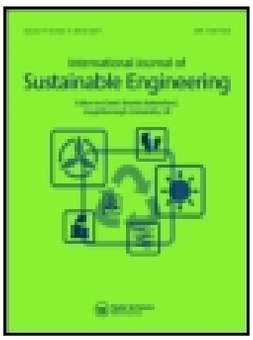

International Journal of Sustainable Engineering

ISSN: 1939-7038 (Print) 1939-7046 (Online) Journal homepage: http://www.tandfonline.com/loi/tsue20

Towards integrating production and consumption to reduce consumer food waste in developed countries

Aicha Jellil, Elliot Woolley & Shahin Rahimifard

To cite this article: Aicha Jellil, Elliot Woolley & Shahin Rahimifard (2018): Towards integrating production and consumption to reduce consumer food waste in developed countries, International Journal of Sustainable Engineering, DOI: 10.1080/19397038.2018.1428834

To link to this article: https://doi.org/10.1080/19397038.2018.1428834

© 2018 The Author(s). Published by Informa UK Limited, trading as Taylor & Francis Group

Published online: 21 Jan 2018.

Submit your article to this journal

Article views: 130

View related articles

View Crossmark data

Full Terms & Conditions of access and use can be found at
http://www.tandfonline.com/action/journalInformation?journalCode=tsue20

INTERNATIONAL JOURNAL OF SUSTAINABLE ENGINEERING, 2018
https://doi.org/10.1080/19397038.2018.1428834

Taylor & Francis
Taylor & Francis Group

Check for updates

Towards integrating production and consumption to reduce consumer food waste in developed countries

Aicha Jellil, Elliot Woolley and Shahin Rahimifard

Wolfson School of Mechanical, Electrical and Manufacturing Engineering, Loughborough University, Loughborough, UK

ABSTRACT

Literature analysing reasons for Consumer Food Waste (CFW) revealed that it cannot be reduced to consumer behaviour alone. In fact, CFW should not be conceptualised as the problem but as a symptom of a food system that oversupplies and encourages consumerism. This research focuses on preventing CFW in the United Kingdom (UK), as a representative of a developed country, by improving the traditional food provisioning system to better integrate production and consumption. To achieve this, five stages are identified to design a sustainable product service system (PSS) capable of supporting consumers to better manage their food operations: (1) strategic analysis of current food provisioning system, (2) exploring system level innovations leading to minimisation of CFW, (3) refinement and selection of PSS, (4) designing the most promising PSS from an environmental, economic and social perspective, and (5) evaluating designed PSS. This paper considers the first of these stages, reviews reasons for and existing solutions to CFW, and provides a strategic analysis of the current food provisioning system to identify characteristics that could be exploited within a new PSS. Initial investigations reveal applicability of PSS concept to the food provisioning system and potential for reduction of CFW if core causes are addressed.

ARTICLE HISTORY
Received 20 March 2017
Accepted 18 December 2017

KEYWORDS
Consumer food waste; product service system; sustainable consumption; stakeholders

1. Introduction

Consumer food waste (CFW) is particularly problematic because in comparison to waste generated at other stages of the supply chain its associated environmental and economic impacts are the highest. This is due to the cumulative amount of resources (labour, energy, water, etc.) required to produce the final products. For instance, the cumulative energy use for 1 kilogramme of beef can increase from 28.16 MJ at the farm gate to 49.91 MJ at the consumption stage (Foster et al. 2006; WRAP 2013a).

In the UK, 72% of post-farm food waste is generated at household level (Figure 1): some 7.3 million tonnes per annum, of which 5.7 million tonnes (78%) is classed as avoidable or possibly avoidable (WRAP 2017). Avoidable food waste refers to food that is discarded because it is not wanted anymore or has been left to expire, whereas possibly avoidable food waste is food that some consumers eat but not others (e.g. bread crust), or food that can be eaten if prepared differently (e.g. raw potato peeling vs. potato peel crisps) (WRAP 2013b). CFW is not only a UK issue, studies have shown that on a European level, the majority of food waste created is attributed to consumers (European Court of Auditors 2016). These alarming figures suggest that an improvement in how consumers purchase and manage food is needed. Environmentally and economically, prevention is the best option to manage waste (European Commission 2012; Garcia-Garcia et al. 2016), this research focuses on preventing avoidable and possibly avoidable CFW generated in the household.

The choice of UK as a valid case to analyse CFW and explore its potential solutions is underpinned by two main factors. Firstly, UK is identified as one of the EU countries with the highest amount of CFW per capita (Monier et al. 2010; Vanham et al. 2015). Secondly, thanks to the work conducted by WRAP (2013b, 2017) there is a relatively more detailed analysis and quantification of CFW in the UK compared to other countries of the EU (Vanham et al. 2015). Thus, the availability of UK CFW data and the fact that UK is one of the most wasteful nations of the EU informed this research scope.

This paper begins with an analysis of the UK CFW issue and its challenges, provides an overview of the solutions present in the literature that seek to support businesses to reducing it, examines attributes of the current food provisioning system that could support a new product service system (PSS) in substantially minimising CFW and discusses these outputs in terms of designing a new PSS.

2. Causes and solutions to CFW

In relation to causes of CFW, several studies have revealed that reasons for wasting food at household level are various and complex (Evans 2011; Evans and Welch 2015; Stancu, Haugaard, and Lähteenmäki 2016). Direct reasons of CFW include food not used in time, accidents (i.e. burning, spoilage, etc.), personal preferences (WRAP 2013b) and leftover waste (Cicatiello et al.

CONTACT Elliot Woolley E.B.Woolley@lboro.ac.uk

© 2018 The Author(s). Published by Informa UK Limited, trading as Taylor & Francis Group.
This is an Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

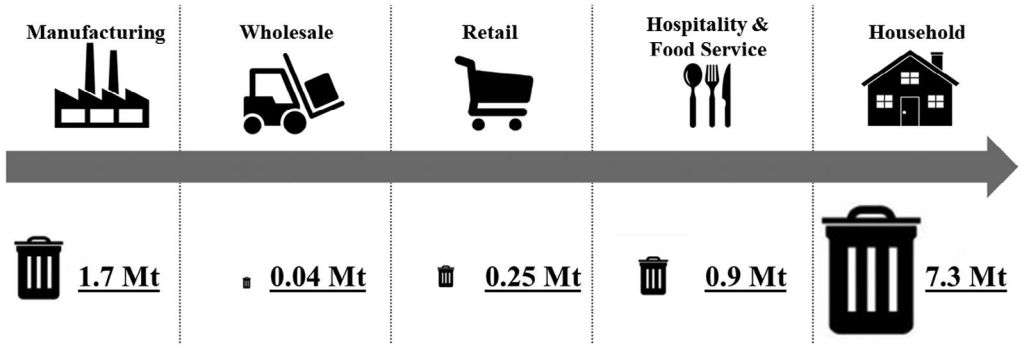

Figure 1. Food waste by sector in the United Kingdom. Source: Data from (WRAP 2017).

2016). These reasons are in turn consequences of unplanned grocery shopping (Stefan et al. 2013) – interestingly, consumers who make shopping lists are found to be more concerned about CFW issue (Principato, Secondi, and Pratesi 2015) – over-purchasing (Cicatiello et al. 2016), poor management of stored food (WRAP 2007), incorrect storage (Cicatiello et al. 2016), lack of cooking skills, over-preparation (Cicatiello et al. 2016) and over-serving (WRAP 2013b). Thus, it is observed that CFW is a consequence of how consumers purchase, store, cook and consume food.

Furthermore, studies within the fields of social science and psychology reveal that CFW is influenced by factors related to (1) the individual, (2) the society/area and (3) the retail-manufacturing system (Aschemann-Witzel et al. 2015; Quested et al. 2013; Secondi, Principato, and Laureti 2015). Factors related to the individual include (a) socio-demographic aspects such as age, gender and household composition, (b) psycho-demographic aspects such as motivation, attitudes, values and habits, and (c) socio-economic aspects such as income, level of education and household storage infrastructure. Regarding the society and area factors, studies show that social norms influence how consumers handle food operations (e.g. family norm), and that economic, environmental and governmental characteristics of the country of residency have some impact on CFW generation. Interestingly, Secondi, Principato, and Laureti (2015) argue that the more land consecrated for agriculture a country has the less food waste its citizens generate. Additionally, characteristics of the retail-manufacturing system are believed to influence consumers' wasteful behaviour. For instance, retail environment is designed to make consumers buy more by providing special offers such as buy one get one free and competing on relatively low prices. Thus, consumers are encouraged to buy more than what they need which results in almost one-fifth of food purchased by UK consumers being wasted (WRAP 2013b).

