Food waste within global food systems

Global Food Security

Sustainable, healthy food for all

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Global Food Security Programme

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Preface

This report was commissioned by the UK's Global Food Security (GFS) programme to better understand the issues surrounding food waste in developing and developed countries, with a particular focus on understanding where new approaches and new research may be instrumental in reducing waste. The report is an independent assessment of the state of knowledge of the food waste area, and is aimed at all stakeholders involved in the programme. The findings of this research are to guide future research funding priorities, but do not represent the policy position of GFS partners. This report is underpinned by an extensive literature review, analysis of a survey circulated to a number of interested parties within the food system and over 40 consultations with GFS partner organisations and external stakeholders. The GFS secretariat would like to thank all who contributed to this report.

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Glossary

AD	Anaerobic digestion
BOGOF	'Buy one, get one free'
BRIC	Brazil, Russia, India & China
CO_2 (e)	Carbon dioxide (equivalent)
CPFR	Collaborative Planning, Forecasting and Replenishment
CRM	Customer relationship management
ECR	Efficient consumer response
FAO	Food and Agriculture Organisation of the United Nations
FEI/HEI	Further/Higher Education Institutes
GDP	Gross domestic product
IVC	In-vessel composting
kcal	Kilocalories
LCA	Life-cycle assessment
LFHW	Love Food Hate Waste
MDG	Millennium Development Goal
Mt	Million tonnes (Megatonne)
NGO	Non-Government Organisation
NHR	Non-host resistance
QoL	Quality of life
RD	Refuse derived fuel
RFID	Radio-frequency Identification
ROI	Return of investment
SIK	Swedish Institute for Food and Biotechnology
SME	Small & medium-sized enterprises
VMI	Vendor-managed inventory
WRAP	Waste & Resources Action Programme

Executive Summary

The global population exceeded seven billion people during 2011 and is predicted to reach 9.3bn by 2050, with a projected increased food demand of 50-70%. Against this backdrop of rising demand, 868 million people are chronically under-nourished, equating to one in eight people worldwide. At the same time, it is estimated that over one third of all food produced globally for human consumption goes to waste. In the UK, 5.6 million people live in deep poverty, where basic food provision is a daily challenge; yet at the same time, 15 million tonnes of food is wasted annually, with nearly half discarded within UK households. Therefore, reducing the scale of losses and waste throughout the entire food system is a crucial step towards improving global food security. This report provides an independent assessment of the issues around food waste in developing and developed countries and suggests a number of potential future research priorities across the food supply chain.

Variation in National wealth, across different countries, has a direct impact on capability in terms of capital infrastructure, technological adoption and a reliance on agricultural, manufacturing or knowledge economies. In developing countries, food is largely wasted at the pre and post-harvest stage, before the farm gate. Pre-harvest losses occur through significant yield and livestock losses, from a lack of resilience and control of natural assaults (biotic and abiotic stresses) characterised by basic agricultural inefficiencies and technological limitations. Post-harvest losses (PHLs) in developing countries are sizeable due to poor storage facilities and frequent infestation from rodents, pests and diseases. Dry and cold storage facilities provide farmers and growers with more market flexibility (e.g. not having to sell grain as soon as it is harvested) and economic benefit (e.g. reducing losses and improving overall produce quality). In developing countries, storage capability benefits are only possible when they are affordable and a general improvement in farm income occurs. A current evidence gap exists in understanding local, social and cultural drivers when establishing successful agri-tech schemes and how best practices may be more readily adopted.

In developed countries, current priorities are polarised between early production and late consumption stages. Agricultural priorities seek to advance farming competitiveness, to reduce in-field yield losses and to address retail grading practices. Technological priorities centre on extending product freshness and shelf-life by enhancing ripening characteristics, innovative storage, packaging solutions, process efficiencies and food supply chain efficiencies to bring food to consumers faster and with more available shelf-life.

The food and drinks industry in the UK is a major economic asset, with the agri-food sector collectively contributing over £89 billion to the national economy (7% GVA) and employing 14% of the UK workforce. At the production stage, agricultural losses of 15-20% are incurred through pests and disease, whilst retailer standards (e.g. size, shape and blemish criteria of fruit and vegetables) can reject up to 40% of edible produce (avoidable waste), which may never reach market. The UK food chain has been working to become more resource efficient, through a number of commitments (e.g. the Courtauld Commitment, the 5-fold ambition of the Food and Drink Federation, the Federation House Commitment and the British Retail Consortium's 'A better retailing climate'). Work is also being undertaken to reduce weather related losses through better forecasting, so that waste from harvesting crops at the wrong time and from inefficient supermarket stocking can be reduced. Grading standards are also being redefined, e.g. by marketing odd shapes and sizes of fruit and vegetables.

