Food waste prevention

State of the art in impact assessment and empirical evidence for Denmark

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Summary

Food losses and waste (FLW) have recently been debated as one of the major aspects to focus upon in order to achieve a more sustainable food system. Thus, FLW has been addressed, to a steadily increasing degree, in scientific literature as well as on regional, national and international policy agendas. In this context, the Danish Ministry of Environment and Food requested this report with the aim to receive science-based support regarding potential FLW prevention strategies. For this purpose the current report aimed at (i) providing a review of the current state of the art in assessing FLW prevention strategies and (ii) providing own cost-effectiveness estimates for different prevention strategies to reduce FLW in Denmark. More specifically, different FLW prevention strategies were evaluated in terms of their expected FLW prevention potential (expressed in tonnes), monetary costs and benefits as well as the associated environmental benefits in terms of prevented GHG emissions. The results indicate the following: First, in line with previous studies, the results show that FLW strategies targeting the food service and household level are estimated to be the most beneficial strategies to prevent FLW. This result is driven by the fact that in high-income countries such as Denmark, FLW occurs predominantly at later stages of the food supply chain (FSC) and that food at these stages embodies more value-added and a higher environmental foot print in comparison to previous supply stages. Second, the report shows that different FLW prevention strategies will reduce different FLW compositions and thus will have different associated environmental benefits. For example, improved knowledge about date labels among consumers is expected to reduce FLW within food product categories that possess a relatively high CO_2-equivalent burden on a per-unit basis, such as dairy and meat.

Abbreviations & Definitions

CO_2-eq. – CO_2-equivalents

EDBP – Expiration Date Based Pricing

FLW – Food losses and waste

FSC – Food supply chain

GHG – Greenhouse gas

Kg – Kilogram

LCA – Life Cycle Assessment

TEIA – Total Environmental Impact Avoided

Ton – American ton (equal to 2,000 U.S. pounds = 907.2 kg)

Tonne – Metric tonne (equal to 1000 kg)

1 Background

The topic of food losses and waste (FLW) has gained increasing attention in recent years ranking high on regional, national and international policy agendas. In Europe, for example, FLW is included in the Circular Economy (CE) package as one of the priority areas. These are areas that should be carefully considered to strengthen the circularity of the European economy (European Commission, 2015). At global level, one of the stated UN Sustainable Development Goals is to halve per-capita global FLW at the retail and consumer levels and reduce FLW along production and supply chains, including post-harvest FLW by 2030[1].

Reducing FLW, besides changes in agricultural production systems and dietary patterns, is considered one way to achieve a more sustainable food system, which uses limited resources such as, among others, land and water more efficiently. While in developing countries FLW occurs mainly in the upstream stages of the food supply chain (FSC) due to for example inadequate infrastructure, in developed countries FLW is estimated to be mainly concentrated at the end of the FSC (e.g., Parfitt et al., 2010; van der Werf & Gilliland, 2017). Thus, several governmental and non-governmental initiatives in developed countries aim at reducing consumer-related FLW via awareness and education campaigns such as the *Stop Spild af Mad* initiative in Denmark, the *Zu gut für die Tonne* initiative in Germany or the *Love food – Hate waste* initiative in the UK, respectively.[2]

Besides these governmental and non-governmental initiatives set up to reduce current FLW levels, a growing number of scientific studies analysing different aspects of FLW have become available (Chen et al., 2017). The majority of these studies have addressed research questions surrounding waste management, waste treatment and disposal methods. However, especially in current years, there is a growing body of literature providing estimates of the extent of FLW for different countries: e.g. Beretta et al. (2013) (Switzerland); Bräutigam et al. (2014) (EU-27); Hafner et al. (2012) (Germany); Stenmarck et al. (2011) (Nordic countries), for different stages of the FSC: (primary production): Beausang et al. (2017); Hartikainen et al. (2018); (retail): Cicatiello et al. (2016; 2017); Eriksson et al. (2012; 2014); Lebersorger and Schneider (2014); (food service): Betz et al. (2015); Eriksson et al. (2017); Heikkilä et al. (2016); Silvennoinen et al. (2015); Strotmann et al. (2017); (households): Edjabou et al. (2016); Silvennoinen et al. (2014) as well as studies addressing the underlying drivers of FLW, especially at the household level: e.g. Aschemann-Witzel et al. (2015); Graham-Rowe et al. (2014); Hebrok and Boks (2017); Romani et al. (2018); Stancu and Lähteenmäki (2018); Stancu et al. (2016); Stefan et al. (2013); Williams et al. (2012). Most of these latter studies aimed at identifying and understanding several constructs related to FLW, such as consumers' knowledge and awareness, attitudes, motivations, and behaviours. Attitudes towards FLW have been studied most extensively using the Theory of Planned Behavior (Ajzen, 1991)[3]. Moreover, there

[1] http://www.un.org/sustainabledevelopment/sustainable-consumption-production/

[2] http://www.stopspildafmad.dk/; https://www.zugutfuerdietonne.de/; https://www.lovefoodhatewaste.com/

[3] The Theory of Planned Behavior is today one of the most popular social-psychological models for understanding and predicting human behaviour. Briefly, in the TPB, the immediate antecedent of a particular behaviour is the "intention"

is a small but growing literature addressing the topic of FLW at the consumer level from a microeconomic perspective, primarily applying Becker's (1965) household production model (e.g. Ellison & Lusk, 2018; Höjgård et al., 2013; Katare et al., 2017; Lusk & Ellison, 2017). Becker's household production model states that consumers do not derive utility directly from purchased goods but from commodities consumers produce by combining purchased goods and time (e.g., meals are produced by combining time and food inputs). Lusk and Ellison (2017) pointed out that Becker (1965) himself already noted that this framework might be used to explain why, as wages rise, people will tend to waste more food in an effort to save on meal preparation or shopping time. Put differently, in high-income countries consumers have higher opportunity costs of time (usually proxied by the wage rate) relative to the cost of food.

To sum up, there has been a shift from purely technological studies focusing on FLW towards studies, addressing the problem of FLW and possible solutions to mitigate it via socioeconomic approaches. These studies are definitely needed in order to generate a solid knowledge base on which recommendations to policy makers and other FSC stakeholders can be based. In this context, it has been pointed out, mainly by economics scholars, that FLW should be considered as any other economic phenomenon arising from existing preferences, incentives and constraints (e.g. Koester, 2014; 2014; Lusk & Ellison, 2017; Teuber & Jensen, 2016). Thus, FLW can be considered as the outcome of a trade-off between the direct costs of FLW (e.g. food inputs not used) on the one hand, and the cost of extra resources or inconveniences to avoid or reduce FLW (e.g. time use) on the other hand. Yet, economic analyses providing theoretical or empirical evidence on the impacts of potential FWL, mitigation measures including anticipated costs and expected benefits are rare. The current report aims at contributing to this research gap by providing an overview of the state of the art in FLW prevention modelling and own empirical estimates for different FLW mitigation measures applied to the case of Denmark.

The remaining report is structured as follows. The next section provides an overview of the current knowledge regarding the extent of FLW, followed by a section summarising existing study results with respect to FLW mitigation approaches and their potential impacts. Section 3 introduces the considered measures investigated for the case of Denmark, as well as a presentation of the derived results. Section 4 discusses the obtained results in a broader context and provides recommendations for policy makers as well as an outlook on future research topics. The last section concludes.

to perform the behaviour in question. This intention is assumed to be determined by three kinds of considerations or beliefs, namely *behavioural beliefs* (i.e. perceived positive or negative consequences of performing the behaviour and the subjective values or evaluations of these consequences), *normative beliefs* (i.e. the perceived expectations and behaviours of important referent individuals or groups, combined with the person's motivation to comply with the referents in question), and *control beliefs (i.e. beliefs* concerned with the perceived presence of factors that can influence a person's ability to perform the behaviour) (Ajzen, 2015)

2 Current knowledge about the extent and impact of FLW

Key points in chapter 2

- Current definitions of FLW differ in their (i) considered system boundaries, (ii) the use and destination of food products, and (iii) the aspect of edibility versus inedibility of food product parts
- Most FLW estimates are available for the consumption stage, while only few estimates are available for the primary production and processing stages
- There is a high degree of variability in existing FLW estimates, in part due to differences in used definitions and methodologies
- Available evidence indicates that in developed countries, FLW is most pronounced at the consumption stage
- With regard to the monetary value of FLW, some researchers propose to define the costs of FLW as the total value of the food that goes to the landfill at each stage of the supply chain, whereas others propose a Full-Cost-Accounting (FCA) framework to address the externality costs associated with the social and environmental impacts.

2.1 Definitions of FLW

Currently, no uniform definition but a variety of different approaches to define FLW exists. The available definitions differ in their (i) considered system boundaries, (ii) the use and destination of food products, and (iii) the aspect of edibility versus inedibility of food product parts (see for a more detailed discussion, Chaboud and Daviron (2017) as well as Teuber and Jensen (2016)).

With regard to the considered system boundaries, the majority of proposed definitions define FLW from the point of harvest (e.g. Östergren et al., 2014). However, there are also definitions available proposing to include pre-harvest losses and unrealised potential production, referring to this as potential food loss & waste (PFLW) (IFPRI, 2016). With respect to the use and destination of food products, some definitions describe FLW as all products originally intended for human consumption but not consumed, including food products that are not ending up on landfill but are used for other purposes such as animal feed (Gustavsson et al., 2011). According to other definitions, however, food, that is not consumed, but redirected for animal feed or other industrial processes, is not regarded as FLW (Östergren et al., 2014). In this vein, Bellemare et al. (2017) proposed to define FLW as the difference between all the food produced and the sum of all food used for productive purposes (e.g., human consumption, animal feed, fertilizer, biofuel). Thus, only food that ends up on landfill is considered as FLW. Regarding the aspect of edibility versus inedibility, some authors differentiate further between avoidable and unavoidable FLW according to the edibility of food product parts (e.g. peels and bones are, according to this differentiation, considered as unavoidable FLW).

To sum up, FLW is not a straightforward concept, and it has been argued that the introduction of a uniform definition of FLW might be an important step in order to facilitate the comparison of generated results. Yet, at the same time, different definitions might actually be needed, given different aims and reasons to define and assess FLW (Chaboud & Daviron, 2017; World Resource Institute, 2016).

2.2 Extent of FLW

Despite differing definitions of FLW and the associated challenges with regard to the comparability of existing FLW estimates, van der Werf and Gilliland (2017) as well as Xue et al. (2017) provide a systematic literature review of existing FLW estimates across the different FSC stages. While van der Werf and Gilliland (2017) only included estimates from developed countries, Xue et al. (2017) analysed global FLW data. Their results highlight the following points: First, most FLW estimates are available for the consumption stage, while only few estimates are available for the primary production and processing stages. Second, there is a high degree of variability in existing estimates as illustrated in figure 1. One of the major reasons for this high variability seems to be the type of measurement approach chosen, i.e. direct versus indirect measurement. Indirect measurement approaches, such as mass flow models, were usually found to lead to higher FLW estimates than FLW estimates generated via direct measurement approaches.

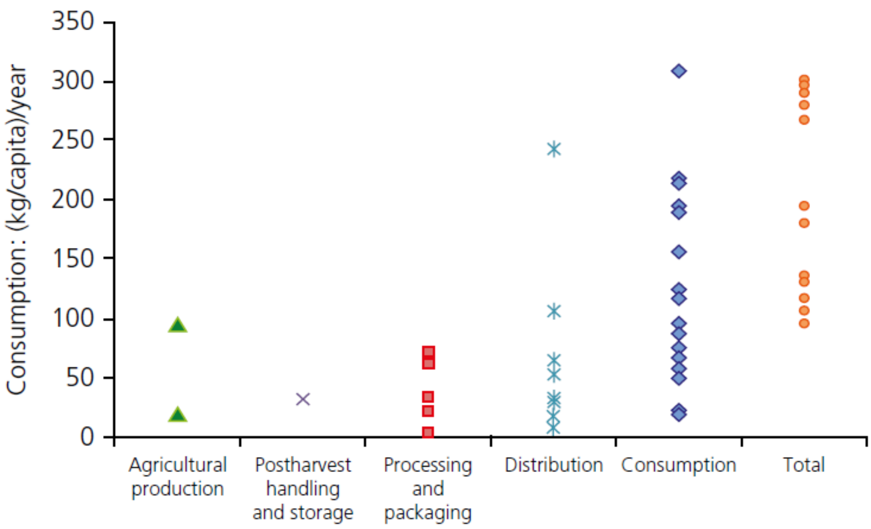

Figure 1. *Estimates of FLW at different supply chain stages*
Source: van der Werf & Gilliland (2017)

Van der Werf and Gilliand (2017) reported especially pronounced differences for the consumption stage with FLW estimates ranging from 18.8 kg per capita per year from an Austrian study (Lebersorger & Schneider, 2011) up to 308 kg per capita per year from a Canadian study (Abdulla et al., 2012). Thus, the Canadian estimate is over 16 times higher than the one reported for the Austrian sample. One assumed important reason for these large differences is the use of primary versus secondary datasets to calculate FLW estimates. As already mentioned above, van der Werf and Gilliland (2017) found that indirect estimates (i.e. derived from secondary data sources via a top-down approach[4]) were generally higher than direct (bottom-up) FLW estimates, which are based on primary waste data (i.e. collected from a sample of households or companies). Xue et al. (2017) also pointed out that the majority of available FLW estimates are based solely on secondary data, which implies relatively high uncertainties in the existing global FLW database. Besides significant differences in estimates due to the methodology employed, the existing data indicate that per-capita FLW at the household level increases with increasing income level (Xue et al., 2017) and that North American estimates are generally higher than European ones (van der Werf & Gilliland, 2017) – findings that have been reported by other studies as well.

To sum up, the available evidence indicates that in developed countries FLW is the most pronounced at the consumption stage. Moreover, due to different methodologies employed (top-down versus bottom-up approach) existing FLW estimates differ quite substantially. Thus, one should always take the available evidence on FLW with caution, paying attention to the employed definition and methodology applied to generate the estimates.

2.3 Associated costs of FLW

The FLW measures described above were all expressed in mass, i.e. either in kilograms or tonnes. Yet, it has been criticised that expressing FLW in mass might not be very informative. Thus, one kilogram of lettuce has not only a very different energy and nutrients content than for example one kilogram of beef, but even the environmental and monetary costs of these two products on a per-unit basis differ quite tremendously (e.g. Koester, 2013; Kummu et al., 2012). Hence, besides measuring the extent of FLW in mass, several other measures have been proposed such as expressing FLW in terms of energy (i.e. in kcal), environmental inputs embodied (e.g. in CO_2-eq. kg), or in monetary terms (i.e. monetary value per kg FLW). These measures are considered to depict the social, environmental, and economic impact (costs) of FLW.

With regard to the monetary value of FLW, Bellemare et al. (2017) proposed to define the costs of FLW as the total value of the food that goes to the landfill at each stage of the supply chain. Thus, at each stage, the price of FLW is equal to its average cost (e.g., at the grower level the cost of FLW is equal to the grower's average cost of production[5]). This approach focuses on the monetary value of FLW in terms of accounting costs. However, economic costs also include social and environmental costs such as landfill-related costs of FLW and environmental impacts of production of food that in the end is wasted (Bellemare et al., 2017).

Along these lines, FAO (2014) proposed a Full-Cost-Accounting (FCA) framework to address the externality costs associated with the social and environmental impacts of FSC, including FLW in monetary terms. Theoretically, such an approach allows determining an optimal level of FLW by

[4] A top-down approach is an approach where FLW is estimated by decomposition of aggregate-level data.

[5] In this context, Bellemare et al. (2017) pointed out that existing estimates of the costs of FLW are often overestimated due to the fact, that studies use transaction prices to monetarise the value of FLW. For example, using retail prices to evaluate FLW at the retailer stage overestimates the cost of FLW by the per unit mark up.

comparing the economic benefits with the economic costs of FLW prevention.[6] However, given the complexity of such an approach, we are not aware of any empirical study so far that addressed valuing the social and environmental costs of FLW prevention in monetary terms[7].

[6] Theoretically, the optimum is reached when the marginal costs equal the marginal benefits.
[7] There are several studies calculating the environmental impact of FLW (see section 3). However, in these studies the environmental impact is expressed in non-monetary terms (e.g. CO_2-equivalents etc.).

3 Impact assessment of FLW mitigation strategies from the literature

Key points in chapter 3

- The so-called *waste hierarchy* is often considered as a guiding principle for priority ordering of waste management, with prevention measures being the most preferred option, followed by reuse, recycling, recovery and the least preferred option disposal
- Environmental benefits of FLW prevention would mainly stem from avoided food production and would be highest for the food category of beef meat, followed by bread and cereal products
- Cost-benefit or cost-effectiveness studies with respect to FLW prevention hardly exist, but results of the few existing studies suggest that the waste hierarchy in most cases seems to be a valid guiding principle for FLW mitigating strategies by showing that prevention measures should be prioritised
- Maximising the Total Environmental Impact Avoided is not equivalent to maximising the total amount of FLW avoided in mass
- Prevention interventions targeting at the last stage of the FSC, i.e. consumers, seem to be most cost-effective and should be implemented first (given a limited governmental budget).

The following section will provide an overview of existing studies aiming at assessing different FLW mitigation strategies.

In this context, the so-called *waste hierarchy* is often considered a guiding principle (see e.g., Cristóbal et al., 2017; Eriksson & Spångberg, 2017). The waste hierarchy has been introduced in the Waste Framework Directive (WFD) (European Union, 2008) as the key legally binding principle upon which European waste management should be based. More specifically, it introduced a priority order for waste management with the aim to ensure that the environmentally soundest waste management options are chosen. According to this waste hierarchy, prevention measures are the most preferred option, followed by reuse, recycling, recovery and, the least preferred option, disposal[8]. The waste hierarchy applied to the case of FLW is illustrated in the following figure.

[8] In this context, it should be mentioned that there is evidence that this hierarchy does not necessarily hold in general but should always be evaluated taking the local context into account (e.g., Eriksson & Spångberg, 2017; van Ewijk & Stegemann, 2016).