Considering the reviewed models above, it is understood that CFW is more than a behaviour issue but rather a symptom of a bigger societal problem shaped by an unsustainable production and consumption system that relies on oversupply, consumerism and competition on cheap prices (Aschemann-Witzel et al. 2015; Lang 2013). It is therefore important to not only address the symptoms but also the core causes when formulating a solution that could lead to a significant reduction of CFW. Figure 2 represents this research conceptual framework which enumerates the different causes and factors influencing CFW, found in the literature, revealing a need for a food system that caters for individualisation, changes food provisioning processes, takes into consideration environment where it operates, and is scalable.

The current research recognises the role of food providers, particularly manufacturers and retailers, in supporting the minimisation of CFW. This is primarily due to the fact that some manufacturing and retail activities can contribute to the generation of CFW (i.e. packaging, promotions, portioning, etc.), and also the power that manufacturers and retailers hold in controlling the majority of the flow of food products from producers to consumers. This enables them influence both production and consumption. Hence, a review of the literature regarding the solutions supporting businesses in fostering more sustainable consumption and preventing CFW is conducted. It is noticed that the majority of published academic articles around food waste provide an analysis of the issue rather than a solution. Thus, solutions discussed on commercial websites and in generic reports are also considered.

Regarding actions that can be taken by providers, some solutions call for the abolishment of best before dates to prevent people from throwing away perfectly edible food (Adam 2015) while other solutions promote innovative technology to offer more precision in detecting if food is spoilt such as temperature sensitive smart labels (Zhang et al. 2013), and bio-reactive tactile tags made of gelatine that can change texture (Smithers 2016). Other solutions helped in extending product shelf-life (or percentage of shelf-life available to consumers) through packaging technology (Kirtil and Oztop 2016; Sand 2015; Smithers 2016) or though logistics and supply chain management (i.e. first-expired-first-out transportation model) (Jedermann et al. 2014). Furthermore, packaging and mobile apps have been used to provide guidance on how to store food to preserve its quality (WRAP 2014) as well as how to utilise stored food before it expires (Woolley et al. 2016). Providing flexible portioning is also one of the actions that can be taken by food providers to facilitate prevention of CFW, examples of solutions that offer this flexibility are pre-cut and resealable packages (Sand 2015). Those are examples of technologies that businesses could implement to assist consumers in maximising their use of food resources.

In relation to actions that can be taken by consumers, one of the most prominent educative programmes in the UK is love food hate waste (LFHW) (WRAP 2015) which raises consumers' awareness around planning, portioning, storing and understanding date labels. This programme also stresses the importance of efficiently managing stored food and purchasing only needed

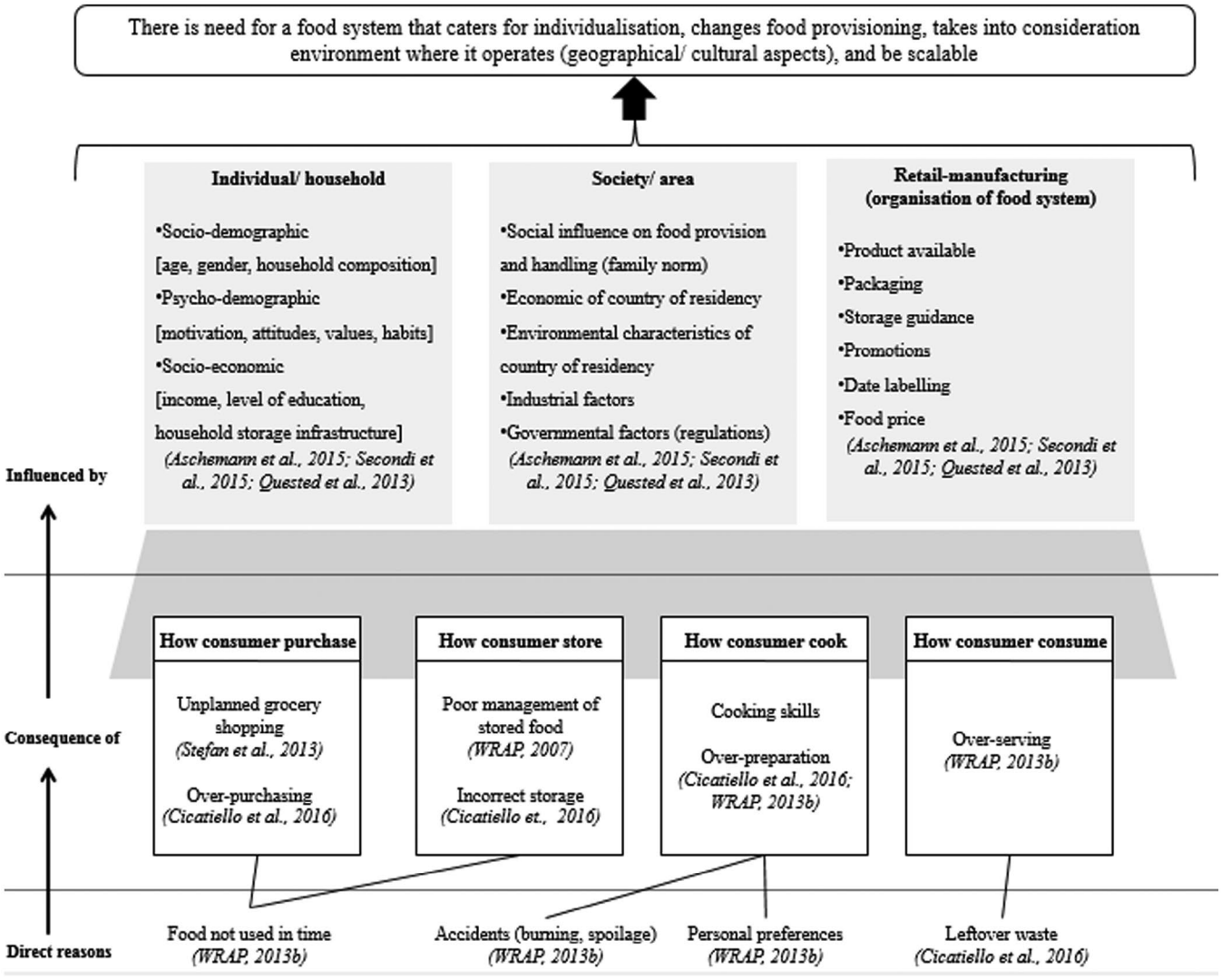

Figure 2. Research conceptual framework.

items by encouraging consumers to plan and shop for specific ingredients with meals in minds. Since LFHW launch in 2007, CFW in the UK reduced from 8.2 million tonnes in 2007 to 7.0 million tonnes in 2012 but then increased to 7.3 million tonnes in 2015 (WRAP 2017). Although the latest change from 2012 to 2015 is regarded as statistically insignificant (WRAP 2017), it can support the suggestion that the decrease in CFW from 2007 to 2012 was mainly due to price inflation and other economic factors and not solely to the effectiveness of the various engagement campaigns (WRAP 2013b).Thus, it can be argued that educating consumers is an important enabler to change their behaviour but is not enough to minimise CFW.

The existing solutions reviewed suggest that reduction of CFW can be achieved through actions that can either be taken by food providers or actions that can be taken by consumers which providers could support and facilitate as presented in Figure 3. It is also identified that the majority of developed or underdevelopment solutions encourage businesses to deploy communication, innovation, technology and policy-making to minimise CFW. Furthermore, it is observed that the majority of proposed solutions address the direct reasons for CFW and ignore the core issues previously discussed.

One potential approach to address food surplus issue is by improving the existing food provisioning system such that providers could work in partnership with consumers to develop smart, value-adding and targeted solutions. To achieve this, this research proposes to apply the PSS concept within a food waste context to design a more sustainable food provisioning system where CFW is prevented. PSS is defined by Mont (2004) as 'a system of products, services, networks of actors and supporting infrastructure that is developed to be competitive, satisfy customers and be more environmentally sound than traditional business models'. The most prominent case study where PSS concept has been applied within a food context is the ODIN project analysed by the pioneers of PSS Goedkoop et al. (1999). The aforementioned project's main aim was not to reduce CFW; however, it has led to environmental improvements via reduction of transportation and prevention of food loss at production level. Thus, these research main hypotheses are:

(a) Consumer food waste is a symptom of a complicated societal issue affected by inefficiencies related to the current conventional food provisioning system, and (b) developing and implementing a new product service food provisioning system will lead to a significant reduction of consumer food waste.