Within the UK post-production supply-chain, nearly one quarter of waste is generated during manufacturing processes, although this is largely the inedible (unavoidable) parts of produce. In contrast nearly three quarters of food waste occurs at the consumer stage; with two thirds of this being 'avoidable' waste, equalling a £11.8bn economic loss, at an average annual cost of £480 per household and £680 per family. Food losses from within distribution and retail average just 3% of total losses. Products most prone to household waste are short shelf-life chilled products (perishables), most frequently associated with over-purchasing and poor household food skills (e.g. cooking and storage). Whilst consumers generally value food, many are unaware of food levels discarded, although sizeable reductions of household waste have been achieved in recent years. Three primary factors guide consumer choices; price, convenience and quality with modern consumers spending proportionally less income on food and less time on food preparation than previous generations. Various mechanisms to reduce post-production food waste. These include, reducing pack sizes, considering the impact of in-store promotions (e.g. BOGOF), clarifying date labelling and targeting particular households at risk of producing larger quantities of

waste (i.e. households which are single person, lower economic status and families with children).

Currently, evidence gaps exist around how to nurture a social environment where consumers are nudged towards sustainable and healthy food choice, within a resource-constrained environment. There is a need for government agencies, NGOs and the food & drinks industry to engage with consumers to raise awareness and elicit change. Further research into the UK's position on food waste, health and sustainable societies requires continued investigation to unravel the complexities of human behaviours, perhaps over multiple generations. Research priorities and needs for waste reduction have been suggested in this report (see pages 17-19), supported by survey analysis and stakeholder consultation. Priority areas take into account the whole supply chain; from food production, through to food processing and retail.

Food waste within global food systems

This report provides an overview on the state of food waste in the context of global consumption, and explores in detail the challenges around reducing food waste within the UK. The aim of the report is to inform all stakeholders involved in the Global Food Security programme and identify key knowledge gaps and areas where research and innovation may particularly address the challenge of reducing waste. Part one provides an outline of food waste in the context of hunger and supply-chain capabilities within developing and developed countries. The major causes of food waste within the UK supply-chain are discussed in Part two, with a particular focus on UK households as a significant contributor. Part three proposes potential solutions which address the major challenges of food waste within food supply-chains, and Part four provides a forward-looking perspective into consumer behaviours and the UK food supply-chain.

Part one: Global food security and hunger

Introduction

The global population exceeded seven billion people during 2011 and is predicted to reach 9.3 bn by 2050. Alongside more mouths to feed, increasing economic development allows people to consume more, leading to a projected increased food demand of 50-70% by mid-century[1 2 3]. Reducing global food waste will have a significant part to play in increasing the availability of food in the future. The challenge is to fulfil rising consumption demands through an environmentally, economically and socially sustainable approach that provides safe and healthy food for all.

Against this backdrop of rising demand, 868 million people are chronically under-nourished, equating to one in eight people worldwide. At the same time, it is estimated that over one third of all food produced globally for human consumption goes to waste and one third of global grain is fed to cattle. In addition to population growth, increasing urbanisation and rising incomes compound the demand for diverse and resource-intensive foodstuffs, including greater meat and fish consumption[4 5]. Increasing demand for food, coupled with climate change, is increasingly pressurising global natural resources, including land, water, energy and fertiliser (e.g. phosphate) and the ecosystem services on which society relies[3]. Reducing the scale of losses and waste throughout the entire food system is therefore a step towards achieving global food security.

Global food security occurs "when all people at all times have access to sufficient, safe, nutritious food to maintain a healthy and active life"[6]. This aim needs to be addressed within an understanding of the total food system to allow the core principles of food security (i.e. access, availability and utilisation) to be considered alongside environmental, social, political and economic influences to ensure food security is sustainable. A food systems analysis captures inputs and outputs, processes and infrastructure factors throughout the supply-chains (including production and post-consumption) thereby allowing the full determination of impacts of wasted food to be quantified[7].

Food waste definitions

Food waste most commonly refers to edible food products, which are intended for the purposes of human consumption, but have instead been discarded, lost, degraded or consumed by pests, and does not include the inedible or undesirable portions of foodstuffs[a 3 8 9 10]. Food waste may be more finely classified as food loss when incurred during early phases of the food supply-chain, and as food waste within latter phases[11]. Food loss occurs in production, storage, transport, and processing, which are the stages of the value chain with the lowest returns. Conversely, food waste generated at the end of the supply-chain within retail and final consumption is synonymous with higher value-chain potential; but also represents higher costs when diverted away from human consumption[12].

[a] Numerous definitions have been constructed to accommodate differing perspectives of food waste debates, as cited in the references above.

