amounts as well as the consideration of different parts of the supply chain and different food loss fractions and drivers.

Only few previous studies address the question of what happens to produce not complying with retailer requirements. In our study, a share of 6% is not used for human consumption due to the non-compliance. This part is predominantly not being harvested or purchased by the suppliers, used as animal feed or being disposed. Hartikainen et al. (2018) estimate this proportion of so-called side-flow between 1 and 26% for vegetables and 10 and 14% for fruits. However, they did not narrow their scope to food loss induced by retailers' specifications. For the remaining substandard produce, in this study most frequently utilised channels are wholesale, other retailers and the processing industry. In line with Delgado et al. (2021), Fernandez-Zamudio et al. (2020) and Baker et al. (2019), leaving non-conforming products in the field during the harvesting process is a common strategy. It does not make economic sense to harvest produce unlikely to be sold for a reasonable price afterwards. What happens to substandard products also depends on the potential marketing channels at hand. For instance, in our sample some products can be processed more easily than others. Furthermore, farmer suppliers are more likely to be able to use produce as animal feed due to their network and some products can be marketed to other supermarkets as the respective requirements may differ. It also influences the further path of the products, at which point in the supply chain grading processes and quality controls take place. Meyer et al. (2017) make similar observations and state that hand-picked crops, such as salad, cauliflower and broccoli, are out-graded during harvesting while for crops like apples, potatoes, carrots and onions, alternative food use is more likely due to later grading.

We ultimately aimed at answering the question whether the alignment with the retailer-requirements is harder to achieve for certain crops, product specifications and suppliers than for others. The statistics revealed that some crops, such as cauliflower, iceberg lettuce, carrots, peppers, peaches/nectarines, grapes and tomatoes are less likely to fail meeting the requirements. Interestingly, loss rates due to the retailer's standards in carrots and bell peppers in our study are nonetheless significantly higher. This might be due to restricted alternative processing options and the higher chance of carrots becoming animal feed. This shows that the further path of substandard products depends on the crop and underscores the relevance of diverse distribution channels for food loss prevention (Chaboud and Moustier, 2021). As opposed, Baker et al. (2019) found rather low loss rates for tomatoes but high loss rates for salads and cabbages, which might be due to the broader focus on food loss drivers apart from quality standards. There are also requirements that seem to be harder to reach, such as pesticide residue limits, calibre but also shape and curvature. The relevance of pesticide

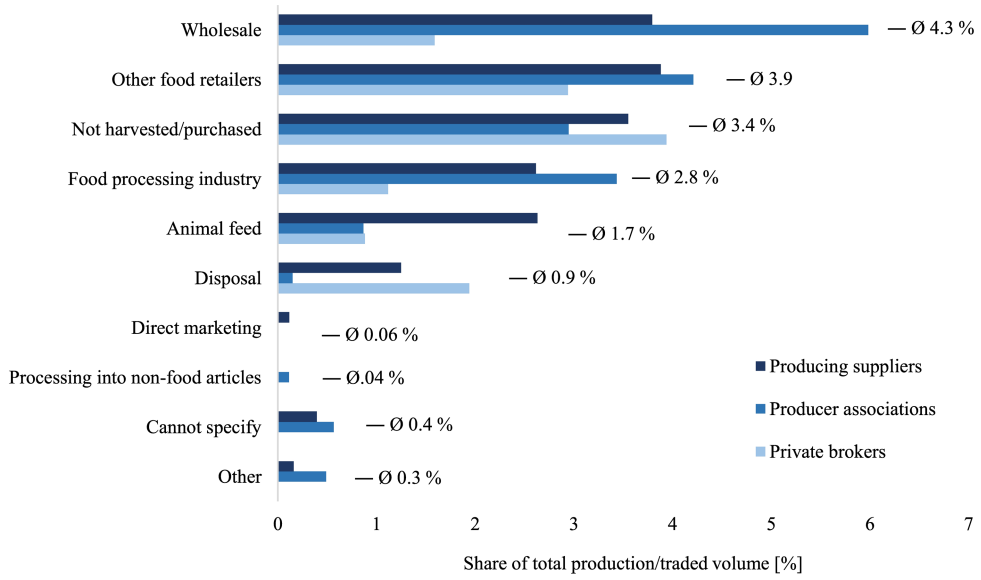

Fig. 7. Trade and utilisation channels for products that do not meet the retailer's requirements (as a percentage of total production for farmer suppliers and of traded volume for producer associations and private brokers, n = 139).

Table 3
Results of quantile regression models for dependent variables A and B for 0.25, 0.5 and 0.75 quantiles.

Variables	Model 1 with dependent variable A: Share of products not fulfilling requirements			Model 2 with dependent variable B: Share of products becoming food loss		
	Regression results per quantile			Regression results per quantile		
	q25	q50	q75	q25	q50	q75
Country/agency						
DE	base	base	base	base	base	base
ES	−9.40*	−12.44*	−11.58	−0.05	−4.00	−9.56
IT	−6.93	−11.19*	−11.07	2.30	2.81	0.52
Supplier type						
Farmer supplier	base	base	base	base	base	base
Producer association	0.94	2.76	0.12	2.05	2.22	1.10
Broker	−1.68	−2.30	−4.43	−5.17	−9.24	−7.83
Selected crop						
Apples	base	base	base	base	base	base
Avocados	3.46	−5.70	−27.29	6.03	10.73	13.92
Cauliflower	−3.73	−19.33	−54.07**	3.18	8.75	13.47
Iceberg lettuce	−2.15	−14.02	−48.44**	7.24	15.80	20.57
Strawberries	−2.62	−16.39	−34.15	8.00	17.49	111.82
Cucumbers	−3.37	−1.14	−26.75	5.29	8.51	25.90
Mandarins	−2.19	−1.58	−18.64	6.30	14.56	21.82
Carrots	4.78	−1.95	−37.39*	22.29	30.68	35.49*
Peppers	−1.84	−9.81	−38.71*	7.04	12.81	32.54.
Peaches/Nectarines	−1.96	−11.97	−37.63*	1.71	10.46	15.15
Tomatoes	- 2.40	−6.05	−29.01.	6.94	11.96	18.82
Grapes	−3.93	−13.65	−45.42**	6.55	14.26	15.95
Organic produce						
Yes	base	base	base	base	base	base
No	2.18	1.22	0.26	0.74	1.51	2.38
Total produced or traded volume [t/year]	< −0.01	< −0.01	< −0.01*	< −0.01	< −0.01	< −0.01
Number of buyers apart from this retailer	0.10	0.82	−0.35	0.30	0.07	0.13

Note: . indicates p-value <0.1; * indicates p-value <0.05; ** indicates p-value < 0.001.

residue requirements of retailers as a food loss driver is, compared to cosmetic requirements, taken into account by only few scholars, e.g. by Ludwig-Ohm et al. (2019) and Meyer et al. (2017). Our study shows that this topic should be given a much higher priority. With respect to the suppliers' characteristics, we were able to show that German suppliers exhibit a significantly higher share of substandard products. This is likely due to them producing a large amount of carrots and due to the high percentage of farmers in this sub-sample.

It has been found that many retailing companies in different countries set product specifications for distinct fruits and vegetables (Devin

and Richards, 2018; Meyer et al., 2017; Porter et al., 2018; Willersinn et al., 2015). Although the exact specifications differ between retailing chains (Baker et al., 2019; Herzberg et al., 2022), we are able to draw general suggestions for retailers regarding the adjustment of certain product specifications and business practices from the results. Retailers should check whether they can handle product requirements less strictly, in particular when it comes to pesticide residue limits and calibre. With business cases such as 'Bio-Helden' (organic heroes) and 'Die krummen Dinger' (the crooked things) some retailers located in Germany have already proven that marketing of selected substandard fruits and vegetables can work (Aldi Süd, 2023; Kaufland, 2023; Rewe Group, 2023). It has been shown that there is scope to market suboptimal products, especially when deviations in shape and size are moderate (Loebnitz et al., 2015). Potential strategies include reducing prices (Aschemann-Witzel et al., 2020), mixing suboptimal and optimal foods and highlighting their naturalness and authenticity (Qi et al., 2022), or appealing to consumers' value orientation, commitment to environmental sustainability, and perceived environmental effectiveness (de Hooge et al., 2017). Retailers, especially in the organic segment, may have untapped potential to sell suboptimal products and may even lose opportunities to improve their image by missing out on selling these products (Louis and Lombart, 2018). Of course, which standards to liberalise must be chosen with sound judgement so as not to induce an increase in food loss and waste at processing, storage, retail and consumption stages (Soma et al., 2021; Willersinn et al., 2015). As suppliers, contrarily to company representatives, perceive product specifications as rigid, it seems that potentially existing flexibility and tolerance must be communicated better along the supply chain. Additionally, promotion campaigns should be synchronised more with production peaks to enable a more reliable planning of quantities and yearly consultations should be aligned better with short-term calls of quantities. By setting ambitious pesticide residue limits, retailers aim to meet societal demands for health, environmental conservation and sustainability and avoid negative publicity. However, retailers must consider arising trade-offs between pesticide residue reduction and food loss reduction (for sustainability trade-offs and food waste reduction see Latka et al. (2022)). Similar to Chaboud and Moustier (2021), this study underlines the importance of diverse marketing channels and networks for food loss reduction. Therefore, retailers should maintain already existing marketing networks and actively support access to further alternative marketing and processing channels for their suppliers. They should also ensure that corporate packaging design and early packing do not hinder taking advantage of these channels. Actively promoting alternative marketing also implies taking responsibility, and potentially even ownership, of the produce earlier in the supply chain (Devin and Richards, 2018). Ownership would create economic incentives for retailers to reduce food loss. In this way, retailers would not only benefit from improved supply chain governance, but would also have to bear the cost of food lost in the early stages of the supply chain.

There are limitations within the study design and implementation that are likely to influence our results. An underestimation of food loss quantities is likely as our data is based on supplier estimates. Baker et al. (2019) showed for California, that direct measurement of loss on the field is 157% (median) higher than growers' estimation. Two studies conducted in North Carolina (USA) show that on-field measurement results in considerably higher field-loss figures than estimates by involved experts, such as farmers (Johnson et al., 2018a,b). In addition, the potentially highly relevant loss point of upstream primary producers is not incorporated in this paper. Moreover, sample sizes for some crops are rather low and we cannot appraise the representativeness of the sample due to missing information on the population characteristics. The involvement of Lidl was administratively helpful, but a potential biasing effect, for example due to sending out of the questionnaires by the agencies, cannot be precluded. The potential for bias due to a lack of confidence in the anonymity of the survey as promised to respondents must also be taken into account.

5. Conclusions

The conducted case study with the German based retailing company Lidl underpins that retailer-specific product specifications and business practices represent drivers of food loss within their supply chain. Suppliers regard product requirements as the second most important reason for food loss, after natural causes. They state that 15% of the produce grown or traded does not meet the retailer's requirements. Although a large fraction of this produce is marketed elsewhere, 6% of fruit and vegetables in the Lidl supply chain becomes food loss due to sorting out according to its specific product requirements. These percentages are comparably low due to the narrow focus on retailers' specifications as food loss driver, the focus on suppliers rather than producers, potential underreporting and further methodological limitations within this paper.

Diverging from previous findings that highlight traits like shape and colouring as problematic, in our case calibre requirements (mass and size) as well as pesticide residue limits most frequently lead to food loss. In order to reduce food loss levels in the upstream supply chain, retailers should reconsider the level of strictness and rigidity of their own requirements, prioritise potential trade-offs between food loss and pesticide residue requirements, better coordinate promotional campaigns and adjust ordering processes. They should moreover take responsibility for the produce earlier in the supply chain and therefore actively promote alternative marketing and processing channels for suboptimal produce and minimise rejection practices.

All in all, it seems that a differentiated view on product specifications and business practices is required. This view should consider that different specifications and practices affect certain crops and supply chains more than others. However, in our study we could only statistically verify this statement for the sourcing country and for some crop types. Future research should be based on larger sample sizes and be complemented by on-site quantification. A further basic requirement for understanding and tracking food loss that occurs due to retailers' product requirements is to consider pre-harvest and harvest losses. Moreover, future research should replicate similar studies with other retailing companies and for further countries, crops and supply chains to learn more about the reasons why some suppliers perceive specifications and practices as food loss drivers and still many do not. Finally, the effect of potential implementations of the recommendations developed in this paper should be scientifically monitored.

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Declaration of competing interest

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

Data availability

The data that has been used is confidential.

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Appendix A. Supplementary data

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4.3 Policy instruments to reduce food loss prior to retail – perspectives of fruit and vegetable supply chain actors in Europe

Ronja Herzberg, Felicitas Schneider, Martin Banse*

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** corresponding author*

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Research Paper

Policy instruments to reduce food loss prior to retail – Perspectives of fruit and vegetable supply chain actors in Europe

Ronja Herzberg *, Felicitas Schneider, Martin Banse

Thünen Institute of Market Analysis, Bundesallee 63, Braunschweig, 38116, Germany

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ABSTRACT

Food loss and waste burdens the food system with an unnecessary use of natural resources such as soil, land and water as well as with the avoidable generation of further climate-relevant emissions. These negative externalities may provide a rationale for public sector intervention where feasible and efficient.

Semi-structured interviews with 22 experts (farmers, producer organisations and retailers) in Germany and a questionnaire survey with 215 suppliers of a retailing company from Germany, Spain and Italy were conducted. The material reveals the perspectives and claims of relevant actors in upstream fruit and vegetable supply chains on political intervention.

Stakeholders identified policy instruments from four overarching thematic categories: (I) communicative and cooperative policies, (II) subsidisation and food prices, (III) regulation and political framework conditions and (IV) questioning of necessity and effectiveness of food loss interventions. Four further categories of private sector measures were identified: (I) mechanisation, innovation and process optimisation, (II) communication and cooperation, (III) reconditioning and repackaging and (IV) processing, alternative marketing and redistribution.