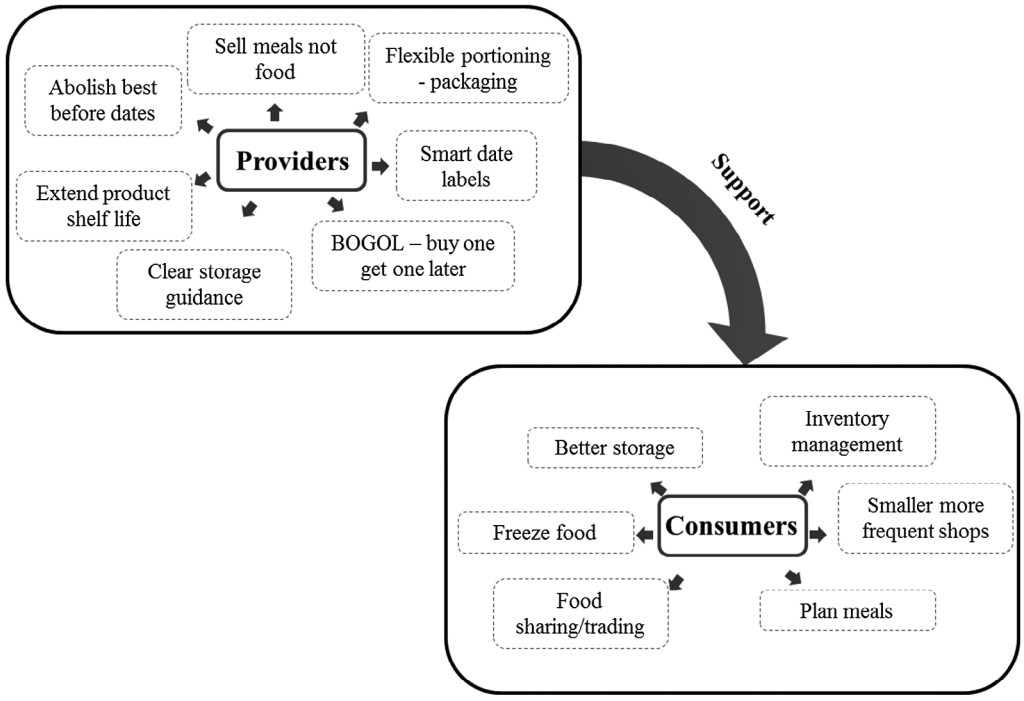

Figure 3. Examples of solutions that can be taken by providers and consumers to reduce CFW.

In order to investigate the aforementioned hypotheses, the following research questions should be addressed:

(1) How could the current food provisioning system be improved?
(2) What are the specific products, services and system attributes that manufacturers and retailers could adopt to influence consumer behaviour towards food waste?
(3) How could they be clustered to form a system?
(4) What are the changes required for single companies, supply chains and consumers to implement such a change? What is the design of this change (new system) from both production and consumption sides?
(5) How can the financial, economic and environmental benefits of this change be evaluated? Do the results of this evaluation verify the research hypothesis?

This paper is concerned with the first and second research questions.

3. Methods

The literature consists of several methodologies that support the design, development and implementation of PSSs. This research methodology is influenced by four major design methodologies aimed to support the design of PSS that would foster more sustainable consumption:

(1) MSDS: Methodology for system design for sustainability (Vezzoli, Kohtala, and Srinivasan 2014);
(2) MEPSS: Methodology for PSS development (Van Halen, Vezzoli, and Wimmer 2005);
(3) Sushouse methodology: Strategies towards the sustainable households (Quist et al. 2001); and
(4) SOPMF: Solution-oriented partnership methodological framework (Manzini, Collina, and Evans 2004).

The aforementioned methodologies have many similarities and some differences as shown in Table 1. Reviewing all these methodologies it is observed that the design and development of a PSS should include (a) project initiation and current system analysis, (b) brainstorming and general PSS concept design, (c) PSS detailed design, (d) PSS trial and assessment and (e) PSS implementation and realisation. As this project aims to improve the conventional provisioning system rather than create a new business entity that would foster more sustainable consumption, PSS implementation and realisation phase is not applicable. Thus, this research methodology consists of the following stages:

(1) *Current food provisioning system analysis:* Strategically analyse the current UK food provisioning system (from manufacturer to consumer, including also retail and logistics) in terms of its characteristics that lead to or encourage a reduction of CFW;
(2) *Identifying general PSS concepts:* Identify feasible opportunities for converting the food provisioning system into a PSS that could lead to reduced levels of CFW,
(3) *Refinement and selection of PSS:* Select PSS concepts based on economic and technological feasibility, user acceptability, and potential environment benefits;
(4) *PSS design:* Design (and demonstrate) the most promising PSS (from economic, environmental and social points of view) that facilitates an overall reduction of CFW; and
(5) *PSS assessment:* Evaluate the new PSS against the current food provisioning system in terms of CFW

Table 1. Reviewed system level design methodologies and current research methodology.

MSDS	MEPSS	Sushouse methodology	SOPMF	Current research methodology
(1)Strategic analysis (2)Exploring opportunities (3)Designing system concepts (4)Design and engineering the system	(1)Strategic analysis (2)Exploring opportunities (3)PSS idea development (4)PSS concept design (5)Development and implementation of PSS project	(1)Problem orientation (2)Stakeholder analysis and involvement (3)Stakeholder creativity workshop (4)Scenario construction (5)Scenario assessment (6)Back-casting workshop and stakeholder consultation (7)Realisation and implementation	(1)Solutions promoters identification and contexts-of-use exploration (2)Platform exploration (3)Platform development (4)Solution exploration	(1)Current food provisioning system analysis (2)Identifying general PSS concepts (3)Refinement and selection of PSS (4)PSS design (5)PSS assessment

reduction as well as other potential environmental, economic and social implications.

In order to meet the requirements of research questions 1 and 2 (Section 2), this paper is concerned with the first stage of this methodology and presents an assessment of the existing system in regard to its potential in supporting minimisation of CFW as well as exploration of customer needs in terms of support needed throughout the whole provisioning and consumption processes. This paper uses analysis tools included in the strategic analysis stage of the MSDS and MEPSS methodologies. The latter stages of the methodology will be presented in future manuscripts.

The strategic analysis stage is important in gathering necessary information that can support, feed in and facilitate the generation of possible system level innovations. This assessment is comprised of three processes of analyses selected and modified from MSDS and MEPSS methodologies. These processes are: stakeholder identification, current system and macro-trend analysis, and customer needs analysis, and have been used because they allow to assess the interest and influence of stakeholders in developing a new PSS, identify the current system capabilities in order to optimally utilise them in the design of the new PSS, and identify customers' needs that should be met in order to facilitate prevention of CFW. The content of these analyses is derived from the literature review and from discussions with a broad set of industry and third sector organisations, and the tools used to guide each of these three processes are presented in Table 2.

3.1. Stakeholder identification methodology

The first process of this stage was to identify the main actors and their respective motivations for changing the current provisioning system. Supported by information gathered from the literature review and discussions with business experts, a number of brainstorming workshops were organised to address the following questions:

Table 2. Processes and tools used to strategically analyse the current food provisioning system.

Process	Tool
Stakeholder identification	System map, Stakeholder prioritisation matrix
Current food provisioning system analysis	SWOT analysis
Customer needs analysis	Means-end chain analysis

Who are the stakeholders of the current system used by the consumer to acquire food?

Who should be the main actors of the new PSS?

Who could be the potential customers for the new PSS?

The identification of primary and secondary stakeholders that could play a role in reducing CFW was first conducted. Then, using the stakeholder prioritisation matrix, the main actors to be involved in PSS development were selected based on their interest and influence in changing consumer behaviour. As for the potential customers, a discussion was conducted whether focus should be on the whole market or just a niche market.

3.2. Methodology for current food provisioning system analysis

As argued in Section 2, the current food provisioning system is not efficient in terms of CFW prevention. However, it still has characteristics that present a potential for addressing this issue. Thus, a SWOT analysis was conducted to assess the current system environmental, economic, social and technological strengths and opportunities that could support the reduction of CFW. The current system dynamics and macro-trends were also analysed in relation to their capacity of forming an opportunity to prevent CFW.

Moreover, weaknesses of and threats (challenges) to the current system in relation to CFW minimisation were also investigated to identify the capabilities needed to improve the provisioning system. Under this angle, some challenges and weaknesses can be regarded as opportunities if they are addressed effectively.

3.3. Customer needs analysis methodology

The third process of the strategic analysis stage aims to analyse consumers' needs in terms of solutions that could enable them waste less food. The content of this analysis was mainly based on the investigation of reasons for CFW discussed in Section 2. This investigation helped in identifying services, products and support that need to be available to address CFW causes.

To guide this analysis, the means-end chain method is used which is a tool that enables the understanding of how consumers perceive the value of a certain product or a service, by clearly linking the product/service tangible and intangible attributes to their consequential benefits and eventually to their instrumental and terminal values. This tool has previously been adapted for

different uses and purposes where some studies used it to understand consumers values behind either 'wasting' or 'not wasting' behaviours in a foodservice context (Mirosa et al. 2016).

In this research, the means-end chain analysis is used to identify products, services and system attributes that could support consumers to purchase, store, prepare and consume food efficiently so that food waste is minimised. This is in addition to identifying solutions that could support the efficient utilisation of leftovers and the analysis of any waste created. This tool is also used to facilitate the generation of innovative sustainable PSS ideas and thus is regarded as a link between the current system analysis stage and the general PSS concepts identification stage.