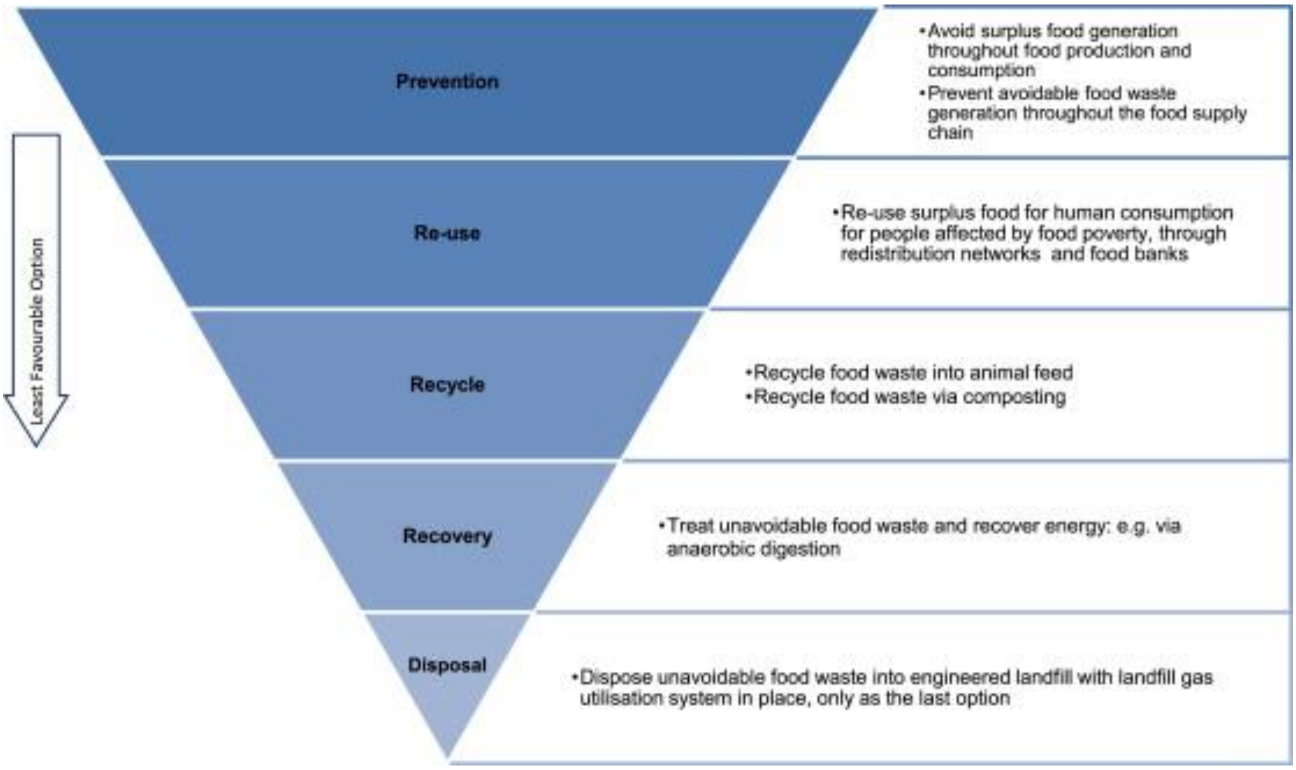

Figure 2. *FLW Hierarchy*

Source: Papargyropoulou et al. (2014)

3.1 State-of-the-Art

As mentioned in the introduction, there is a large and growing body of literature available investigating FLW management options (Chen et al., 2017). These studies typically analyse and compare FLW mitigation options such as landfill, incineration, composting and anaerobic digestion with respect to the associated global warming potential, using a Life Cycle Assessment (LCA) approach (for a review, see Bernstad and la Cour Jansen (2012)). Some studies also addressed recycling options such as animal feed (e.g. Vandermeersch et al., 2014; Salemdeeb et al., 2017). Hence, referring to the FLW hierarchy presented in figure 2, the focus has been on mitigation options at the bottom of the FLW hierarchy, while only few studies are available analysing and comparing mitigation options at the top of the FLW hierarchy, i.e. prevention and reuse strategies. Nevertheless, these last mentioned studies are the most relevant, given the focus of this report and thus, they will be highlighted in the following.

Overall, studies investigating the environmental impacts of FLW typically highlight that the environmental benefits of FLW prevention would mainly stem from avoided food production and would be highest for the food category of beef meat, followed by bread and cereal products (e.g., Birney et al., 2017; Hall et al., 2009; Kummu et al., 2012; Vanham et al., 2015). Martinez-Sanchez et al. (2016) and Salemdeeb et al. (2017) further analysed the impacts of FLW mitigation approaches using LCAs for Denmark and the UK, respectively. The considered scenarios, central assumptions, major results and derived (policy) implications of these two studies are presented in table 1.

Table 1. *Environmental impact of FLW mitigation strategies – LCA Approach*

Study	Martinez-Sanchez et al. (2016)	Salemdeeb et al. (2017)
Central assumptions	• Rebound effects included • International trade excluded	• Rebound effects included • International trade included
Scenarios	I. Baseline scenario: Incineration of FLW with mixed municipal solid waste II. Source segregation of FLW and subsequent co-digestion with manure III. Source segregation of vegetable FLW and treatment to be used as animal fodder IV. Prevention of 100 % of the edible FLW.	I. Baseline scenario: FLW is sent to be processed in an anaerobic digestion (AD) plant II. Partial reduction scenario: 60 % reduction in FLW III. Total-Reduction scenario: 77 % of FLW is prevented[a] In scenario (II) and (III), different rebound scenarios are considered.
Major results	• Without rebound effects prevention of FLW (scenario IV) appeared to be the preferred option generating the highest environmental benefits • In contrast, when rebound effects are taken into account, prevention appeared to be environmentally worse than the alternatives.	• Scenario (II) and (III) lead to substantial GHG savings of 700-900 kg CO_2-eq. per tonne of FLW prevented; this is mainly due to the avoidance of food production (i.e. avoided fertilizer and energy use in primary production), followed by food-related household activities (e.g. grocery shopping) • The rebound effects reduces the potential GHG savings significantly • GHG savings occur mainly abroad due to the high share of food imports in the UK and the, often lower, GHG efficiencies in agriculture of developing countries (e.g. rice imports from India).
Conclusions/ Policy implications	• Including income (rebound) effects is crucial in order to assess FLW prevention strategies • FLW prevention measures should also aim at making consumers aware about allocating monetary savings on low-impact goods/services.	• The derived environmental benefits from FLW reduction are substantial but much lower than presented in previous studies, due to taking into account significant rebound effects • Moreover, most GHG savings would take place abroad due to reduced food imports.

[a] These scenarios are based on results from the Waste and Resource Action Programme (WRAP) estimating that 60 per cent of household FLW in the UK is avoidable, while a further 17 per cent has the potential to be avoided. The remaining 23 per cent of FLW is unavoidable (i.e. tea bags, bones).

The major conclusions derived in these studies are that (i) rebound effects might be substantial and important to consider when assessing the potential environmental benefits from FLW prevention scenarios, and (ii) given the international scope of FSC, trade effects need to be taken into account to derive a complete picture of potential FLW prevention impacts. Rebound effects refer to the way potential economic savings, generated by preventing FLW, can induce new negative environmental impacts via spending the saved money on other goods (Binswanger, 2001)[9]. As pointed out by Höjgård et al. (2013), reducing FLW can be considered as an increase of the efficiency in food utilisation and, therefore, rebound effects will occur.

The following graphic illustrates the large range of existing estimates with respect to GHG savings related to FLW prevention. One of the major reasons for these large differences in generated estimates across studies is assumed to be the inclusion of rebound effects (Martinez-Sanchez et al., 2016; Salemdeeb et al., 2017) versus exclusion of rebound effects (Bernstad Saraiva Schott & Andersson, 2015; Chapagain & James, 2011; Gentil et al., 2011; Venkat et al., 2011).

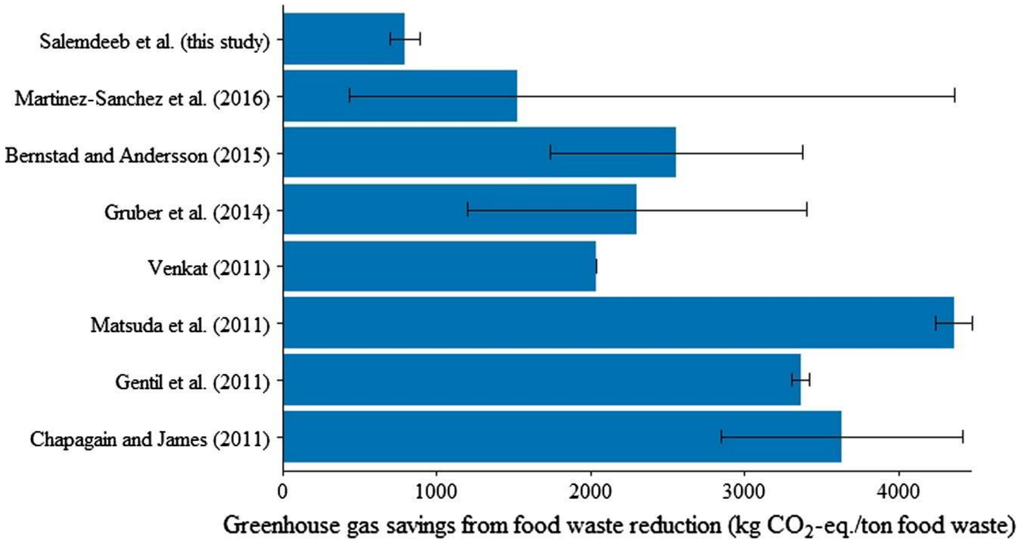

Figure 3. *A comparison of different estimates of GHG savings from avoiding one tonne of FLW*

Note: Error bars illustrate the range of reported estimates. No distinction between food types.
Source: Salemdeeb et al. (2017)

Even though these LCA studies provide important knowledge on the potential environmental impacts of FLW prevention measures, they do not provide any knowledge on *how* this reduction might be achieved and at what cost. Cost-benefit or cost-effectiveness studies with respect to FLW

[9] In energy economics, the rebound effect has been widely discussed and analysed. It is defined as the reduction in expected gains from new technologies that increase the efficiency of resource use, because of behavioural or other systemic responses. Usually one distinguishes between direct and indirect rebound effects. An example of a direct rebound effect is, when households, that have replaced traditional light bulbs with compact fluorescents, choose to use higher levels of illumination or not switch lights off in unoccupied rooms because lighting has become cheaper. In contrast, indirect rebound effects refer to an increased consumption of other goods and services (e.g. clothing) due to the cost savings from more energy efficient lighting (Chitnis et al., 2014).

prevention hardly exist. Exceptions are the studies by DEFRA (2012), ReFED[10] (2016), and Cristóbal et al. (2018).

The study by DEFRA (2012) used marginal abatement cost curves (MACCs) in order to record how much FLW (in tonnage) could be reduced by different actions, and the financial costs and benefits associated with these actions (including rebound effects). MACCs allow for graphically ranking of the cost-effectiveness of different environmental impact reduction measures and they are widely used in climate change modelling (e.g. FAO, 2012). The MACC plots the cost of the measures against the cumulative amount saved by the measures. This study highlighted that FLW, together with the waste streams construction and textiles, offers the greatest potential for savings in both monetary and environmental terms (DEFRA, 2012). Moreover, the results indicated that all considered FLW prevention actions were more or less equal in terms of cost-effectiveness but that the greatest waste-saving potential might be achieved through consumer education as well as changes to food products, packaging and labelling, including for example pack sizes, extended shelf-life, and optimised guidance on storage and freezing.

A more recent report by ReFED (2016) identified and analysed in more detail 27 possible FLW mitigation strategies comprising prevention, recovery (i.e. reuse for human consumption) and recycling (e.g. feeding animals, creating energy) options. These strategies were selected, based on four core criteria: (i) data availability, i.e. quantifiable data from one or more credible sources, (ii) cost-effectiveness – a positive or near-breakeven economic value to society, (iii) scalability, i.e. the potential to achieve significant waste diversion volume, and (iv) feasibility, i.e. stakeholders who can implement the solution without major changes to technology or policy.

Table 2 provides an overview of these strategies. The majority of these strategies target consumer-facing food businesses, where market share is concentrated among a small set of companies that influence FLW both upstream (through farms and manufacturers) and downstream (through consumers).

[10] ReFED is a multi-stakeholder group, formed in 2015 in the U.S. with the aim to reduce FLW. https://www.refed.com/

Table 2. *FLW mitigation strategies considered*

Strategy	Description	Stakeholders targeted/involved
Prevention measures		
Standardised Date Labelling	Standardising food label dates and instructions	Manufacturers, Retailers, Consumers
Packaging Adjustments	Optimising food packaging size and design to ensure complete consumption by consumers	
Spoilage Prevention Packaging	Using intelligent packaging to prolong freshness and avoid spoilage	
Produce Specifications (Imperfect Produce)	Accepting and integrating the sale of off-grade produce for use in food service/restaurants/retail	Producers, Foodservice, Retail
Smaller Plates	Use of smaller plates to reduce FLW	Foodservice
Trayless Dining	Eliminating tray dining in all-you-can-eat dining establishments	
Waste Tracking & Analytics	Providing restaurant/food service with data on wasteful practices to inform behaviour and operational changes	
Cold Chain Management	Reducing product loss during shipment to retail distribution centres	Retailers
Improved Inventory Management	Improvements in the ability of retail inventory management systems to track an average products' remaining shelf-life	
Secondary Resellers	Businesses that purchase unwanted processed food and produce directly from manufacturers/distributors for discounted retail sale	
Manufacturing Line Optimisation	Identifying opportunities to reduce FLW from manufacturing/processing operations	Manufacturers
Consumer Education Campaigns	Conducting large-scale consumer awareness and information campaigns	Consumers
Reuse strategies		
Donation Matching Software	Using a technology platform to connect individual donors with recipient organisations to reach smaller-scale food donations	Farms, Retailers, Food Recovery Organisation
Donation Storage & Handling	Expanding temperature-controlled food distribution infrastructure and labour availability to handle additional donation volumes	
Donation Transportation	Providing small-scale transportation infrastructure for local recovery	
Value-added processing	Extending the usable life of donated foods through processing	
Donation Liability Education	Educating potential donors on donation liability laws	
Standardised Donation Regulation	Standardising local and state health department regulations for safe handling and donation of food	
Donation Tax Incentives	Expanding federal tax benefits for food donations to all businesses and simplifying donation reporting for tax deductions	

Recycling Solutions		
Centralised Anaerobic Digestion (AD)	Series of biological processes in which microorganisms break down biodegradable material in the absence of oxygen, resulting in two different end products: biogas and digestate	Municipalities, Manufacturers, Retailers
Water Resource Recovery Facility (WRRF) with AD		Retailers, Municipalities, Foodservice, Consumers
In-Vessel Composting	Composting at small scale at institutions/businesses	Foodservice
Commercial Greywater	On-site treatment technology to break food organics down until soluble > flushed into the sewage system	
Community Composting	Small, community-level compost facilities	Foodservice, Consumers
Centralised Composting	FLW is transported to a centralised compost facility	Municipalities, Retailers, Foodservice, Consumers
Animal Feed	FLW to animals after it is heat-treated and dehydrated	Manufacturers, Foodservice, Retailers
Home Composting	"Backyard" compositing managed locally	Consumers

Source: ReFED (2016)

For each of these strategies the economic value per ton of FLW avoided was calculated as an annualised Net Present Value (NPV) that sums all costs and benefits for each strategy over 10 years, using a social discount rate of 4 per cent. The costs associated with each strategy include the initial investment capital, ongoing implementation and operating costs, advocacy costs, and other expenses. Financial benefits from prevention solutions include direct cost savings to food business and consumers, and additional revenues generated by food businesses.

Moreover, in order to take into account real-world constraints for each strategy, the FLW diversion potential was calculated based on assumptions about net and addressable FLW. The net FLW (also called the net opportunity) represents the estimated quantity of FLW currently sent to landfill[11]. Addressable FLW is the assumed maximum amount of FLW that potentially can be diverted from landfill, based on the characteristics of the strategy. The FLW diversion potential is calculated based on the addressable FLW reflecting what a certain FLW mitigation strategy can feasibly achieve, if appropriate resources are provided.

Based on these calculations, the different FLW mitigation strategies were ranked according to their cost-effectiveness and FLW diversion potential using MACCs as illustrated in figure 4. The MACCs display the considered strategies arranged by the greatest to the lowest economic value (not

[11] In the Unites States, sending FLW to landfill is the common procedure and thus the reference scenario. However, in most of the Danish municipalities incineration of FLW with mixed municipal solid waste is the common treatment (Martinez-Sanchez et al., 2016).

including possible externality gains) in dollars per ton of FLW diverted. A positive number on the y-scale indicates that the benefits outweigh the costs, and the width of each bar reflects the feasible FLW diversion potential (i.e. tons[12] of FLW reduced per year). Consequently, the total area of each bar represents the economic value, and the colour of the bar indicates the prevention, recovery, or recycling categories, respectively.

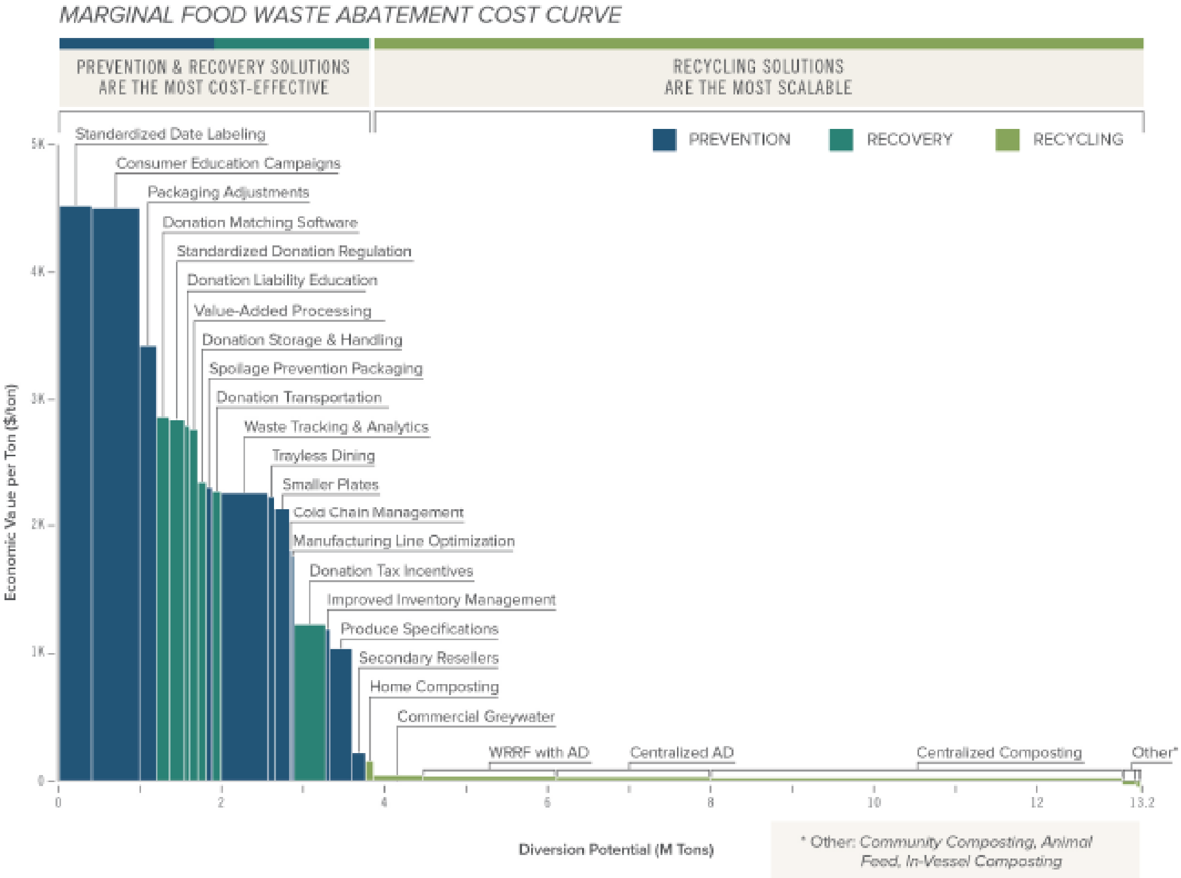

Figure 4. *Marginal Food Waste Abatement Cost Curve ranking solutions by cost-effectiveness and landfill diversion potential*

Source: ReFED (2016, p. 20)

According to these results, FLW prevention strategies targeted at consumers (i.e. standardised date labelling, awareness & information campaigns, packaging adjustments) can be considered the most cost-effective, i.e. they possess the highest economic value per ton FLW prevented. Recycling strategies, however, possess the highest potential for reducing FLW.

[12] It is important to note that studies conducted for the United States usually use ton instead of tonnes. In the U.S., a *ton*, also called a *short ton*, is equal to 2,000 U.S. pounds (abbreviated lbs.). Most other industrialised nations use the metric system and thus the *metric ton*. A *metric ton* (or tonne) is equal to 1,000 kilograms (abbreviated kg). Thus, a *metric ton* is slightly larger than a *U.S. ton* – it converts to 2,204.6 pounds.