Within the UK, it is common for a generic food waste term (including liquids) to be used, which encompasses all food and drinks discarded throughout the entire food supply-chain, from production through to post-consumption (as defined by WRAP). Additionally, food waste may be disaggregated into three forms of waste (Figure 1), which in contrast to alternative definitions includes the inedible portion of food (unavoidable waste), as well as food of personal preference (possibly avoidable) and edible waste (avoidable waste)[13 b]. Including inedible food waste into the definition is advantageous, because it enables a consideration of food waste infrastructure requirements to be taken (e.g. composting or anaerobic digestion), so that biodegradable waste can be diverted from landfill.

Figure 1: WRAP classification of Household waste.

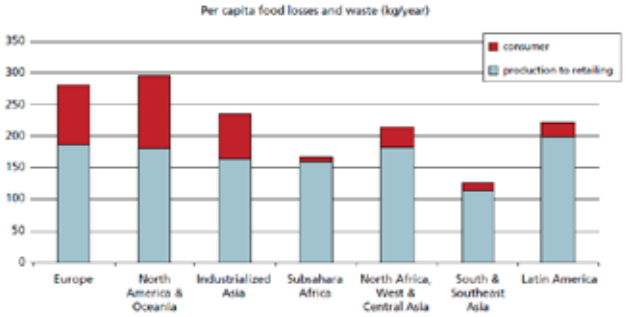
Source: WRAP (2009). Household Food and Drink Waste in the UK.

The above classification of food waste provides advantages when investigating patterns of food consumption and disposal in the UK, identifying potential value-adding channels of organic waste-streams and for more accurately determining the collective impacts of waste throughout the supply-chain and in landfill decomposition. The classification is largely relevant for the later stages of the food supply chain, post farm-gate. Economic and environmental costs are associated with input expenditure (e.g. water, energy, pesticides, fertilisers, seed or feed) and output impacts (e.g. processing, transport and landfill) which may be summarised as a carbon dioxide equivalent (CO_2e).

Greenhouse gas (GHG) emissions derived from total UK energy consumption is approaching 1 billion tonnes CO_2e annually[14]. Nearly one fifth of emissions may be attributed to the food and drinks sector, largely through agricultural outputs and imported goods[15 16]; although this figure may differ depending upon the particular methodologies used. Therefore, when considering the production, consumption and disposal of food, there are inseparable impacts on the environment; and consequently, the food systems concept is an appropriate tool in which to frame food waste.

[b] WRAP definitions for food waste (including drinks). Avoidable is food which prior to its disposal was edible. Possibly avoidable is food that can be eaten depending on personal preference (e.g. bread crusts) or by food preparation preference (e.g. potato skins). Unavoidable is waste that under normal conditions is not intended for human consumption (e.g. teabags, bones, eggshells). Reference 13.

Figure 2: Supply-chain food losses.



Source: Gustavsson et al (2011).

Global characteristics of food waste

Global food loss and waste is estimated at 1.3 billion tonnes annually across the food supply, equalling one third of global food production[17 18]. Data sources supporting the statistics for global food production are however sparse and estimates therefore need to be treated with a degree of caution. Surprisingly, the proportion of food not consumed within developing and developed nations is similar; albeit through very different channels. Of the one third global food wasted, a significant proportion (40% of total waste) is lost during early stage post-harvest and processing within developing countries; whilst conversely, in developed countries, an equally significant proportion is wasted during the latter stages of retail and consumption. These food losses are explored in relation to supply-chain characteristics and dietary intake. In highly developed countries, food waste is most prevalent during consumption, which also represents the highest point of value-chain potential for food types such as fresh fruit and vegetables (rather than grain) (Figure 2)[11 c].

[c] The international data presented in Gustavsson et al 2011 (Ref. 11) tabulates the extent of food loss and food waste along the supply chain, defined as: Agricultural production, Post-harvest handling & storage, Process & packaging, Distribution (supermarket retail) and Consumption.

An estimated 95-115kg of food waste is produced per person annually in developed regions, such as Europe and North America. In contrast, one tenth of this level of consumer food waste is generated within the low-income nations, especially Sub-Saharan Africa and South/Southeast Asia, at 6-11kg per capita annually[11]. However, these losses also reflect the differential susceptibilities of commodity groups along the supply-chain, and the different challenges faced by developing and developed nations; equalling average losses of 40-50% of all root crops, fruits & vegetables; and 20-30% of cereals, fish, meat, dairy and oilseeds[11 19 d].

An observed trend between developing and developed countries relates to increasing food intake (as dietary calories) and higher national economic growth (i.e. GDP/capita)1; there also exists the expanding transition economies in Europe, the former Soviet Union and Asia, which exhibit common characteristics between the two (Figure 3)[1 4 5].