4. Results

The results of the stakeholder identification, current food provisioning system and customer needs analyses are presented in the following sections. The significance of these results is also explored and discussed.

4.1. Actors identification

To identify the current system stakeholders that could participate in reducing CFW, a system map is developed (Figure 4) focusing on the actors that collaborate to provide consumers with food.

This exercise helped listing the stakeholders that need to be analysed, using the stakeholder prioritisation matrix, in terms of their potential contribution in developing and/or supporting the new PSS. The identified stakeholders include: consumers, retailers, manufacturers, logistics providers, primary producers, packaging manufactures, crop producers, local shops, market stalls and food subscriptions. Takeaways are excluded in this exercise as this research does not cover food operations happening in the food service and hospitality sector.

The stakeholder prioritisation matrix as presented in the MEPSS methodology by Van Halen, Vezzoli, and Wimmer (2005) has been modified for this research as the focus is not on one branded specific company, but the production–consumption system. Thus, the word stakeholder is replaced by system actor. Moreover, to help attain an objective classification of system actors, a score from 1 to 5 has been allocated to each party's influence and interest in developing the desired PSS. The scoring was guided by answering two main questions:

(1) To what extent does the actor influence decisions taken by consumers?
(2) To what extent is the actor interested in changing their business model/behaviour?

The first analysed actor is the consumer. Consumer interest is considered to be medium to high (score 4) because UK consumers

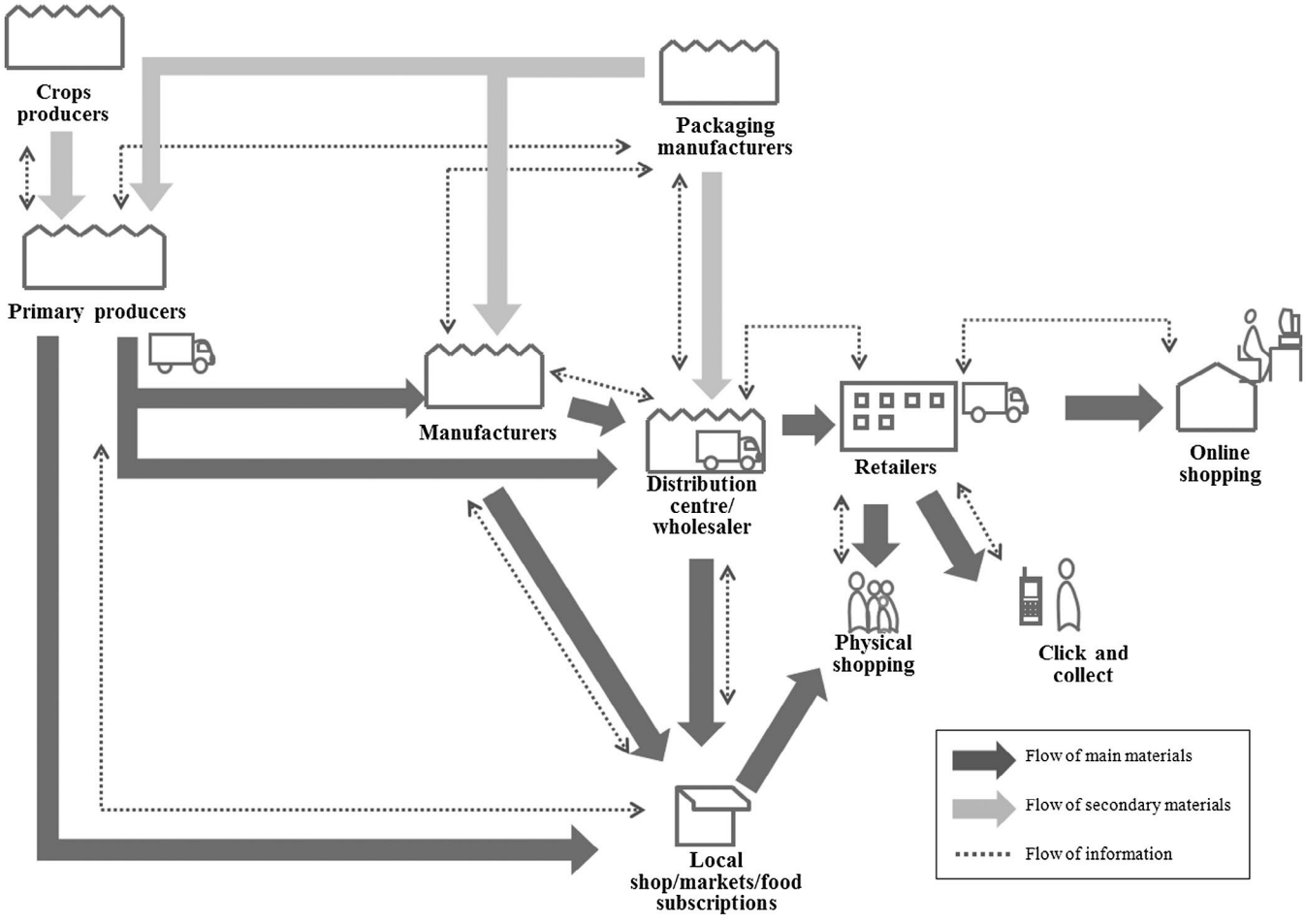

Figure 4. Current food provisioning system map.

are increasingly interested in reducing their food waste (67% make a great deal of effort to reduce food waste [WRAP 2007]). They are also demanding more convenience and better level of services in relation to their food provisioning operations. As for their influence, consumers are the ones generating food waste and therefore they are the ones who can take actions to prevent it. Moreover, in a service-based supply chain, consumers are able to play several roles that are normally assumed by manufacturers in traditional supply chains (Sampson and Spring 2012). They can be *suppliers* of information which helps manufacturers and retailers better understand their needs and therefore produce adequate offers that would prevent generation of waste. They can be *design engineers* or *production managers* by providing design specifications, directing and influencing the production of the final offer. Moreover, consumers can also assume the *quality assurance* function by measuring the offering quality through provision of feedback. Therefore, it can be argued that consumers can have a high influence (score 5) in the PSS development.

Retailers and manufactures are both believed to have a medium to high interest (score 4) in the PSS development as it could be an opportunity to increase their offering value. The PSS could also be an opportunity for these two actors to differentiate from the market fierce competition on low prices. Moreover, retailers' brand image could benefit from the PSS as there is an increase market demand on eco-friendly and socio-ethical products. Manufactures could also profit from the PSS as it would help them increase their production planning accuracy by closely collaborating with end-consumers which could lead to a reduction in their internal waste as seen in ODIN project (Goedkoop et al. 1999).

Regarding retailers and manufacturers influence in the PSS development, it is considered to be medium to high (score 4) and medium (score 3), respectively. Retailers are considered to be the chain managers since they are the system touchpoint. They also hold a powerful position as more than 70% of the UK grocery market share is controlled by only four big players (Tesco, Sainsbury's, Asda and Morrisons) (Kantar Worldpanel 2017). Furthermore, manufactures have the ability to produce innovative offers that could address consumers need and demand.

In this exercise, logistics are isolated from retail and manufacturing to emphasise their importance in the PSS development. Logistics here do not only refer to third-party logistics providers but to any actor performing this function whether it is outsourced or not. Due to their ability in facilitating interactions between all other actors, and their responsibility for managing the flow of products and services across the supply chain, logistics influence in PSS development is argued to be medium (score 3). Moreover, the new PSS might lead to an increased demand for logistics services, especially as the new system model would require a higher engagement with end consumers (interest score 4).

Primary producers and packaging manufacturers are considered to have medium influence (score 3) and low to medium interest (score 2) in the PSS development. The new PSS can be of interest to primary producers as it could improve their forecasting since they should be able to better understand the market demand. Producers could also contribute in the new PSS by providing advice on the product content of the offering. Furthermore, the new PSS might necessitate more variated (i.e. flexible portioning) and innovative (i.e. provision of cooking/storing guidance) packaging in order to provide consumers with high-quality and -personalised offerings.

Food subscriptions are an alternative way for consumers to acquire food. The organisations managing these schemes aim to satisfy consumers demand for convenience and quality food. Thus, the development of the desired PSS could be of medium to high interest (score 4) to these enterprises as it could pose a potential competition to their business or a possible business opportunity in case of collaboration with the conventional food providers. As for their influence, the existing food subscription schemes attract a niche market and thus, only influence behaviour of a relatively small group of consumers (score 1).

Regarding crop producers, local shops and market stalls, their interest and influence in the PSS development is agreed to be low (score 1) as it is outside of their business interest and expertise. Furthermore, although information and communication technology (ICT) does not have a physical role in the PSS, this research recognises its high importance in facilitating and enabling the integration of production and consumption. The above actors' influence-interest analysis is summarised in Tables 3 and 4, and Figure 5 presents the final prioritisation matrix where the dark-shaded areas refer to the primary system actors and the white areas refer to the secondary system actors. Based on this, the system map presented in Figure 4 is updated to draw system boundaries (Figure 6).