Closely connected to this report is the study by Cristóbal et al. (2017). These authors aimed at providing a tool for decision makers to identify the optimal combination of FLW mitigation measures to be prioritised in order to maximise the environmental impact benefit along the whole FSC within a defined budget[13]. Analogue to the ReFED report (2016), Cristóbal et al. (2017) differentiated between the quantity of FLW generated ($FLW_{generated}$), the maximum FLW quantity that potentially could be avoided by a certain measure ($FLW_{potential}$), and the actual quantity of FLW prevented ($FLW_{prevented}$)[14]. In order to calculate $FLW_{potential}$ and $FLW_{prevented}$, scope and participation factors need to be taken into account. The scope factor defines the target group (e.g. all consumers in Denmark), while the participation factor is defined as the share of the target group participating/ reacting to the strategy implemented (e.g. 30 per cent of the consumers in Denmark).

Furthermore, in order to evaluate the environmental impact of a certain FLW mitigation measure, a composite index called total environmental impact avoided (TEIA), consisting of 15 different impact categories (e.g. land use, climate change, human toxicity, etc.) was used. The environmental impact avoided by FLW prevention is thereby equal to the sum of the impact of the avoided amount of food produced and the impact of disposing the quantity of FLW prevented (Cristóbal et al., 2017).

Using linear programming with the objective to maximise the TEIA (environmental objective) under a certain budget constraint (economic objective), the key findings of this study are as follows. First, there is a list of measures that can be considered *quick wins* since they achieve a high TEIA at a low cost. These measures which should be the first measures considered to be implemented are: consumer education campaigns, waste tracking analytics, standardised labelling, smaller plates, trayless dining, improved inventory management, cold chain management, manufacturing line optimisation, standardised donation regulation and feeding FLW to animals[15]. Packaging adjustments and spoilage prevention packaging should be considered thereafter. The secondary resellers' strategy (i.e. increased utilisation of off-grade products, see also table 2) was found to be the most expensive measure but was prioritised in medium budget options, while donation tax incentives, centralised composting and centralised anaerobic digestion were the least prioritised measures, due to their high costs and relatively low environmental savings.

Thus, overall the results suggest that in most cases the waste hierarchy seems to be a valid guiding principle for FLW mitigating strategies by showing that prevention measures should be prioritised. However, some exceptions exist, such as the prioritising of standardising donation regulation and using FLW for animal feed (reuse and recycle measures) before the implementation of packaging adjustments (prevention measure). Besides, the results of the study highlighted that maximising the TEIA is not equal to maximising the total amount of FLW avoided in mass. Consequently, while planning and implementing FLW mitigation strategies, stakeholder should target at maximising the TEIA and not FLW in mass.

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[13] The social dimension was excluded from the analysis due to lack of indicators and reliable data.

[14] In the ReFED report, these quantities are called net FLW, addressable FLW and the FLW diversion potential.

[15] See table 2 for a more detailed description of each measure.

To sum up, the existing evidence so far suggests that prevention interventions at the last stage of the FSC, i.e. those targeting consumers, seem to be the most cost-effective, and given a limited governmental budget they should be implemented first. However, these studies do not provide any detailed analyses of *how* consumer behaviour might be influenced by awareness and education campaigns and what kind of campaigns should be set up in order to reduce FLW at the consumer level. We will elaborate further on this crucial point in the following section, while discussing interventions specifically targeting Danish consumers.

4 Case studies for Denmark

Key points in chapter 4

- The distribution of FLW across the different stages of the Danish FSC is in line with studies for other high-income countries highlighting that the largest share of FLW is estimated to occur at the consumer/household level, followed by the retail and the primary production sector.
- Increased utilisation of second grade produce in food service kitchens is estimated to bear an annual FLW prevention potential of 212-1,063 tonnes, yielding a net economic gain of around 1.0 DKK per kg FLW prevented, and a reduction in GHG emissions of 34-170 tonnes CO_2-equivalents per year.
- The total amount of FLW that potentially could be prevented via waste tracking and analytics in the food service sector is estimated to be up to 2,300 tonnes, with an average net gain of 9.65 DKK per kg FLW prevented and a reduction in GHG emissions of up to 4,400 tonnes of CO_2-equivalents.
- Optimized buffet management in self-service restaurants and canteens is estimated to lead to a reduction of FLW in the food service sector of around 4,100 tonnes, with an average net benefit of 9.08 DKK per kg FLW prevented, and a reduction in environmental impact of 6,100 tonnes CO_2-equivalents.
- An intervention with smaller plates in self-service restaurants and canteens is in general cost-neutral. This might lead to a total reduction of 72 tonnes FLW in the food service sector and a consequent reduction in GHG emissions of 82 tonnes of CO_2-equivalents.
- Improved inventory management in food retailing bears a potential to reduce the retail sector's FLW by 4,700 tonnes, with an average net value of almost 14 DKK per kg FLW prevented, and a potential to reduce food-related emissions by 9,800 tonnes CO_2-equivalents.
- Optimization of temperature management in the cooling chain is estimated to bear a potential to reduce aggregate retailer FLW by 355 tonnes, primarily in meat and seafood, gaining an average net benefit of around 41 DKK per kg FLW prevented and a a GHG emission reduction potential of 1,600 tonnes CO_2-equivalents.
- Increased awareness and knowledge about date labels has the potential to reduce FLW at the household level by 2,372-11,983 tonnes per year, with an estimated economic value per kg of FLW prevented around 26 DKK, and GHG emission reductions amounting to 9,072-45,139 tonnes CO_2-equivalents.
- Consumer education has an estimated FLW prevention potential of 13,000-65,000 tonnes, with an associated reduction in GHG emissions of 25,233-126,165 tonnes, and an economic net gain of around 19 DKK per kg FLW prevented.

4.1 Extent and composition of FLW

Several studies have been conducted for Denmark estimating either the extent of FLW at different stages of the FSC (*primary production*: Hartikainen et al., 2018; *retail & food service*: Petersen et al., 2014; *household level*: Edjabou et al., 2016) or analysing the environmental impact of FLW and/or

FLW mitigation strategies (Martinez-Sanchez et al., 2016; Tonini et al., 2017). Table 3 provides an overview of the most recent FLW estimates for the different FSC stages in Denmark.

Table 3. *Existing FLW estimates for Denmark, in tonnes per year*

Primary Production[a]	Manufacturing[b]	Food Service[c]	Retail	Households[d]
117,000	*133,000*	*41,000-78,000*	*167,300*	*252,164 – 275,088*
353,000	*101,000 - 160,000*	*115,700*	*172,300*	*473,000 - 494,000*

Notes: Red numbers refer to so-called avoidable FLW, i.e. this definition comprises the edible parts of food only. Black numbers refer to total FLW, i.e. includes both edible and inedible parts.

[a] Based on Hartikainen et al. (2018): This study introduced the term *side flow* to refer to the edible part of food lost. These side flow estimates are based on primary data collected via questionnaires, direct in-field measurements and interviews with farmers and other stakeholders. The black number refers to a FLW estimate (according to the FUSIONS definition) which is based on FAOSTAT data and includes edible and inedible parts.

[b] Based on Tonini et al. (2017)

[c] The Food Service sector comprises commercial kitchens, restaurants, hotels, and public kitchens serving food to nursing homes, day care institutions, schools, and hospitals.

[d] Based on Edjabou et al. (2016): Avoidable FLW: 48(+/-4)kg per capita per year, Total FLW: 1.6 kg per person per week; All estimates are based on residual household waste samples from ~1500 households (primary data, bottom-up approach)

Source: Teuber and Jensen (2016)

Overall, the distribution of FLW across the different stages of the FSC is in line with studies for other high-income countries highlighting that the largest share of FLW is estimated to occur at the consumer/household level, followed by the retail and the primary production sector.

With respect to environmental impacts, Tonini et al. (2017) concluded that Danish households and the Danish food service sector seem to possess the highest GHG emissions saving potential, per unit of FLW prevented. This is simply due to the fact, that these sectors are placed at the end of the FSC and additional cooking/cooling activities are placed on top of food production and land use change implications, which are common to all sectors[16]. Thus, these authors concluded that addressing FLW at these two stages should be prioritised.

Moreover, their results confirmed previous findings in the fact that the environmental impact in terms of GHG emissions from FLW in the food category fruits and vegetables is rather minor compared to meat and dairy items on a per unit basis, because of the significantly lower environmental impact of fruits and vegetables production. Overall, pork, beef and cheese products have by far the highest environmental footprint on a per unit basis (kg). Nevertheless, the results

[16] It needs to be noted, that Tonini et al. (2017) did not include the primary production sector in their analysis. The functional unit of their study is the prevention of one tonne of avoidable food waste, as wet weight generated by each individual sector involved in the Danish food supply chain, with the exception of the primary production sector (agriculture).

highlighted that the impact of FLW in the food category fruits and vegetables on other environmental categories such as *ecotoxicity* and *resource depletion* is relatively important[17].

Available FLW estimates for Denmark regarding different food product categories and the share of these in total FLW (i.e. the composition of FLW) at the different FSC stages are presented in the following figure 5 and table 4, respectively.

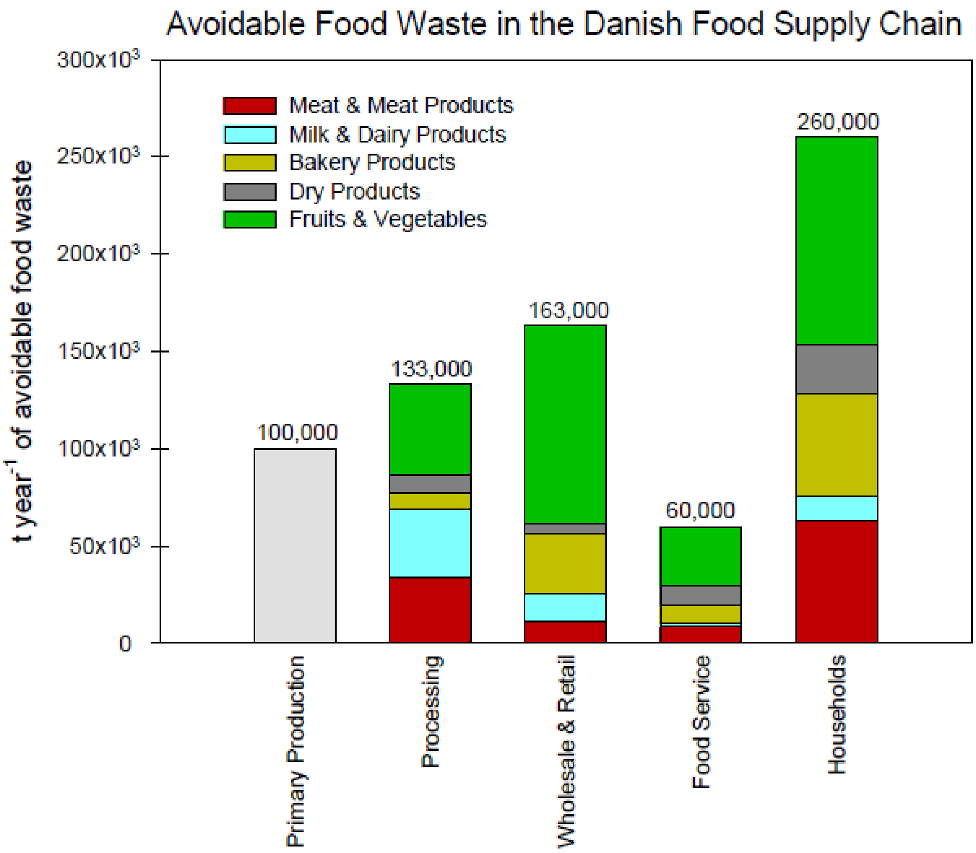

Figure 5*. Composition of avoidable FLW in the Danish FSC, absolute in tonnes per year*

Note: The primary production stage was not included in their analysis and thus, no FLW composition is displayed.
Source: Tonini et al. (2017, p. 17)

[17] Tonini et al. (2017) included the following environmental impact categories in their LCA: Global Warming, Terrestrial Acidification, Eutrophication - Nitrogen, Human Toxicity, Ecotoxicity, and Resource Depletion.

Table 4. *Available estimates concerning the composition of avoidable FLW, relative mass shares of total FLW expressed in mass (in per cent)*

Product categories	Primary Production	Manufacturing	Wholesale/Retail	Food Service	Households
Fruits & Vegetables	60	35	38	51	40
Grain products	8	6	18	15	20
Meat & Fish	16	25	12	15	24
Milk & Dairy[a]	16	27	15	3	5
Dry products[b]	-	7	18	16	10
Total	100	100	100/100	100	100

[a] The estimated share of milk and dairy product in total FLW at the household level might be underestimated since only solid waste was included in the calculations. However, some studies have shown that dairy products such as milk are often discarded via the sink. [b] This category comprises sugar, rice and other cereal products, with the exception of bread.
Sources: Hartikainen et al. (2018), Tonini et al. (2017).

4.2 Methodological framework

Overall, this report employs a similar approach to the one proposed by ReFED (2016) as well as Cristóbal et al. (2018). Thus, for each intervention strategy estimate, with respect to the amount of prevented FLW ($FLW_{prevented}$), the assumed direct and indirect costs and benefits of the strategy/ intervention, and the associated environmental impact expressed in CO_2-equivalents will be presented[18].

More specifically, in order to calculate the amount of $FLW_{prevented}$, estimates of $FLW_{generated}$ (see table 3) need to be combined with assumptions about scope and participation factors. Given the rather large uncertainties surrounding these factors for most interventions, three different scenarios are depicted assuming different degrees of participation (i.e., a very conservative, intermediate and best-case scenario). $FLW_{prevented}$ is estimated both in physical quantities (i.e. in kilograms or tonnes) and in monetary terms, taking into account five major food categories: fruits and vegetables, grain products, meat and meat products, milk and dairy products, and fish and seafood[19]. The monetary valuation of the amount of $FLW_{prevented}$ was based on the average unit costs displayed in table 5. For example, the price of grain in primary production (1.06 DKK per kg) was calculated as the ratio between total national output value of grain production in 2016 (9655 million DKK), divided by the total physical output (9130 million kg). The price of grain products at the household level was calculated as the ratio between the households' aggregate expenditure in 2007 for grain products (flour, flakes, pasta, rice, bread, bakery, etc.) (12449 million DKK), divided by the estimated total

[18] In principle, other environmental impacts could be considered as well, such as e.g. water footprint (Kummu et al., 2012; Tom et al. 2016) or nitrogen footprint (Leip et al., 2013). However, the data formats used in the mentioned existing studies of these footprints are not compatible with the aggregations and supply chain perspectives of the present study.

[19] Thus, our product categories differ slightly from the study by Tonini et al (2017). We consider fish and seafood as a separate category, while our grain products category comprises bread as well as other grain products such as pasta, rice, etc. The latter named grain products were classified as dry products in the case of Tonini et al. (2017).

quantity consumed of these goods in 2007 (549,5 mill. kg) and then inflated by the consumer price index for grain-based foods from 2007 to 2016 and adjusted for value-added tax.

Table 5: Average commodity prices at different FSC stages in Denmark in DKK per kg, 2016

Product categories	Primary Production	Manu-facturing	Wholesale	Retail	Food service	Households
Fruits & Vegetables	3.83	3.83	5.15	11.06	11.06	13.51
Grain Products	1.06	1.06	5.08	9.24	9.24	22.42
Meat & Meat products	11.90	11.90	13.73	29.45	29.45	39.20
Milk & Dairy	2.27	2.27	2.64	5.65	5.65	14.87
Fish & Seafood	10.42	10.42	12.49	26.79	26.79	65.54

Notes: The prices in primary production are estimated in a top-down way for each of the commodity groups, i.e. aggregate output value divided by aggregate output volume, and thus represent transaction prices including mark-ups. Prices in the manufacturing, wholesale and retail sector reflect purchasing prices, i.e. no mark-ups are included. Consumer prices have been estimated as the ratio between macro-level expenditure and consumed quantity in a base year, and this has been updated to 2016-level using consumer price indices. Thus, consumer prices are defined as retail prices.
Source: Statistics Denmark

The monetary costs associated with a specific prevention strategy are calculated compromising initial investment costs as well as ongoing implementation and operating costs. When feasible, the cost estimates of each intervention distinguish between three different components. There are (i) costs to stakeholders that are directly involved in the intervention (e.g. increased personnel costs to reduce FLW), (ii) indirect costs to other stakeholders in the FSC (e.g. increased transaction costs and restrictions to consumer choice) and (iii) costs to public authorities (public budget outlays for education campaigns, administration, subsidies, etc.).

For the estimation of costs in business sectors (i.e., primary production, manufacturing, wholesale/retail and food service), it is generally assumed that the considered businesses exhibit cost minimising behaviour at the outset, and that their direct costs of the intervention are estimated assuming that they will adjust to the intervention to minimise their costs. Generally, estimates of extra resources required to set up and implement different interventions stem from the literature. Furthermore, we generally assume that the cost of extra labour is 295 DKK per hour (pre-tax), that extra investments will require an annual return of 4 per cent, and that conversion between economic figures in DKK and EUR is done at an exchange rate of 7.45 DKK/EUR.

Consumers/households are assumed to exhibit utility maximising behaviour, which implies that interventions may induce behavioural adjustments to the consumers (such as substitution effects) in order to minimise their adjustment costs (see box 1 for more details on the modelling approach). Consumers' possible utility gains (good conscience) from low food waste *per se* are not included in the calculation[20].

[20] One approach to incorporate such gains could be to apply estimates of consumers' willingness to pay for food products that are certified as *low-waste*. However, it was not possible to find such estimates in the literature.

Most existing studies assume that education and awareness campaigns targeting behavioural change at the consumer level represent the most cost-efficient intervention strategies to reduce FLW. However, empirical evidence from other fields of consumer research (e.g., healthy eating campaigns) indicates that the impact of such campaigns on consumer behaviour is often rather marginal. One potential reason for this difficulty in changing consumer behaviour has been termed the *taste cost* of change (Irz et al., 2015; 2016). This taste cost of change refers to the utility loss induced by a behavioural change that brings a new balance between long-term health or environmental goals and short-term pleasure and hedonistic reward. Along these lines, it is assumed that behavioural adjustments in order to reduce FLW also include such a utility loss for consumers. The potential value of this utility loss can be calculated on the basis of a simple two-commodity CES utility function (the commodity in focus versus a composite of all other commodities) $U = \left(a \cdot x_1^{\rho} + (1-a) \cdot x_2^{\rho}\right)^{1/\rho}$ with the parameter $\rho = {(\sigma - 1)}/{\sigma}$ reflecting the elasticity of substitution σ. This functional specification assumes that if one commodity becomes less accessible (e.g. due to higher price or lower availability), the consumer can compensate for the utility loss from this lower accessibility by increasing the consumption of other goods. The elasticity of the substitution parameter determines how easy it is for the consumer to replace one commodity with another. The larger the elasticity, the easier.