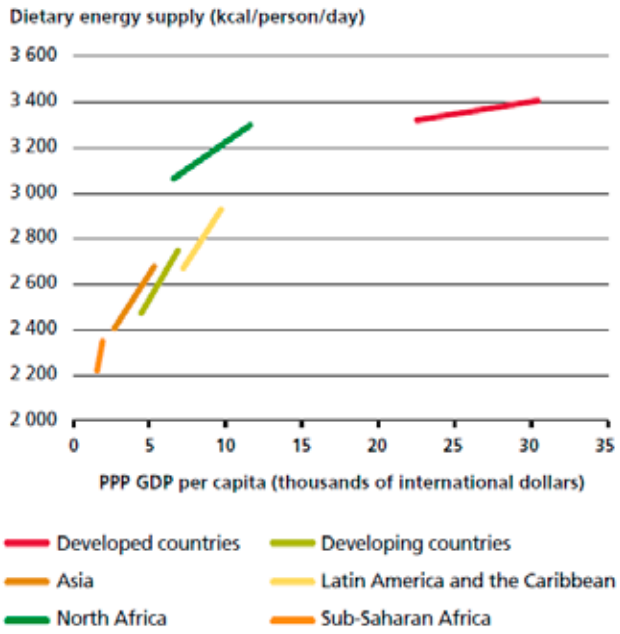
Low income countries are dominated by smallholder farmers, facing considerable challenges from harsh climates, inefficient agriculture (e.g. poor storage, hygiene and management practices) and fragmented supply-chains. Smallholders have limited access to information or trade with non-local food markets; however if market barriers such as access to market information or agricultural extension services can be overcome, innovation and the overall performance of farmers can be improved. Agriculture can act as a key driver in easing poverty for the world's poorest communities; a 1% increase in agricultural GDP generates a 6% increase in personal expenditure. Non-agricultural GDP meanwhile, fails to return any direct financial benefits to the poorest 10%[20 e].

Transition countries are countries which are changing from central planning, to free markets and are moving toward high national income status. Transition countries may be characterised by population growth, increased urbanisation, rising incomes and a dietary shift more inclusive of meat, fish and dairy. This cultural shift is accompanied by higher calorific intake towards a nutrition transition with preponderance towards obesity and wider health implications, as observed in the BRIC nations; especially Brazil and China[5]. This transition is also paralleled by greater food losses and waste, due to both infrastructural inadequacies and consumption excesses[21].

[d] Graphical outputs and datasets are presented in Annex 1, summarising the relative losses of these different food groups throughout the supply-chain.

[e] Agricultural GDP also provides a sliding-scale in increased expenditure to 4% for the 10-20% decile; and 3% for the 30-40% decile poor populations.

Figure 3: Demand for Food Consumption. (PPP = purchasing power parity).



Source: FAO, WFP & IFAD (2012)

High income countries possess supply-chains which are integrated and mechanised, albeit to differing capabilities. Even though these countries have a relatively high affordability for food (as a proportion of total income) these countries can still experience food insecurity. For example even today in the USA, 40% of food goes to waste at an economic cost of $165bn annually, whilst one in six citizens lack food security[22]. Within the EU27, nearly 90 million tonnes (Mt) of food waste was generated annually (2006 data) and in the UK, 5.6 million people live in deep poverty[23]. Food provision in the UK is an on-going challenge and 2 million people are affected by under-nutrition[20].

National wealth is the primary differentiator of the above national income types, reflecting capability differences in capital infrastructure, technological adoption and a reliance on agricultural, manufacturing or knowledge economies. Food insecurity diminishes further along this (value-adding) supply-chain. In terms of supply-chain development and food diverted away from human consumption, Table 1 provides indicative causes of food waste within developing and developed countries.

The shape and characteristics of food markets in the BRIC countries, affect food waste and losses. Brazil and China commonly adopt a supermarket driven supply chain, displaying characteristics more associated with developed countries (i.e. late stage food waste), although evidence suggests that losses do occur at the storage stage, as infrastructure development fails to respond to increased volumes of demand. Conversely in India, less than 1% of food is sold through supermarkets, with a high dependency on traditional wet markets and street vendors. India still lacks mature capital infrastructure and cohesive supply-chain capabilities, and therefore exhibits many of the traits more commonly observed for developing countries[24]. These examples demonstrate that when considering differences in food waste between nations, each system has advantages and disadvantages.