In relation to the potential customers for the new PSS, studies have shown that consumers waste food regardless of their age, social class, housing tenure, gender, etc. (WRAP 2007). Hence, at this stage of research, customers of the new PSS are believed to be the whole UK market. Moreover, as the ultimate benefit of the new PSS is to address individual needs and to provide targeted solutions, consideration will be taken to develop different satisfaction subsystems during stage 2 of this project.

4.2. Current food provisioning system analysis

The main tool used to analyse the current food provisioning system in terms of its potential to lead to a reduction of CFW was a SWOT analysis (Table 5). The objective of this analysis was to obtain an understanding of the system strengths that could be used in the new PSS, the different opportunities that the new system could exploit, as well as the weaknesses, threats and challenges that are facing the current system and which should be tackled within the new PSS. The focus of the SWOT analysis is on the primary stakeholders identified in Section 4.1 (manufacturers, retailers, logistics providers and consumers) and the newest available reports analysing food and drink industry (BIS 2010), food manufacturing sector (BDO 2016), grocery retail sector (IGD 2016a; PwC 2014; Retailthinkthank 2014), food logistics sector (IGD 2009) and consumers behavioural change (IGD 2016b; PwC 2014) are used. This is in addition to reports and researches analysing reasons for CFW discussed in Section 2.

The analysis shows that the current system already has many strengths that could be of benefit in reducing CFW. The main three strengths are: its ability for flexible production, its efficient delivery and its advancement in ICT. These three capabilities in addition to the changing consumer behaviour, where UK citizens demand more convenience, better service levels and

Table 3. System actors influence on PSS development.

	Influence on PSS development					To what extent does the actor influence decisions taken by consumers?
Actor	1	2	3	4	5	Note
Consumers					x	Consumers are the actors performing food operations at the household
Retailers				x		Retailers are the front office of the conventional food supply chain they influence consumers decisions by controlling product availability, promotions, retail environment, etc.
Manufacturers			x			Manufactures can influence consumer behaviour through food product design (e.g. portioning) and through their branded packaging by controlling what messages to display on the packaging
Logistics			x			Logistics manage the flow of products and services and enable retailers and manufacturers to get the right product to the right market at the right time while protecting products quality and optimising overall costs
Primary producers			x			Although primary producers have a great impact on food products availability, in the conventional supply chain they are managed by retailers and manufacturers. Thus, they are subject to these actors demands. Moreover, they can influence the product content of the offering
Packaging manufacturers			x			Although packaging providers have control over food packaging, they are bound by manufacturers and retailers specification. Moreover, using packaging, they can facilitate offering more flexible portioning and better targeted information
Food subscriptions	x					Food subscriptions are actors of the alternative food network, they have influence over a niche of consumers decisions (influence exists but not of a large scale)
Crop producers	x					Crop producers have little influence on decisions taken by consumers (i.e. purchase, storage, preparation, consumption)
Local shops	x					Local shops are actors of the alternative food network, they have some influence over a niche of consumers decisions (influence exists but not of a large scale)
Market stalls	x					Market stalls are actors of the alternative food network, they have some influence over a niche of consumers decisions (influence exists but not of a large scale)

Table 4. System actors interest in PSS development.

	Interest in PSS development					To what extent is the actor interested in changing their business model/behaviour?
Actor	1	2	3	4	5	Note
Consumers				x		Sixty-seven per cent of UK consumers make a great deal of effort to reduce food waste, they are also demanding more convenience and better service levels from retailers
Retailers				x		Retailers are continuously seeking to meet their customers demand, new PSS can form an opportunity to differentiate from competitors
Manufacturers				x		New PSS can form an opportunity to differentiate from competitors, it could also help in improving production planning accuracy
Logistics				x		With the increase of customer demand for online shopping and quick delivery, logistics are pushed to adapt their models to satisfy end-user needs
Primary producer		x				Primary producers are bound by retailers and manufacturers requirements and thus should change their models if needed, moreover, new model can improve primary producers forecasting accuracy
Packaging provider		x				Primary producers are bound by retailers and manufacturers requirements and thus should change their models if needed
Food subscription				x		Existing food subscriptions are mostly SMEs with business models that aim to satisfy consumers demand for convenience and comfort
Crop producers	x					Crop producers lack the capabilities to change their business model
Local shops	x					Local shops lack the capabilities and the investment capital to change their business model
Market stalls	x					Market stalls lack the capabilities and the investment capital to change their business model

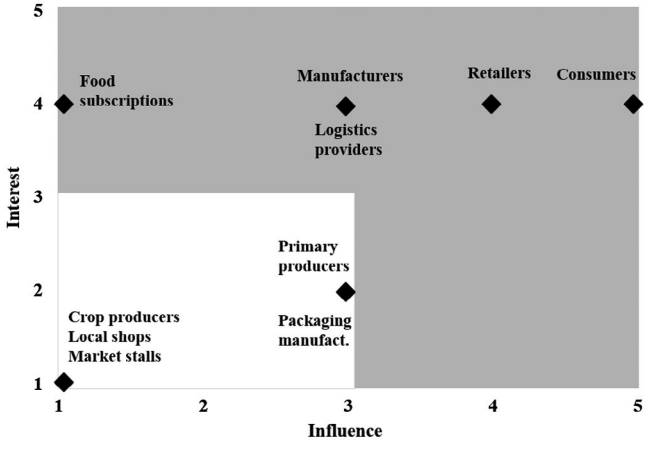

Figure 5. System actors prioritisation matrix. Source: Adapted from (Van Halen, Vezzoli, and Wimmer 2005).

more connectivity, can form a foundation for the development of the new PSS. Alternatively, despite its flexibility, the current system does not enable for personalisation. For instance, food portioning is very standardised and does not take into consideration individual needs. Moreover, technology in packaging, for example, is mainly driven by preserving food until first use, and similarly, ICT advances are mainly exploited within business-to-business contexts.

Therefore, it is clear that the current food provisioning system focuses on improving its industrial operations but there is not much focus on improving household operations. This means that the system is set up so that production and delivery run efficiently, but fails to consider if the operations carried out by consumers at household level are efficient. This gained insight could be summarised using Fisher's (1997) definition of supply chain.

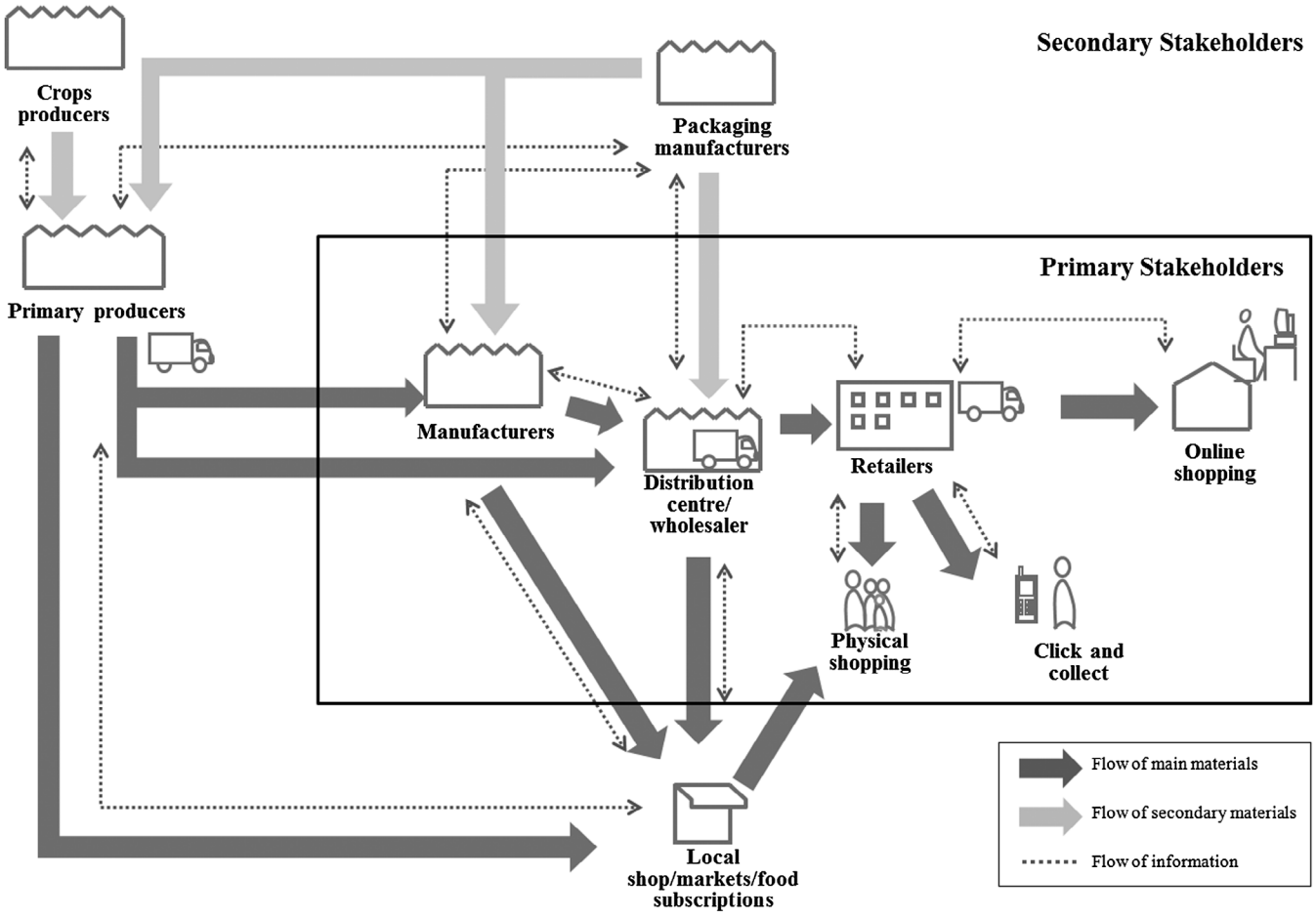

Figure 6. Current food provisioning system map with boundaries.