Assuming utility maximisation in a particular observation point (implying that the marginal rate of substitution equals the price ratio in this point), we can calibrate the weight parameter $= \frac{(x_2^0/x_1^0)^{\rho-1}}{p_2^0/p_1^0 + (x_2^0/x_1^0)^{\rho-1}}$. Given the parameters σ and a, we can invert the utility function to get the iso-utility (compensated) demand for the composite commodity x_2 as a function of the commodity in focus x_1, i.e. $x_2 = \left(\frac{U^{\rho} - a \cdot x_1^{\rho}}{(1-a)}\right)^{1/\rho}$

Hence, if we restrict the supply of commodity x_1, the consumer will demand extra amounts of x_2 to compensate for the reduced availability of x_1, as given by this expression, in order to maintain the desired utility. The economic consequence for the guest can be calculated by the compensating variation expression:

$$CV = p_1 \cdot (x_1 - x_1^0) + p_2 \cdot (x_2 - x_2^0) = p_1 \cdot (x_1 - x_1^0) + p_2 \cdot \left(\left(\frac{U^{\rho} - a \cdot x_1^{\rho}}{(1-a)}\right)^{1/\rho} - x_2^0\right)$$

Elasticities of substitution have been estimated on basis of household panel data for Denmark (GfK ConsumerTracking Scandinavia panel) for five commodity categories vis-a-vis all other foods and beverages, based on Lewbel and Pendakur's (2009) EASI demand system.

Elasticity of substitution estimates

Grain products	Fruits and vegetables	Dairy products	Meat	Seafood
0.63	0.97	1.22	1.29	0.31

Source: Derived from Irz et al. (2017): estimates for Denmark

Please note that these elasticity-of-substitution estimates represent household-level substitution between food aggregates. FLW prevention interventions affecting consumer choice may often be at a more detailed product level, where closer substitutes may be available to the consumer. Hence, the elasticities shown represent lower-end estimates in relation to FLW prevention interventions, and using these elasticity estimates may over-estimate the consumers' utility loss from e.g. reduced availability of a certain product.

A similar CES approach is used to model the consumers' trade-off between food consumption and time use, which applies in cases where FLW prevention interventions might demand more time spent by the consumers on food consumption, including meal planning, grocery shopping and meal preparation. The initial idea goes back to Becker's (1965) household production theory, which states that households combine market goods as a commodity with specific time activities to produce final goods. FLW prevention might require larger time efforts at home, which might create a trade-off on how time is spent (working, household, leisure). The traditional valuation method of time spent in domestic activities is the market substitution method, which uses the hourly minimum wage in the market as the opportunity cost of time. Few studies exist that estimated the elasticity of substitution between money and time inputs in home food production to be in the range of 0.22–0.60 (Hamermesh, 2008; Davis & You, 2013). Hence, we assume an elasticity of substitution of 0.4 between time and money (i.e. food purchases) inputs.

Box 1. *Utility maximisation behaviour of consumers*

Monetary benefits from a certain intervention strategy include direct cost savings to food businesses and consumers, and additional revenues generated by food businesses. Direct cost savings are usually modelled as the monetary value of $FLW_{prevented}$, i.e. the estimated volume of $FLW_{prevented}$ multiplied by the average production costs (see table 5). Benefits in terms of reduced disposal fees and/or lower waste collections and management costs were not considered.

Even though it has been pointed out previously (see section 3) that indirect effects such as rebound effects might reduce the assumed GHG emissions savings from reduced FLW levels substantially, these effects were not addressed and included in this report. Given the lack of information upon which assumptions about potential rebound effects could be based, the inclusion of these effects would only add uncertainty to the analysis without improving the reliability of the results. Changes in price relations/structure over time are not taken into account in a quantitative way, but are addressed qualitatively. Moreover, for strategies with relatively high set-up costs in comparison to the assumed FLW diversion potential, the economic value per ton of FLW avoided was calculated as an annualised Net Present Value (NPV), that sums all costs and benefits for each strategy over 10 years, using a social discount rate of 4 per cent.

Environmental impacts of FLW in terms of GHG emissions depend on the stage of the FSC where the FLW occurs. Table 6 displays assumed CO_2-equivalent emission coefficients per kg food in the respective food categories and in the respective stages of the food supply chain. The coefficients are estimated on the basis of product-level CO_2 emission coefficients at the consumption stage (Mogensen et al., 2016), combined with estimated coefficients for breakdown of total food-related CO_2-emissions into different stages of the food value chain (Garnett, 2011).

Table 6. *Cumulative GHG emission from FLW at different stages of the FSC expressed in CO_2-equivalents*

kg CO_2e/kg product	Primary Production	Manu-facturing	Wholesale	Retail	Food service	Households
Fruits & Vegetables	0.16	0.23	0.36	0.43	0.42	0.55
Grain products	0.54	0.77	1.02	1.17	1.15	1.40
Meat & Meat products	5.02	7.13	7.39	7.53	7.51	7.77
Milk & Dairy	1.11	1.57	1.83	1.97	1.96	2.21
Fish & Seafood	1.69	2.40	2.65	2.80	2.78	3.03

Source: Own estimates based on Mogensen et al. (2016) and Garnett (2011)

The outlined quantitative modelling framework was used for a range of FWL mitigation interventions. Yet, for some strategies/interventions, a fully quantitative analysis was considered infeasible, due to a lack of reliable data or assumptions. Thus, for some intervention strategies only certain aspects have been quantified, while other aspects are discussed and presented solely in a qualitative way.

4.3 Overview of considered interventions

The choice of strategies considered for further investigation was based on previous research (e.g. Cristóbal et al., 2018; ReFED, 2016; Stenmarck et al., 2011; Tonini et al., 2017), published business experience from other countries (e.g. Hanson & Mitchell, 2017 for the UK), current policy discussions (see e.g. European Commission, 2018a), as well as direct communication with representatives of the Danish Ministry of Environment and Food. An overview of the interventions considered for this report is provided in table 7.

Table 7. *Overview of interventions considered for Denmark*

Name of the initiative	Description	Targeted stakeholders
Imperfect produce use in food service institutions	Fostering of using second grade onions and leeks in food service institutions in Denmark	Primary producers, food service institutions
Waste tracking and analytics	Review the practices and procedures in the kitchen, including measurements and identification of drivers of FLW	Food service institutions
Optimised buffet management	Optimised buffet management in order to reduce serving FLW	Food service institutions
Smaller Plates	Use of smaller plates to reduce plate FLW	Food service institutions
Inventory management	Optimisation of the logistics and management in retail stores	Retailers
Temperature management	Shelf life of food products in retail may be enhanced by product-specific optimisation of the temperature in cooling facilities	Retailers
Staff training	Reduce risk of mistakes in food handling and cooling chain	Retailers
Date labels – Consumer education campaign, expiration date based pricing (EDBP) and advanced tracking technology	Media campaigns and education material about the meaning of use by and best before dates as well as public-private partnership fostering EDBP	Retailers, Consumers
Education campaigns targeting at households' menu planning and food preparation skills	Improve menu planning and food preparation/reuse skills	Consumers

Source: Own presentation

4.4 Results

In the following, each intervention strategy will be described in more detail. More specifically, for each initiative the data used, the underlying assumptions and the outcomes in terms of the estimated amount of prevented FLW, expected financial costs and benefits as well as the associated environmental impact (expressed in CO_2-equivalents), will be presented.

Imperfect produce use in food service institutions

FLW in primary production is assumed to occur mainly due to unfavourable weather conditions, the perishable nature of many fruits and vegetables as well as non-compliance with market standards (e.g. Garrone et al., 2014; Redlingshöfer et al., 2017). Thus, one proposed and discussed FLW prevention strategy in the literature is to foster the emergence of markets for so-called cosmetically imperfect or second grade produce (e.g. de Hooge et al., 2018; ReFED, 2016)[21]. This strategy might target either retailers or foodservice institutions. We focus here on the second case, as the demand from retail consumers seems to be highly sensitive to cosmetic imperfections of fresh produce (Bunn et al., 1990), and overcoming this barrier may require substantial efforts to inform and educate consumers[22]. In order to provide estimates for this potential FLW mitigation strategy, data from two Danish reports focusing on the use of second grade vegetables in food service institutions (Miljøstyrelsen, 2018; Lynnerup et al., 2016)[23] and from Hartikainen et al. (2018), providing estimates of the extent of FLW in primary production for different crops were used. Selected estimates by Hartikainen et al. (2018) are presented in the table below. Overall, the share of vegetables lost in primary production was estimated to be around 15 per cent of gross production, amounting to a total FLW of vegetables in Danish primary production of 33,000 - 49,000 tonne per year.

In a study of the potential use of second grade vegetables, Lynnerup et al. (2016) concluded that, taking into account the additional working time spent on preparing second grade vegetables as well as the purchasing price, there is an economic advantage for food service institutions to use second grade onions, a moderate advantage to use second grade leeks and almost no advantage to use second grade carrots. Moreover, the report by the Environmental Protection Agency (Miljøstyrelsen, 2018) highlighted that depending on the way vegetables are harvested, there are only certain crops for which it seems to make economic sense for primary producers to sell them as second grade produce. These crops comprise onions, leeks and red beets. Given these results plus the fact that onions and leeks are not used for animal feed, i.e. there are no opportunity costs in terms of foregone fodder to consider, the analysis was carried out for the case of using second grade onions and leeks in food service institutions in Denmark. Data about prices for first and second grade onions and leeks were taken from Lynnerup et al. (2016).

[21] Synonyms used in the literature are: oddly-shaped, ugly, or suboptimal foods (de Hooge et al., 2018).

[22] De Hooge et al. (2018) for example report recent results from interviews with producers and retailers carried out in Germany and the Netherland pointing out that standards were often considered central to the desired positioning of the company or of the supply chain as a high quality producer who does not compromise on quality (including sub-optimality).

[23] Both projects were conducted by AgroTech Denmark and were funded by the Environmental Protection Agency.

Table 8. *FLW estimates for the primary production stage in Nordic countries, in percentage of gross production measured in mass*

Food category	FLW (%)
Grains	1.0 -14.0
Potatoes	2.5 - 10.0
Pulses	4.0 - 17.0
Oil Crops	3.0
Vegetables	
Tomatoes	1.0
Onions	15.0
Cabbages & brassicas	15.0
Lettuce & chicory	17.0
Peas, green	17.0 - 19.0
Carrots	14.0 - 26.0
Vegetables, others	15.0
Fruits	
Apples/Pears	10.0
Berries	14.0

Source: Hartikainen et al. (2018)

First, $FLW_{generated}$, $FLW_{potential}$ and $FLW_{prevented}$ were calculated. Initial assumptions with respect to the scope and participation factor were taken from ReFED (2016). This report assumed that from the generated FLW, around 60 per cent is potentially fit for food service applications, and 35 per cent of this quantity could be captured in a cost-effective manner for food service applications ($FLW_{potential}$). Moreover, 5 to 10 per cent of this potentially avoidable FLW might be prevented by the strategy. However, as pointed out above, given the relatively large uncertainties about the assumed participation factor, in this report results were calculated for three different scenarios (i.e. participation factor of 10, 20, and 50 per cent, respectively).

With respect to costs, it is expected that businesses (i.e. agricultural producers as well as food service institutions) will directly invest in these new market channels given the potential economic benefits of selling and purchasing second grade onion/leeks. In the US some start-up businesses have already emerged (Hungry Harvest, Imperfect Produce)[24] matching farmers offering imperfect produce with businesses in the food service sector and/or consumers, respectively. However, given the fact that most Danish food service institutions are unfamiliar with cost-saving opportunities associated with buying imperfect produce and might not be offered it by their suppliers, governmental support seems to be needed. This support might take the form of grants such as the ones spend on the research and development projects conducted by AgroTech Denmark on the use of second grade vegetables in food service institutions in order to create awareness and provide (technical) assistance. With regard to farmers, it is assumed that they generate additional income

[24] The case of Imperfect Produce has been analysed by Richards and Hamilton (2018), concluding that these market-based solutions seem to be very promising and thus policy tools to facilitate transactions in these secondary markets could be highly effective in reducing FLW.

from selling second grade produce. This assumption might be challenged by additional transport/logistic costs and potential cannibalisation effects for first grade produce[25]. The detailed results are presented in the following table.

Table 9. *Estimates of diversion potential, cost and benefits of using second grade onions and leeks in the food service sector*

	Participation scenarios		
	10 %	20 %	50 %
Diversion potential (in tonnes)			
$FLW_{generated}$		10,627	
$FLW_{potential}$ (scope factor: 0.2)		2,125	
$FLW_{prevented}$	212	425	1,063
Costs & Benefits (in 1000 DKK)			
Financial costs			
Initial costs (i.e. pilot projects, awareness campaigns)	1,000	1,000	1,000
Operational costs[a]	240	481	1,203
Financial benefits[b]	433	867	9,484
Net present value[c]	1,734	4,469	12,672
Economic value per kg FLW prevented (in DKK)	**0.8**	**1.0**	**1.2**

[a] Annual costs of buying the second grade produce, [b] Annual food costs saved by food service institutions plus farmers' additional profit, [c] The net present value sums all costs and benefits for each strategy over 10 years using a social discount rate of 4 per cent.
Source: Own calculations

Overall, it is estimated that this intervention has a potential prevention potential ranging between 212 tonnes (10 per cent participation rate) and 1,063 tonnes (50 per cent participation rate). The estimated positive net gain is around 1.0 DKK per kg FLW prevented and the associated GHG emissions are estimated to amount to 34 tonnes (10 per cent participation rate) up to 170 tonnes (50 per cent participation rate) CO_2-equivalents per year.

Waste tracking and analytics in the food service sector

Baseline assumptions for the analysis of interventions in the food service sector are provided in table 10. FLW assumptions are derived from tables 3 and 4, supplemented with information from a study by Thorsen and Jensen (2016). During the last years, Denmark has run a subsidy programme to stimulate the conversion of public food service institutions into meal production based on organic ingredients. This subsidy programme has covered costs of consultancy services, planning of the conversion as well as training of personnel, which is often necessary, as such conversion is typically supposed to be budget-neutral, despite the generally higher price of organic ingredients. Reduction of FLW seems to play a key role in the long-term financing of the conversion to organic meals in many kitchens. In a study of the economic aspects of such a conversion, Thorsen and Jensen (2016) estimated the amount of total FLW based on physical measurements before and after the

[25] To the extent that such cannibalisation effects exist, this might pose a downward pressure on the demand for first-grade produce, thus implying a potential rebound effect in terms of increasing the risk that they are not utilised.

conversion, using two town hall canteens as cases. Moreover, the amount of FLW was decomposed into three FLW components: (i) production/kitchen FLW (i.e., peels, stems, skin, etc.), (ii) serving FLW (i.e., food put on the buffet but not taken to the plate) and (iii) plate waste (i.e., food put on the plates but not eaten) [26]. This differentiation into three FLW categories can also be found in other studies investigating FLW in the food service sector (e.g. Heikkilä et al., 2016).

Table 10. *Baseline assumptions- food service sector*

	Input	Baseline FLW		Input price	Production FLW	Serving FLW	Plate FLW
	1000 t	1000 t	% of input	DKK/kg	- - % of total FLW - -		
Grain products	46.5	18.6	40%	9.24	10	50	40
Fruits & Vegetables	122.4	30.6	25%	11.06	55	40	5
Milk & Dairy	5.1	1.8	35%	5.65	55	40	5
Meat	20.6	7.2	35%	29.45	55	40	5
Fish & Seafood	5.1	1.8	35%	26.76	55	40	5

Source: Teuber and Jensen (2016); Thorsen and Jensen (2016)

The analyses in the following are based on these data from canteens, although it is acknowledged that FLW patterns, costs and price structures may differ between different types of food service operations (such as restaurants, hospitals, nursing homes, schools, etc.).[27]

It is assumed that the strategy *Waste tracking and analytics* will typically require the involvement of an expert or consultant reviewing the practices, procedures and flows in the kitchen, including measurements or observations of FLW, identification of drivers of FLW, interviews with personnel and recommendation of actions to reduce FLW. The recommendations will then require a follow-up from the kitchen, in terms of changed procedures and practices, and possibly some investments.

Table 11 displays the estimated FLW figures as ratios to the purchased quantities, before and after the conversion to organic production. Total ingredient input amounted to around 90 and 50 tons per year, respectively, in the two canteens. According to this study, the canteens reduced their FLW in the process of organic conversion in all food categories substantially. In monetary terms, FLW was reduced to an extent corresponding to 20-24 per cent of total ingredient cost after conversion to organic meals.

[26] Production FLW comprises both avoidable and unavoidable FLW, whereas all serving FLW and plate FLW is considered avoidable.

[27] Tonini et al. (2017) provide some estimates with respect to FLW patterns across different food service institutions. These estimates indicate that the share of meat and meat products in total FLW tends to be higher in institutions such as homes for the elderly, hospitals and schools/kindergartens in comparison to hotels and restaurants.

Table 11. *FLW rates by mass (in per cent) in two town hall canteens, 2013-2014*

	Canteen A (500 users)		Canteen B (200 users)	
	before	after	before	after
Grain products	28	15	21	12
Fruit & Vegetables	30	7	19	5
Milk & Dairy	46	15	27	8
Meat	46	15	27	8
Fish & Seafood	46	15	27	8

Source: Thorsen and Jensen (2016)

It must be noted that in comparison to other published estimates of FLW in food service institutions, these FLW estimates seem to represent upper-end estimates. Betz et al. (2015) provided estimates based on data from two Swiss food service institutions suggesting that total FLW represent 18 per cent of input and avoidable FLW 13.5 per cent of input, respectively. Engström and Carlsson-Kanyama (2004) provided FLW estimates from four food service institutions in Sweden of similar range, namely 20 per cent of inputs. Katajajuuri et al. (2014) reported results for the Finnish food service sector, estimating FLW expressed as share of food produced to range from 8 per cent in fast food restaurants to 27 per cent in day care institutions. Considering these estimates, as well as a supposedly large variation in the FLW patterns in different parts of the Danish food service sector, the following analysis of FLW prevention interventions in the food service sector also considers a more conservative scenario where the current extent of FLW is half of the amounts outlined in table 11.

The costs of implementing this FLW prevention strategy are assumed to consist of hiring experts for reviewing procedures and tracking waste flows (a one-time fixed cost of 100.000 DKK per food service operator). Assuming this cost is considered as an investment with an amortisation period of three years, this corresponds to an annual cost of 36,035 DKK per food service operator. For canteen A, this corresponds to a cost of 0.41 DKK per kg ingredient input, and for canteen B, this corresponds to 0.76 DKK per kg ingredient.

Assuming further that the detailed review of procedures can halve the amount of production and serving FLW in the respective food categories, this amounts to about 120 g FLW reduction per kg grain or fruit/vegetable input, and about 170 g FLW reduction per kg dairy, meat and seafood input. As this type of intervention is very much about increasing the awareness of practises to avoid FLW, no rebound effects are presumed. Using the canteens' purchase prices of ingredients to assess the economic value of this FLW reduction, the savings amount to 0.90-4.90 DKK per kg ingredient input – with about 4.50-4.90 DKK per kg for seafood and meat, and around 1 DKK for other ingredient categories. For all food input categories, there is hence a net saving for the food service operator.

The impacts of the waste tracking and management intervention are summarised in table 12. It appears that, depending on the taken assumptions for all ingredient categories, the savings from reduced FLW exceed the costs, both for large and small food service operators. The net benefit per kg saved FLW ranges between 2.33 DKK per kg (for dairy products) and 26.21 DKK per kg (for meat and meat products).