Issues that should be addressed by policy include consumer education and awareness, supply chain cooperation and power relations, food prices, marketing standards, alternative marketing and processing and promotion of technologies, infrastructure and agronomic practices to reduce food loss. The study shows that additional leverage points for policy action are still unrecognised and that stakeholders should be more involved in tackling the root causes of food loss. These policies should be holistically embedded in the sustainability transformation of the food system.

1. Introduction

Wasting food implies the depletion of natural resources utilised for its production (Garske et al., 2020b), such as phosphorus, land and freshwater, as well as environmental degradation in the form of eutrophication and contamination of waterbodies and soil, greenhouse gas emissions and effects on biodiversity (WWF, 2021). According to Springmann et al. (2018) halving food loss and waste by 2050 could contribute largely towards keeping the food system within the planetary boundaries. Such negative externalities are often not incorporated in the economic assessments of the supply chain stakeholders but carried by society as a whole. Hence, losing or wasting food may deliberately be accepted by supply chain stakeholders as their optimal market outcome while standing in contradiction to the best interest of society (FAO, 2019; Koester, 2014). Negative externalities are one kind of market failure that may provide a rationale for public sector intervention (Döring and Töller, 2018; FAO, 2019).

Policies and legislation play a crucial role in driving choices towards reducing food loss and waste by all actors along the food supply chain (Segrè et al., 2014). Flanagan et al. (2019) and the UN (2020) underline the need for governmental action towards more sustainable consumption and production patterns established in the Sustainable Development Goal (SDG) 12 of the *Agenda 2030*. SDG 12.3 explicitly aims at halving food waste amounts on consumption and retail stages and merely reducing the food loss amount within the remaining stages of the food supply chain. A large variety of national policies exists to directly or indirectly counteract the emergence of food loss and waste. The examples range from food loss and waste measurement over investments into infrastructure and manufacturing processes, changes of standards, tackling of so-called Unfair Trading Practices (UTP), tax-incentives and fees and voluntary agreements to behaviour change campaigns (Reynolds, 2023). International strategies, such as the Circular Economy

* Corresponding author.
E-mail addresses: ronja.herzberg@thuenen.de (R. Herzberg), felicitas.schneider@thuenen.de (F. Schneider), martin.banse@thuenen.de (M. Banse).

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Action Plan (European Commission, 2020) and the European Green Deal (European Commission, 2019b), also suggest that food loss and waste should be ranked high on the political agenda. However, scientific evidence regarding policy actions remains scarce (Cattaneo et al., 2020b; Reynolds, 2023). In recent scientific literature, a focus is laid on two main topics. On the one hand, food loss and waste prevention measures targeting consumers at the household level are investigated (Eičaitė et al., 2021; Giordano and Franco, 2021; Herzberg et al., 2020; Karunasena et al., 2021). On the other hand, legislation targeting the redistribution and reuse of surplus food as well as recycling of food loss and waste is being evaluated to a large extent (Giordano et al., 2020; Soma et al., 2021). However, redistribution and reuse represent minor priorities of the food waste hierarchy compared to prevention (Papargyropoulou et al., 2014).

We identified two research gaps to be addressed in this paper. First, evidence on policy measures in the upstream supply chain (primary production to retail) remains scarce, although large reduction potentials exist at the production stage and in industrialised regions such as Europe and North America (FAO, 2019; WWF, 2021). Kuiper and Cui (2021) showed in their modelling approach, that policy measures focussing on primary stages of the food supply chain, as well as on the product groups of fruit and vegetables, promise positive effects on food security and environmental sustainability on a global scale.

Second, the perspectives of supply chain actors with regard to food loss and waste prevention policies are often neglected (Johnson et al., 2019). This can result in policies failing to address the underlying causes of food loss and waste (Herzberg et al., 2022; Johnson et al., 2019; Kinach et al., 2020). From this, we derive the following research questions:

I. Which policy instruments have so far dominated in tackling food loss in the early supply chain and which approaches have been neglected?

II. What are the demands of relevant stakeholders of the food supply chain on policy interventions to reduce food loss in the early supply chain?

III. How can policies be designed to meet these demands and to address the underlying causes of food loss in the early supply chain?

The proposed research questions will be answered on the basis of qualitative expert interviews and a quantitative supplier survey. These reflect the subjective views of stakeholders on the question of what can and should be done in order to reduce food loss. The empirical findings are exemplary for fruit and vegetable supply chains fully or partially situated in Germany, although some findings are translatable to other geographic regions and product groups.

2. Political intervention from a sustainability governance perspective

In environmental policy, or sustainability governance, distinct political instruments are at hand to tackle the respective environmental or resource-related problem. Within this paper, we largely follow the categorisation of policy instruments in accordance with Döring and Töller (2018) and use it as a theoretical foundation for our expert interviews. Table 1 provides a summary of existing classifications of environmental policy instruments, including a selection of arguments in favour of and against their implementation as well as selected examples of application fields in sustainability governance.

2.1. Direct regulation or command-and-control instruments

Direct regulation, also referred to as “command-and-control regulation”, works by “imposing mandatory obligations or restrictions on the behaviour of firms or individuals” (Perman et al., 2011, p. 217). Traditional regulation, according to Driesen (2006), implies performance standards and work practice standards. While performance standards set a certain target, which needs to be reached by any means, work practice standards refer to the regulation of means or techniques in connection with a certain aim. It is argued that this kind of environmental policy may not foster innovation as it might not provide incentives for technical progress (Döring and Töller, 2018, p. 421; Johnstone et al., 2010). However, it is debated whether regulation in fact inhibits innovation as some studies have shown that particularly flexible performance standards enhance innovation by giving an incentive to minimise control costs (Driesen, 2006; Lanoie et al., 2011, p. 837). Further, financial resources for the executive enforcement of the regulation must be available and carried by the governing entity (Döring and Töller, 2018, p. 421). Moreover, governance problems such as rebound and shifting effects and lack of rigour could weaken the desired positive environmental effects (Ekardt, 2016; Garske et al., 2020a). Nonetheless, Taylor et al. (2012, p. 274) claim that direct regulation proved to be an effective instrument to prevent environmental degradation in many cases. Döring and Töller (2018, p. 421) specify, that particularly in the event of a low number of damage causers with similar abatement costs, regulation can be the instrument of choice in reducing environmental damage.

2.2. Market-based or monetary incentive instruments

The second of the two most frequently cited sets of environmental policy instruments encompasses market-based instruments or economic

Table 1
Instruments of environmental policy, respective advantages and disadvantages as well as examples of application.

policy instrument	specifications	advantages	disadvantages	examples from sustainability governance
direct regulation / command-and-control	performance standards, work practice standards	potentially high effectiveness	do not foster innovation, resources for executive enforcement	ambient (water, air) pollution requirements and targets, restrictions in pesticide use, mandatory use of catalytic converters
market-based instruments / economic incentive programs	taxes, subsidies, certificates, liability law, tradable rights and permits	positive effect on innovation, potentially high effectiveness	unclear adjustment behaviour in market, undesirable avoidance behaviour and distributional effects, market distortions	Emissions Trading Schemes (ETS), landfill tax, agri-environment payments and conservation payments
cooperative instruments / self-/ co-regulation	voluntary/ environmental agreements, disclosure of information	less costly than regulatory and market-based approaches, businesses can make own contributions	risk of low effectiveness, cooperation hampered by power imbalances	sector-wide voluntary agreements on food waste reduction, corporate social responsibility programs
information-based instruments	targeted information provision, naming and shaming/faming, labelling and certification	low costs, low degree of intervention	rely on consumer sovereignty and morality, limited to processable amount of information	“right-to-know-programs”, emission inventories, eco-labelling of food

Note: based on Döring and Töller (2018), Taylor et al. (2012), Driesen (2006), Perman et al. (2011) and Gouldson et al. (2008).

incentive programs which are described by Driesen (2006) as an alternative between liberalisation and regulation. This set of policy measures operates by influencing incentives to encourage firms or individuals towards a behaviour change on a voluntary basis (Perman et al., 2011, p. 217). Döring and Töller (2018, p. 421) divide environmental policy instruments into taxes, subsidies, certificates and liability laws. Taylor et al. (2012, p. 274) list tradable rights and payments besides taxes and subsidies. Price-based instruments imply negative incentives such as taxes on environmentally destructive activities while positive incentives, such as subsidies, encourage environmentally beneficial activities (Driesen, 2006). An argument raised against market-based instruments is the limited knowledge of political entities on the adjustment behaviour of private entities facing taxes, subsidies or other economic incentives (Döring and Töller, 2018, p. 421). Hence, it cannot be reliably estimated whether or to which extent actors react to the incentive and whether the targeted environmental effect will be reached (Taylor et al., 2012, p. 274). Furthermore, market incentives may entail harmful avoidance behaviour, create socially undesirable distributional effects and lead to market distortions and rising prices (Taylor et al., 2012, p. 280). An advantage of economic instruments is the positive effect on innovation (Johnstone et al., 2010) as any further abatement of negative environmental effects leads to further monetary advantages (Döring and Töller, 2018, p. 421). This set of instruments moreover provides an incentive for an individual cost-efficient abatement of environmental degradation (ibid.).

2.3. Cooperative instruments or co–/self-regulation

Besides the described rather traditional instruments, Döring and Töller (2018) list cooperative policy instruments, defined as cooperation between the state and private actors. Examples of cooperative instruments are voluntary agreements, environmental agreements and voluntary disclosure of information (ibid.). Taylor et al. (2012, p. 281) describe this equivalently as self-regulation or co-regulation. Voluntary agreements (VAs) in this context are commitments of private entities or stakeholders to reach certain qualitative or quantitative objectives (Burgos et al., 2019). These agreements may be supported by governments, businesses or other actors and implemented besides prevalent legislation or individually (ibid.). A major advantage of voluntary action is that additional costly regulation and legislation might be avoided. It moreover gives businesses the opportunity to make their own contributions and engage in the action as ambitiously as desirable or feasible (UNEP, 2014). Especially if key organisations commit to voluntary engagement, this can trigger wider implications within the whole sector (ibid.). Taylor et al. (2012, p. 281) nevertheless argue that the flexibility and voluntary nature of cooperative action carries the risk of businesses not engaging much more than they would have done without the instrument, as they weigh implementation costs against potential effects. The participation in the voluntary agreement then gives the illusion of positive environmental behaviour without leading to significant environmental outcomes, also referred to as “green-washing” (Taylor et al., 2012, p. 281). Döring and Töller (2018, p. 417) further argue that in case of power imbalances the mutual will of cooperative action may be hampered.

2.4. Information-based instruments

Taylor et al. (2012) and Gouldson et al. (2008) understand information-based instruments as a fourth category of environmental policy instruments. Information-based instruments will, in accordance with Döring and Töller (2018), be united with cooperative instruments and self-/co-regulation in the frame of this paper. The lines between cooperative instruments or self-/co-regulation and information-based instruments are blurred as illustrated by the similar examples of “disclosure of information” and “targeted information-provision” (Table 1). Information-based instruments function by providing knowledge based on which businesses and individuals make decisions towards better environmental performance (Taylor et al., 2012, p. 280). According to Gouldson et al. (2008), three types of information-based instruments exist: targeted information provision, naming and shaming/faming and labelling and certification schemes. Naming and shaming or right-to-know programs and eco-labelling are frequently used tools in several European countries to inform consumers on the environmental traits of different products which might influence their respective purchase decisions (Driesen, 2006). Information and education campaigns also represent a frequently applied tool in food waste prevention and reduction (Priefer et al., 2016). Nonetheless, this kind of policy relies completely on consumer sovereignty and morality and is limited to the amount of information that consumers can process (ibid.), thereby creating a tension between comprehensive information provision and simplification (Driesen, 2006).

Overall, there are different types of instruments in sustainability governance, each with its own set of advantages and disadvantages. In this paper, we examine whether some of these instruments are being used in the context of food loss prevention, and what challenges may arise if they are used in the future. We draw on the categorisation of environmental policy instruments as a theoretical background for the conduct, analysis and interpretation of our interviews.

3. Data and methods

The objective of the applied methodology is to intersect demands and claims of relevant supply chain stakeholders on food loss measures with potentially applicable policy instruments in sustainability governance.

By “food loss and waste” we refer to the entire supply chain, while “food loss” describes losses from primary production to the retail gate (FAO, 2019). Although the respective European legislation (European Commission, 2019a) does not consider produce left in the field as food loss and waste, we also consider this fraction as do other researchers (Hartikainen et al., 2018; Parfitt et al., 2021; Stenmarck et al., 2016).

Qualitative expert interviews and questionnaire data serve to explore the demands and claims of supply chain actors regarding food loss policies. Information on policy instruments for sustainability governance are derived from scientific findings and theoretical literature from the field of economic and environmental policies (Section 2).

3.1. Semi-structured expert interviews in fruit and vegetable supply chains

The acquisition of participants as well as the implementation of the expert interviews is described in detail by Herzberg et al. (2022). Parts of the interviews specified therein also form the basis of the present study. We identified the following stakeholders as the most relevant in fresh fruit and vegetable supply chains (Garming et al., 2018; Schmidt and Orr, 2019; Strohm et al., 2016): first, producers (fruit and vegetable growers), second, fruit and vegetable producer organisations and third, food retailers. The inclusion of interviewees from both the production and retail side allows the diversity of potentially controversial and self-interested claims about policy measures to be captured.