> A supply chain performs two distinct types of functions: a physical function and a market mediation function. A supply chain's physical function is readily apparent and includes converting raw materials into parts, components, and eventually finished goods, and transporting all of them from one point in the supply chain to the next. Less visible but equally important is market mediation, whose purpose is ensuring that the variety of products reaching the marketplace matches what consumers want to buy.

It can be argued that the current system has all the components that support the physical function of its supply chain in producing and delivering finished products to the customers, but it lacks the capabilities to support the market mediation function in producing what consumers want and need in terms of products and service that will facilitate the reduction of CFW.

This market mediation function could be improved through exploitation of the current system strengths. The system's ability for flexible production could be used to initiate the development of future smart factories that are capable of producing high-personalised offerings that meet specific consumer needs and demands in a manner that leads to CFW reduction. For instance, it is possible to foresee a system that is able to recognise consumers in terms of their lifestyle, household mix, preferences, etc. and adequately providing them with food packages that are specific to their needs in terms of portions, allergies, taste, etc. This high level of system efficiency would also benefit from the existing efficient distribution network and the Omni channel retail which is predicted to profit from more variety that should provide more options to different types of consumers. This is in addition to the support that the advanced ICT could provide from utilising big data to understand consumer behaviour, to facilitating real time information sharing among all actors of the supply chain (including consumers).

4.3. Customer needs analysis

To analyse customers' needs in terms of support that could enable customers to reduce CFW, the means-end chain analysis tool is used. This analysis is carried out based on the four stages of the food provisioning process where food waste generation or actions leading to food waste occur. These stages are purchasing, storage, preparation and consumption. A fifth stage 'post-consumption' is also added to enable for the waste generation analysis. Providing adequate support for these stages is believed to lead to the instrumental value which is 'eating while producing less waste'. This instrumental value is in turn believed to lead to the terminal values which are reducing environmental impact, saving money, supporting individual high self-esteem and supporting food security.

This analysis helped in identifying products, services and system attributes that can support consumer during the five aforementioned stages. For instance, a replenishment service providing remote access to household inventory (fridge and cupboards) in terms of what products are stored, their quantity and

Table 5. Current food provisioning system SWOT analysis.

Strengths	Weaknesses
Flexible manufacturing • Versatility of products • Modularisation of products	Food oversupply • 1/5 of food purchased is wasted (WRAP 2013b) • Retail environment/marketing/special offers designed to make consumers buy more
Efficient distribution network Excellent transport infrastructure	Functional supply chain • Standardised production • Standardised food portioning • Inaccurate Forecasting capability/Bullwhip effect
Omni channel retail • Internet shopping/ ordering • Consumer delivery service • % 81 of UK adults have smart phones (Deloitte 2016)	Relatively low prices makes food waste *affordable* Consumers adopting sustainable lifestyle are still a niche market
Connectivity, smart-phones Access to consumer data	Consumers lack food management skills • Seventy-nine per cent of avoidable CFW is due not being used in time or due to portioning issues (WRAP 2013b) • Little guidance on how to best store food and on how much to prepare
Big data analysis capability Real time information sharing across supply chain • Accurate Forecasting capability • Use of system management tools (WMS …)	Short available % of product shelf-life Consumers confusion/misunderstanding of date labels • Highly risk averse consumers • Poor date setting procedures (e.g. 10 day rule)
Few major retailers (more potential for impact) Quality food affordable for majority of UK consumers Increasing awareness/consciousness of sustainability among consumers Advances packaging technology % 93.4 of households with refrigerators (Hulme, Beaumont, and Summers 2013) Use of preservatives UK cool climate Great choice for consumers	Packaging technology focus on preserving food until first use
Opportunities	**Threats (challenges)**
Reduce CFW through • Innovation (e.g. offering suitable services) • Choice editing (e.g. cancelling out potential CFW at production stage) • Consumer engagement (e.g. engaging them in the offering design)	Increase in urbanisation/middle class Price war is damaging the sector
Increase offering value through offering services	• Decreasing perceived value of food • Increased popularity of discounters (i.e. Lidl and Aldi)
Smart factories • Just-in-time processing • High-value personalised products • Flexible production and delivery to address demand when it is made	Consumers chaotic/busy lifestyle Consumer reluctance to accept new offerings
Increased variety of retail channels • Emergence of drive-through supermarkets • Third party companies offer collective food picking and delivery	Cost of home delivery to consumers Inability to see the actual products discourages some consumers from shopping online
Consumers demand more convenience, better service levels, and more loyalty programmes Increase in top-up shops/Decline in weekly shop Emergence of food subscription companies Rise in food to go Courtauld 2025 Legislations and regulations can be demanding zero food waste in the future	Demand for choice to enable instant gratification Costs of online sales and home delivery model are still very high to businesses Cost of changing provisioning system Cyber-attacks, data privacy Skills shortage in food manufacturing • 109,000 new recruits needed by 2022 to fulfil industry needs (FDF 2016)
• An opportunity if business is proactive • Needs an intermediate mechanism	
Hypermarkets are becoming obsolete (use of these properties to support new system might be possible)	

their expiry dates can support consumers during their purchasing so that they only buy what they need in the quantity needed. Moreover, a service analysing the environmental impact and cost of the waste generated by consumers, could increase consumers' awareness of the amount of waste they generate, and support businesses better understand individual households' needs. The remaining results of this analysis are detailed in Figure 7. Furthermore, it is observed that many of these services, products and attributes are already developed, or under development, but they exist independently and are not within a system which could lead to synergies and an improved reduction of CFW. Thus, the challenge is to combine and integrate all these solutions and

organise all stakeholder interactions within a system that could enable the integration of production and consumption. The specific design of this system is what stage 3 of this research is concerned with.

5. Discussion

A review of the literature has suggested that CFW is a consequence of societal issues shaped by an inefficient retail-manufacturing system and influencing how consumers provision and handle food. This review revealed the need for a system level solution that will not only address the direct reasons for CFW but also the core issues driving it. Research hypotheses and questions were then formulated to investigate how this system level solution can be developed and how its effect on CFW generation could be assessed. This paper has focused on addressing the first and second research questions which aim to examine how the current food provisioning system could be improved and identify the products, services and attributes that would support food providers influence consumer behaviour.

Moreover, the literature review prompted the application of PSS thinking to the existing food provisioning system in order to effectively address the central reasons for CFW. PSS application has been proven to be, in many cases, environmentally, economically and socially beneficial. However, it is also accepted that adoption of such concept has some inherent risks: the traditional and transitional investment costs of the system, and the capabilities it will need to acquire in order to enable its transition from offering pure products to offering products and services.

In this research, aspects of a combination of existing methodologies have been adopted to strategically analyse the current food provisioning system. The methodology was modified so that analysis is focused on the production–consumption system rather than a single company. This strategic analysis has demonstrated that the current food provisioning system has many characteristics and potentials that can facilitate the reduction of CFW. However, its main weakness resides in its adoption of a standardised production system which fails to address individual needs and lifestyles. Moreover, means-end chain analysis of the existing food provisioning system revealed some 30 aspects that could support a reduction in CFW. This analysis indicates that through the adoption of a PSS, providers would be able to access information that could help them better understand consumer behaviour, and that consumers would have access to evidential information that could increase their awareness regarding the environmental impact of their purchasing and consumption behaviour.