Table 12. *Estimated FLW prevented, benefits and costs of waste tracking and analytics intervention*

	$FLW_{prevented}$ (in kg per kg ingredient)	Financial savings, DKK/kg Ingredient	Intervention cost DKK/kg ingredient[1]
Grain products	0.12	1.11	0.41 - 0.76
Fruits & Vegetables	0.12	1.31	0.41 - 0.76
Milk & Dairy	0.17	0.94	0.41 - 0.76
Meat & Meat products	0.17	4.90	0.41 - 0.76
Fish & Seafood	0.17	4.45	0.41 - 0.76
Total	0.14	1.98	0.41 - 0.76

Note: [1.] Lower-end estimate: canteen with 500 daily guests, upper-end estimate: canteen with 200 daily guests

In a more conservative assessment where the current extent of FLW (and hence the potential for reduction) is only half of the figures presented in table 11, the waste tracking and analytics procedures will only lead to half the reduction in $FLW_{prevented}$ and financial savings, whereas the intervention costs will be the same. In this case, the net benefits will range from a net cost of 1 DKK per kg FLW reduction (for dairy products) to a net gain of almost 23 DKK per kg (for meat).

The waste tracking and analytics intervention is not assumed to influence the profitability or utility of other stakeholders in the FSC (but may lead to other efficiency gains in the meal production, which have not been included here). In case that the investment cost for consultancy service is subsidised by the government, the investment cost is shared between the food service operator and the government.

Assuming a scope factor of 0.5 (i.e. only production and serving FLW are addressed via this strategy) and a participation factor of 0.3 (the share of food service institutions in Denmark taking part), the total amount of FLW that could potentially be prevented via this strategy is estimated to 2,300 tonnes, with an average net gain of 9.65 DKK per kg FLW prevented. This would be lead to a reduction in GHG emissions of 4,400 tonnes of CO_2-equivalents. In a more conservative scenario with half of the reduction potential considered here, the amount of prevented FLW reduces to 1,200 tonnes and the reduction in CO_2-emissions reduces to approximately 2,200 tonnes.

Optimised buffet management

For food safety reasons, food that has once entered the buffet, cannot be returned and served later. Thus, the strategy *Optimised buffet management* is about ensuring that as little food as possible is brought to the buffet without being taken by the customers – and that the food left on the buffet represents as little value as possible. Thus, changed buffet management aims at reducing serving FLW to a minimum. This may require some extra planning and surveillance by the kitchen management.

On the one hand, this strategy implies savings for the kitchen in terms of production costs associated with serving FLW. According to table 10, serving FLW is estimated to constitute 50 per cent of the FLW for grain-based foods, and 40 per cent for the other food categories. On the other hand, a more restrictive buffet management might incur a potential loss of utility to guests, due to a higher probability of facing an empty bowl or tray on the buffet.

According to the baseline data in table 10, the buffets are currently 'over-filled' by 20 per cent (= 50 per cent * 40 per cent) for grain products, 10 per cent for fruits and vegetables, and by 14 per cent for meat, seafood and dairy products - on average. Assuming that the demand for the dish type is a stochastic variable given by the normal distribution, $N(\mu_x, \sigma_x)$, the probability of shortage for a given supply $\bar{x}$ (reflecting a given filling rate) is given by the right-hand tail of this distribution, i.e. $P(x > \bar{x}|\mu_x, \sigma_x)$. It is assumed that for grain products, fruit/vegetables and dairy products, the coefficient of variation (ratio between standard deviation and mean) is 10 per cent, whereas for meat and seafood it is 7 per cent[28]. Since the costs and effects are analysed on a per-kg basis, the mean value of demand μ_x is normalised to one.

Reducing the filling by 5 percentage points (reflecting a scope factor of 0.386, i.e. 38.6 per cent of the total serving FLW) will reduce this over-filling by slightly more than 5 per cent, and the food service operator saves costs of the dishes corresponding to the reduction of over-filling[29]. This saving expressed as FLW reduction is shown in table 13.

Table 13. *Effects of optimised buffet management on serving FLW*

	Probability of shortage		FLW change		
	Baseline	**Intervention**	**Per kg buffet**	**% of serv. FLW**	**Cost saved, DKK/kg ingredient**
Grain products	0.032	0.072	-0.054	-27%	0.46
Fruits & Vegetables	0.154	0.299	-0.049	-49%	0.55
Milk & Dairy	0.085	0.178	-0.054	-39%	0.28
Meat products	0.032	0.101	-0.055	-39%	1.47
Fish & Seafood	0.032	0.101	-0.055	-39%	1.34

However, as mentioned above, reduced over-filling also increases the probability of shortage on the buffet, depending on the standard deviation of the normal distribution, as well as the baseline rate of over-filling. The larger the standard deviation, the larger is the risk of shortage, but if the baseline rate of over-filling is high, a reduction in the filling rate may have limited effect on shortage risk. Overall, an attempt to quantify, by means of the methodology, the potential customer utility loss due to an increased risk of facing empty trays is outlined in box 1 (section 4.2).

[28] The underlying assumption is that meat and seafood is usually offered in relatively standardised sizes on buffets (e.g. a slice of meat, a steak, etc.), whereas the amount of vegetables, rice, pasta, etc. per serving can be more variable.
[29] As this strategy will consciously be undertaken to reduce buffet waste, no rebound effects are presumed.

Results for the estimated customer utility loss are presented in table 14, expressed as per kg of food in the considered food category. For example, for each kg of grain-based foods (bread, pasta, rice, etc.) consumed, 3.30 kg of other commodities (composite product) are consumed in the baseline, and for each kg of fruit/vegetables consumed, 0.63 kg of other commodities are consumed.

In the concrete case of restricting the filling rate for grain-based foods by 5 percentage points, the customers on average consume 4 per cent less (1–0.96), however with some variation due to heterogeneity in preferences, etc. In order to compensate for the lower consumption of grain-based food commodities to obtain the same utility level, the customers will have to increase their consumption of other types of food commodities (represented as a *composite good*) - by almost 1 per cent, from 3.30 to 3.32 kg. This is the amount of the composite good that would leave the customer with the same utility level as in the baseline, given that the consumption of grain-based commodities is reduced by 4 per cent. Assuming that prices represent the value of the customers' utility from the different types of food commodities, the value columns in table 14 show that if the filling rate for grain products is restricted as assumed, the customers would need to be compensated by 0.01 DKK per kg grain product consumed, in order to obtain the same level of utility as without the intervention. Hence, the 0.01 DKK per kg represents the economic value of the utility loss induced by this shortage risk for grain-based dishes on the buffet.

Table 14. *Buffet management - customer utility loss, DKK per kg food input*

	Baseline		**Intervention**		**Value**			**Cost-effectiveness**
	Product	CP	Product	CP	Baseline	Inter-vention	Change	DKK/kg FLW
Grain products	1	3.30	0.96	3.32	66.07	66.09	0.01	-8.23
Fruits & Vegetables	1	0.63	0.86	0.72	24.55	24.80	0.25	-6.05
Milk & Dairy	1	37.84	0.91	37.88	611.71	611.73	0.02	-4.82
Meat products	1	8.71	0.93	8.89	131.25	131.32	0.07	-25.65
Fish & Seafood	1	37.84	0.93	37.98	604.89	605.13	0.24	-20.19

Note: CP- Composite Product

The difference between the benefits of this strategy, reflected in reduced production costs (i.e. *Cost saved, DKK per kg* in table 13), and the costs in terms of customer utility loss (i.e. *Change* in table 14), divided by the FLW reduction *per kg buffet,* represents the 'cost-effectiveness' of the restrictive buffet management strategy for the five commodity categories per kg food (where negative numbers refer to a net gain).

It is assumed that the buffet management intervention has no economic impacts on other parts of the FSC, and that it does not require resources from the government budget.

Overall, with a participation factor of 0.4, this intervention might lead to a reduction of FLW in the food service sector. This would amount to 4,100 tonnes and an average net benefit of 9.08 DKK per kg FLW prevented (with a higher value on meat and seafood and a lower value for other food categories), corresponding to an environmental impact of 6,100 tonnes CO_2-equivalents.

Smaller plates in restaurants and cafeterias

Plate FLW is estimated to constitute 40 per cent of total FLW for grain-based foods and 5 per cent for the other food categories (cf. Table 10) in the food service sector.

The underlying idea of introducing smaller plates in self-serve food service settings is to reduce plate FLW. The direct costs of changing to *smaller plates* are limited to the investment in new (and smaller) plates. However, there may also be indirect costs involved, in terms of inconvenience for the customers in the restaurants and canteens.

According to dietary survey data published in Christensen et al. (2013), adults[30] on average have an energy intake of 2 MJ for lunch, with 10- and 90-percentiles at 0.9 and 3.2 MJ, respectively. Assuming that 2 MJ corresponds to around 250 g food, this implies that about one third of these adults consume more than 300 g food at lunch. Hence, introducing plates with a capacity of 300 g food may be expected to affect about one third of the adults, either by reducing their food intake (compared with their current intake) or by making them spend time on refilling their plates. Refilling the plates may however lead to a rebound effect on FLW in terms of over-refills (assumed to occur for 20 per cent of the refilled plates) – an effect that has been included in the calculation.

The direct cost of this intervention is the investment in new plates, which is assumed to be done at a price of 10 DKK per plate[31]. The plates are assumed to last for 2 years on average, to be used 220 days per year and to be big enough for 300 g food on average, corresponding to a fixed cost of 0.10 DKK per kg food served, or 0.02 DKK per 250 g serving. In the calculations below, this fixed cost per kg is assumed equal for all food commodity categories.

Table 15. *FLW reduction potential, direct costs and benefits of smaller plate interventions*

	FLW reduction rate (kg $FLW_{prevented}$ per kg food)	Fixed costs DKK/kg	Direct savings DKK/kg
Grain products	0.019		0.04
Fruits & Vegetables	0.004		0.13
Milk & Dairy	0.000		0.00
Meat products	0.001		0.06
Fish & Seafood	0.000		0.01
Total	**0.024**	**0.096**	**0.25**

In total, the saving amounts to an economic value of 0.25 DKK per kg food served – or 0.06 DKK per 250 g serving, which can be compared with the 0.10 DKK investment cost for new plates, i.e. a net saving of 0.15 DKK for the food service operator per kg food served.

[30] The study by Christensen et al. (2013) focused on adults with short education, i.e. with primary school or vocational education as their highest education level.
[31] Source: Jyske Storkøkken, http://jyskestorkokken.dk/

As the smaller plates may imply some probability that not all customers will be satiated with one portion, it is assumed that 18 per cent of customers (those who normally consume more than 350 g food for lunch) will go for a refill (based on the assumption that lunch meal sizes reported in Christensen et al. (2013) are normally distributed). The utility loss of this *under-satiation* is estimated using the methodology outlined in Box 1 (section 4.2), and assuming that a refill requires an average extra time use of 2 minutes at an hourly cost of DKK 125 (net of wage taxes, i.e. representing *leisure* time). Based on these assumptions, this intervention is estimated to impose an average utility loss on the customers at a value of 0.03 DKK per kg food served. The probabilities for plate FLW for the refillers are assumed to be the same as for one-fillers. Furthermore, this intervention is assumed to not require any involvement from the public sector, and hence it is not affecting the governmental budget.

Overall, this intervention strategy might lead to a total reduction of 72 tonnes FLW in the food service sector, which implies a reduction in GHG emissions of 82 tonnes of CO_2-equivalents. The intervention is by and large cost-neutral, however depending quite strongly on the calculation of the utility loss imposed on the customers, which is subject to some uncertainty.

It is acknowledged that in addition to the direct cost implications of the intervention in the food service sector, there might be indirect (cost) implications for the suppliers of food service institutions such as wholesalers and farmers, given the reduction in the food service sector's purchase of ingredients. It is, however, assumed that the suppliers will simply sell these ingredients to other customers at unchanged prices and hence will not be economically affected by the interventions.

Retail level

The total amount of $FLW_{generated}$ at the wholesale and retail level in Denmark is estimated to be 163,000 tonnes (see table 3). Table 16 outlines some of the baseline assumptions for the analysis of FLW prevention measures in the retail sector. Taking domestic food consumption data (Statistics Denmark) as a proxy for domestic retail food sales, the sector's total FLW constitutes between 3 and 12 per cent of the total commodity turnover in the respective commodity groups. The lowest estimate refers to dairy products and the highest one to grain products and seafood. Average wholesale prices for the commodity groups (as input for the retail sector) are estimated based on aggregated data from Statistics Denmark (Teuber & Jensen, 2016). For all the five commodity groups, we assume a 23 per cent gross margin rate, based on Statistics Denmark data for firm-level economic accounts in the Danish supermarket/grocery sector. Of this gross margin, 51 per cent is assumed to cover labour costs, whereas the remaining 49 per cent covers capital costs and profits.

Table 16. *Baseline assumptions for the retail sector*

	Sales, 1000 t	Waste, 1000 t	Personnel costs of gross margin	Share of waste, errors & defects	Share of waste, product degradation	Share of FLW, expired products
Grain products	548.2	57.1	0.51	0.01	0.01	0.98
Fruit & Vegetables	1127.0	61.9	0.51	0.09	0.75	0.16
Milk & Dairy	821.7	24.5	0.51	0.21	0.01	0.78
Meat & Meat products	461.6	11.7	0.51	0.11	0.32	0.57
Fish & Seafood	63.6	7.8	0.51	0.11	0.32	0.57

Sources: Teuber and Jensen (2016); Statistics Denmark; Tonini et al. (2017)

For the calculations below, further assumptions regarding the causal composition of FLW in the retail sector were made, distinguishing three major causes: (i) technical defects and errors (e.g. breach of cool chain, mistakes, etc.), (ii) 'natural' product degradation, and (iii) expired products (i.e. products that were not sold before expiry date). Based on results from Lebersorger and Schneider (2011), it is assumed that around 8 per cent of the sector's FLW is a result of the first cause, 33 per cent is due to natural degradation, whereas the remaining 59 per cent of FLW is due to products that have not been sold before the expiry date[32].

Improved inventory management

A study by Kiil et al. (2017) suggests that optimisation of the logistics and management in retail stores may serve as a strategy that can lead to reduced FLW levels. According to the baseline data in table 16, retail stores are currently *over-stocked* by around 10 per cent (the FLW that is due to over-matching of demand) for grain products, and 3-4 per cent for other commodity categories. Assuming that the demand for the commodity groups is given by the normal distribution $N(\mu_x, \sigma_x)$, the probability of shortage for a given supply $\bar{x}$ (reflecting a given shelf stocking rate) is given by the right-hand tail of this distribution, i.e. $P(x > \bar{x}|\mu_x, \sigma_x)$. Assuming that the mean value of demand μ_x is normalised to one (reflecting that the analysis is made per kg commodity sold), table 17 displays the parameter assumptions made for the analysis of inventory management.

As an illustration, the waste reduction potentials shown in the first column display, how much waste can be avoided if the extent of over-stocking is reduced by 1 percentage point, e.g. from 2 to 1 per cent. The coefficient of variation (relative standard deviation) represents the heterogeneity in consumers' demand for the commodity categories – across consumers and over time. In case of a large standard deviation, a shelf stocking close to the mean expected demand will imply a relatively high probability of consumers with unsatisfied needs (the right-hand tail of the distribution of demand).

[32] Even though products may be sold after 'best before' date, in reality no – or very little – is sold by retailers after this date.

Table 17. *Parameter assumptions*

	Waste reduction potential (share of sales)	Baseline inventory	Coefficient of variation
Grain products	0.74 %	1.102	0.2
Fruits & Vegetables	0.06 %	1.009	0.2
Milk & Dairy	0.17 %	1.023	0.1
Meat	0.10 %	1.014	0.15
Fish & Seafood	0.50 %	1.070	0.2

Reducing the inventory to an amount $\tilde{Q} < Q$ will reduce the expected FLW via two mechanisms: 1) Reduce the probability of excess inventory, and 2) reduce the excess amount when there is excess. As the intervention will be presumed to be undertaken specifically to reduce FLW, no rebound effects are assumed.

Table 18. *Economic effects of 1 percentage point reduction in over-stocking*

	Baseline inventory (% of expected demand)	Baseline probability of shortage (%)	Baseline expected waste (kg FLW/kg food)	Changed inventory (% of expected demand)	Changed probability of shortage (%)	Reduction in expected food waste (kg FLW/kg food)	Retailer cost, DKK/kg sales
Grain products	110.2	29.6	0.072	109.2	31.4	0.04	-0.08
Fruits & Veg.	100.9	48.1	0.005	099.9	50.3	0.05	-0.03
Milk & Dairy	102.3	40.3	0.014	101.3	44.4	0.11	-0.04
Meat	101.4	45.9	0.008	100.4	48.8	0.11	-0.08
Fish & Seafood	107.0	35.6	0.045	106.0	37.6	0.03	-0.19

In addition to the direct economic consequences for the retailers, there is also a loss to the consumers in terms of an increased probability of unmet expectations in the shopping, similar to the situation in the food service buffet management case (cf. above and box 1). Results of the analysis of this utility loss are displayed in table 19.

Table 19. *Consumers' loss of utility due to one percentage point reduction in over-stocking*

	Consumer cost, DKK/kg sales
Grain products	0.01
Fruits & Vegetables	0.00
Milk & Dairy	0.01
Meat	0.01
Fish & Seafood	0.03

The calculations show that the retailers can save costs by reducing the shelf stocking to become closer to the expected sales, due to the reduction in food products that have to be scrapped. For all five product categories, this cost saving clearly exceeds the expected consumer welfare loss. As mentioned, this calculation was made for a 1-percentage point reduction in over-stocking. For larger reductions, the cost saving per kg FLW reduction could be expected to be smaller, because the marginal FLW reduction effect is decreasing with larger reductions in over-stocking, due to the assumed normal distribution of demand.

Overall, the inventory management intervention bears a potential to reduce the retail sector's FLW by 4,700 tonnes (provided a participation factor of 0.5), with an average net value of almost 14 DKK per kg FLW prevented. This reduction in FLW bears a potential to reduce food-related emissions by 9,800 tonnes CO_2-equivalents.

Changed temperature in cooling facilities

The shelf life of food products in retail may be enhanced by product-specific optimisation of the temperature in cooling facilities, implying that for some food products such as meat and dairy products, the temperature should be lowered by a few degrees. Such a targeted temperature optimisation may involve some reorganisation of store departments (which may be considered as a one-time cost), and it would also have implications for the stores' energy consumption for refrigerators. In Sweden, a campaign with the message "reduced storage temperature (from 8°C to 4-5°C) in the whole food supply chain" was launched in 2011 and in this context, Eriksson et al. (2016) carried out a study on the potential FLW prevention impact of such an intervention and the associated costs.

Based on some of the findings from Eriksson et al. (2016), this report estimated the FLW prevention potential FLW from reducing the storage temperature for dairy, meat and seafood products - keeping in mind that the Danish food safety regulation requires a maximum temperature of 5°C for storage of these food categories (Fødevarehygiejnebekendtgørelsen, bilag 3). Inter- and extrapolation of results from Eriksson et al. (2016) suggest that by lowering the temperature from 5°C to 2°C the shelf-life can be extended by 40-50 per cent for meat products, and by 20-25 per cent for dairy products.

This report considers a scenario, where the temperature is reduced from 5°C to 4°C, and where dairy products have a baseline shelf life of 8 days (at 5°C) and meat and seafood products have a baseline shelf life of 4 days (at 5°C). It is further assumed that the effect of temperature lowering will have similar effects for seafood as for meat products. The effects of extended shelf life on FLW is estimated by means of the formula

$$\Delta W = (1-r)^{T_0+\Delta T} - (1-r)^{T_0}$$

where r is the category-specific daily turnover-rate of the commodity. The logic behind this expression is that each day, the fraction r is sold from the shelves, and hence the fraction $(1-r)^T$ will still be on the shelves after day T. And if T_0 is the expected day of expiry, the fraction $(1-r)^{T_0}$

will not be sold before expiry. The larger T, the smaller the share of unsold expired goods, and an extension of the shelf life will then imply a reduction in FLW. No rebound effect on FLW is foreseen with this type of intervention.