Pre and post-harvest losses before the farm gate significantly contribute to food wastage in developing countries[25]. Pre-harvest losses occur through significant yield and livestock losses from a lack of resilience and control of natural assaults (biotic and abiotic stresses)[26 f] characterised by basic agricultural inefficiencies and technological limitations. Post-harvest losses (PHLs) are sizeable due to poor storage facilities and frequent infestation from rodents, pests and diseases[27]. A lack of contiguous cold-chain, packaging, transportation and distribution networks all contribute to poor market access, thereby restricting opportunities to return investment and stability back into family smallholdings[10]. Methods to reduce PHLs in developing countries include more widespread education of farmers in the causes of PHLs, better infrastructure to connect smallholders to markets, more effective value chains that provide sufficient financial incentives at the producer level, opportunities to adopt collective marketing and better technologies supported by access to microcredit[28]. The extent, to which demands for higher quality produce from formal markets or traders can lead to reduced losses on the farm, is a potential area for future research[29]. It is expected that climate change will increase waste in post-harvest agriculture, because higher temperatures will lead to increased drying and fire risk of mature crops. There will also be greater losses from pests or diseases, both during production and storage[30].

For cereal grains, pulses and oil seeds, losses occur from grain scattering or deterioration caused by the activity of pests and micro-organisms, which themselves can be attributed to poor harvesting techniques, inadequate drying, poor threshing and inadequate transport and storage systems[31]. It has been estimated that the quantitative losses of cereal grains are 15-30% per annum[32] and the value of cereal grain quantity losses for the whole of sub-Saharan Africa amounts to about 4 billion US dollars per annum[33]. Further PHLs occur from root and tuber crops, which are susceptible to physical damage once harvested, because of their high moisture content and losses from fruit and vegetables. A survey in Ghana, put losses of onions and tomatoes at 13.6% and 30.4% respectively, whilst losses from mangoes reached 60%[34]. Processing (e.g. canning, freezing or drying) has been identified as a solution to post harvest losses of fresh fruit and vegetables.

[f] Abiotic stress is elicited from non-living factors (e.g. drought, salinity or toxic heavy metals), whilst biotic stresses are induced through living organisms (i.e. weeds, pests and diseases from: viruses, bacteria, fungi and insects).

Livestock products are highly perishable and can incur large losses in developing countries, especially when a cold chain is absent. Trekking animals to market may appear the cheapest way of transporting animals; however weight losses (estimated at 30% in Africa[35]) may make the method more expensive. Furthermore, inadequate care of the meat due to poor hygiene, high ambient temperatures and lack of refrigeration during and after slaughter can also lead to losses from spoilage due to mechanical damage, pathological damage caused by the invasion of bacteria and fungi and physiological deterioration due to ripening.

In the developed world, better forecasting of consumer demand and weather can reduce waste (e.g. if it is a hot summer, more tomatoes may be needed which should be planted in early spring; if it is a wet summer, much of what has been grown will not sell) (Table 1). For the developing world, the issue between matching demand and supply is less acute. Better weather forecasting at the seasonal level, allows farmers to have prior knowledge about when to plant successfully, so that crops can go all the way through and reduce pre-harvest losses.

Whilst food insecurity exists within population sub-groups of developed countries, the majority of food wasted occurs during the late supply-chain stage of (household) consumption (Table 1). This is coupled with substantial quantities of edible goods being rejected during primary production, through contractual constraints (i.e. over-production contingencies) or by retail grading of fruit and vegetables in higher income countries (see sections 'Retail-driven food production losses' and 'Retail supply chains' for further details). Once food goods enter the post-production supply-chain, relatively low levels of avoidable food waste are amassed, and even within manufacturing processes the majority of waste generated are the inedible portions of foodstuffs (unavoidable waste)[36].

A key aspect of food waste generation also lies within retail provision (and consumer choice), where the most compelling retail driver and competitive advantage is to maintain stock availability and provision of food commodities throughout the year. This modern day supply-chain generates food waste through the culmination of forecasting inaccuracies, product-gradings, over-production and a push of promotions (and potential waste) onto consumer households[12 36]. Retail promotions are an established part of the retail - consumer interface and are currently running at historically high rates, because of declining grocery sales leading to competition for market shares. Some retail promotions offer good value for money, with little change in food waste (e.g. on non-perishable products), whilst other promotions (like BOGOF's on perishable food items) can lead to more food waste, if not accompanied by good storage or preparation advice on recipe ideas. These drivers of food waste are explored further in Part two, specifically in context of the UK food supply-chain and consumerism.

Table 1: Typical causes for food waste arising within developing and developed countries. Sources: Sampled from references cited.