All in all, we conducted 22 expert interviews between September 2020 and January 2021. Geographically, producers and producer organisations are located in distinct federal states of Germany and the main fruit and vegetable growing areas are included. Grown and marketed fruit and vegetables comprise carrots, potatoes, salads, onions, blue berries, pomaceous fruit (e.g., apples) and others. The interviewed retailers range from regionally through to internationally represented companies and enterprises. Purely organic as well as full range providers and discounters are included in the sample. Some interviews were conducted face-to-face at the interviewees’ premises, while the majority were held online or by telephone due to the COVID19-pandemic. Further details on the conduct and analysis of the interviews can be found in Herzberg et al. (2022). Fig. 1 provides an overview of the acquisition method and the respondents’ position within the respective

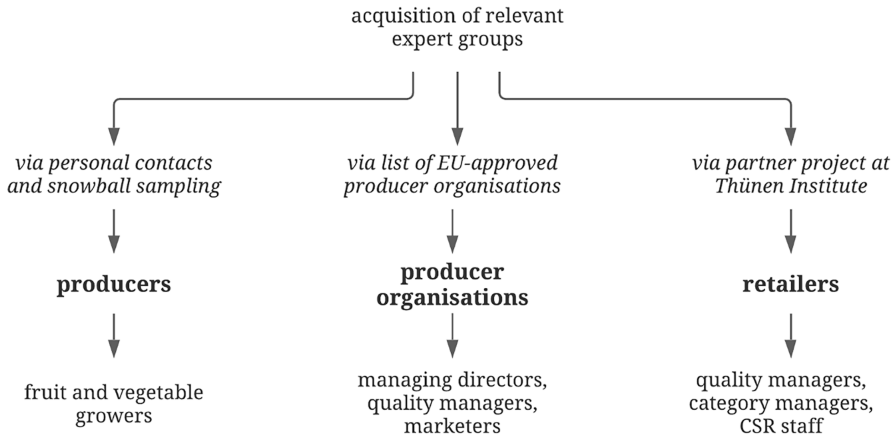

Fig. 1. Expert acquisition procedure from Herzberg et al. (2022) (means of selection and acquisition, expert group, and position of interviewees within the enterprise).

enterprise or organisation.

The initial aim of the expert interviews was to improve the comprehension of the supply chain stakeholders' interactions and relationships that either result in or prevent the emergence of food loss and waste. We developed an interview guideline consisting of the following thematic priorities:

(1) Structure of value chain and business relationship
(2) Perception of food loss
(3) Contracts, agreements, orders, and quantities
(4) Quality management and quality standards
(5) Trading practices and bargaining power
(6) Options for action (policy and private sector)

The focus of the present study lies on priority six "options for action (policy and private sector)" (see above). Interviews were audio-recorded, transcribed and pseudonymised. Then, the software MAXQDA was used to perform a structuring content analysis to the textual material guided by Kuckartz (2018) and following Mayring (2015). In a first step, all approaches and measures to reduce food loss and waste along the supply chain mentioned by the experts were coded using the superordinate codes "policy intervention" or "private sector measures". In a second step, we derived sub-codes of "policy interventions" mainly deductively, informed by the theoretical basis on environmental policy and sustainability governance presented in Section 2. We drew the sub-codes of the superordinate code "private sector measures" from the interview data in an inductive manner. This was due to the lack of a theoretical foundation on private sector interventions as compared to policy interventions.

3.2. Quantitative survey with suppliers of a retailing company

As a second component of this paper, we analysed parts of a quantitative survey conducted at Thünen Institute with 215 fruit and vegetable suppliers (producers, producer organisations and private traders) of a retailing company. These deliver fruits and vegetables from Germany, Spain and Italy via so-called agencies to the retailer's stores in Germany. The survey was conducted between April and July 2022 as part of a project aiming to analyse the influence of the retailing company's quality standards and business practices on food loss in 12 crops. The questionnaire was distributed online via the communication channels of the retailing company and its upstream fruit and vegetable agencies in the respective countries. It collects data on the following aspects:

(1) Quantities and trading partners
(2) Product specifications: existence, types and manner of passing on specifications
(3) Non-compliance with product specifications: shares and marketing channels of sub-standards produce
(4) Food loss drivers with a focus on product specifications and business practices
(5) Crop specific food loss drivers: comparison of retail standards with specific EU and UNECE standards
(6) Options for action: own options, retailer's options, policy options
(7) Supplier characteristics: size, fruit and vegetable volumes produced or traded, organisational structure, crop management

Further details on how the questionnaire was administered and how it was analysed can be found in Herzberg et al. (2023). In the following, only results on aspect six will be presented descriptively. The analysis of the questionnaire data of the items presented was performed using IBM SPSS 23 and Microsoft Excel 2019. The development of the respective Likert-scaled questionnaire items was inspired by the results of the expert interviews (Section 3.1). Between 134 and 143 respondents provided answers to these optional questionnaire items assessed within this paper.

4. Results

The content analysis of the expert interviews resulted in two overarching codes, namely potential policy interventions (1) and private sector measures (2) that contain four sub-codes each. In the case of policy measures, these are:

(1a) Communicative and cooperative measures
(1b) Subsidisation and food price related measures
(1c) Regulatory measures and political framework conditions
(1d) Political intervention not necessary or wanted

And in the case of private sector measures:

(2a) Mechanisation, innovation and process optimisation
(2b) Communication and cooperation of supply chain actors
(2c) Reconditioning and repackaging
(2d) Alternative marketing, processing and redistribution

The following sections will elaborate on and provide examples of these categories.

Table 2
Superordinate and subordinate codings of structured content analysis per expert group indicated as absolute numbers and percentages per line.

	retail		producer organisations		producers		total	
	no. of codings	percentage per line	no. of codings	percentage per line	no. of codings	percentage per line	no. of codings	percentage per line
(1) policy interventions	**23**	**43 %**	**19**	**36 %**	**11**	**21 %**	**53**	**100 %**
(1a) communicative and cooperative measures	5	42 %	5	42 %	2	17 %	12	100 %
(1b) subsidisation and food price related measures	7	54 %	4	31 %	2	15 %	13	100 %
(1c) regulatory measures and political framework conditions	11	48 %	6	26 %	6	26 %	23	100 %
(1d) political intervention not necessary or wanted	0	0 %	4	80 %	1	20 %	5	100 %
(2) private sector measures	**59**	**52 %**	**19**	**17 %**	**35**	**31 %**	**113**	**100 %**
(2a) technologies, innovation and process optimisation	14	56 %	3	12 %	8	32 %	25	100 %
(2b) communication and cooperation of supply chain actors	11	37 %	8	27 %	11	37 %	30	100 %
(2c) reconditioning and repackaging	7	64 %	2	18 %	2	18 %	11	100 %
(2d) alternative marketing, processing and redistribution	27	57 %	6	13 %	14	30 %	47	100 %
total	**82**		**38**		**46**		**166**	

Overall, the participants more frequently mentioned private sector measures than policy interventions, in particular the retailers (Table 2). They highlight alternative marketing and processing options but also regulatory policies. Interviewees from producer organisations seem to bank on an improved cooperation within the value chain and state more often that politics should not interfere at all to bring about a food loss reduction. As compared to other interviewees, producers speak least on political interventions. Alternative marketing, processing and redistribution as well as communication and cooperation are the private sector measures that most often came to their mind (Table 2).

4.1. Policy interventions suggested by the interviewed experts

This section summarises recommendations and claims the interviewed stakeholders expressed with regard to political intervention for food loss reduction (see also Table 3). In the following, these potential policy interventions are structured according to the corresponding codes of the interview material.

4.1.1. Communicative and cooperative measures

Most of the proposed communicative and cooperative measures relate to communicating the environmental burden of food loss to consumers. In this sense, it is argued that a respective policy should influence the consumers' choice, promote their appreciation of agriculture at large (B03:89; B13:105–110), address their food preparation skills (B15:117–120) and increase their awareness of the potential internal quality of "ugly" or "misshapen" produce (B20:99–103). With respect to consumer education, interviewees from retail and a producer organisation stress the responsibility of policy-makers to communicate, but not necessarily price in, the "true cost of food" to consumers (B06:147; B03:89). The quality manager of an organic retailing company explains the "true" or environmental costs of food waste as follows: "*Well, we have many goods that don't even show the true price, because now you don't see the costs that the sewage treatment plant or the water industry has to pay to get all the glyphosate back out of the groundwater. […] but society has paid the price in another form. And I think that would also be a topic that politics could take up*" (B06: 147).

As a second line of thought and apart from consumer education, communicative and cooperative approaches directed at the cooperation between governments and retail, and between governments and producers were mentioned. Accordingly, politicians should approach large retailers and urge them to offer more regional products at "fair" prices (B19:148–150). Participants further expect political decision makers to communicate changes in provisions on agronomic practices (e.g., on pesticide use) early enough to enable farmers to adapt accordingly. The train of thought is to prevent farmers from incurring losses through pest infestations or due to products exceeding the acceptable pesticide residue limits (B20:99–103).

4.1.2. Subsidisation and food price related measures

Some interviewees highlight the relation between low food prices and food loss due to lacking lucrativeness of harvesting or processing fruits and vegetables. They consider it the politicians' responsibility to work towards "fair" prices and reflecting the "true" costs of food and food loss. The argument is to modify food prices in a way that they contain environmental costs, notwithstanding the associated difficulties of political enforceability (B06:147; B11:99–104).

Particularly, the representatives of producer organisations emphasise the macro-perspective of food price developments and food loss. It is argued that differences in framework conditions between Germany and other European and non-European countries, such as minimum wages, put pressure on domestic production (B02:116–119; B03:89; B09:101–103). Accordingly, strong competition occasionally leads to harvesting and processing of produce becoming non-lucrative and thereby promotes food loss. An employee of a producer organisation in this regard suggests the "Swiss system", in which imports are only allowed if domestic produce does not suffice (B02:122–131). Nonetheless, the experts find themselves in the dilemma of import bans and tariffs contradicting the principles of the free intra-European market (B03:89; B09:101–103) and protectionist measures are also seen critical: *"[…] If you compare a Polish apple with a German apple, then you are no longer on an equal footing, because there are also other framework conditions in the background, and we should at least (…) try to make a difference. […] Yes, that is always difficult, then one would talk about compulsory tariffs, which is not possible within Europe […]"* (B09:101–103).

When it comes to subsidisations, a retailer highlighted the potential of financing packaging machines and corresponding operational trainings to adhere to corporate design packaging requirements (B07:75–76). Other participants mentioned the subsidisation of modern crop protection and irrigation techniques, warehouses, cooling and sorting facilities as well as the staff-intensive product management or direct treatment of food products as food loss reduction approaches (B14:126–128;

Table 3
Summary of suggestions risen by the interviewed experts concerning present and potential policy interventions to reduce food loss.

(1a) communicative and cooperative measures	• communicate true (environmental) costs of food to consumers • enhance food preparation skills through educational offers • work towards a higher appreciation of the agricultural sector within the population • communicate to consumers that the appearance of products is not a quality indicator • communicate adjustments to agronomic provisions (e.g., concerning the application of pesticides) reasonably early
(1b) subsidisation and food price related measures	• subsidisation of packaging machinery and related trainings so that producers can adhere to retailers' packaging requirements • subsidisation of infrastructure and modern agronomic techniques (crop protection, irrigation, storage, cooling, sorting) • financial compensation for harvest of unprofitable products (e.g., small products) • bonus-malus-regulation: subsidisation of participation in food loss reduction activity and charging of non-participation • policies should address labour costs and framework conditions resulting in low competitiveness of domestic products • "Swiss system" to protect domestic market: imports are only allowed if domestic supply does not suffice
(1c) regulatory measures and political framework conditions	• establish legal framework conditions for innovations to prolong shelf-life (e.g., coating technologies) • ensure legal protection for selling products with labelling mistakes • acknowledge legal pesticide residue limits and quality requirements as sole binding provisions • critically assess the necessity of EU marketing standards for certain fruits and vegetables • curb private product requirements and Unfair Trading Practices of retailers, e.g., through independent ombudsperson • make it mandatory for retailers to redistribute, sell or process lower quality produce • acknowledge conflicting goals and set priorities (e.g., food waste reduction vs. packaging reduction) • create framework conditions that ensure reasonable producer prices in European Economic Community
(1d) political intervention not necessary or wanted	• the food loss problem must be solved by market participants, politics should not and cannot intervene • market and price interventions are per se critical • politics can only set framework conditions, market actors themselves must intervene

B18:92–93). One interviewee suggests a financial compensation for harvesting of non-lucrative produce, such as small products and surplus produce during peak season. He moreover proposes a bonus-malus-regulation in which entities would be subsidised for participation and charged for non-participation in food loss reduction activities.

4.1.3. Regulatory measures and political framework conditions

Regulation includes not only "classical" instruments such as prohibitions and provisions, but also the design of legislative framework conditions. In the eyes of the experts (particularly producers, but also one retailer), loss-preventing framework conditions should largely focus on the power relations between the producing and the retailing side of the supply chain. Accordingly, regulatory law should ensure the surveillance and control of trading practices, e.g., through an ombudsperson (B12:94–95; B16:125–139; B06:146–147).

Improved legislative framework conditions should, in the eyes of the interviewees, aim at the marketing of sub-optimal, mislabelled or incorrectly packed produce. Hereby, legal protection for marketing or donation should be provided and guaranteed (B05:51). Further, politics should urge retailers to market or process products not fulfilling their specific requirements (B05:49; B07:73; B22:77) and even prohibit retailers from setting private norms, if in line with the competition law (B10:125–127; B1:218–222): *"What would really be a concrete recommendation, to say that the laws that are set must be sufficient. If a maximum residue limit was 0.1 mg, then a [retailing] chain would not be allowed to say, 'But I only want 0.001.' or so. That's nonsense, you know."*.

One of the experts additionally highlighted the importance of policy coherence pointing out that policy-makers also need to recognise conflicting goals (e.g., packaging material and pesticide residue reduction vs. food loss and waste reduction) and work towards a coherent data base for priority setting (B05:53).

4.1.4. Political intervention not necessary or wanted

Although they recognise the existence and problematic nature of food loss within the early supply chain, some producers and producer organisations believe that politics cannot or should not intervene to reduce food loss levels. Therefore, markets should regulate themselves and it would be wrong in itself to undermine market mechanisms (B03:89; B21:123): *"But it is always bad when politics intervene in markets, also in market price regulating mechanisms, that is always dangerous. It's best to stay away from such things. Maybe it will somehow regulate itself"* (B03:89). Two interviewees further argue that lawmakers are not able to change the situation, and therefore the responsibility should be left to market actors (B10:120–123; B13:99–100).