Assuming that the relationship between energy cost and temperature is given by the function $C_E = C_E^0 - \gamma \cdot \tau$, the change in energy cost ΔC_E is given by $\Delta C_E = \gamma \cdot \left(\hat{\tau} - \tau^*\right)$

It is assumed that it requires 0.5-1.0 kWh per kg capacity[33] to maintain a refrigerator temperature at 5°C, and that for a 1°C decrease in temperature, the electricity use will increase by 3-5 per cent[34], corresponding to around 0.02 kWh per year (the γ parameter). In the last quarter of 2017, the average net price of electricity in Denmark was 0.73 DKK per kWh (net of taxes), 0.90 DKK per kWh (including PSO tax), 1.80 DKK per kWh (net of VAT) and 2.26 DKK per kWh (including VAT)[35]. Assuming a retailer price of electricity at 0.90 DKK per kWh, the additional energy use per kg food sold by lowering the temperature by 1ºC can be determined as ${}^{1}/_{365} \cdot 0.02 \cdot electricity\ price = 0.0000493\ DKK/kg$ per day of expected shelf life.

Table 20. *Effect of optimised cooling temperature on FLW and retailers' costs*

	Daily turnover rate	Change in shelf-life, days	Changed waste	Value of changed waste	Retailer, energy cost change, DKK/kg
Milk & Dairy	0.5	0.56	-0.13%	0.01	0.0008
Meat	0.5	0.68	-2.35%	0.71	0.0004
Fish & Seafood	0.3	0.68	-5.17%	2.63	0.0004

With an assumed participation factor of 0.5, the lower-temperature intervention bears a potential to reduce aggregate retailer FLW by 355 tonnes, primarily in meat and seafood, gaining an average net benefit of around 41 DKK per kg FLW prevented. This food waste reduction bears a GHG emission reduction potential of 1,600 tonnes CO_2-equivalents, from which the GHG emissions derived from extra electricity consumption for cooling should be subtracted.

Date labels: Expiration date based pricing (EDBP) at retail level and consumer education campaigns

According to Regulation (EU) No 1169/2011 on Food Information to Consumers (short the FIC Regulation), most pre-packed foods are required to display a date mark and accompanying wording that explains whether the date signals a threshold in the product's safety (use by) or its quality (best before). The date mark is primarily intended for use by consumers, but is also used for example by retailers in their stock management (European Commission, 2018b).

[33] Source: https://sparenergi.dk/forbruger/el/koel-og-frys
[34] Source: https://www.de3bedste.dk/blog/temperatur-i-koleskab-hvad-er-den-rette-koleskabstemperatur.html
[35] http://energitilsynet.dk/fileadmin/Filer/0_-_Nyt_site/EL/Prisstatistik/2017/Ny_Elprisstatistik_4._kvartal_2017.pdf

Some studies have argued that existing date labels are confusing for consumers, and that this confusion encourages unnecessary levels of FLW (e.g., Newsome et al., 2014; WRAP, 2011). More specifically, it has been found that consumers sometimes perceive best before-labels as indicating microbial safety rather than freshness and thus discard foods that might have been fully edible (e.g., van Boxstael et al., 2014). Thus, educating consumers about the meaning of the best before-label might prevent a certain extent of FLW at the consumer level. This has also been one of the main findings and recommendations of a project focusing on FLW and date labels in the Nordic countries (Nordic Council of Ministers, 2017). More specifically it was stated, that consumer information about date labelling and durability of food products needs to reach out to a much higher degree. However, at the same time Stancu and Lähteenmäki (2018) reported that among a sample of Danish consumers, date labelling concerns were mentioned less frequently in the context of FLW[36]. Moreover, the awareness of FLW among the interviewed consumers was very high, with 85 per cent of respondents saying that they had seen or heard something about this topic in the past year. Of those respondents who had seen or heard something about FLW in the past year, most individuals had seen or heard information about the amounts of FLW (72 per cent), followed by ways to avoid it (69 per cent), and information regarding expiration date labelling (57 per cent). Thus, these data indicate that the awareness of date labels and their meaning among Danish consumers seem to be high already. This might be a result of the high media attention devoted to the topic of FLW in Denmark in recent years. This assumed high awareness level will be reflected in the assumed scope and participation factors for this specific strategy.

Besides, in order to decrease retailers' in-store FLW[37], expiration date based pricing (EDBP) has emerged as a particular topic of interest (Aschemann-Witzel et al., 2015). The practice of EDBP, which simply means that the price for food items close to the expiration date is reduced, is nothing new and has long been a common practice by retailers (Theotokis et al., 2012). However, given the increasing focus on FLW prevention, EDBP has received a renewed interest as a potential FLW prevention strategy (e.g., Aschemann-Witzel, 2018; Halloran et al., 2014). EDBP is a common practice in most Danish grocery stores that often is combined with communication strategies either stressing the topic of FLW or budget saving (Aschemann-Witzel, 2018; Kulikovskaja & Aschemann-Witzel, 2016).

In order to provide empirical evidence on the factors impacting consumer likelihood of choosing price-reduced suboptimal products[38], Aschemann-Witzel (2018) conducted an online survey

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[36] More specifically, consumers were asked an open-ended question on their understanding of food waste. The most frequent types of answers were that food waste is mainly about excessive buying and the second most frequent type of answer was that food waste is about throwing away leftover food or products (Stancu & Lähteenmäki, 2018, p. 25).

[37] FLW in grocery retail can be grouped into pre-store FLW, recorded in-store FLW, unrecorded in-store FLW, and missing quantities (FUSIONS, 2014). Pre-store and recorded in-store FLW are assumed to account for the largest share in grocery retail's FLW (Eriksson et al., 2012). Pre-store FLW occurs when a grocery retail outlet does not accept the food delivered from suppliers because of quality defects, while recorded in-store FLW refers to food that is sorted out and discarded, due to poor aesthetics, structural damage or surpass of the expiration dates (Eriksson et al., 2012).

[38] Suboptimal foods have been defined as products that deviate from normal or optimal products on the basis of (i) appearance standards (in terms of e.g. weight, shape, or size), (ii) date labelling (e.g. close to or beyond the best-before

experiment among 842 Danish consumers. The results show that neither communicating budget saving nor FLW avoidance had an influence on choice likelihood, but perceived quality and estimated likelihood of consumption at home were identified as major determinants. Moreover, it was concluded that consumer acceptance of EDBP of suboptimal food can be increased through furthering consumer familiarity with the practice. Such an increased familiarity can be achieved if all retailers are encouraged to enact the practice, so that all consumers become increasingly familiar with this food marketing practice, therewith up-scaling the success and efficiency of the policy. In addition, information campaigns might contribute to improving perceived quality and capability to consume and use food close to or past the expiration date, and thus acceptance of price-reduced suboptimal food.

Thus, making consumers aware about the meaning and difference of *best before* and *use by* labels might not only affect the acceptance of price-reduced products close to the expiration date in the store, but also decrease the likelihood of still edible products being discarded at home. Consequently, the impacts of these two closely related interventions are considered jointly.

It is assumed that EDPB will be implemented in 80 per cent of all grocery stores in Denmark[39] and primarily for the product categories meat and fish, milk and dairy, grain products, and fish and seafood. More specifically, it is assumed that in these product categories, 60 per cent of products that currently end up as FLW are advertised via EDBP. With respect to fruits and vegetables, it is assumed that only 20 per cent of the products currently ending up as FLW can be sold via EDBP. Aschemann-Witzel (2018) showed that consumer acceptance of suboptimal fruits and vegetables tends to be relatively low, leading to this relatively low assumed scope factor for fruits and vegetables.[40]. Taking these considerations into account, the potential amount of FLW that might be targeted by this strategy is 59,201 tonnes. With regard to the participation factor, the three scenarios considered refer to 20, 30 and 50 per cent, respectively.

With respect to costs and benefits, this intervention strategy requires initial costs for setting up a public-private partnership with retailers supporting the implementation of EDBP on a larger scale. Moreover, it is assumed that a training of retailer staff is needed, as well as investment in more advanced tracking systems, in order to be able to put more products close to the best before/use by date on sale. The investment in more advanced tracking systems is modelled as a one-time investment per store. The training of staff members is considered as an annual fixed cost of 10,000 DKK per store.

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date), and/or (iii) packaging (e.g. a torn wrapper, a dented can), without deviation on the intrinsic quality or safety (Aschemann-Witzel, 2018).

[39] Given a lack of more detailed data, we further assume that the generated FLW is equally distributed across different retailers/outlets. This assumption implies that 80 per cent of generated FLW at the retail can potentially be targeted by this strategy.

[40] It should be noted that we are not referring here to second grade produce that is misshapen, but to damaged fruits and vegetables that will be quickly spoiled.

Table 21. *Estimated prevention potential, costs and benefits of expiration-date based pricing by retailers*

	Participation scenarios		
	20 %	30 %	50 %
Diversion potential (in tonnes)			
$FLW_{generated}$		163,000	
$FLW_{potential}$		59,201	
$FLW_{prevented}$	11,840	17,760	29,600
Costs & Benefits (in 1000 DKK)			
Financial costs			
Initial costs (fixed costs for better tracking system)[a]	134,225	134,225	134,225
Operational costs (annual operating costs per store)[b]	38,350	46,2020	53,690
Financial benefits	201,779	302,669	504,449
Net present value [c]	1,191,336	1,947,433	3,521,837
Economic value per kg FLW prevented (in DKK)	8.04	8.77	9.52

[a] Fixed costs of 35,000DKK per store are assumed. [b] Annual costs of 10,000DKK per store are assumed [c] The net present value sums all costs and benefits for each strategy over 10 years using a social discount rate of 4 per cent.

The increasing use of EDBP by retailers is assumed to have the potential to prevent between 11,840 tonnes (20 per cent participation rate) and 29,600 tonnes (50 per cent participation rate) of FLW. A possible rebound effect in terms of higher FLW at the household level has not been included in this calculation. The estimated economic value per kg FLW prevented ranges between 8.04 and 9.52 DKK. The estimated associated GHG emissions range from 35,467 to 85,931 tonnes of CO_2-equivalents.

Regarding the household level, the benefits are calculated as the food costs associated with the amount of FLW prevented by households valued at the retail value of food. This may be a lower-end estimate, as changes to the price structure of foods may induce some utility-improving substitution possibilities for the consumers, cf. box 1, section 4.2. It is assumed that around 15 per cent[41] of FLW at the household level is due to confusion about date labels (scope factor), and that awareness and education campaigns might be able to achieve a change in consumer behaviour ranging from a 10 per cent participation rate (very conservative scenario) up to 50 per cent participation (best-case scenario).

To start such a campaign, it is assumed that governmental spending is required in terms of initial costs, as well as operating costs for regular media presence. No consumer costs due to potential increased risks regarding food safety are taken into account. The results are presented in table 22.

[41] This is within the range of assumptions in previous studies: ReFED (2016), assumption 20 per cent; European Commission (2018b), 9.5-12 per cent.

Table 22. *Estimated prevention potential, costs and benefits of increased consumer awareness and knowledge of date labels*

	Participation scenarios		
	10 %	20 %	50 %
Diversion potential (in tonnes/year)			
$FLW_{generated}$(excl. Fruits & vegetables)		158,175	
$FLW_{potential}$ (Scope factor: 15%)		23,726	
$FLW_{prevented}$	2,372	4,745	11,863
Costs & Benefits (in 1000 DKK)			
Financial costs			
Initial costs (i.e. media campaign plus info material)	7,000	7,000	7,000
Annual operational costs (i.e. regular media presence)	2,000	2,000	2,000
Financial benefits[a]	79,767	153,535	398,839
Net present value[b]	623,767	1,270,757	3,211,726
Economic value per kg FLW prevented (in DKK)	26.3	26.8	27.1

[a] Financial benefits are calculated as the annual costs saved by households by reducing FLW, assuming that the share of different food categories in reduced FLW is as follows: 50 per cent milk and dairy, 25 per cent meat and meat products, 25 per cent fish and seafood. [b] The net present value sums all costs and benefits for each strategy over 10 years using a social discount rate of 4 per cent.

Overall, an increased awareness and knowledge about date labels is assumed to have the potential to reduce FLW at the household level by 2,372 tonnes (10 per cent participation rate) up to 11,863 tonnes (50 per cent participation rate) per year. With around 2.7 million households in Denmark, this is equivalent to 0.9-4.4 kg per household. The estimated economic value per kg of FLW prevented is around 26 DKK. The associated GHG emissions amount to 9,072 tonnes CO_2-equivalents (10 per cent participation rate) and 45,139 tonnes (50 per cent participation rate) CO_2-equivalents, respectively.

Education campaigns targeting households' menu planning and food preparation skills

One of the central findings of existing cost-benefit analyses is that awareness and education campaigns targeting consumers seem to be some of the most cost-effective strategies, due to the large share of FLW occurring at this stage and the associated high monetary and environmental costs of FLW at this stage. Thus, implementing awareness and education campaigns is considered quick wins (e.g. Cristóbal et al., 2017).

However, more specific empirical evidence with regard to real-world impacts of different awareness and education interventions on FLW is scarce, given the lack of data and the only recent nature of many campaigns/initiatives. Only a very few studies are available providing first empirical evidence on this topic. Young et al. (2017) reported results from a field experiment carried out in cooperation with a UK retailer. For this purpose, FLW prevention/reduction tips were mentioned in the retailer's print magazine, e-newsletter and on its Facebook page. Their results showed that none of the three interventions tested in the field managed to perform better than the control, i.e. no intervention.[42] Besides, Romani et al. (2018) conducted an education intervention directed at increasing consumers' skills in meal planning which has been mentioned as one of the central drivers of households FLW levels (e.g., Stancu et al., 2016; Stefan et al., 2013). Both before and after the program, their levels of domestic FLW were assessed in their actual home environment via an FLW diary. The intervention was providing education material consisting of an article illustrating the advantages associated with the organisation of a weekly menu and the use of an Excel file based sheet in order to support the planning of a weekly menu. The results tend to show that the intervention on average decreased FLW levels. However, unfortunately, the authors do not report any number on how much the FLW decreased.

For Denmark, Stancu and Lähteenmäki (2018) reported that making meal plans does not seem to be a common practice among Danish consumers. Moreover, many respondents indicated that they often buy food products that were not planned (see figure 6).

To sum up, empirical evidence on the potential impact of education campaigns on consumers' FLW levels is scarce. However, it seems that strengthening the menu planning skills might lead to decreased FLW levels in households. In this context, it is important to note that improved menu planning might also bear opportunity costs the household needs to face (see box 1, section 4.2). Thus, consumers with different opportunity costs of time will most likely differ in their decision to discard food or not. This reasoning seems to be supported by data presented by Stancu and Lähteenmäki (2018), showing that Danish respondents who reported being in a part-time job or being unemployed were less likely to be categorised in a *high waste cluster*[43], compared to the respondents who reported having a full-time job. This is in line with the study by Höjgård et al. (2013) stating that important reasons for FLW among households are that food is cheap, easily decays, and that the households' time is valuable. Moreover, they pointed out that engagement in more careful planning of meal production is time-consuming and, hence, households might actually experience welfare losses by reducing FLW, since time is a scarce resource. Landry and Smith (2018) developed a structural model of household FLW based on Becker's household production model and applied this to observation data of food stock usage and meal consumption. Their results show that FLW seems to be a luxury good with an expenditure elasticity of about 1.4 and an own-price elasticity of -1.5.

[42] All groups including the control group reported to have reduced FLW over time. The authors pointed out that a reduction in salad FLW seems to be a driving factor for this result across all groups (interventions plus control). The study relies on self-reported FLW levels, which can be considered a rather imprecise measure. Moreover, unfortunately, nothing is mentioned about the aspect of seasonality, which might explain the findings at least to some extent (the data were collected within a time span of 5 months).

[43] Respondents were asked to self-report their FLW levels and based on this they were classified in either the *high waste* or *low waste* cluster.

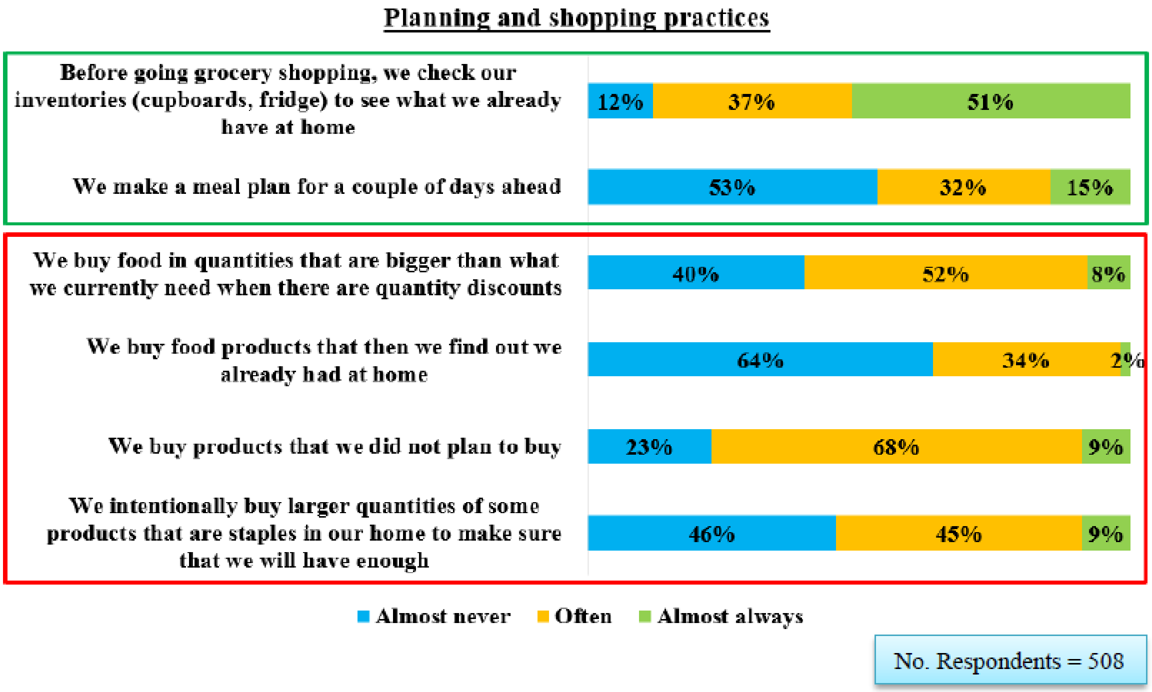

Figure 6. *Menu planning and shopping practices of Danish consumers*

Source: Stancu and Lähteenmäki (2018, p. 48)

Given this background, education campaigns targeting at households menu planning and food preparation skills might mainly be relevant for consumer segments that indicated that they barely make plans, or consumer segments that barely check their stocks, i.e. around 50 per cent of consumers (see figure 6). Thus, it is assumed that in a best-case scenario an awareness/education campaign (e.g. media campaigns, apps to provide advice) might achieve a participation rate of 50 per cent (more conservative participation scenarios refer to 10 and 20 per cent, respectively). Additionally, it is assumed that 50 per cent of total FLW (scope factor) at the household level is caused by poor menu planning and/or food preparation skills. With respect to the potential utility cost/loss discussed in box 1, it is assumed that the education campaigns increases consumers' food preparation skills and thus efficiency in producing meals/using food inputs. Thus, no substitution as described in box 1 is modelled here. The estimated costs and benefits are provided in table 23.

The estimated prevention potential ranges from 13,000 tonnes (10 per cent participation rate) to 65,000 tonnes (50 per cent participation rate). The estimated economic value per kg $FLW_{prevented}$ is in the range of 19 DKK, and the associated GHG emissions amount to 25,233 tonnes (10 per cent participation rate) and 126,165 tonnes (50 per cent participation rate), respectively.