Developing countries	Developed countries
+ Pre-harvest losses: Extreme weather, pests, disease & weeds, less resilient crop varieties, poor soil quality and water shortages. + Agricultural production: weather effects, poor agricultural practices (e.g. tilling, continuous flood irrigation etc.). Technological limitations, often from manual farming with traditional implements, although increasingly with some level of crude mechanisation. + Labour limitations: Many women and children farmers miss educational opportunities when working in the field. High incidences of ill-health (e.g. HIV/AIDS) can also lead to labour shortages, especially at peak harvesting times. + High animal mortality rates: Poor animal welfare standards and high occurrence of disease (e.g. mastitis) which lowers productivity and potential market opportunities. + Early harvesting: Forced through weather conditions, alleviating hunger and financial constraints. Early harvest results in lower nutritional foods and lower returns on selling goods. + Post-harvest handling: Inefficient use of traditional and crude processes, for example: threshing, drying and winnowing practices. Poor or non-existent transit packaging and staff training in pack houses, lead to increased rates of product damage (e.g. through the crushing and bruising or produce). + Post-harvest storage: Losses from spillage or spoilage (pests and diseases) and foraging losses by birds and rodents etc. + Lack of physical infrastructure: Especially important in harsh climates. Poor storage and distribution facilities including cold-chain apparatus. + Processing facilities: Low number of processing facilities, which limits scale of produce to be processed (i.e. higher value-chain) and preserved (shelf-life extension). Inadequate storage facilities affect food supply chains and networks. + Market networks: Distribution and market networks (e.g. too few wholesale, supermarket and retail outlets). Transport infrastructure, power supply and storage infrastructure (e.g. cold chain) affect food supply chains, networks and waste levels. Further problems include, poor information exchange between growers & markets, lack of grading of what's sent to market, lack of price differentiation of quality, markets not functioning well for small holders, because of too many middlemen. + Low Private sector investment: Private sector has ability to provide sustained market access and supply-chain capabilities - including distribution, processing, preservation and market networks.	+ Demand Forecasting: At the retailer end and at the growing stage is inherently complex and inaccurate, affected by seasonality, weather, time lag in crop production, marketing campaigns, product launches and special occasions/events leading to highly unpredictable demand. Sales channels are also becoming increasingly complex (e.g. in-store and online sales). + Pre-harvest losses: Climate change is likely to increase the prevalence of severe weather and certain pests, disease & weeds in crop varieties and animal breeds which have been chosen for yield rather than resilience or resistance. + Mechanisation: Losses attributed to farming practices and machine inefficiencies. + Over-production: For farmers to meet contractual obligations, an excess in yield is forecast to serve as contingency – but may not reach market. + Storage: Losses from insects, microbial spoilage, shrinkage and storage failures (cold-chain, modified atmospheres etc.). + High retail grading standards. Produce which does not meet strict quality standards relating to appearance, weight, size, colour and shape may be rejected, often being diverted as animal feed or even ploughed back into the ground. + Food trimming: Excessive waste from automated or manual trimming. Additional processor errors. Processed food often requires additional packaging and assigned retailer date labels (unlike many unprocessed produce). + Poor handling: Packaging failures, spillages, product damage and cold-chain efficiencies. + Supply-chain: Shrinkage, product recalls, packaging changes, labelling errors, cold-chain failures, contamination. + Retailers: Forecasting, out-grading standards, delivery rejections, poor stock rotation, promotions management. + Fast-food time limits: Commercial outlets set 'standing' timelines after which cooked food must be discarded if not sold. These timelines can be short (e.g. 10-20 minutes). + Consumers: Affordability, attitudes, behaviours, choice, promotions, date labelling, food safety concerns, poor shelf life of fresh products after purchase. + Household practices: Portion sizes, discarding leftovers, poor meal planning and cooking abilities, low awareness of food handling or safety and optimal storage (including correct storage options, refrigeration maintenance or freezing practices).

Part two: Food waste in the UK

This section draws out the main characteristics of the UK food and drinks sector and provides an insight into the major causes of food waste generation, metaphorically walking through the food chain from farm to fork. In the UK, the highest levels of food waste are generated during primary production and during the latter supply-chain stage of consumption, in part influenced by retailer practices which resonate throughout the entire food supply-chain and consumer attitudes and behaviours.

Structure of the UK food supply-chain

The food and drinks industry is a major economic asset to the UK, being the largest manufacturing sector in the country, and 4th largest globally. The agri-food sector collectively contributes over £89 billion to the national economy (7% GVA) and employs 14% of the UK workforce. UK consumers spend £179bn on food and drink annually, with over £100bn purchased from retail outlets[15]; and nearly three-quarters from 'the Big Four' supermarkets[37 38]. Despite the on-going economic challenges, total expenditure within this sector within recent years has sustained continued growth[15 39], although once inflation is taken into account, this growth is minimal.