4.2. Views on policy interventions based on supplier survey

The quantitative assessment within the supplier survey of the retailer's value chain provides insights into the magnitude of the perceived importance of various policy measures (Fig. 2). Overall, all potential policy measures available received quite high approval. About half of the respondents strongly agreed with the view that policy should engage in consumer education, work towards a balance of power and foster technologies and infrastructure to reduce food loss amounts. Suppliers also consented to the support of alternative marketing and processing, examining product specifications set by law or by the UNECE, counteracting retailers' specific product standards and providing legal certainty for loss-reducing measures (e.g., liability issues or shelf life-prolonging technologies). With 42 % approval, the political support for reprocessing and repackaging was slightly less popular among suppliers. A noticeably smaller, but still non-negligible share of 29 % suggested that policy-makers should fully refrain from implementing food loss reduction measures.

4.3. Private sector measures suggested by the interviewed experts

Although this paper primarily deals with political intervention, the potential options for action of supply chain stakeholders are presented as well (see also Table 4). These may provide further leverage points for policy recommendations to support activities of private entities.

4.3.1. Technologies, innovation and process optimisation

Experts raised the argument that enhanced precision in horticultural practice and storage as well as optimised processes will substantially lower food loss levels. With respect to technologies, producers mentioned the modernisation of cold systems and CO_2-storage-facilities

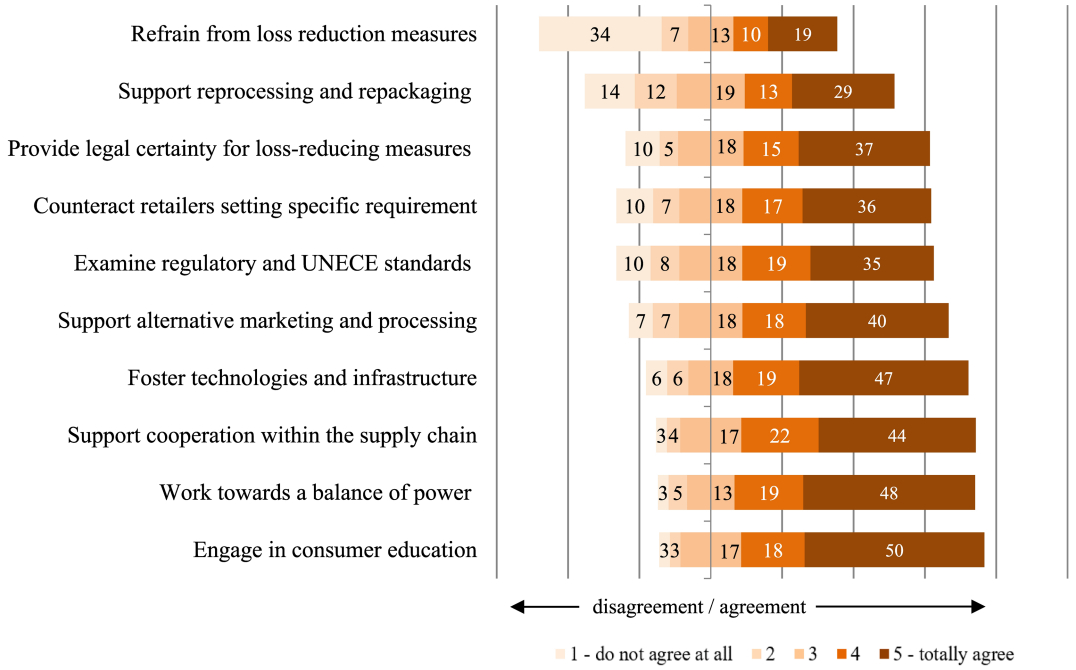

Fig. 2. Suppliers views on what politics should do to reduce food loss in upstream fruit and vegetable supply chains as percentages of respondents (measured on a 5-point Likert scale, n = 134 to 136, percentages do not sum up to 100 % due to omitting NAs).

(B12:27; B18:35), greenhouses (B10:45), crop protection sprayers, fertiliser spreaders and irrigation systems (B18:92–93). Retailers highlighted the adoption of shelf life-prolonging coating technologies, picking robots and drones with ripeness detection (B08:163–167; B14:122). Shifting towards new robust and storable, but still tasty, varieties was mentioned by both retailers and producers (B08:163; B12:27; B18:35;89–91). However, there is the concern that new technologies and modernisation require large investments. A blueberry producer, for instance, explains, that the replanting of this perennial crop will only pay off after decades and therefore after his retirement (B18: 89–91). Apart from purely technical solutions, enhanced forecasting systems for purchasing (B06:135), an improved planning reliability and better coordination of advertising periods (B13:94) are process optimisations that minimise the risk buffer in agricultural production as well as overproduction (B10:101): *"Maybe (…) sometimes short-term promotions in retail would help to pass production peaks […]. It would have to be really short-term within a few days. Not all of our buyers are willing or able to do that"* (B13: 94).

4.3.2. Communication and cooperation of supply chain actors

Communication and cooperation to reduce food loss does not only take place between governments and the private sector (Section 4.1.1) but also on a voluntary basis within the supply chain. In this regard, retailers themselves highlight their own potential to influence consumers' purchase decisions (B05:7; B06:141; B07:73; B10:45–47). Producers claimed that particularly consumer information with respect to diverging product appearance ("ugly produce") is essential and should be fostered by retailers as well as by the media (B16:125; B19:110–112; B20:97; B21:111). Furthermore, an improved cooperation in the form of long-term arrangements, personal contact and a respectful interaction with each other may lower overproduction, grade out losses and rejections (B06:135–137; B10:123; B12:91–93). A producer believes that particularly expertise and comprehension at the product reception as well as internal communication between purchasers and product reception of retailing companies are lacking: *" They [product reception] should have the possibility to call the purchaser or an intermediary. Someone who really has expertise, who has an overview of the weather situation in the field, and that on that day the raspberries might be a bit softer, but with cooling they will be a bit better again"* (B16:131–133).

4.3.3. Reconditioning and repackaging

A frequent problem causing food loss within the supply chain is the spoilage of parts or single pieces of fruits and vegetables within one packaging unit. In these cases, resorting, repackaging and reconditioning enables to market the unspoiled fraction. The experts added for consideration that this approach is usually not economically bearable by any of the supply chain participants (B07:78; B08:86; B14:130; B17:58–61). A retailer explains: *"The topic of repackaging is perhaps interesting in general. Because we can't afford that. If a truck full of lemons came, I couldn't say, 'okay, now we have two people here to unpack lemons all day and repack them and deliver them.' That is not viable"* (B22:130–136). In the event of spoilage or a quality defect, usually the whole product unit is discarded or returned to the supplier. The supplier only repacks, if he/she would otherwise lack products to fulfil a delivery obligation and therefore accepts the non-lucrative reconditioning (B02:95–97).

4.3.4. Alternative marketing, processing and redistribution

In case products are not spoiled, but other traits impede the initially intended outlet as fresh fruit or vegetable (e.g., irregular calibre, shape or internal traits), the alternative marketing, processing and redistribution (donation) of food was mentioned as a food loss reducing strategy. Retailers highlighted already existing product lines that enable value creation by selling suboptimal produce directly at the supermarket in the form of "party tomatoes", "gourmet onions", "weather apples", ready-to-eat salads, dips, soups, etc. (B07:65–68 and 89–91; B11:90–94; B14:23–24). Producers and producer organisations associate themselves largely with the retailers' positive views on such campaigns (B04:109;

Table 4
Summary of suggestions risen by the interviewed experts concerning present and potential private sector measures to reduce food loss.

(2a) mechanisation, innovation and process optimisation	• improve forecasting systems and product management in store • introduce modern technologies, such as coatings, harvesting robots and drones with ripeness detection • grow resistant and storable cultivars under consideration of relevant product traits (e.g., taste) • organise advertising campaigns to offer surplus produce at short notice • use modernised greenhouses to control growing conditions • further improve plannability on purchasing side to minimise risk buffers in primary production • improve storage facilities, e.g., to prevent from germination and to shift surplus produce into periods of low supply • improve crop protection sprayers, fertiliser spreaders, irrigation systems, storage and sorting facilities
(2b) communication and cooperation of supply chain actors	• retail should make use of point of sale to influence consumers' purchase decisions • foster stakeholder dialogue, cooperation and idea generation regarding food loss and waste along the supply chain • foster long-term arrangements and improve business relationship between retailers, suppliers and producers • purchasers of retail should grant short-term flexibility of product requirements in case of short supply • retail should act more reliably and foster personal communication with business partners • retail and media should educate consumers towards acceptance of irregular appearance of produce • increase comprehension at product reception as well as direct communication between producers and purchasers
(2c) reconditioning and repackaging	• repacking if parts of a packaging unit are spoiled or in case of rejection • reconditioning of stored vegetables, e.g., removal of the outer leaf of stored cabbage • relabelling of products with labelling mistakes • extension of best-before date
(2d) alternative marketing, processing and redistribution	• establish product-lines and brands creating added value from marketing or processing of suboptimal produce (e.g., jams and frozen foods) • promote sales of suboptimal and mixed products as well as products without trade category • process products not fulfilling standards and surplus produce • utilise products not fulfilling standards and surplus produce as animal feed, biogas or compost • donate to food banks or staff • sell substandard products to food service or cutting businesses • in field cultivation, crops can be ploughed back; protected crops must be harvested and brought to biogas plant

B09:87–97; B16:113–115; B19:84–90; B20:39–43). Misshapen or broken produce may also be marketed to the food service industry or be donated to employees, food banks or other recipients (B05:9; B07:73; B15:83–84; B17:95–102). Some interviewees endorsed the processing of fruits and vegetables to food articles such as juices, jams and frozen foods (B16:65) as well as its utilisation as animal feed, agricultural material, biogas and compost. Although the latter two are legally defined as waste treatment procedures, some participants perceive them as reasonable food loss reduction strategies (B05:9; B22:29; B17:52–55; B18:50–51). All alternative marketing, processing and redistribution options have in common that they are, for the most part, not economically viable: "*So if a juice apple is only paid five cents for at the factory and the production costs for the apple are nine cents, then it is clear that this apple was never put on the market. Because why throw money out the window, so it's just left on the ground*" (B09:105–107). Moreover, some alternative marketing channels may simply not be accessible by producers due to a limited network (B15:82; B19:39–44; B17:63; B21:37).

4.4. Views on private sector measures from supplier survey

The online-survey further breaks down which private-sector courses of action suppliers expect from retail companies with respect to lowering food loss levels along the supply chain (Fig. 3). All in all, the respondents' approval of items available for selection was lower than for political options for action (Fig. 2). With more than 50 % of all respondents, the endorsement of better coordinating promotion campaigns with seasonal peaks, tolerating deviations from the private calibre standard and establishing alternative marketing and processing networks was rather high. Almost half of all suppliers moreover expect retailers to ensure long-term and neutral packaging designs and tolerate deviations in terms of product appearance. There was less support among suppliers for the statement that retailers should improve their planning of orders, tolerate deviations in terms of pesticide residue limits and ensure higher reliability of their own product requirements.

5. Discussion

Our analysis indicates that there is a potential for the implementation of further kinds of policy instruments in food loss reduction. In line with Schanes et al. (2018) and Giordano et al. (2020) it becomes apparent, that transnational and national food loss and waste policies rely largely on cooperative and information-based policy approaches and mainly target consumption and retail stages. Such voluntary action and corporate social responsibility programs can indeed form an integral part of a sustainability transformation (Croci, 2005) and already do so in the case of food loss and waste reduction (Burgos et al., 2019). However, they cannot fully replace supplementary regulatory approaches (Ekardt, 2020; Sinclair Taylor et al., 2019). Engagement of involved parties towards a sustainability transformation is often insufficient (Ekardt, 2020) as supply chain stakeholders are not willing to voluntarily reduce interstage drivers or root causes that provoke losses on other supply chain stages (e.g., product requirements and business practices) (Herzberg et al., 2022; Mena et al., 2014). Messner et al. (2021) apply the concept of lock-ins in the food loss reduction debate, meaning established ways of seeing and doing things that resist transformation. They argue that different types of lock-ins, such as legislation and policies, accepted views and paradigms and existing infrastructures, result in food surplus becoming waste. Messner et al. (2021) and Messner et al. (2022) suggest focusing more on this systems-based understanding and the interconnected processes of overproduction and food loss when designing food loss policies, rather than focusing on 'end-of-pipe' solutions. Garske et al. (2020a) suggest that in the case of food loss and waste reduction the application of economic instruments, such as the subsidisation and food price related measures presented within this paper, might be a comprehensive solution to address multiple interlinked challenges in a more comprehensive manner.