Furthermore, the strategic analysis demonstrates that the generation of system level innovations could be deployed within a new PSS to achieve a minimisation of CFW. From an early vantage point, two potential PSS scenarios could be:

(a) Services that can offer supporting platforms to customer i.e. a PSS scenario where consumers are provided with ingredients that help make a meal at home. These ingredients are provided in adequate portions, are accompanied with cooking guidance and necessary tools to prevent generation of food waste. These ingredients could be either delivered or sold in physical stores; or

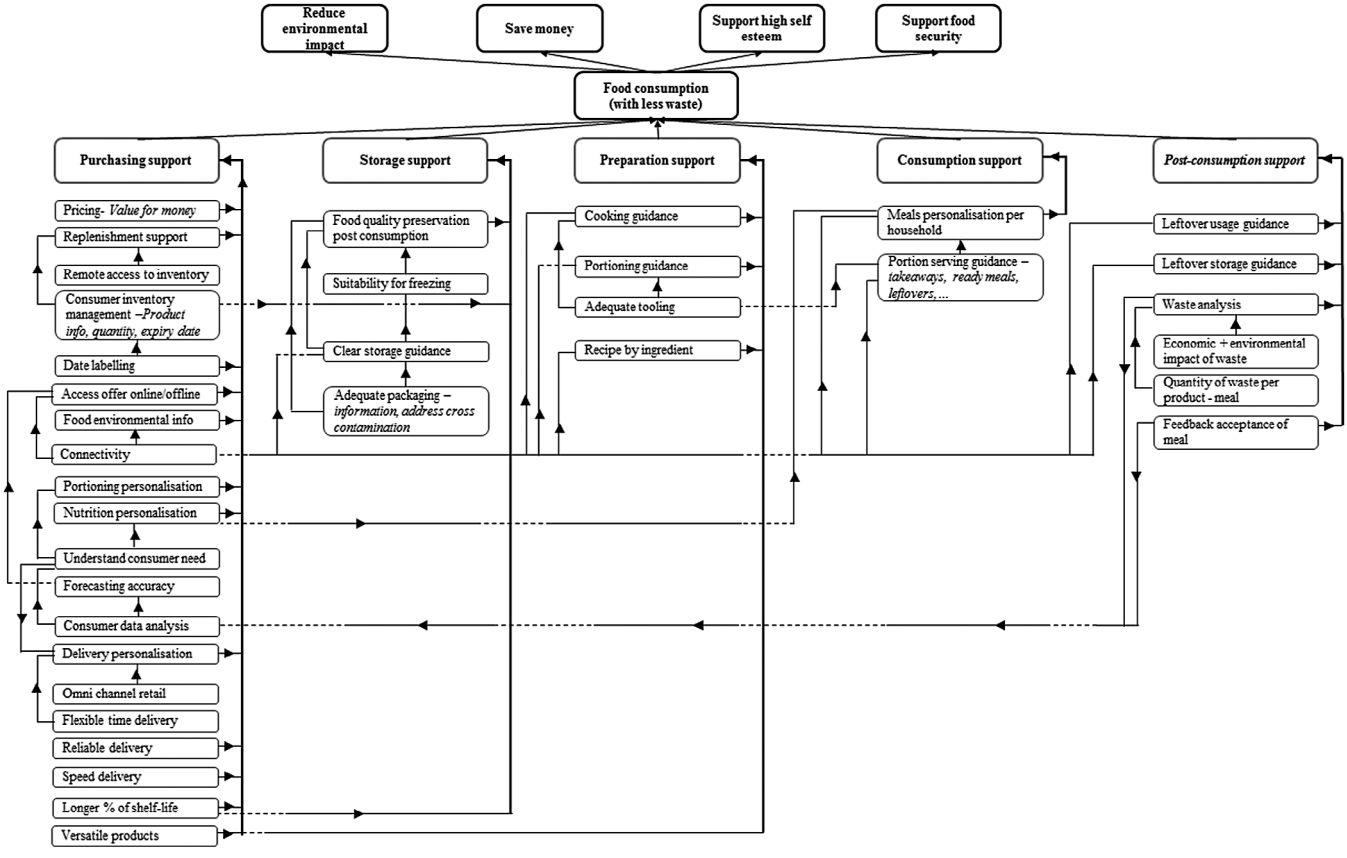

Figure 7. Means-end chain analysis to identify consumer needs.

(b) Services that can offer final results to consumers i.e. a PSS scenario where consumers are provided with chilled, frozen or warm ready-meals which are suitable for their taste and which are portioned adequately so food waste is prevented. These ready-meals could be either delivered or displayed in physical stores.

These two general scenarios are two of the three types of PSS discussed by Manzini and Vezzoli (2003). The next stage of the current research will seek to generate product service sub-systems where specific sub-satisfactions are identified and interactions between actors involved in these sub-satisfactions are defined. Once the most promising ideas are identified, variations of the MSDS, MEPSS, Sushouse methodology and SOPMF tools will be used to guide the actual design of these PSS and modification will be introduced to emphasis the role consumers should play in co-designing the final solutions. Moreover, discussions with key retailers and manufacturers will be conducted to closely investigate how the new PSS could be implemented in the real business world. What is clear is that a food provisioning system that inherently produces low levels of CFW is unlikely to be based on the transactional business approach now broadly adopted across much of the developed world. A minimisation of CFW is likely to require a more adaptive, bi-directional relationship between food providers and consumers. Such a change cannot happen overnight, but a long path of planning, implementation and acceptance is required.

6. Conclusions

This work has highlighted the importance of system level collaboration between actors, including manufacturers, retailers and consumers, in minimising CFW. It also discussed a major flaw in the current food provisioning system in that it focuses on improving operations until point of purchase, and thus, creating a disparity between production and consumption. To bridge this gap and enable food providers to support consumers at household level, the application of PSS concept to the existing system was proposed. A strategic analysis was conducted as a primary step in designing the potential PSS. The strategic analysis included an assessment of the existing food provisioning system in terms of its strengths and weakness in addressing CFW, and the identification of specific solutions that could support consumers waste less. The primary analyses demonstrated the applicability and potential feasibility of a PSS within the food waste context. Finally, this change is believed to support food providers to transition from being a pure economic entity to an organisation that uses profits as an outcome and facilitator of sustainable activities.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by the Engineering and Physical Sciences Research Council (EPSRC) UK [grant number EP/K030957/1].

Notes on contributors

Aicha Jellil MSc, BSc Research student. Interest Product Service Systems, Sustainable Comsumption.

Elliot Woolley MPhys, PhD Lecturer in Sustainable Manufacturing. Expertise: Energy Management and Modelling, Renewable Energy, Environmental Enterprise Resource Planning.

Shahin Rahimifard BSc MSc PhD CEng FIMechE FHEA Professor of Sustainable Engineering. Expertise: Sustainable Manufacturing, Sustainable Design, Automation in Remanufacturing/Reuse/Recycling, Business Models.

References

Adam, A. 2015. "Drivers of Food Waste and Policy Responses to the Issue: The Role of Retailers in Food Supply Chains." Accessed November 12, 2015. http://www.ipe-berlin.org/fileadmin/downloads/working_paper/ipe_working_paper_59.pdf/

Aschemann-Witzel, J., I. de Hooge, P. Amani, T. Bech-Larsen, and M. Oostindjer. 2015. "Consumer-related Food Waste: Causes and Potential for Action."*Sustainability* 7 (6): 6457–6477.

BDO. 2016. "The Food and Drink Report 2016." Accessed January 16, 2017. https://www.bdo.co.uk/en-gb/insights/industries/manufacturing/the-food-and-drink-report-2016/

BIS. 2010. "Manufacturing in the UK: An Economic Analysis of the Sector." Department for Business Innovation & Skills. Accessed January 14, 2017. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/31785/10-1333-manufacturing-in-the-UK-an-economic-analysis-of-the-sector.pdf/

Cicatiello, C., S. Franco, B. Pancino, and E. Blasi. 2016. "The Value of Food Waste: An Exploratory Study on Retailing." *Journal of Retailing and Consumer Services* 30: 96–104.

Deloitte. 2016. "There's No Place like Phone – Consumer Usage Patterns in the Era of Peak Smartphone: Global Mobile Consumer Survey 2016 UK Cut."Accessed February 19, 2017. https://www.deloitte.co.uk/mobileuk/assets/pdf/Deloitte-Mobile-Consumer-2016-There-is-no-place-like-phone.pdf/

European Commission. 2012. "Guidance on the Interpretation of Key Provisions of Directive 2008/98/EC on Waste." Accessed January 4, 2016. http://ec.europa.eu/environment/waste/framework/pdf/guidance_doc.pdf/

European Court of Auditors. 2016. "Combating Food Waste: An Opportunity for the EU to Improve the Resource-Efficiency of the Food Supply Chain." Accessed September 5, 2017. http://www.eca.europa.eu/

Evans, D. 2011. "Blaming the Consumer – Once Again: The Social and Material Contexts of Everyday Food Waste Practices in Some English Households." *Critical Public Health* 21 (4): 429–440.