The structure of the UK food supply-chain is comprised of a small number of multi-national corporations (e.g. Nestlé, Coca Cola) and a 'long tail' of smaller businesses (SMEs). This is an intensely competitive sector, characterised by high levels of new businesses (and business losses), new products and low profit margins[38]. As a consequence, there is a barrier to long-term capital investment for many businesses[40 g]. Daily challenges faced by many of these businesses include processing non-uniform goods (e.g. fruit & vegetables) and inefficient process switchovers between multiple product ranges[41]. As a result, the sector is not readily suited to advanced automated supply-chain systems compared to other major sectors (e.g. automotive) and consequently, the sector has tolerated high levels of waste (food, water, packaging and energy) to remain competitive within national and global markets[38 42 43].

The UK food chain is working to become more resource efficient through a number of commitments. The Courtauld Commitment was launched in 2005 and is a voluntary commitment, aiming to improve resource efficiency and reduce the carbon and wider environmental impact of the grocery sector[44]. In 2007, the Food and Drink Federation (FDF) established their 5-fold ambition, which has had a role in helping FDF members to drive improved environmental performance in their businesses[45]. The Federation House Commitment aims to reduce overall water usage across the Food and Drink sector by 20% by the year 2020[46] and the British Retail Consortium's (BRC) 'A better retailing climate' has established a set of climate goals, which respond to the threat of climate change in both the operations of their members and those of their suppliers and customers[47].

Food waste within primary production

Agricultural production is challenged by relative extremes in weather conditions and a host of pests and diseases. In the UK, agriculture is largely committed to meeting the quality standards of major supermarket retailers, export markets and the hospitality & food service sector. These quality standards can lead to edible food not entering the human food supply chain, reducing the amount of food available for human consumption, and therefore acting as a form of food waste. The following section explores these factors in greater detail and presents steps which can be used to address them.

[g] As a more detailed guide to food waste and process inefficiencies within the UK food supply-chain, a series of sector maps have been produced for drinks (Ref :41), meat (43), fruit & vegetables (56) and fish and shellfish (57).[a resource map for pre-prepared foods has also been completed].

Weather related food losses

Severe weather events (e.g. extremes in temperature, rainfall or wind) are expected to increase in frequency in the future[48]. During 2012, some areas of the UK had extremes of both drought and rainfall and were described as experiencing "the wettest drought ever"[49]. Agricultural productivity was highly impacted with yield reductions in the order of 25% (e.g. for potato and apples), whilst the UK's main cereal crop of wheat witnessed yields more typical of three decades ago (down 15%) and all incurring consequential price rises[50]. More recently, the severe snows in March 2013 resulted in extraordinary levels of livestock mortalities, with English, Scottish and Welsh sheep losses in April more than 50% higher in 2013 than in 2012; this was equivalent to 35,000 additional lives[51].The UK Met Office is currently working with major retailers to mitigate the effects of severe weather events in the future. Various lead times are being used to help optimise the food supply chain and realise reductions in waste through inappropriate lifting of crops and supermarket stocking.

Agricultural losses attributed to weeds, pests & disease within the UK (and Northwest Europe) are still substantial at 15-20% of expected yield (although variability in losses does occur across crops); but these losses are the lowest globally compared to over one third in other industrialised regions and over half in developing countries[52]. Livestock and fisheries are also affected by a host of endemic and exotic diseases, which affect productivity and mortality rates. Over the last decade, the UK has endured over 14 exotic disease outbreaks (from Avian flu to Bluetongue)[53] with Schmallenberg virus (SBV) being the most recent arrival to affect livestock in 2011[54].

Retail-driven food production losses

The main UK retailers have a large impact on UK farming production practices, by providing advice, investment and contracts for produce. Contractual obligations can include "On Time In Ful" contracts, which require farmers to have produce available at a specified time and with a predefined amount. This practice encourages contingency planning by farmers to ensure yield agreements are met; if the farmer is tied into an exclusivity deal, excess goods may result from there being few alternative markets for selling the surplus[55].

In addition, consumers consistently demand high quality produce, and retailers respond to this need through applying stringent product grading standards. However, such criteria can result in rejected goods affecting up to 40% of total yields, and in the absence of alternative markets, sub-standard but still edible produce is redirected as animal feed or simply ploughed back into the ground[24 56]. Whilst overseas suppliers are also subject to stringent criteria for UK markets, international suppliers utilise multiple market options to channel differing standards of goods, whereas many UK farmers are contracted to the big retailers with few alternate market options for residual goods. In an examination of the sustainability of European food supply chains, Defra deemed such high grading standards to be unsustainable[55] and some progress being made with retailers marketing "odd shapes and sizes" for fruit and vegetables, to minimise waste. There is also a growing body of evidence that more UK consumers are prepared to accept, so called 'ugly' fruit and vegetables, because of sustainability and also food price inflation concerns.