It also becomes clear that the supply chain actors' demands partially diverge from current political interventions. Supply chain actors agree with current policies in that they emphasise the need for instruments that encourage consumers to change their behaviour and increase their appreciation of agricultural practices. Nonetheless, de Gorter et al. (2021) and Kuiper and Cui (2021) challenge such a narrow focus on

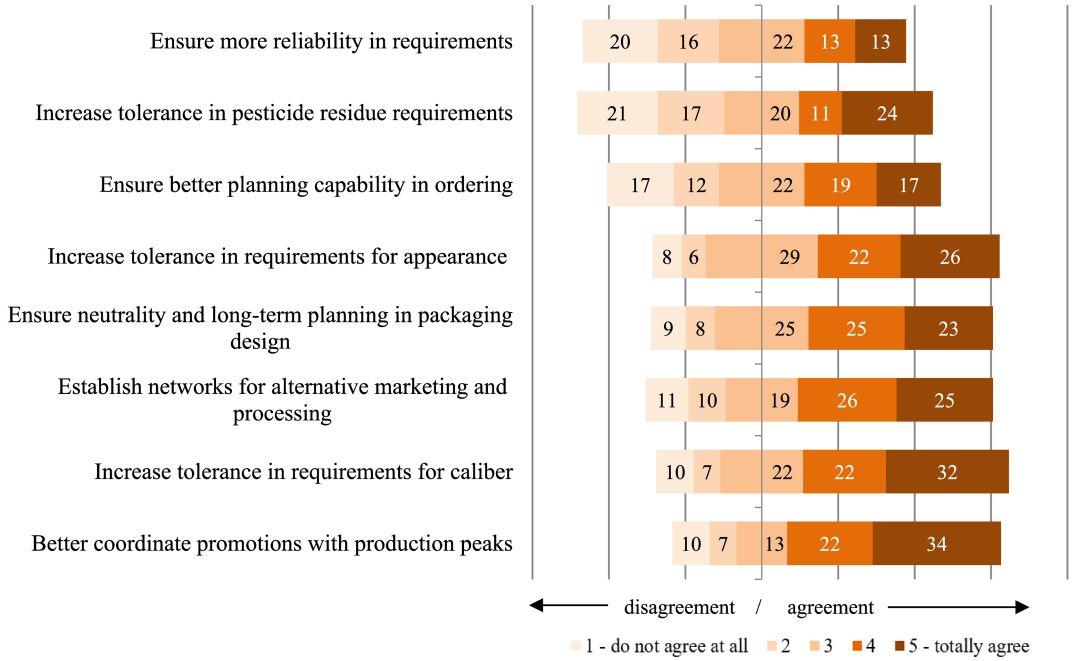

Fig. 3. Suppliers views on what retailing companies should do to reduce food loss in upstream fruit and vegetable supply chains as percentages of respondents (measured on a 5-point Likert scale, n = 143, percentages do not sum up to 100 % due to omitting NAs).

consumers' food waste behaviour. Similar to the findings of Johnson et al. (2019), our study reveals that recent policies partially bypass other claims of supply chain actors. Examples of further policies are the subsidisation of loss reducing agricultural and food-related practices, the containment of private standards and power imbalances, the design of political framework conditions that favour domestic produce at acceptable prices and the fostering of alternative processing, marketing and redistribution channels. All of these measures may however present major challenges. To name an example, the suggested redistribution of surplus to employees might not be feasible from a legal point of view as it is considered a benefit of employment for tax purposes, similar to a company mobile phone or car. Hence, such a measure would due to the great effort required probably be discontinued immediately.

Thyberg and Tonjes (2016) argue that policies to prevent food loss and waste should increasingly address the actual causes and motivations for loss and waste generation. A focus on "strong" prevention measures addressing root causes, such as reduced production and consumption and alternative business models, is needed when aiming at more sustainable food systems and circular economy but is neglected in the public debate and actual policy making (Mourad, 2016).

Therefore, a holistic agri-food systems approach can assist in designing coherent food loss and waste policies. Many of the solutions promoted tend actually to manage surplus than prevent food loss in a systemic way and in line with the food waste hierarchy (Giordano et al., 2020; Mourad, 2016). Such a holistic view on food loss and waste is required from a circular economy perspective (Vilariño et al., 2017). A concrete example is that food loss and waste measures could be introduced again into the Common Agricultural Policy (CAP) (Garske et al., 2020a). In the past, redistribution policies of surplus produce had formed a part of the CAP (Caraher, 2015). Measures to tackle food loss and waste within the CAP should this time also be aimed at prevention, not just redistribution. Moreover, in Pillar Two of the CAP, investments in rural development programs and infrastructures that prioritise food loss reduction should be focused on more intensely.

Food loss reduction targets in the upstream supply chain could also be synchronised with the Directive on so-called Unfair Trading Practices (European Parliament, 2019) and its implementations into national laws. The framework set by the directive is a starting point. However, it currently fails to explicitly state food loss reduction as a secondary objective and does not capture short-notice ordering and the informal nature of agreements upon quantity and quality of produce in the fruit and vegetable sector (Herzberg et al., 2022). The leeway that the directive grants national member states should be used to prevent such food loss inducing practices. To provide an example, the Agricultural Organisations and Supply Chains Act (Deutscher Bundestag, 2021), which translates the UTP-Directive into German law, regulates unilateral contract changes upon the quantity and quality of produce and forbids short-term cancellations. However, if neither such contract clauses nor short-term cancellations exist within the sector, the law bypasses the actual problems related to imbalanced trade relations and food loss.

Sorrentino et al. (2018) moreover suggest that the entanglement of food loss with marketing channels and power constellations could be captured in existing legislation on producer organisations. The European regulation of the Common Organisation of the Markets in agricultural products (COM) defines among others the following aims of producer organisations: ensuring quantity planning, management of by-products and waste and contribution to a sustainable use of natural resources. However, to embed food loss reduction targets, the regulation should even more explicitly motivate producer organisations to support alternative marketing and processing of their members' surplus produce.

Arising governance problems and advantages and disadvantages of distinct instruments must be considered in the design of food loss and waste preventing policies. Many synergies and trade-offs exist between food loss and waste reduction and further demands on the food system (Reynolds, 2023). Cattaneo et al. (2020a) and de Gorter et al. (2021) stress trade-offs between reducing natural resource use and for instance

increasing farm welfare and potential greenhouse gas emissions through further cold-chains and processing. Therefore, "win–win–win" solutions are in many cases not achievable, as actors with different interests in commodity chains likely suggest competing solutions (Mourad, 2016). Rebound, shifting and cascading effects must also in the case of food loss and waste policies be considered. A technical or behavioural improvement may have a positive effect on the level of food loss. However, this effect may be outweighed or even exceeded by spending monetary savings on other environmentally damaging goods or processes and hence simply shifted to other sectors, products, regions, resources or stages of the supply chain (Albizzati et al., 2022; de Gorter et al., 2021; Ekardt, 2020; Kuiper and Cui, 2021; Vilariño et al., 2017).

Limitations of our study emerge, which also provide direction for future research. The interviews and questionnaires primarily aimed at topics other than options for action, namely power imbalances, product specifications and business practices. This setting might influence the views of participants on options for action. Additionally, the interviewees and survey respondents are the norm addressees of potential policies. It is likely that their suggestions are driven by potentially self-interested motives besides food loss and waste prevention and might therefore not consider overall benefits to society. Hence, the results can provide insights into different stakeholders' demands and claims but do not reflect on the actual effectiveness or even efficiency of policies. Future research could look more closely at the effectiveness and efficiency of some of the proposed policies, such as subsidising reworking and repackaging, or introducing various forms of process optimisation and mechanisation. It could use ex-ante and ex-post analysis to assess the expected outcomes and welfare effects of the policies proposed in this paper.

6. Conclusions

This paper analyses expert interviews with retailers, producer organisations and producers and a quantitative survey with suppliers of a German retailing company to grasp policy and private sector options for action to tackle food loss in upstream fruit and vegetable supply chains. We found that the focus of a majority of policies in Germany and other industrialised countries lies on downstream supply chain stages and applies voluntary and communicative approaches. Actors in the field agree upon the need for a change in consumer behaviour to lower food loss levels but also suggest interventions addressing the broader context of the food system beyond already existing ones. Accordingly, market-based approaches could assist by fostering the adoption of robust cultivars, alternative marketing channels as well as processing, reworking and repackaging facilities. Regulatory framework conditions could prevent food loss by adjusting legal framework conditions to facilitate donation as well as the adoption of innovative food loss reducing technologies. Regulatory laws should moreover address power relations and setting of private quality standards within supply chains. In order to take account of policy coherence, these policies should be aligned with leverage points of existing laws and communications such as the Circular Economy Action Plan, the Farm-to-Fork Strategy, the Directive on Unfair Trading Practices, the Common Agricultural Policy of the European Union and legislation on producer organisations. We suggest that translations of the UTP-Directive into national law should be implemented in a way that takes food loss into account, e.g., by restricting short-notice orders rather than cancellations and by a containment of private quality standards. Already existing legislation on producer organisations could in the future comprise incentives for the creation of supplier and processor networks as well as processing facilities. A policy mix from the field of cooperation and communication, regulatory law and market-based instruments seems appropriate to address the manifold drivers of food loss on upstream supply chain stages. The exact effects of these policies are still to be determined by further research. Horizontal alignment of policies between ministries and departments as well as vertical alignment between different governance levels is essential to reach this aim. This should take into account potential trade-offs between policy objectives within and outside the food system, as well as governance problems, and give greater priority to the wider context in which reducing food loss and waste is embedded.

CRediT authorship contribution statement

Ronja Herzberg: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data curation, Writing – original draft. **Felicitas Schneider:** Conceptualization, Validation, Writing – review & editing, Supervision. **Martin Banse:** Writing – review & editing, Supervision.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: The mentioned retailing company supported the supplier survey, which serves as an additional data source of this paper besides the expert interviews, financially. At the time of the preparation of the paper draft, the respective project had already expired. The contents of the paper do not form part of the respective project and are unknown to the retailing company. The retailer is kept anonymous in this paper. No salaries of co-authors or other expenses related to the paper were funded by the retailer. All authors certify that the funding source had no influence on the contents of the paper.

Data availability

The data that has been used is confidential.

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5 Discussion

This thesis contributes to the research on FLW by identifying inter-stage drivers of food loss in upstream supply chains by relating these drivers to power constellations and by proposing appropriate private sector and policy measures. Chapter 5 is structured according to the research objectives presented in chapter 1. It also discusses the transferability of the findings to other contexts, such as other product groups and regions, and its limitations as well as implications for future research.

5.1 Mechanisms causing food loss across stages of the supply chain

The first and second research objectives of this thesis are

(1) to identify mechanisms of food loss creation across early stages of the fruit and vegetable supply chain and
(2) to analyse the extent of the specific food loss mechanism of retailer's product requirements.

The thesis focuses on the interactions between the retail sector and its upstream fresh fruit and vegetable supply chain. It shows that the causes of food loss, and therefore the potential to reduce food loss, do not necessarily lie with the actor at which the loss occurs. In particular, food loss that occurs during primary production can be caused by decisions made later in the supply chain and are therefore beyond the control of producers (WWF, 2021). In article 1 these drivers are defined as inter-stage drivers of food loss.

This dissertation shows that decisions taken and requirements set in the retail sector can increase food loss in upstream supply chains and provides insights into the mechanisms behind this. Critical issues identified are the planning of quantities to be purchased by retail, the nature of agreements and contracts at the producer-retailer interface and the handling of orders. Retailers have a rather low level of reliability regarding the quantities of fruit and vegetables needed, which are often loosely planned during annual consultations and are not binding. These quantities are called off or ordered shortly before delivery, prompting suppliers to produce buffer quantities and to harvest and pack the expected orders in advance. If retailers order different quantities than previously agreed, or if the timing of orders is irregular, then overproduction and food loss can occur. Beausang et al. (2017) also describe unpredictable ordering by retailers due to weather conditions, which affect not only the quantities of food supplied, but also consumer demand for fruit and vegetables. Crop ripening and harvesting cannot be precisely determined or fully controlled. This is why, short-term mismatches between supply and demand are in the nature of fresh fruit and vegetable markets (Meyer et al., 2017). However, on the demand side, retailers require a predictable supply of consistent quality products (ibid.). Therefore, short-term ordering allows retailers to ensure a steady flow of produce without incurring the economic risks of having bought too much. Gille (2013) sums it up by noting that there is not only a mechanism of adverse weather conditions leading to food

loss, but also a mechanism of favourable conditions leading to excess food quantities and potential loss in food supply chains.

Another mechanism causing food loss in upstream supply chains is the top-down implementation of promotions. It became clear throughout the thesis, that in most cases the decision to use promotions, as well as the size of the promotions, is taken by the retailer and is not necessarily based on actual surpluses. These promotions are set up to six weeks before delivery, which is too early to react flexibly to short-term surpluses in certain crops. Similarly, Beausang et al. (2017) describe that promotions are not aligned with supply peaks and crop availability. Meyer et al. (2017) find that retailers plan campaigns quite early and without a sufficient data basis. Sinclair Taylor et al. (2019) add that promotions, combined with forecasting errors and over-optimistic predictions of increased product demand are drivers of food loss prior to the retail stage.

Another key aspect of how retailers can contribute to loss in the upstream supply chain is outlined in article 1 and in the specific case study in article 2. This aspect concerns product requirements with regard to appearance, packaging and pesticide residue limits. The results presented in these articles show that the retailers in the present samples have customer-specific requirements, which is consistent with Devin and Richards (2018), Meyer et al. (2017), Porter et al. (2018) and Willersinn et al. (2015). The establishment of product requirements by retailers has also been identified as a driver of food loss in upstream supply chains in the present dissertation as well as by Beausang et al. (2017), Johnson et al. (2019), Ludwig-Ohm et al. (2019) and Porter et al. (2018) (see also section 2.2.3). The resulting proportion of food loss occurs at very early stages in the supply chain, mostly during the sorting process at harvest. This finding is supported by the results of Fernandez-Zamudio et al. (2020), Baker et al. (2019), Soma et al. (2021) Johnson et al. (2019) and Delgado et al. (2021).

The case study presented in article 2 provides a first quantification regarding product specifications by stating that 15 % of the total production/traded volume does not meet the retailer's standards. 6 % of the total production/traded volume of fruit and vegetables is no longer used for human consumption and 1 % is actually sent to waste treatment as a result of the retailer's requirements. These figures seem unexpectedly low compared to Meyer et al. (2017), Johnson et al. (2018a), Baker et al. (2019), Fernandez-Zamudio et al. (2020) and Porter et al. (2018). However, the above studies look at broader fractions of food loss, rather than isolating those fractions that are purely attributable to product requirements set by retailers. Moreover, these studies use different methodological approaches and were conducted in different settings, which is why the findings are only partially comparable (see also section 2.2.3).

In addition to the described quantification of specific food loss shares, article 2 provides a ranking of product specifications in terms of their potential to cause food loss. The most important specifications identified are calibre requirements and pesticide residue limits. Pesticide residue limits increase food loss by restricting marketing channels and by increasing the propensity for pest infestation. This is an emerging issue that should be given much higher

priority and has so far only been mentioned by Meyer et al. (2017) and Ludwig-Ohm et al. (2019).