Table 23. *Estimated prevention potential, costs and benefits of an education campaign targeting at menu planning/food preparation skills*

	Participation scenarios		
	10 %	20 %	50 %
Diversion potential (in tonnes/year)			
$FLW_{generated}$		260,000	
$FLW_{potential}$ (Scope factor: 50%)		130,000	
$FLW_{prevented}$	13,000	26,000	65,000
Costs & Benefits (in 1000 DKK)			
Financial costs			
Initial costs (i.e. developing education material/tools)	10,000	10,000	10,000
Annual operational costs	4,000	4,000	4,000
Financial benefits[a]	313,183	626,366	1,565,915
Net present value[b]	2,497,751	5,037,945	12,658,529
Economic value per kg FLW prevented (in DKK)	19.2	19.4	19.5

Summary of calculations

Table 24 provides an overview of all investigated intervention strategies and the estimates with regard to the potential of prevented FLW, the cost-benefit ratio (economic value in kg per $FLW_{prevented}$), and the associated GHG emissions expressed in CO_2-equivalents.

Table 24. *Summary of interventions with regard to estimated prevention potential, economic value, and associated GHG emissions*

Strategy	Estimated amount of $FLW_{prevented}$ in tonnes/year	Economic value in DKK per kg $FLW_{prevented}$	Estimated CO_2-equivalents embodied in the $FLW_{prevented}$ in tonnes/year
Primary production/Food service			
Using second grade produce in food service	106-1,063	0.8-1.2	34-170
Food service			
Waste tracking and analytics	1,200-2,300	9.65	2,200-4,400
Optimised buffet management	4,100	9.08	6,100
Smaller Plates	72	0 (cost-neutral)	82
Retail			
Inventory management	4,700	13.68	9,800
Temperature management	355	41.12	1,600
Retail & Consumers			
Date labels			
• Consumer awareness and education campaign	2,372-11,863	26.5	9,072-45,139
• Expiration date based pricing (EDBP)	11,840-29,600	8 - 9	35,467-85,931
Consumers			
Education campaigns targeting at households menu planning and food preparation skills	13,000-65,000	19	25,233-126,165

4.5 Existing Business cases

Table 25 provides an overview of existing start-ups/businesses related to FLW preventions aiming at using the business case FLW, i.e. to make money while reducing FLW. As has been termed by some authors "The Fight Against Food Waste Is Becoming Big Business".[44] This report is not claiming the same statement, since only time will tell whether these businesses will sustain in the long run. Nevertheless, the emergence of these businesses indicates that business opportunities for FLW prevention and reduction might exist, implying the fact that governmental intervention is probably not needed (or only to a limited degree).

For example, supermarkets that only sell so-called suboptimal foods have been established. In Denmark, Wefood is selling goods that regular supermarkets no longer sell due to overdue best before dates, incorrect labels or damaged packaging (https://www.danchurchaid.org/join-us/wefood). A similar concept is followed in Germany by a start-up called Sirplus (https://sirplus.de/). Unlike similar surplus supermarkets around Europe, Wefood and Sirplus are for everyone and not restricted to people with low-income. Other start-up businesses such as Too good to go, aim at matching food service institutions, shops and retailers with consumers who are willing to purchase and pick up food/meals close before closing time at a substantially reduced price.

Table 25. *Selected business cases that have evolved in the context of FLW prevention/reduction*

Company name	Target group/ involved FSC stages	Business model
Too good to go (founded in Denmark) https://toogoodtogo.com	Retailers, food shops, restaurants, consumers	The app allowing users to order surplus food from local restaurants, cafes, hotels, bakeries and shops to be picked up shortly before closing time in biodegradable packaging delivered by the company to keep things as 'green' as possible. The average food costs around 30 DKK. The app is currently available in eight countries and the company has grown from 15 to 70 employees. Around 5,000 businesses are taking part and the app has 3 million users. It is stated further on the website that the app has managed to prevent 2.7 million portions of food from being waste that otherwise would have been thrown out.
Weefood (in Denmark)	Retailers, consumers	FLW supermarkets
Sirplus (in Germany)	Retailers, consumers	FLW supermarkets
MisFit https://misfitjuicery.co/products	Farmers, consumers	Juice made from imperfect fruits and vegetables that farmers cannot sell and scraps from manufacturers.
Imperfect Produce https://-www.imperfectproduce.com/	Farmers, consumers	Delivery service of boxes of imperfect produce
Yume https://yumefood.com.au/how-yume-works	Farmers, wholesalers, retailers, food service	Online marketplace for selling oversupplied and imperfect food from suppliers to buyers. The products are priced at least 20 per cent below wholesale price.
FoodMaven https://foodmaven.com/	Producers, manufacturers, food service	Online marketplace for selling oversupplied and imperfect food from distributors, manufacturers and producers to restaurants and institutional kitchens at a significant discount.

Source: Own compilation and presentation

[44] https://www.huffingtonpost.com/selina-juul/the-fight-against-food-wa_b_14632156.html

5 Discussion and policy recommendations

Key points in chapter 5

- There seems to be a robust business case for countries, cities, and companies to reduce FLW.
- Preventing FLW downstream in the FSC chain seems to be particularly impactful, because at that point food includes all the embodied energy used in harvesting, processing, distribution, and preparation.
- The composition of FLW targeted is quite important to consider in order to derive meaningful estimates concerning monetary and environmental benefits.
- Consumer costs of behavioural change seem to be of central importance targeting at reduced FLW at the household level.
- In addition to implying positive net economic benefits, some of the considered interventions may also incur redistributional effects, because an intervention may save costs in one stage of the FSC but may incur costs at other stages
- The present report does not discuss purely governmental interventions but in fact mainly initiatives that might only need governmental support in the beginning or no governmental support at all.
- FLW prevention interventions with a net cost may even be attractive from a welfare economic point of view, if the value of negative externality reductions exceeds the intervention costs, and this may broaden the range of FLW interventions considerably, compared to the selection analysed in this report.

Despite the fact that differences in definitions and estimates concerning the extent of FLW across the FSC exist, there is no question that current FLW levels are problematic and should be tackled. However, the way to tackle FLW is not clear-cut and straightforward, given the complexity of FSCs and the underlying factors of FLW. Nevertheless, there is increasing evidence that all stakeholders involved in FSC are paying increasing attention to FLW and possible ways to reduce it.

Overall, from an environmental and GHG reduction perspective, preventing FLW downstream in the FSC chain is particularly impactful, because at that point food includes all the embodied energy used in harvesting, processing, distribution, and preparation. Thus, from this perspective FLW prevention in high-income countries such as Denmark should predominantly focus on the food service sector, retail and household level. The results generated for this report underline this. As can be seen from the results presented in summary table 24, the interventions with the highest prevention potential (both in mass FLW as well as in terms of CO2-eq.) are the ones targeting the consumer level.

Besides, the composition of FLW targeted/reduced is quite important to consider, if different environmental goals are pursued. In the case that the goal is to reduce FLW-related GHG emissions, prevention strategies such as expiration date based pricing and consumer awareness of date labels seem to be especially relevant. This is because these strategies are assumed to mainly reduce FLW in the categories of grain products, dairy and meat, which all have a relatively high environmental impact on a per-unit basis and for which the expiry date plays a role[45]. However, it has also been pointed out that production of fruits and vegetables wasted in high proportions carries environmental burdens as well, particularly due to relatively high rates of pesticide use and irrigation (e.g., Cristóbal et al., 2017) – issues that we were not able to analyse quantitatively due to lack of appropriate data. Incorporation of externality elements such as pesticide load, water footprint or nitrogen footprint might hence modify the conclusions when it comes to targeting interventions towards product categories. Thus, since GHG emissions are not a proxy for the full range of environmental impacts associated with food production, the priority list of FLW prevention strategies might change with different environmental goals.

Moreover, the results illustrate that all considered FLW prevention interventions are found to have a positive net economic gain. While this result is, at least partially, driven by the choice of investigated interventions[46], it is at the same time in line with the observation that an increasing number of stakeholders have already established strategies to reduce FLW and that there is an increasing number of start-ups aiming at making money by helping to reduce current FLW (see table 25). The cases of *Imperfect produce* or *Too good to go* as examples, underline that business opportunities to decrease FLW exist. As pointed out by Richards and Hamilton (2018) even though these businesses were originally motivated by purely environmental and other social concerns, these start-ups achieved financial independence over time. The cases seem to have in common the immersive use of technology in order to match suppliers and customers in the best possible way. Thus, even though FLW might be considered as a negative externality calling for governmental action, there is evidence that market-based solutions evolve and governmental actions might be restricted to raising awareness and fostering the evolvement of such businesses by granting initial funding.

This is also reflected in experiences from the UK for which Hanson and Mitchell (2017) conclude that there seems to be a robust business case for countries, cities, and companies to reduce FLW. They highlight for example that according to estimates, the nationwide initiative to reduce household FLW launched in 2007 achieved a 21 per cent reduction in household FLW over a five-year period. Moreover, they claim that the ratio of purely financial benefits to financial costs attributable to the UK initiative was more than 250:1 (250 to 1), a very substantial return on investment. Of course, these numbers raise the question why FLW prevention strategies have not already been implemented on a sufficient scale by countries, cities, and companies. Hanson and Mitchell (2017) argue that based on information from interviews with public and private sector decision-makers many FSC stakeholders may not be aware – or may not believe – that there is a solid business case in reducing FLW. For instance, the associated costs of FLW may be buried in operational budgets, accepted as the *cost of doing business* or considered not worth the investment needed to achieve

[45] It should be noted that the present analysis did not assess the potentials of EDBP for fruits and vegetables (where expiry date label is only used to a limited extent) nor seafood.

[46] The interventions were chosen based on previous studies that have shown that these strategies might generate positive net befits (e.g. ReFED, 2016; Cristóbal et al., 2017).

reductions. Based on such considerations, governmental actions in terms of setting up private-public partnerships, awareness campaigns etc. might be justified to foster the evolvement of self-financing FLW prevention business strategies within the first years that do not need any governmental support in the long-run.

The present report does not discuss purely governmental interventions but in fact mainly initiatives that might only need governmental support in the beginning or no governmental support at all (e.g. smaller plates). Moreover, even though most of the investigated interventions have been discussed in previous studies, quantitative estimates are scarce and the present report provides a more nuanced picture for different FLW prevention strategies for the specific case of Denmark. Especially, the aspect of potential consumer costs resulting from more restricted consumer choices in the food service sector (see the strategies restricted/optimised buffet management and smaller plates) has not been addressed, at least not in a quantitative way, so far.

The last point, consumer costs of behavioural change seems to be of central importance targeting at reduced FLW at the household level. Households face a number of trade-offs while making food consumption decisions. For example, it has been pointed out that reducing FLW might potentially require more time spent on meal planning or a higher food safety risk. Thus, given the fact that for most households, food costs only make up a relatively small share of the budget, such trade-offs might inhibit tremendous reductions in FLW at the household level. However, this does not mean that there are no possible interventions to tackle FLW at the household level. As laid down in the results section, different scenarios have been calculated assuming different participation rates reflecting simply the above described trade-offs consumer face. Hence, the report has aimed at providing a realistic outlook on reduction potentials, taking into account the real-world circumstances. Put differently, aiming at zero FLW waste as sometimes brought up in the discussion does not seem a realistic goal. Nevertheless, the report's analyses suggest that there are a number of ways to reduce the extent of FLW without imposing costs on the stakeholders in the FSC, nor on the society as such.

For some of the considered interventions, although they imply a positive net benefit, they may also incur redistributional effects, in that an intervention may save costs in one stage of the FSC but may have impacts on other stages (e.g. reduced choice for the consumers). Supplementary measures to compensate for such redistributional effects may then be considered, although this is outside the scope of the present analysis.

Taking into consideration that externality costs, such as those related to GHG emissions, are to an increasing extent internalised into policy decisions, FLW prevention interventions with a net cost may even be attractive from a welfare economic point of view, if the value of negative externality reductions exceeds the intervention costs. This may broaden the range of FLW interventions considerably, compared to the selection analysed in this report (although a proper assessment of the welfare economic impacts will require an economic valuation of the externality reductions). However, in contrast to the measures considered in the report, interventions involving a net cost to the decision making units will require more active government involvement in order to materialise, in terms of e.g. legislation or manipulation of economic incentives (via subsidies or taxes) to stimulate stakeholders' undertaking of such interventions.

References

Abdulla, M., Martin, R.C., Gooch, M. & Jovel, E. (2013). The importance of quantifying food waste in Canada. *Journal of Agriculture, Food Systems, and Community Development,* 3(2), 137-151. http://dx.doi.org/10.5304/jafscd.2013.032.018

Ajzen, I. (1991). The theory of planned behavior. *Organizational Behavior and Human Decision Processes,* 50(2), 179-211.

Ajzen, I. (2015). Consumer attitudes and behavior : The theory of planned behavior applied to food consumption decisions. *Rivista Di Economia Agraria*, LXX(2), 121-138. http://doi.org/10.13128/REA-18003

Aschemann-Witzel, J. (2018). Consumer perception and preference for suboptimal food under the emerging practice of expiration date based pricing in supermarkets. *Food Quality and Preference*, 63, 119-128. https://doi.org/10.1016/j.foodqual.2017.08.007

Aschemann-Witzel, J., de Hooge, I., Amani, P., Bech-Larsen, T. & Oostindjer, M. (2015). Consumer-related food waste: Causes and potential for action. *Sustainability*, 7(6), 6457-6477. http://doi.org/10.3390/su7066457

Beausang, C., Hall, C. & Toma, L. (2017). Food waste and losses in primary production: Qualitative insights from horticulture. *Resources, Conservation and Recycling*, 126(January), 177-185. http://doi.org/10.1016/j.resconrec.2017.07.042

Becker, G.S. (1965). A theory of the allocation of time. *The Economic Journal*, 75(299), 493-517.

Bellemare, M.F., Çakir, M., Peterson, H.H., Novak, L. & Rudi, J. (2017). On the measurement of food waste. *American Journal of Agricultural Economics*, 99(5), 1148-1158. http://doi.org/10.1093/ajae/aax034

Bernstad, A. & la Cour Jansen, J. (2012). Review of comparative LCAs of food waste management systems: Current status and potential improvements. *Waste Management*, 32(12), 2439-2455. http://doi.org/10.1016/j.wasman.2012.07.023

Bernstad Saraiva Schott, A. & Andersson, T. (2015). Food waste minimization from a life-cycle perspective. *Journal of Environmental Management*, 147, 219-226. http://doi.org/10.1016/j.jenvman.2014.07.048

Beretta, C., Stoessel, F., Baier, U. & Hellweg, S. (2013). Quantifying food losses and the potential for reduction in Switzerland. Supplementary Information. *Waste Management*, 33(3), 764-773. http://doi.org/10.1016/j.wasman.2012.11.007

Betz, A., Buchli, J., Göbel, C. & Müller, C. (2015). Food waste in the Swiss food service industry: Magnitude and potential for reduction. *Waste Management*, 35, 218-226. http://doi.org/10.1016/j.wasman.2014.09.015

Binswanger, M. (2001). Technological progress and sustainable development: what about the rebound effect? *Ecologial Economics*, 36(1), 119-132. http://doi.org/10.1016/S0921-8009(00)00214-7

Birney, C.I., Franklin, K.F., Davidson, F.T. & Webber, M.E. (2017). An assessment of individual foodprints attributed to diets and food waste in the United States. *Environmental Research Letters,* 12(10), 105008. https://doi.org/10.1088/1748-9326/aa8494

Bräutigam, K.R., Jörissen, J. & Priefer, C. (2014). The extent of food waste generation across EU-27: Different calculation methods and the reliability of their results. *Waste Management and Research*, 32(8), 683-694. http://doi.org/10.1177/0734242X14545374

Bunn, D., Feenstra, G.W., Lynch, L. & Sommer, R. (1990). Consumer acceptance of cosmetically imperfect produce. *Journal of Consumer Affairs*, 24(2), 268-279.

Chaboud, G. & Daviron, B. (2017). Food losses and waste: Navigating the inconsistencies. *Global Food Security*, 12, 1-7. http://doi.org/10.1016/j.gfs.2016.11.004

Chapagain, A. & James, K. (2011). The Water and Carbon Footprint of Household Food and Drink Waste in the UK. Banbury, Oxon: Waste & Resources Action Programme. http://www.wrap.org.uk/retail_supply_chain/research_tools/research/report_water_and.html

Chen, H., Jiang, W., Yang, Y., Yang, Y. & Man, X. (2017). State of the art on food waste research: a bibliometrics study from 1997 to 2014. *Journal of Cleaner Production*, 140, 840-846. http://doi.org/10.1016/j.jclepro.2015.11.085

Chitnis, M., Sorrell, S., Druckman, A., Firth, S.K. & Jackson, T. (2014). Who rebounds most? Estimating direct and indirect rebound effects for different UK socioeconomic groups. *Ecological Economics*, 106, 12-32. http://doi.org/10.1016/j.ecolecon.2014.07.003

Christensen, L.M., Kørup, K., Trolle, E. & Fagt. S. (2013). Måltidsvaner for voksne med kort uddannelse 2005-2008. DTU Fødevareinstituttet. http://orbit.dtu.dk/files/72794211/Rapport-M%C3%A5ltidsvaner%20kortuddannede%20voksne%20okt%2013.pdf

Cicatiello, C., Franco, S., Pancino, B. & Blasi, E. (2016). The value of food waste: An exploratory study on retailing. *Journal of Retailing and Consumer Services*, 30, 96-104. http://doi.org/10.1016/j.jretconser.2016.01.004

Cicatiello, C., Franco, S., Pancino, B., Blasi, E. & Falasconi, L. (2017). The dark side of retail food waste: Evidences from in-store data. *Resources, Conservation and Recycling*, 125(February), 273-281. http://doi.org/10.1016/j.resconrec.2017.06.010

Cristóbal, J., Castellani, V., Manfredi, S. & Sala, S. (2017). Prioritizing and optimizing sustainable measures for food waste prevention and management. *Waste Management*, 72, 3-16. http://doi.org/10.1016/j.wasman.2017.11.007

Davis, G.C. & You, W. (2013). Estimates of returns to scale, elasticity of substitution, and the thrifty food plan meal poverty rate from a direct household meal production function. *Food Policy*, 43, 204-212. http://doi.org/10.1016/j.foodpol.2013.09.002

DEFRA (2012). Waste Prevention Actions for Priority Wastes. Economic Assessment through Marginal Abatement Cost Curves.