Evans, D., and D. Welch. 2015. "Food Waste Transitions: Consumption, Retail and Collaboration towards a Sustainable Food System." Accessed February 3, 2016. http://www.sci.manchester.ac.uk/library/evans-d-welch-d-2015-food-waste-transitions-consumption-retail-and-collaboration-towards/

FDF. 2016. "Statistics at Glance." Accessed February 19, 2017. http://www.fdf.org.uk/statsataglance.aspx/

Fisher, M. L. 1997. "What is the Right Supply Chain for Your Product?" *Harvard Business Review* 75: 105–117.

Foster, C., K. Green, M. Bleda, P. Dewick, B. Evans, A. Flynn, and J. Mylan. 2006. *Environmental Impacts of Food Production and Consumption: A Report to the Department for Environment, Food and Rural Affairs. Manchester Business School*. London: Defra.

Garcia-Garcia, G., E. Woolley, S. Rahimifard, J. Colwill, R. White, and L. Needham. 2016. "A Methodology for Sustainable Management of Food Waste." *Waste and Biomass Valorization*: 1–19. doi:10.1007/s12649-016-9720-0.

Goedkoop, M., C. Van Halen, H. TeRiele, and P. Rommens. 1999. "Product Service Systems, Ecological and Economic Basics." Report for Dutch Ministries of Environment (VROM) and Economic Affairs

(EZ). Accessed March 1, 2016. http://teclim.ufba.br/jsf/indicadores/holan%20Product%20Service%20Systems%20main%20report.pdf/

Hulme, J., A. Beaumont, and C. Summers. 2013. "Energy Follow-up Survey – Report 9: Domestic Appliances, Cooking & Cooling Equipment." Accessed February 19, 2017. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/274778/9_Domestic_appliances__cooking_and_cooling_equipment.pdf/

IGD. 2009. "UK Food and Grocery Retail Logistics Overview." Accessed February 15, 2017. http://www.igd.com/Research/Supply-chain/UK-food–grocery-retail-logistics-overview/

IGD. 2016a. "What Will the UK Food and Grocery Market Look like by 2021?" Accessed February 11, 2017. http://www.igd.com/Research/Retail/Five-year-forecast-the-grocery-market-by-2021/

IGD. 2016b. "Consumer Engagement." *The Champions of Change Events 2016*.

Jedermann, R., M. Nicometo, I. Uysal, and W. Lang. 2014. "Reducing Food Losses by Intelligent Food Logistics." *Philosophical Transactions A* 372: 1–20.

Kantar Worldpanel. 2017. "Great Britain Grocery Market Share." Accessed January 29, 2017. https://www.kantarworldpanel.com/en/grocery-market-share/great-britain/

Kirtil, E., and M. Oztop. 2016. "Controlled and Modified Atmosphere Packaging." *In Reference Module in Food Science Elsevier*. doi:10.1016/B978-0-08-100596-5.03376-X.

Lang, T. 2013. "Food Waste is the Symptom, Not the Problem." *The Conversation*. Accessed February 2, 2017. https://theconversation.com/food-waste-is-the-symptom-not-the-problem-15432/

Manzini, E., L. Collina, and S. Evans. 2004. *Solution Oriented Partnership*. Cranfield: Cranfield University.

Manzini, E., and C. Vezzoli. 2003. "A Strategic Design Approach to Develop Sustainable Product Service Systems: Examples Taken from the 'Environmentally Friendly Innovation' Italian Prize." *Journal of Cleaner Production* 11 (8): 851–857.

Mirosa, M., H. Munro, E. Mangan-Walker, and D. Pearson. 2016. "Reducing Waste of Food Left on Plates." *British Food Journal* 118 (9): 2326–2343.

Monier, V., M. Shailendra, V. Escalon, C. O'Connor, T. Gibon, G. Anderson, M. Hortense, and H. Reisinger. 2010. "Preparatory Study on Food Waste across EU 27." European Commission (DG ENV) Directorate C-Industry. Accessed September 1, 2017. http://www.ec.europa.eu/environment/eudds/pdf/bio_foodwaste_report.pdf/

Mont, O. 2004. "Institutionalisation of Sustainable Consumption Patterns Based on Shared Use." *Ecological Economics* 50 (1–2): 135–153.

Principato, L., L. Secondi, and C. Pratesi. 2015. "Reducing Food Waste: An Investigation on the Behaviour of Italian Youths." *British Food Journal* 117 (2): 731–748.

PwC. 2014. "Front of the Line – How Grocers Can Get Ahead for the Future." Accessed January 24, 2017. http://www.pwc.com/us/en/advisory/customer/assets/grocery-customer-insights-global-experience-radar-2014.pdf/

Quested, T., E. Marsh, D. Stunell, and A. Parry. 2013. "Spaghetti Soup: The Complex World of Food Waste Behaviours." *Resources, Conservation and Recycling* 79: 43–51.

Quist, J., M. Knot, W. Young, K. Green, and P. Vergragt. 2001. "Strategies towards Sustainable Households Using Stakeholder Workshops and Scenarios." *International Journal of Sustainable Development* 4 (1): 75–89.

Retailthinkthank. 2014. "The Future of the Grocery Sector in the UK." Accessed January 21, 2017. http://www.retailthinktank.co.uk/app/uploads/2015/12/RTT_Whitepaper_2014_06_19_TheFutureOfTheGrocerySectorInTheUK.pdf/

Sampson, S., and M. Spring. 2012. "Customer Roles in Service Supply Chains and Opportunities for Innovation." *Journal of Supply Chain Management* 48 (4): 30–50.

Sand, C. K. 2015. "Decreasing Consumer-derived Food Waste." *Food Technology Magazine*. Accessed May 27, 2016. http://www.packagingtechnologyandresearch.com/decreasing-consumer-derived-food-waste.html/

Secondi, L., L. Principato, and T. Laureti. 2015. "Household Food Waste Behaviour in EU-27 Countries: A Multilevel Analysis." *Food Policy* 56: 25–40.

Smithers, R. 2016. "Tech Innovations That Could Reduce Food Waste." *The Guardian*. Accessed July 14, 2016. https://www.theguardian.com/business/2016/jul/14/tech-innovations-that-could-reduce-food-waste/

Stancu, V., P. Haugaard, and L. Lähteenmäki. 2016. "Determinants of Consumer Food Waste Behaviour: Two Routes to Food Waste." *Appetite* 96: 7–17.

Stefan, V., E. van Herpen, A. Tudoran, and L. Lähteenmäki. 2013. "Avoiding Food Waste by Romanian Consumers: The Importance of Planning and Shopping Routines." *Food Quality and Preference* 28: 375–381.

Van Halen, C., C. Vezzoli, and R. Wimmer. 2005. *Methodology for Product Service System Innovation: How to Develop Clean, Clever and Competitive Strategies in Companies*. Assen: Van Gorcum.

Vanham, D., F. Bouraoui, A. Leip, B. Grizzetti, and G. Bidoglio. 2015. "Lost Water and Nitrogen Resources due to EU Consumer Food Waste." *Environmental Research Letters* 10: 1–15.

Vezzoli, C., C. Kohtala, and A. Srinivasan. 2014. *Product-Service System Design for Sustainability*. Sheffield: Greenleaf Publishing Limited.

Woolley, E., G. Garcia-Garcia, R. Tseng, and S. Rahimifard. 2016. "Manufacturing Resilience via Inventory Management for Domestic Food Waste." *ProcediaCIRP* 40: 372–377.

WRAP. 2007. "Food Behaviour Consumer Research: Quantitative Phase." Accessed December 21, 2015. http://www.wrap.org.uk/sites/files/wrap/Food%20behaviour%20consumer%20research%20quantitative%20jun%202007.pdf/

WRAP. 2013a. "An Initial Assessment of the Environmental Impact of Grocery Products." Accessed February 16, 2016. http://www.wrap.org.uk/sites/files/wrap/An%20initial%20assessment%20of%20the%20environmental%20impact%20of%20grocery%20products%20final_0.pdf/

WRAP. 2013b. "Household Food and Drink Waste in the United Kingdom 2012."Accessed November 9, 2015. http://www.wrap.org.uk/sites/files/wrap/hhfdw-2012-main.pdf.pdf/

WRAP. 2014. "From Concept to Consumer – Preventing Food Waste in the Home – How Can You and Your Business Make an Impact?" Accessed January 8, 2016. https://partners.wrap.org.uk/assets/4083/

WRAP. 2015. "Introduction to Love Food Hate Waste Resource Pack." Accessed February 20, 2017. https://partners.wrap.org.uk/assets/3453/

WRAP. 2017. "Household Food Waste in the UK, 2015." Accessed January 15, 2017. http://www.wrap.org.uk/sites/files/wrap/Household_food_waste_in_the_UK_2015_Report.pdf

Zhang, C., A. Yin, R. Jiang, J. Rong, L. Dong, T. Zhao, L. Sun, J. Wang, X. Chen, and C. Yan. 2013. "Time–Temperature Indicator for Perishable Products Based on Kinetically Programmable Ag Overgrowth on Au Nanorods." *ACS Nano* 7: 4561–4568.