This thesis fills a research gap by showing that product requirements are treated as tacit and implicit knowledge, making them difficult to capture. According to Devin and Richards (2018), Feedback (2017) and Rakesh and Belavina (2020), the fact that product requirements are not formally set is used by retailers as an excuse for unjustified refusals. This thesis does not endorse that the rejection of surplus products on the pretext of not meeting quality requirements is a systematic problem. On the contrary, there is no need to use product specifications under false pretences, as the retailer bears little risk in terms of overproduction due to short-term ordering and lack of commitment to purchase predefined quantities (as described above). Although the findings of this thesis suggest that product specifications are handled informally and can change with fluctuating market conditions, suppliers and farmers appear to be generally aware of the requirements placed on them and describe the specifications as being clear. Hence, there is not necessarily a contradiction between informal practices in the market and the comprehensibility and clarity of the specifications.

There are mechanisms that cause food loss transcending the stages of the supply chain and affecting actors at other stages of the supply chain that have been discussed in this section. These mechanisms are often subtle and work in an indirect manner. The following section 5.2 examines one aspect of how and why these drivers occur, namely the underlying power relations in food supply chains.

5.2 The role of power constellations in the creation of food loss

The third research objective aims

(3) to analyse how power relations between supply chain actors relate to food loss in early fruit and vegetable supply chains.

Section 5.1 demonstrates that retailers are able to exert some control over upstream supply chains through the mechanisms discussed. On the basis of these findings, it can be argued that they do not behave in this way out of malice, but because they are able to transfer uncertainty and economic losses and thereby gain an advantage over other market participants. This is where the conceptualisation of power relations outlined in section 2.2.2 comes into play.

The theoretical underpinning of article 1 was inspired by Beckert (2009). He argues that actors seek to reduce the uncertainty inherent in market transactions with respect to their incomplete knowledge of the intentions of exchange partners (cooperation problem), their own profit expectations (competition problem) and the difficulties in assessing the value of commodities (value problem). The thesis, in particular in articles 1 and 2, shows that the underlying power relations become visible in informal modes of governance. One example is the low degree of reliability of contracts and agreements, especially regarding quantities demanded by retail. In addition, the use of short-term orders by retailers to avoid stock-outs in a highly competitive environment can be seen as a form of solving the competition problem. The value problem

manifests itself in the need for suppliers to specialise in certain channels or to meet the most stringent requirements across the market. This is due to the value of the products being highly dependent on a predefined set of product characteristics. Within these coordination problems, power relations are manifested and result in uncertainties and economic costs being passed on to suppliers. This includes, for example, the risk of disposing of suboptimal products as well as the cost of overbuying. The theory can thus be linked to the empirical evidence on FLW, which suggests that it is a symptom of structural issues related to power imbalances that create a lack of incentives to minimise FLW (Hernandez et al., 2023).

The concepts of power introduced by Latour (1984) and Foucault (1982) (see also section 2.2.2) add to this issue and help to conceptualise power and its expression in market relations. Accordingly, power becomes visible in the relationships and subtle mechanisms analysed in this thesis. Power only exists when put into practice, through actions upon actions (Foucault, 1982). In this case, actions upon actions can be found in inexplicit rules, e.g., to prohibit or to complicate the sale of suboptimal products, to fully determine the timing of orders and the time horizon of deliveries as well as to keep quantity estimates vague. Latour (1984) adds the understanding of the diffusion and translation of tokens, which in this case can be orders, specifications or norms. Power is manifested in the degree of inertia against their diffusion and the degree of shaping, dropping or modifying them according to one's own goals. The ability to decelerate, shape or even drop orders, specifications and standards in the upstream supply chains analysed can be described as low. Only some suppliers with a unique selling point seem to be able to exercise some power to shape conditions in pursuit of their own objectives (see article 1). Russo (2020) also found that unpredictable orders and the imposition of production standards are common practices in fruit supply chains. Especially in Germany, unpredictable orders seem to be a pressing issue (Pietrangeli et al., 2023; Russo, 2020), highlighting the need for further analysis of the circumstances leading to the low ability of these suppliers to actively shape the imposed conditions.

In terms of the theoretical lens, economic geography perspectives such as the global value chain perspective (Gereffi et al., 2005; Gereffi, 1994) and the perspective of global production networks (Coe et al., 2008; Henderson et al., 2002) could further support the understanding of the existence and development of the observed supply chain practices. Gereffi (1994) first described producer-driven and supplier-driven global commodity chains. When this approach was criticised for not being sufficiently differentiated, Gereffi et al. (2005) developed it further and established a new understanding of global value chains. This understanding distinguishes four forms of governance, namely market governance, modular governance, relational governance and captive governance. The supply chains studied here can primarily be assigned to the captive governance mode, which is characterised by the fact that the buyer sets the conditions of production (i.e., standards, quantities, prices). Increasing regulatory pressures in terms of private governance mechanisms, particularly supermarket standards, have been observed by Messner et al. (2021) as creating surplus and FLW. Captive governance is also associated with high switching costs and control by the 'lead firm' (Gereffi et al., 2005).

Switching costs are a crucial aspect of the exercise of power in the event of the threat of terminating trade relations, as reported, for example, by 11 % of Slovak fruit suppliers in the study by Barathova et al. (2022). Captive suppliers are independent on paper, while in fact they are tied to the lead firm (Gereffi et al., 2005). However, there are also aspects of modular governance within the supply chains analysed, such as the increasing customisation of products. In the future, it will be important to monitor how increasing product differentiation in agricultural commodity markets affects the mode of governance and hence power relations in contemporary fruit and vegetable supply chains.

The global production networks' (GPN) perspective (e.g., Coe et al., 2008; Henderson et al., 2002) complements the supply chain perspective (Gereffi et al., 2005; e.g., Gereffi, 1994) by emphasising the geographical and network dimensions of global value networks, rather than limiting the view to the relationship between two actors. It also takes into account the political context and other relevant actors such as the state, NGOs and civil society organisations (Coe et al., 2008). It provides a framework for analysing global production networks, structured around the three categories of value (creation, enhancement and capture), power (corporate, collective and institutional) and embeddedness (territorial and network) (Henderson et al., 2002). This framework might be helpful in terms of coping strategies for less powerful actors to create, enhance and capture value and to improve their position to actually enforce value claims, considering their territorial and network embeddedness and other relevant actors. As an example, Szulecka et al. (2019) describe how successful FLW reduction efforts in Denmark started with a consumer movement, supported by influential activists. An analysis of the influence of civil society and many other relevant actors on the power position of suppliers, and thus their ability to enforce demands, could be informed by the GPN perspective. In terms of the territorial and network embeddedness, it could provide insights into why in some countries take-back-agreements and short-notice-cancellations lead to food loss in upstream supply chains (Feedback, 2017; Piras et al., 2018; Sinclair Taylor et al., 2019), whereas in this thesis neither take-back-agreements, nor short-notice-cancellations, but rather short-term orders, were identified as systematic drivers of food loss.

It can be argued that the theoretical lenses of the sociology of markets and power constellations can also be applied to power relations in agricultural supply chains. The conceptualisations help to establish a relationship with food loss and thus provide an explanatory approach to the emergence of the mechanisms described in section 5.1. However, further theoretical grounding is needed to better understand the partly divergent empirical findings in this dissertation and other studies.

5.3 Recommendations for policies and measures to reduce food loss

The fourth research objective is forward-looking and aims

(4) to assess private sector and public policy options to reduce food loss in upstream supply chains.

From an environmental policy perspective, FLW can be considered a negative externality that may give rise to public sector intervention (article 3). However, public sector intervention is only justified if benefits of FLW reduction policies are greater than the corresponding avoidance costs (Koester, 2014). While this thesis does not provide evidence on the effectiveness or efficiency of future food loss policies, it does identify policies that have the potential to address the drivers of food loss. The following sections discuss six key messages, or recommendations, that can be drawn from this dissertation in terms of food loss interventions and policies.

The **first key message** is that a better planning of food quantities, orders and promotions by the retail sector is needed to systematically reduce food loss in upstream supply chains. Articles 1 and 2 demonstrate that there is a need for more reliability in market transactions, particularly in terms of quantity planning (see also section 5.1). On the one hand, more reliability is needed; on the other hand, short-notice informal arrangements and communication may also be important to prevent food loss. All three articles address the issue of promotional campaigns that are not well aligned with peak harvest seasons and not flexible enough to buffer surpluses, which is in line with Meyer et al. (2017). Article 3 highlights that better planning of quantities, orders and promotions could be achieved by improving forecasting systems, better collaboration, as well as better communication with the points where products are received by retailers. Policies that enforce contract terms that ensure greater reliability and discourage short-term orders and inappropriate promotions are therefore desirable.

As a **second aspect**, food loss could be reduced if more suboptimal products would find their way into the food supply chain. This could be achieved through efforts by retailers to adjust product specifications and widen tolerances, particularly in relation to calibre and pesticide residue limits. As a first step, all retail stakeholders would need to recognise that they do indeed establish product requirements, even if these are more tacit. Strategies to reduce upstream food loss are identified by Frieling et al. (2013) as lowering aesthetic criteria, offering more Class 2 items and selling per kilogram rather than per piece. Such adaptation and lowering of product requirements could be part of cooperative action, e.g., in the context of voluntary agreements between retail and governments. Such collaborative action gives companies the opportunity to make their own contributions to FLW reduction and can have positive effects across the sector, especially if key organisations get involved (UNEP, 2021). Indeed, in the 'Pact against Food Waste' signed in Germany in 2023, the waiving of appearance or size requirements for fruit and vegetables that go beyond the legal requirements is listed as an optional measure at the retail-production interface (BMEL, 2023). Nevertheless, there is a risk of 'green washing' and insufficient commitment to achieve a pre-defined target (Taylor et al., 2012) (see also section 2 of article 3). Mourad (2016) found for example that large companies tend to delegate FLW

issues to the corporate social responsibility department in order to achieve a positive image effect while maintaining day-to-day practices.

Another option would be to implement information-based policies to educate consumers about the environmental costs associated with food loss. Those measures might increase their appreciation of suboptimal food products. However, since information-based instruments rely entirely on the morality and sovereignty of consumers and are limited by the amount of information consumers can process (Priefer et al., 2016), the effectiveness of such information campaigns is likely to be limited.

Another possibility would be to restrict the setting of quality requirements by the retail sector, which would be very difficult to achieve due to the low tangibility of quality requirements. One option could be to monitor the setting of private quality requirements and the associated rejection of products by an ombudsperson, which Member States under the UTP Directive (European Commission, 2018) had to set up anyway.

A **third key message** is that cooperation and collaboration in the form of business relationships, communication and contracts between supply chain actors is critical but may not happen by itself. On the one hand, article 1 points to the importance of maintaining informal modes of governance within the supply chain. On the other hand, article 2 highlights that informality in the communication of product specifications can be a challenge. It can be concluded that the imposition of more fixed terms and conditions can reduce food loss by increasing reliability within the cooperation. At the same time, an informal nature of business relationships seems to be necessary to maintain a degree of flexibility. Article 3 suggests that stakeholders want politics to engage in improving supply chain collaboration. According to Szulecka et al. (2019), polycentric governance systems, multi-stakeholder collaboration and public-private partnerships are necessary to find solutions for FLW reduction. Voluntary cooperative action is an integral part of FLW action, for example in Germany (BMEL, 2019), and can be an important piece of the puzzle. However, cooperative action may be limited to the same stage of the food supply chain, as it seems unlikely that powerful actors voluntarily take the risk of paying for lost and wasted products. Devin and Richards (2018) therefore suggest that retailers should take ownership and responsibility for products at an earlier stage, which would incentivise them to get involved more in reducing FLW in upstream supply chains. Similarly, Rakesh and Belavina (2020) find that contracts often fail to integrate the cost of FLW into the incentive structure of all supply chain actors. This is also observed by Moraes et al. (2022) for Brazilian fruit and vegetable supply chains. The authors show that despite an interest in avoiding FLW, retailers are focused on internal operations, resulting in a lack of collaboration. Private sector and collaborative action is therefore hampered by the fact that retailers currently have little incentive to change practices that decrease food loss, such as improving ordering processes, as long as they do not have to pay for excess products (Gille, 2013). This thesis recommends not only relying on the good will of all actors to increase cooperation and collaboration, but also designing policies to better share the responsibility and costs of food loss among actors in the supply chain.

A fourth aspect concerns power imbalances and strengthening the bargaining position of suppliers and farmers. The UTP Directive is an attempt to do just that. However, both the directive itself and its transposition into national laws could be improved. Nový (2023) analysed the implementation of the UTP Directive in the Czech Republic compared to other European Member States in the light of the concepts of market power, economic dependence and bargaining power. He criticises that (structural) market power is only one important source of buyer power. Accordingly, the UTP Directive should rather build on the concept of bargaining power. This describes the ability to obtain concessions by threatening to impose costs, to withdraw benefits or to switch suppliers. Nový (2023) also notes that the UTP Directive has been transposed quite differently in individual Member States. Germany, for example, grants protection to suppliers with a higher turnover, while other countries apply the threshold set by the directive and still other Member States apply the directive to buyers and suppliers of all sizes.

Another criticism is that the list of UTPs is incomplete. Barathova et al. (2022) found in their analysis of fruit supply chains in Slovakia that some of the given practices are either not relevant or not considered unfair, while other more relevant practices are not included in the list of UTPs. Therefore, the authors recommend to reconsider the list of UTPs. Based on the findings of this dissertation, this recommendation can be followed up. It could be purposeful to include short-term ordering, establishing private product specifications, preventing producers from supplying third parties and switching from one supplier to another (auctioning approach).

A revision of the UTP Directive and its implementation should also address the supervision of UTPs. This thesis underlines the crucial role of the trustworthiness of the ombudsperson in potential complaints. In Germany, this role has been assigned to the Federal Agency for Agriculture and Food (Bundesanstalt für Landwirtschaft und Ernährung), which considers itself not only as a contact point for complaints, but also as a supporter of companies in understanding the German legislation (AgrarOLkG) (BLE, 2022). The next few years will show the extent to which Member State ombudspersons are accepted by suppliers as a confidential point of contact for complaints against UTPs. The European Commission's Joint Research Centre (JRC) intends to monitor the development of UTPs over the coming years (Russo, 2020). The JRC has thereby already made progress in understanding the unintended consequences of restricting UTPs, the differences between supply chains and the subjectivity in the perception of what constitutes unfair commercial behaviour (ibid.).