De Hooge, I.E., van Dulm, E. & van Trijp, H.C.M. (2018). Cosmetic specifications in the food waste issue: Supply chain considerations and practices concerning suboptimal food products. *Journal of Cleaner Production*, 183, 698-709. http://doi.org/10.1016/j.jclepro.2018.02.132

Edjabou, M.E., Petersen, C., Scheutz, C. & Astrup, T.F. (2016). Food waste from Danish households: Generation and composition. *Waste Management*, 52, 256-268. http://doi.org/10.1016/j.wasman.2016.03.032

Ellison, B. & Lusk, J.L. (2018). Examining household food waste decisions: A vignette approach. *Applied Economic Perspectives and Policy*. http://doi.org/10.1093/aepp/ppx059

Engström, R. & Carlsson-Kanayama, A. (2004). Food losses in food service institutions: Examples from Sweden. *Food Policy*, 29(3), 203-213. https://doi.org/10.1016/j.foodpol.2004.03.004

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

Eriksson, M. & Spångberg, J. (2017). Carbon footprint and energy use of food waste management options for fresh fruit and vegetables from supermarkets. *Waste Management*, 60, 786-799. http://doi.org/10.1016/j.wasman.2017.01.008

Eriksson, M., Strid, I. & Hansson, P.-A. (2016). Food waste reduction in supermarkets: Net costs and benefits of reduced storage temperature. *Resources, Conservation and Recycling*, 107, 73-81. https://doi.org/10.1016/j.resconrec.2015.11.022

Eriksson, M., Strid, I. & Hansson, P.-A. (2012). Food losses in six Swedish retail stores: Wastage of fruit and vegetables in relation to quantities delivered. *Resources, Conservation and Recycling*, 68, 14-20. http://doi.org/10.1016/j.resconrec.2012.08.001

Eriksson, M., Strid, I. & Hansson, P.-A. (2014). Waste of organic and conventional meat and dairy products: A case study from Swedish retail. *Resources, Conservation and Recycling*, 83, 44-52. http://doi.org/10.1016/j.resconrec.2013.11.011

European Commission (2015). Closing the loop – An EU action plan for the Circular Economy. Communication COM (2015) 614/2. http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52015DC0614

European Commission (2018a). Food Waste. https://ec.europa.eu/food/safety/food_waste_en

European Commission (2018b). Market study on date marking and other information provided on food labels and food waste prevention. Final report. https://publications.europa.eu/en/publication-detail/-/publication/e7be006f-0d55-11e8-966a-01aa75ed71a1/language-en

European Union (2008). Directive 2008/98/EC on waste (Waste Framework Directive). https://eur-lex.europa.eu/eli/dir/2008/98/oj

FAO (2012). Using Marginal Abatement Cost Curves to Realize the Economic Appraisal of Climate Smart Agriculture Policy Options. http://www.fao.org/docs/up/easypol/906/ex-act_macc_116en.pdf

FAO (2014). Food Wastage Footprint- Full-Cost Accounting. Final Report. http://www.fao.org/3/a-i3991e.pdf

Garnett, T. (2011). Where are the best opportunities for reducing greenhouse gas emissions in the food system (including the food chain)? *Food Policy*, 36, S23-S32. https://doi.org/10.1016/j.foodpol.2010.10.010

Garrone, P., Melacini, M. & Perego, A. (2014). Opening the black box of food waste reduction. *Food Policy*, 46, 129-139. http://doi.org/10.1016/j.foodpol.2014.03.014

Gentil, E.C., Gallo, D. & Christensen, T.H. (2011). Environmental evaluation of municipal waste prevention. *Waste Management*, 31, 2371-2379. http://doi.org/10.1016/j.wasman.2011.07.030

Graham-Rowe, E., Jessop, D.C. & Sparks, P. (2014). Identifying motivations and barriers to minimising household food waste. *Resources, Conservation and Recycling*, 84, 15-23. http://doi.org/10.1016/j.resconrec.2013.12.005

Gustavsson, J., Cederberg, C., Sonesson, U., van Otterdijk, R. & Meybeck, A. (2011). Global food losses and food waste: extent, causes and prevention. Rome: Food and Agriculture Organisation of the United Nations (FAO).

Hafner, G., Barabosz, J., Schneider, F., Lebersorger, S., Scherhaufer, S., Schuller, H., Leverenz, D. & Kranert, M. (2012). Determination of discarded food and proposals for a minimization of food wastage in Germany. University Stuttgart, Institute for Sanitary Engineering, Water Quality and Solid Waste Management (ISWA)

Hall, K.D., Guo, J., Dore, M. & Chow, C.C. (2009). The progressive increase of food waste in America and its environmental impact. *PLoS ONE*, 4(11), 9-14. http://doi.org/10.1371/journal.pone.0007940

Halloran, A., Clement, J., Kornum, N., Bucatariu, C. & Magid, J. (2014). Addressing food waste reduction in Denmark. *Food Policy*, 49, 294–301. http://doi.org/10.1016/j.foodpol.2014.09.005

Hamermesh, D.S. (2008). Direct estimates of household production. *Economics Letters*, 98(1), 31-34. http://doi.org/10.1016/j.econlet.2007.03.008

Hanson, C. & Mitchell, P. (2017). The Business Case for Reducing Food Loss and Waste. Washington, DC: Champions 12.3. https://champions123.org/wp-content/uploads/2017/03/report_-business-case-for-reducing-food-loss-and-waste.pdf

Hartikainen, H., Mogensen, L., Svanes, E. & Franke, U. (2018). Food waste quantification in primary production – The Nordic countries as a case study. *Waste Management*, 71, 502-511. http://doi.org/10.1016/j.wasman.2017.10.026

Hebrok, M. & Boks, C. (2017). Household food waste: Drivers and potential intervention points for design – An extensive review. *Journal of Cleaner Production*, 151, 380-392. http://doi.org/10.1016/j.jclepro.2017.03.069

Heikkilä, L., Reinikainen, A., Katajajuuri, J.M., Silvennoinen, K. & Hartikainen, H. (2016). Elements affecting food waste in the food service sector. *Waste Management*, 56, 446-453. http://doi.org/10.1016/j.wasman.2016.06.019

Höjgård, S., Jansson, T. & Rabinowicz, E. (2013). Food waste among Swedish households: Much ado about nothing. *AgriFood Economics Centre Working Paper*, 2013:8. http://www.agrifood.se/Files/AgriFood_WP20138.pdf

IFPRI (2016). Global Food Policy Report. http://www.ifpri.org/publication/2016-global-food-policy-report

Irz, X., Leroy, P., Requillart, V. & Soler, L.-G. (2015). Economic assessment of nutritional recommendations. *Journal of Health Economics*, 39, 188-210. https://doi.org/10.1016/j.jhealeco.2014.09.002

Irz, X., Leroy, P., Requillart, V. & Soler, L.-G. (2016). Welfare and sustainability effects of dietary recommendations. *Ecological Economics*, 130, 139-155. https://doi.org/10.1016/j.ecolecon.2016.06.025

Irz, X., Jensen, J., Leroy, P., Réquillart, V. & Soler, L.-G. (2017). Simulation of diet recommendations and assessment of their economic, environmental and nutritional impacts. Paper presented at the XV EAAE Congress, August 28-September 1, 2017, Parma, Italy.

Kiil, K., Hvolby, H.-H., Dreyer. H.C. & Strandhagen, J.O. (2017). Inventory allocation of perishables: Guidelines. In: Advances in Production Management Systems: The Path to Intelligent, Collaborativeand Sustainable Manufacturing. 3-7 September 2017, Hamburg, Germany, pp. 113-121. https://link.springer.com/chapter/10.1007/978-3-319-66926-7_14

Katare, B., Serebrennikov, D., Wang, H.H. & Wetzstein, M. (2017). Social-optimal household food waste: Taxes and government incentives. *American Journal of Agricultural Economics*, 99(2), 499-509. http://doi.org/10.1093/ajae/aaw114

Koester, U. (2014). Food loss and waste as an economic and policy problem. *Intereconomics*, 49(6), 348-354. http://doi.org/10.1007/s10272-014-0518-7

Kulikovskaja, V. & Aschemann-Witzel, J. & (2016). Food waste avoidance initiatives in Danish food retail: COSUS WP 6.2 report. Department of Management, Aarhus University. http://bss.au.dk/fileadmin/user_upload/COSUS_WP6.2_Food_waste_avoidance_initiatives_in_Danish_food_retail_Onlineversion.pdf

Kummu, M., de Moel, H., Porkka, M., Siebert, S., Varis, O. & Ward, P.J. (2012). Lost food, wasted resources: Global food supply chain losses and their impacts on freshwater, cropland, and fertiliser use. *Science of the Total Environment*, 438, 477-489. http://doi.org/10.1016/j.scitotenv.2012.08.092

Landry, C. & Smith, T. (2018). Household Food Waste: Theory and Empirics. Paper written September 22, 2018 and available at SSRN: https://ssrn.com/abstract=3060838 or http://dx.doi.org/10.2139/ssrn.3060838

Lebersorger, S. & Schneider, F. (2011). Discussion on the methodology for determining food waste in household waste composition studies. *Waste Management*, 31(9-10), 1924-1933. http://doi.org/10.1016/j.wasman.2011.05.023

Lebersorger, S. & Schneider, F. (2014). Food loss rates at the food retail, influencing factors and reasons as a basis for waste prevention measures. *Waste Management*, 34(11), 1911–1919. http://doi.org/10.1016/j.wasman.2014.06.013

Leip, A., Weiss, F., Lesschen, J.P. & Westhoek, H. (2013). The nitrogen footprint of food products in the European Union. *Journal of Agricultural Science*, 142(S1), 20-33. https://doi.org/10.1017/S0021859613000786

Lewbel, A. & Pendakur, K. (2009). Tricks with Hicks: The EASI Demand System. *American Economic Review*, 99(3), 827-63. http://doi.org/10.1257/aer.99.3.827

Lusk, J.L. & Ellison, B. (2017). A note on modelling household food waste behaviour. *Applied Economics Letters*, 24(16), 1199-1202. http://doi.org/10.1080/13504851.2016.1265070

Lynnerup, D., Gravgaard, A., Gotfredsen, M., Ottesen, H. & Skytte, E.S. (2016). Mindre madspild ved anvendelse af 2. sorterings grøntsager i storkøkkener. Miljøstyrelsen. (Undgå affald, stop spild nr. 11). https://www2.mst.dk/Udgiv/publikationer/2016/04/978-87-93435-54-4.pdf

Martinez-Sanchez, V., Tonini, D., Møller, F. & Astrup, F. (2016). Life-cycle costing of food waste management in Denmark: Importance of indirect effects. Environmental Science & Technology, 50(8), 4513-4523. http://doi.org/10.1021/acs.est.5b03536

Miljøstyrelsen (2018). Fra madspild til storkøkkenernes gryder. (Undgå affald, stop spild nr. 16). https://www2.mst.dk/Udgiv/publikationer/2018/02/978-87-93614-64-2.pdf

Mogensen, L., Knudsen, M.T. & Hermansen, J. (2016). Tabel over fødevarers klimaaftryk. Aarhus Universitet DCA – Nationalt Center for Fødevarer og Jordbrug. http://agro.au.dk/fileadmin/user_upload/Mogensen_et_al_2016_Foedevarernes_klimaaftryk.pdf

Newsome, R., Balestrini, C.G., Baum, M.D., Corby, J., Fisher, W., Goodburn, K., Labuza, T.B., Prince, G., Thesmar, H.S. & Yiannas, F. (2014). Applications and perceptions of date labeling of food. *Comprehensive Reviews in Food Science and Food Safety*, 13(4), 745-769. http://doi.org/10.1111/1541-4337.12086

Nordic Council of Ministers (2017). Food Waste and Date Labelling: Factors determining the durability of refrigerated food. http://norden.diva-portal.org/smash/get/diva2:1120163/FULLTEXT01.pdf

Östergren, K., Gustavsson, J.,Bos-Brouwers, H., Timmermans, T., Hansen, O.-J., Møller, H., Anderson G., O'Connor, C., Soethoudt, H., Quested, T., Easteal, S., Politano, A., Bellettato, C., Canali, M., Falasconi, L., Gaiani, S., Vittuari, M., Schneider, F., Moates, G., Waldron, K. & Redlingshöfer, B. (2014). FUSIONS Definitional Framework for Food Waste. Full Report. http://www.eu-fusions.org/phocadownload/Publications/FUSIONS%20Definitional%20Framework%20for%20Food%20Waste%202014.pdf

Papargyropoulou, E., Lozano, R., Steinberger, J.K., Wright, N. & bin Ujang, Z. (2014). The food waste hierarchy as a framework for the management of food surplus and food waste. *Journal of Cleaner Production*, 76, 106-115. http://doi.org/10.1016/j.jclepro.2014.04.020

Parfitt, J., Barthel, M. & Macnaughton, S. (2010). Food waste within food supply chains: quantification and potential for change to 2050. *Philosophical Transactions of the Royal Society B*, 365, 3065-3081. http://doi.org/10.1098/rstb.2010.0126

Petersen, C., Kaysen, O., Manokaran, S., Tønning, K. & Hansen, T. (2014). *Kortlægning af madaffald i servicesektoren: Detailhandel, restauranter og storkøkken.* http://www2.mst.dk/Udgiv/publikationer/2014/07/978-87-93178-75-5.pdf

Redlingshöfer, B., Coudurier, B. & Georget, M. (2017). Quantifying food loss during primary production and processing in France. *Journal of Cleaner Production*, 164, 703-714. http://doi.org/10.1016/j.jclepro.2017.06.173

ReFED (2016). A Roadmap to Reduce US Food Waste by 20%: Technical Appendix. http://www.refed.com/content-hub/#active_tab=resources

Richards, T.J. & Hamilton, S.F. (2018). Food waste in the sharing economy. *Food Policy*, 75, 109-123. https://doi.org/10.1016/j.foodpol.2018.01.008

Romani, S., Grappi, S., Bagozzi, R.P. & Barone, A.M. (2018). Domestic food practices: A study of food management behaviors and the role of food preparation planning in reducing waste. *Appetite*, 121, 215-227. http://doi.org/10.1016/j.appet.2017.11.093

Salemdeeb, R., zu Ermgassen, E.K.H.J., Kim, M.H., Balmford, A. & Al-Tabbaa, A. (2017). Environmental and health impacts of using food waste as animal feed: a comparative analysis of food waste management options. *Journal of Cleaner Production*, 140, 871-880. http://doi.org/10.1016/j.jclepro.2016.05.049

Silvennoinen, K., Katajajuuri, J.-M., Hartikainen, H., Heikkilä, L., Reinikainen, A. (2014). Food waste volume and composition in Finnish households. *British Food Journal*, 116(6), 1058-1068. https://doi.org/10.1108/BFJ-12-2012-0311

Silvennoinen, K., Heikkilä, L., Katajajuuri, J.M. & Reinikainen, A. (2015). Food waste volume and origin: Case studies in the Finnish food service sector. *Waste Management*, 46, 140-145. http://doi.org/10.1016/j.wasman.2015.09.010

Stancu, V., Haugaard, P. & Lähteenmäki, L. (2016). Determinants of consumer food waste behaviour: Two routes to food waste. *Appetite*, 96, 7-17. http://doi.org/10.1016/j.appet.2015.08.025

Stancu, V. & Lähteenmäki, L. (2018). Consumer food waste in Denmark. DCA Center for Fødevarer og Jordbrug. http://web.agrsci.dk/djfpublikation/index.asp?action=show&id=1258

Stefan, V., van Herpen, E., Tudoran, A.A. & Lähteenmäki, L. (2013). Avoiding food waste by Romanian consumers: The importance of planning and shopping routines. *Food Quality and Preference*, 28(1), 375-381. http://doi.org/10.1016/j.foodqual.2012.11.001

Stenmarck, Å., Hanssen, O.J., Silvennoinen, K., Katajajuuri, J.-M. & Werge, M. (2011). Initiatives on prevention of food waste in the retail and wholesale trades, IVL Swedish Environmental Research Institute, *IVL Report* B1988. http://www.refreshcoe.eu/wp-content/uploads/2017/06/B1988.pdf

Strotmann, C., Friedrich, S., Kreyenschmidt, J., Teitscheid, P. & Ritter, G. (2017). Comparing food provided and wasted before and after implementing measures against food waste in three healthcare food service facilities. *Sustainability (Switzerland)*, 9(8), 1409. http://doi.org/10.3390/su9081409

Teuber, R. & Jensen, J.D. (2016). Food losses and food waste: Extent, underlying drivers and impact assessment of prevention approaches. Department of Food and Resource Economics, University of Copenhagen. *IFRO Report,* No. 254. http://static-curis.ku.dk/portal/files/169753425/IFRO_Report_254.pdf

Theotokis, A., Pramatari, K. & Tsiros, M. (2012). Effects of expiration date-based pricing on brand image perceptions. *Journal of Retailing*, 88(1), 72-87. https://doi.org/10.1016/j.jretai.2011.06.003

Thorsen, A.V. & Jensen, J.D. (2016). Omlægning til økologi – hvad koster det? DTU Fødevareinstituttet. http://www.food.dtu.dk//-/media/Institutter/Foedevareinstituttet/Publikationer/Pub-2016/Rapport-Omlaegning-til-oekologi-hvad-koster-det.ashx

Tom, M.S., Fischbeck, P.S. & Hendrickson, C.T. (2016). Energy use, blue water footprint and greenhouse gas emissions for current food consumption patterns and dietary recommendations in the US. *Environment Systems and Decisions*, 36(1), 92-103. http://dx.doi.org/10.1007/s10669-015-9577-y

Tonini, D., Brogaard, L.K.-S. & Astrup, T.F. (eds)(2017). Food waste prevention in Denmark: Identification of hotspots and potentials with Life Cycle Assessment. København: Danish Environmental Protection Agency.

Van Boxstael, S., Devlieghere, F., Berkvens, D., Vermeulen, A. & Uyttendaele, M. (2014). Understanding and attitude regarding the shelf life labels and dates on pre-packed food products by Belgian consumers. *Food Control*, 37(1), 85-92. http://doi.org/10.1016/j.foodcont.2013.08.043

Vandermeersch, T., Alvarenga, R.A.F., Ragaert, P. & Dewulf, J. (2014). Environmental sustainability assessment of food waste valorization options. *Resources, Conservation and Recycling*, 87, 57-64. http://doi.org/10.1016/j.resconrec.2014.03.008

Van der Werf, P. & Gilliland, J.A. (2017). A systematic review of food losses and food waste generation in developed countries. *Proceedings of the Institution of Civil Engineers - Waste and Resource Management*, 170(2), 66-77. http://doi.org/10.1680/jwarm.16.00026

Van Ewijk, S. & Stegemann, J.A. (2016). Limitations of the waste hierarchy for achieving absolute reductions in material throughput. *Journal of Cleaner Production*, 132, 122-128. http://doi.org/10.1016/j.jclepro.2014.11.051

Vanham, D., Bouraoui, F., Leip, A., Grizzetti, B. & Bidoglio, G. (2015). Lost water and nitrogen resources due to EU consumer food waste. *Environmental Research Letters*, 10(8), 84008. http://doi.org/10.1088/1748-9326/10/8/084008

Venkat, K. (2011). The Climate Change and Economic Impacts of Food Waste in the United States. *International Journal of Food System Dynamics*, 2(4), 431-446. https://doi.org/10.18461/ijfsd.v2i4.247

Williams, H., Wikström, F., Otterbring, T., Löfgren, M. & Gustafsson, A. (2012). Reasons for household food waste with special attention to packaging. *Journal of Cleaner Production*, 24, 141-148. http://doi.org/10.1016/j.jclepro.2011.11.044

World Resource Institute (2016). Food Loss and Waste Accounting and Reporting Standard. Version 1.0. https://www.wri.org/sites/default/files/REP_FLW_Standard.pdf

WRAP (2011). Consumer insight: date labels and storage guidance. http://www.wrap.org.uk/content/consumer-insight-date-labels-and-storage-guidance

Xue, L., Liu, G., Parfitt, J., Liu, X., Van Herpen, E., Stenmarck, Å., O'Connor, C., Östergren, K. & Cheng, S. (2017). Missing food, missing data? A critical review of global food losses and food waste data. *Environmental Science & Technology*, 51(12), 6618-6633. http://doi.org/10.1021/acs.est.7b00401

Young, W., Russell, S.V., Robinson, C.A. & Barkemeyer, R. (2017). Can social media be a tool for reducing consumers' food waste? A behavior change experiment by a UK retailer. Resources, Conservation and Recycling, 117(B), 195-203. https://doi.org/10.1016/j.resconrec.2016.10.016