Power imbalances can also be addressed by increasing horizontal integration and diversifying supply networks. Barathova et al. (2022) found that the risk of multiple UTPs is significantly lower in producer organisations (POs) than in direct relationships with private traders or retailers, providing a justification for Common Agricultural Policy (CAP) support to POs. In line with Sorrentino et al. (2018), this thesis recommends that the legislation on POs could better address the issue of bargaining power and place more emphasis on the creation of further marketing channels and supplier-processor networks.

This leads to the **fifth recommendation** for actions and policies to reduce food loss. It includes creating and supporting alternative marketing and processing networks and opportunities as a key to redistributing produce that would otherwise become food loss. This thesis highlights that suboptimal products are currently returned to suppliers and that it is difficult to find alternative uses for these by now very mature products. Furthermore, article 3 shows that supply chain actors would like to see retailers more actively involved in the marketing and processing of such products by creating appropriate networks. Maintaining the diversity of marketing channels is crucial to avoid food going unsold and becoming loss (Chaboud and Moustier, 2021). Devin and Richards (2018) see exploring access to alternative markets not only as a way to reduce food loss but also for producers to increase bargaining power. This includes finding alternative markets for suboptimal produce and adding value through processing, canning or juicing (Devin and Richards, 2018). A prerequisite for such channels is the economic viability. The problem of low food prices was raised throughout this thesis as an inhibiting factor for the harvesting and processing of fruit and vegetables. In this respect, a tension between free intra-European trade and the different starting conditions in the European Member States became apparent. Creative marketing campaigns and the creation of new product lines to add value are existing measures that could be expanded (see also section 2.3.2).

As noted above, the question again arises as to why retailers should be incentivised to support marketing and processing networks and opportunities, especially given the potential for creating products that compete with their current product lines. If retailers are not incentivised to do so, producer organisations, with their primary role of promoting producer welfare through collective action (Saitone and Sexton, 2010) could assist in this regard. In addition, policymakers should commit themselves to facilitating the establishment of diversified marketing networks by suppliers and farmers. An additional option would be to subsidise the sale and processing of otherwise unprofitable surplus and suboptimal products, as well as appropriate machinery and equipment. In general, Garske et al. (2020) propose more such economic instruments aimed at FLW reduction under the second pillar of the CAP.

The **final key message** is that food loss measures and policies need to be considered from a holistic (food) system perspective, taking into account conflicting objectives as well as rebound, shifting and cascading effects. Thyberg and Tonjes (2016) call for a multifaceted approach that takes into account the circumstances that lead to FLW and that is informed by the underlying motivations of FLW production. There should be an emphasis on ‘strong’ prevention that addresses the actual mechanisms of food loss generation, rather than managing surpluses (Giordano et al., 2020; Mourad, 2016). Regardless of definitional discussions on what falls under FLW, private sector actions and policy measures should aim for the highest quality use of food in terms of the food waste hierarchy (Papargyropoulou et al., 2014) and the circular economy (Vilariño et al., 2017). Messner et al. (2021), Messner et al. (2022) and Richards et al. (2021) have extensively analysed mechanisms of food loss generation in horticultural supply chains in Australia over the past years. They make a strong case for addressing the systemic drivers of overproduction that are likely to become FLW, rather than focusing on ‘end-of-pipe’

solutions (Messner et al., 2021) at individual points in the supply chain that only manage the FLW material and surpluses itself. These suggestions are in line with the findings of this thesis, suggesting measures and policies that address food loss indirectly and systemically, e.g., by improving cooperation, predictability and business behaviour, diversifying marketing channels and buffering overproduction.

In particular, article 2 shows that more attention should be paid to potential trade-offs in the sustainability transformation of the food and agriculture sector. Obviously, the goal of reducing pesticide residues in fruit and vegetables and the goal of reducing food loss in primary production are not easily reconciled. Another potentially conflicting goal is observed by de Gorter et al. (2021), where FLW reduction comes at the cost a reduction in farmers' welfare. In the short term, reducing food loss leads to a reduction in the amount of food produced, falling prices and producers being priced out of the market (FAO, 2019). Latka et al. (2022) modelled different FLW reduction scenarios and showed that halving FLW would reduce the demand for food for human consumption, which would have a negative effect on farmers' revenues. However, the positive effect of FLW reduction within the EU in terms of reduced greenhouse gas emissions abroad would be even higher if market feedbacks are taken into account (Latka et al., 2022).

Another side effect that should not be neglected is the expansionary effect on food and non-food consumption that may result from lower food prices due to FLW reductions (Kuiper and Cui, 2021). Whether more of a product is purchased as a result of lower food prices depends on the elasticity of demand (de Gorter et al., 2021). In the case of elastic demand and increased consumption, an increase in upstream FLW levels is to be expected. Therefore, the value chain stage where food is lost matters for the upstream and downstream welfare effects. Knowledge of these effects is essential for the determination of the indirect effects of potential FLW interventions (ibid). De Gorter et al. (2021) summarise that effects cascading downstream from the point of FLW reduction are positive, while the upstream effects are influenced by demand elasticities.

A critical factor to consider is the direct and indirect rebound effects. These describe the effects that occur when money saved is spent on more of the same or on more of another good or service (Hagedorn and Wilts, 2019). In this view, reducing FLW may reduce GHG emissions in the agri-food sector, but also cause GHG emissions in other sectors where the money saved by reducing FLW is spent (Kuiper and Cui, 2021). Hagedorn and Wilts (2019) modelled FLW reduction scenarios in Germany and found that less than half of the potential reduction in environmental impacts can be achieved when rebound effects are taken into account. Accordingly, only 3.1 instead of 7.3 million tonnes of CO_2eq could be saved (ibid.). Martinez-Sanchez et al. (2016) compared scenarios with different forms of FLW utilisation (combinations of incineration, co-digestion and animal feed) as well as a scenario with 100 % prevention of avoidable FLW, taking into account direct and indirect impacts. Their results show that the impact of FLW prevention on global warming potential depends on where the freed-up income is spent. The most favourable option in terms of global warming mitigation is

the spending on health, education and security, while the least favourable outcomes are expected if money is spent on housing, communication and leisure (Martinez-Sanchez et al., 2016). Salemdeeb et al. (2017) make similar observations, showing that rebound effects reduce GHG emissions savings by between 23 % and 59 %, depending on where the free income is spent. The lower bound can be reached when spending is on education services, real estate services, communication services and regional products. Albizzati et al. (2022) found that, despite accounting for rebound effects, FLW reduction efforts are beneficial at all stages of the supply chain and especially, when prevention efforts are targeted at household level.

Policy implication derived from these studies is at least twofold: first, designers should focus on the drivers of food loss that systemically lead to overproduction and food loss, considering drivers that cut across stages of the food supply chain. Second, the abovementioned literature on rebound effects shows that an overall sustainable consumption behaviour is required for FLW reduction efforts to have a net positive environmental effect. Hagedorn and Wilts (2019) argue that a fundamental rethinking in society about what is enough is essential as well as policy mixes that steer society towards valuing higher quality products and services rather than more goods.

5.4 Transferability of findings

As the empirical evidence in this thesis is based on surveys of fruit and vegetable supply chains in Germany and partly in Italy and Spain, the question arises whether the findings are transferable to other agricultural products, supply chains and regions. For other product groups, the transferability of the results is limited. The analyses show that even within the group of fruit and vegetables, there are significant differences in trading practices, e.g., between perennial and annual crops (article 1), and differences in the relevance of product specifications (article 2). For example, it depends very much on the crop, whether suboptimal produce becomes food loss or is diverted to further processing. In this case, suboptimal carrots are more likely to become animal feed than other crops. This is in line with results of Meyer et al. (2017), who find that carrots are more likely used for non-food purposes as compared to apples, which are most likely used for juicing. It can be derived that this also applies to other products. Accordingly, a marketing or processing channel that is often used for a certain product, is also increasingly used for suboptimal products of this kind. Retailer product specifications are mainly described as an issue in fresh fruit and vegetable supply chains (see also section 2.2.3). However, for other product groups retailer quality standards and consumer preferences beyond pure product safety play an increasing role. For example, Altmann et al. (2023) show that there are specific consumer preferences for the colour of animal products that depend on the geographical region. Although the exact product standards in question vary considerably between product groups, an influence on FLW within the supply chain of products other than fruit and vegetables seems likely.

In terms of power constellations and trading practices, market concentration has increased not only in the fruit and vegetable sector but in the whole agricultural sector, which supports the

transferability of the findings (Hernandez et al., 2023). However, this does not necessarily mean that power is exercised at all, let alone in exactly the same way. For example, there is evidence that the degree of bargaining power depends on the perishability of a product, and that power is more likely exercised in the upstream supply chain for highly perishable products (Kopp and Mishra, 2022). Therefore, similar mechanisms of power exertion are more likely to be found in other perishable products than in durable ones. In addition, orders of imported products with long lead times may be cancelled more often than orders for products produced and distributed in Europe that can be ordered at short notice. Other authors have shown practices in the dairy sector (Russo, 2020) and in bread supply chains (Eriksson et al., 2017) that differ from those in the fruit and vegetable sector presented in this thesis. This shows how the mechanisms of power exertion and potential food loss creation depend on supply chain frameworks that remain to be analysed in detail.

The transferability of the results to other regions of the world is likely to be limited. The retail sector is becoming increasingly concentrated globally, both in the Global North and South (Hernandez et al., 2023). It is therefore likely that power is not only an issue in German or European supply chains. For example, Australian fresh fruit and vegetable supply chains have been extensively studied against the background of drivers of food loss. This research supports findings of this thesis: in most cases, loss already occurs during primary production (Sanad Alsbu et al., 2023) and contracts and trading practices are found to be systemic drivers of food loss (Devin and Richards, 2018; Messner et al., 2021; Richards et al., 2021). Similar to this dissertation, Moraes et al. (2022) describe issues like lack of coordination and information sharing as well as problems with forecasting and ordering in fruit and vegetable supply chains in Brazil.

However, there are also country specific differences. In Germany, retailer specifications are described as quite reliable and clearly defined (Herzberg et al., 2022) in contrast to Devin and Richards (2018), Feedback (2017) and Rakesh and Belavina (2020). Other issues, such as short-term ordering (Russo, 2020) and late taking of ownership (Pietrangeli et al., 2023) seem to be a specific problem of German fruit and vegetable supply chains. It is not clear whether this is a result of the specific conditions in Germany or of methodological constraints (see also section 5.5).

There is limited research on the individual drivers of food loss in low-income countries. Bahadur et al. (2016) note that other aspects such as machinery, telecommunications and transport play an important role in the occurrence of food loss. However, as wealth increases, the drivers of food loss in low-income countries may be increasingly similar to the drivers of food loss in high-income countries. Furthermore, it is crucial to consider regions in the Global South as they are part of globalised supply chains and face the very same standards analysed in this thesis. In addition, a relatively large proportion of food produced for the Global North is lost in the Global South, as the proportion of food lost during production, storage and handling is comparatively high in these regions (Gatto et al., 2023). In fact, approximately 67.5 % of

food loss caused by consumption in higher-income regions abroad occurs in lower-income regions (ibid.).

Hence, hypotheses can be derived about the possible transferability of the results of the dissertation. However, it also becomes clear that differences between the present findings and those of other studies are likely to arise from factors that have not yet been sufficiently explored.

5.5 Limitations and future research

There are certain limitations to the findings presented and discussed. These limitations give rise to suggestions for future research. In general, in empirical social science, it must be mentioned that each response is based on a unique and subjective perception (Baur and Blasius, 2019). This is an advantage where subjective perceptions are sought. However, where numbers and figures are concerned, it is important to note that these are based on the personal judgements of respondents and interviewees in the context of their professional background. In addition, with regard to RO IV concerning measures and policies, the data set is limited to the perceptions of norm addressees of potential policies. This has the advantage of capturing the actors' personal needs but also the disadvantage of potentially self-interested responses outside the FLW issue. Different groups of experts and respondents were selected, from farmers to different types of suppliers to intermediaries and retailers, in order to give as diverse a picture as possible.

Some limitations are specifically related to the interview part of this thesis. Qualitative expert interviews have previously been used to obtain farmers' views on fruit and vegetable loss at the harvest stage (Johnson et al., 2019). Beausang et al. (2017) describe semi-structured interviews as a useful but a rarely applied method in the field of food loss generation in primary production. However, biasing factors such as interviewer characteristics (age, gender, experience in interviewing), the presence of third parties, sensitive questions and content-independent advocacy tendencies need to be considered when interpreting the results (Reinecke, 2019). Some challenges can be mitigated by careful preparation of the guide and the interview itself (see also 3.2.1). Nevertheless, the interview results presented in this thesis may be influenced in particular by third party bias factors, as well as sensitive questions that may have led to some aspects being downplayed and undervalued. Specifically, the situation during the COVID-19 pandemic may have had a negative effect on trust building, as most of the interviews were conducted online or via telephone.

There are also limitations specific to the questionnaire part of this thesis. Previous studies have applied questionnaire surveys to analyse the drivers of food loss in fresh fruit and vegetable supply chains (Sanad Alsbu et al., 2023) and the amount of fresh fruit and vegetables lost in primary production (Hartikainen et al., 2018). However, compared to actual measurements in the field, questionnaire surveys tend to underestimate food loss (Baker et al., 2019; Johnson et al., 2018a; Xue et al., 2017). There is no indication of whether the estimates derived in article 2 are based on regularly monitored data from suppliers or on suppliers' estimates and recalls. Moreover, there is a risk of decontextualisation specific to online surveys (Wagner-Schelewsky and Hering, 2019). This means that the transferability of the responses to everyday social

interactions is limited, as it has been shown that there is less commitment to social norms when completing a questionnaire (ibid). Another issue that needs to be considered is that answers in questionnaires can be influenced by previous questions (Weichbold, 2019). As the questionnaire was also designed to gather information on issues other than policies and measures to reduce food loss, this is a crucial aspect in relation to RO IV.

The limitations and boundaries of this work provide an opportunity for future research. Pre-harvest loss has so far been largely overlooked in research and policy, yet its prevention has the potential to reduce the environmental footprint of food supply chains (Cattaneo et al., 2020). It is often ignored that households have a larger share of unavoidable FLW. For primary production (excluding pre-harvest) in Germany, this share is only 14 %, while for households it is 56 % (Schmidt et al., 2019). Future research should therefore focus more on upstream parts of the supply chain to realise the potential for reducing avoidable food loss.

In general, regular and harmonised monitoring and a more direct quantification are needed to avoid the bias, subjectivity and potential underestimation mentioned above. This is particularly true at the level of primary production. Current initiatives in the European Union (see also section 2.1.1) are a good starting point and should also be extended to other countries. The quantification of FLW should then also assess the exact reasons for sorting out and rejecting products in as much detail as possible to test the perceptions of reasons for sorting out given by respondents in this thesis.

Further research is needed with regard to drivers of FLW considering various product groups, supply chains and regions. For example, case studies similar to the one in article 2 addressing product specifications and business practices could be conducted with other retailers. Section 5.4 suggests that there are differences. However, the published literature is currently too limited to identify patterns of which product groups, regions and supply chain structures are vulnerable to particular drivers and mechanisms of food loss. The study of the causes of food loss should also include analysing these causes at the different stages of the supply chain. Future research should therefore address not only the question of *what* could be done to prevent food loss, but also *why* actors would act in this way and how they could be incentivised to engage in food loss prevention. At household level, this has already been done by Read and Muth (2021), who evaluated four interventions and raised the research question of how to address the mismatch between who has to pay for implementation and who benefits from FLW reduction.

The role of power constellations in relation to the mechanisms that cause food loss has been intensively analysed in this thesis. In further research, it is crucial to observe these mechanisms influenced by power relations, as they are fluid and can alter with changing conditions. With increasing uncertainties in agricultural markets, such as shifting environmental conditions and international relations or the COVID-19 pandemic, the likely changes in business practices in fruit and vegetable supply chains need to be captured (Sanad Alsbu et al., 2023).

Further academic engagement could also include looking at power constellations in relation to food loss through other theoretical lenses. Global value chain perspectives (Gereffi et al., 2005;

Gereffi, 1994) and global production network perspectives (Coe et al., 2008; Henderson et al., 2002) have only been briefly touched upon (section 5.2) and could provide a better understanding of how power relations and practices in supply chains can evolve over time and how further actors are involved. Humphrey and Schmitz (2002) provide a framework of potential upgrading activities related to supply chain management. In particular, functional upgrading, where firms move horizontally into new production activities, could be a key for future research to analyse suppliers' capabilities to establish alternative marketing and processing channels. Particular attention with respect to power issues should be paid to the UTP Directive (European Parliament, 2019). There is a growing body of literature addressing questions about the implementation and effectiveness of the directive (Barathova et al., 2022; Nový, 2023; Russo, 2020; Schebesta et al., 2018). In general, assessing which UTPs exist in which supply chains, whether the list of UTPs should be extended, the effectiveness of different implementations of the directive in Member States and whether complaints are actually made to ombudspersons are questions that need to be addressed. In particular, the link between UTPs and the incidence of food loss should be analysed in more detail. This thesis can be considered a starting point for linking these two issues. Hernandez et al. (2023) note that trading practices depend on the context and may be influenced by several factors other than concentration. They point out that there are still research gaps that need to be filled in order to generalise conclusions on the incidence of UTPs, especially in low-income countries.

Finally, the thesis presented initial policy implications and private sector measures in the course of food loss prevention. However, there is still a lack of research on the effectiveness and efficiency of policies aimed at preventing FLW (Cattaneo et al., 2020; Reynolds et al., 2019). In order for policies and measures to be implemented, their effectiveness and efficiency need to be scientifically assessed prior to and after implementation.

6 Conclusions

The findings of this thesis shed light on the importance of inter-stage drivers of food loss in upstream fruit and vegetable supply chains. The stages of the supply chain influence each other and in particular the retail sector affects the upstream stages of the supply chain in the occurrence of food loss (see also article 1). This happens through mechanisms such as low liability for quantities requested by retailers, short-term ordering practices and a lack of purchase guarantees. In the informal planning process for fruit and vegetable quantities, retailers usually do not contractually commit to specific quantities, but leave these vague and then call off the actual quantities required from the supplier at very short notice. Promotions that do not coincide well with production peaks can exacerbate the mismatch between available product quantities and demand. In addition, customer-specific requirements for product appearance can be a critical driver of food loss in these supply chains. These mechanisms lead farmers and suppliers to overproduce and pre-pack to manage the risk of unpredictable quantities of fruit and vegetable orders. They also cause farmers and suppliers to leave actually edible produce in the field, to sort it out along the supply chain and to face rejection. These mechanisms therefore lead to an increase in food loss, provided that loss before and during harvest and products not used for human consumption are considered food loss.

The setting of retailers' product requirements, combined with business practices, emerges as a specific cause of food loss in fruit and vegetable supply chains (see also article 2). The framing of such requirements leads not only to the rejection of fruit and vegetables by retailers, but also to the sorting out of produce deemed suboptimal early in the supply chain. It is crucial to identify the exact retailer specifications and practices that actually lead to food loss. For example, contrary to expectations, calibre (mass and size) requirements and pesticide residue limits set by retailers are more relevant to food loss than shape requirements.

Particularly, power relations play a central role in shaping the commercial relationship between production and retail. Power in this context is conceptualised as relational and is exercised over other actors rather than being possessed (see also section 2.2.2). Power is manifested in the ability to govern and shape business relationships, such as retailers exercising significant control over the supply chain. Consequently, it can be observed that the exercise of power allows the risk of food loss to be transferred upstream in the supply chain, in the form of mechanisms that cause food loss as described above.

To effectively address the inter-stage mechanisms creating food loss, both private actors and policymakers need to take proactive measures. Such measures do not necessarily have to involve a complete restructuring of markets and a rebalancing of structural market power, but can start at a lower level. Recommendations include creating more accountability in market transactions by adjusting ordering procedures so that they are made with sufficient lead time and certainty about the quantities needed (see also article 3). It is also recommended that product specifications are reviewed and harmonised between retailers to allow previously suboptimal products to enter the market and to ensure greater flexibility in marketing channels.

Well-coordinated promotions are another way to buffer surplus production. Prioritising potential trade-offs between the reduction of food loss and other objectives are vital steps to avoid tilling under, sorting out and rejecting agricultural products and thus reduce food loss.

In terms of policy interventions, relying on voluntary action by stakeholders may not be sufficient. Additional market-based and regulatory policy approaches could be targeted to effectively address the inter-stage drivers of food loss. This is because it needs to be questioned whether actors are sufficiently committed to reduce food loss elsewhere in the supply chain, thereby assuming risks and responsibilities, and potentially incurring costs. Policies should promote the sharing of the costs of food loss between producers and retailers as an incentive to intervene against food loss. In this regard, addressing power relations in supply chains can play a critical role. The creation of alternative marketing and processing channels could be an option to increase bargaining power of suppliers while at the same time providing opportunities for surplus and suboptimal food to remain within food supply chains. Policy coherence, i.e., aligning FLW policy with existing legislation on issues other than FLW, is also of great importance. One potential example is a review of the legislation on producer organisations to strengthen alternative marketing channels. In addition, a revision of the UTP Directive and its national transpositions can be effective, taking into consideration the concern to reduce food loss.

While this thesis has made significant progress in understanding the drivers of food loss in upstream fruit and vegetable supply chains, certain aspects could be improved (see also section 5.5). For example, the conditions of data collection, which were particularly affected by the COVID-19 pandemic, posed a challenge to the research process. In addition, research on FLW is generally hampered by a lack of reliability of existing data and more robust and transparent data should be sought in this area. In this respect, research will always face the challenge of reconciling economic arguments and arguments about the accuracy of the measuring instrument, as has been demonstrated throughout this thesis. In particular, the measurement of field losses requires significant resources in order to provide adequate direct quantification. Furthermore, the sensitivity of the issue of FLW requires researchers to be aware of potential biases in participants' responses. This sensitivity may also make it difficult to collaborate on research projects with companies that have reputational concerns. Patient collaboration, while highlighting the benefits of such collaboration for companies, could encourage a greater number of stakeholders to be more transparent about their data and processes. It must be clear that this is not about pointing the finger at specific actors. Rather, it is about building on the momentum of the FLW debate and the actions that are already underway (see also section 2.3.2).

Looking ahead, future research should extend this work by examining the transferability of the results to other regions, product groups and environments. It is expected that even small differences, such as the perishability of a product, order lead times and different political and organisational frameworks may lead to the emergence of completely different food loss mechanisms (see also section 5.4). Furthermore, the consideration of pre-harvest and harvest loss is essential in the pursuit of coping sustainably with agricultural resources. This does not

necessarily imply the need to call this fraction ‘food loss’, but rather to acknowledge that this fraction also entails environmental issues and therefore should not be excluded from the policy debate as is currently the case. Finally, evaluating the effects of the recommended measures and policies will be crucial in refining strategies to effectively address food loss.

In conclusion, this thesis has provided a comprehensive analysis of the issue of food loss in terms of its drivers and governance in fruit and vegetable supply chains prior to retail. Given the systemic nature of the causes of food loss, it is essential to analyse specific drivers in more detail in order to understand them and recommend appropriate options for action. The main novelty of this thesis lies in its unique combination of power relations in agri-food supply chains and causes of food loss, which has not previously been scientifically analysed. By addressing an under-researched area and adopting an interdisciplinary and methodologically diverse approach, it has contributed significantly to the understanding of food loss in early stages of the supply chain. It has opened up new avenues for future research and underlines the need to continue assessing food loss in agricultural supply chains in order to support the creation of more sustainable food systems.

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Appendix

Scientific curriculum vitae of the author

Ronja Herzberg
Date and place of birth: 22nd March1993 in Blender, Germany

Academic Education

10/2020 – present	**PhD Programme for Agricultural Sciences in Göttingen (PAG)** Georg-August-Universität Göttingen
10/2016 – 09/2019	**M.Sc. Geography: Resource analysis and management** Georg-August-Universität Göttingen Thesis: *GIS-based Multi-Criteria Land Suitability Evaluation in A Luoi District, Vietnam*
10/2012 – 05/2016	**B.Sc. Environmental Sciences** Carl-von-Ossietzky-Universität Oldenburg Thesis: *The vegetation of north-west German lowland ditches in relation to chemical and physical parameters*

Academic Employment History

10/2019 – present	**Thünen Institute of Rural Studies / Thünen Institute of Market Analysis** Research assistant and PhD candidate
09/2017 – 03/2019	**Department of Geography at the Georg-August Universität Göttingen** Student assistant with a two-month research stay in Bangalore, India (Nov./Dec. 2017)

Publications

(1) Herzberg, Ronja; Trebbin, Anika; Schneider, Felicitas (2023): Product specifications and business practices as food loss drivers – A case study of a retailer's upstream fruit and vegetable supply chains. In Journal of Cleaner Production 417, 137940. DOI: 10.1016/j.jclepro.2023.137940.

(2) Pietrangeli, Roberta; Herzberg, Ronja; Cicatiello, Clara; Schneider, Felicitas (2023): Quality standards and contractual terms affecting food losses: the perspective of producer organisations in Germany and Italy. Foods 12, 1984. DOI: 10.3390/foods12101984.

(3) Trebbin Anika, Herzberg Ronja, Schneider Felicitas (2023): Lebensmittelverluste bei Obst und Gemüse - die Rolle von Qualitätsanforderungen und Unternehmenspraktiken des

Lebensmitteleinzelhandels. Braunschweig: Johann Heinrich von Thünen-Institut, 86 p, Thünen Working Paper 202, DOI:10.3220/WP1668584175000

(4) Herzberg, Ronja; Schmidt Thomas G; Keck, Markus (2022): Market power and food loss at the producer-retailer interface of fruit and vegetable supply chains in Germany. In Sustainability Science (2022). DOI: 10.1007/s11625-021-01083-x

(5) Herzberg, Ronja; Schmidt, Thomas G.; Schneider, Felicitas (2020): Characteristics and determinants of domestic food waste: a representative diary study across Germany. In Sustainability 12 (11), p. 4702. DOI: 10.3390/su12114702.

(6) Herzberg, Ronja; Pham, Tung Gia; Kappas, Martin; Wyss, Daniel; Tran, Chau Thi Minh (2019): Multi-criteria decision analysis for the land evaluation of potential agricultural land use types in a hilly area of central Vietnam. In Land 8 (6), p. 90. DOI: 10.3390/land8060090.

Selected Presentations

(1) Beyond the Blemishes - Lebensmittelabfälle bei Obst und Gemüse zwischen Produktion und Handel (5th July 2023, trafo:agrar annual meeting, Hannover)

(2) Qualitätsanforderungen und Lebensmittelverluste bei Gemüse und Obst - Ergebnisse des Forschungsprojektes 'QualiLMV' (14th March 2023, 32. Bundesberatertagung für Fachberater*innen im Gemüsebau, Grünberg)

(3) Market power and food loss at the producer-retailer interface of fruit and vegetable supply chains in Germany (25th March 2023, 2nd annual conference of the working group on 'Agri-food geographies', Hohenheim/online)

(4) What can politics do about fruit and vegetable losses from the field to the retailers' warehouse? Supply chain actors' perspectives on food loss policy options (20th October 2022, RETASTE – rethink food waste conference, Horokopio University Heraklion)

(5) Food loss and bargaining power at the producer-retailer interface: a qualitative assessment of food loss drivers in German fruit and vegetable supply chains (8th May 2021; RETASTE – rethink food waste conference, Horokopio University Heraklion/online)

Awards

(1) Award for the best scientific poster at the GEWISOLA Annual Conference 2022
Title: *Food loss in European fruit & vegetable supply chains. The impact of retailers' product specifications.*

(2) Third place in the ‚trafo:nachwuchspreis 2023' for the contribution of the dissertation to the sustainable transformation of the food system, awarded by the ‚trafo:agrar' association