Post-production food waste

Following primary production, food produce enters the post-farm gate supply-chain either for distribution as final products (e.g. fresh goods) or via manufacturing supply-chains[41 43 56 57 58]. During manufacturing, foodstuffs undergo one of a whole range of procedures from basic primary processing (e.g. milling, animal slaughter) through to multiple complex process (and logistics) stages in the preparation of ready meals for example. These finalised products are then distributed to consumer retail outlets or to the hospitality and food service sectors[15]. A Defra commissioned study[59] identified a need for research to improve raw material quality (e.g. crop plant breeding) to support processing needs, to meet consumer demand and to meet the challenges posed by land use constraints, resources and the impact of climate change. Further detail about this report may be found in Annex 3.

Retail supply-chains

Businesses may not be aware of the costs of food waste within production processes, because management focus is instead on yields and increasing sales. Furthermore, the industry has sometimes tolerated waste as a supply-chain by-product, in order to secure sectoral competitive advantage and profit. Business practices between suppliers and retailers (pre-consumption) allows waste generation through three causal factors; relating to management practices, product integrity (e.g. quality and packaging) and environmental & consumer influences[38]. Central to the generation of food waste within the commercial supply-chain is the dynamic relationship between retail management practices and consumer demands and influence, as discussed within the context of research priorities (Part two).

Management practices are often culturally embedded across the industry which focuses on maintaining replenished retail shelves to attract high consumer satisfaction and long-term loyalty[38 60]. This constant supply-chain push leads to food waste generation; in part, driven by corporate penalties relating to sales and availability targets. As a consequence, perhaps the largest challenge for retail management is forecasting demand and inventory management to ensure appropriate levels of stock rotation to maximise sales whilst minimising waste. Product forecasting still proves highly problematic for retailers and this 'inaccurate science' is further complicated by the seasonality of goods, weather patterns, consumer trends and calendar events, from designated holidays to sporting fixtures and national events[38].

Commercial food supply-chains are viewed as inefficient compared to other manufacturing sectors, because manufacturing processes generate nearly one quarter of all food waste (post-production to consumption). The majority of this waste is inedible (unavoidable) components, such as peelings, offcuts, stones, shells etc. and the amount depends upon whether by-products are sent animal feed or alternative outlets. Distribution and retail generate proportionately low levels of food waste (just 3% of total), but this still amounts to 366,000 tonnes per annum[61]. The economic value of finished goods from distribution and retail is high, so their loss and waste may significantly affect the profitability of the sector. The process by which food waste is amassed and potential preventative initiatives behind food waste are discussed below.

Food waste during consumption

Food consumption patterns can be differentiated between food that is consumed within households and food consumed away from the home (i.e. the hospitality sector) (Figure 4). In total, UK households create over 7Mt of food waste annually, and combined with the hospitality sector; the stage of intended consumption accounts for half of all food waste (post-production)[15].

Hospitality and food service sectors

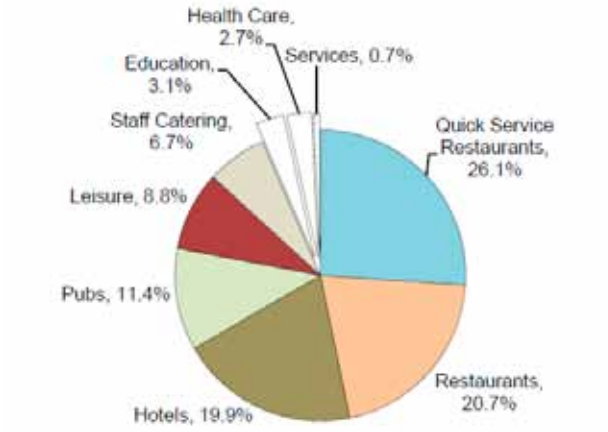
Nearly £80bn is spent on food goods purchased through external services (profit and cost sectors)[h]. Initial findings indicate that the four major hospitality

[h] The profit sector comprises of businesses primarily trading in catering and or accommodation services with the objective to maximise profits, with the four largest market outlets of: quick service restaurants (QSRs), restaurants, hotels and pubs. The profit sector also includes guesthouses, bed & breakfast establishments and youth hostels.

The cost sector differs in that hospitality is not the primary function; and profit is not the main driver, whereby service provision is the over-riding objective; these include: catering and accommodation services within the premises of schools, hospitals, prisons, military facilities etc.

segments generate 0.4Mt avoidable food waste that enters landfill; at an economic loss of £722m annually[62] (as illustrated, Figure 4). A WRAP-operated Hospitality and Food Service voluntary agreement has been initiated to support the sector in recycling and reducing waste. Further research is required in this area, because eating out is becoming increasingly popular and the current evidence base for the scale of waste produced across this sector is small[63 64 65].

Figure 4: Public sector food procurement and sales of food and drink in the UK food service sector, 2011.



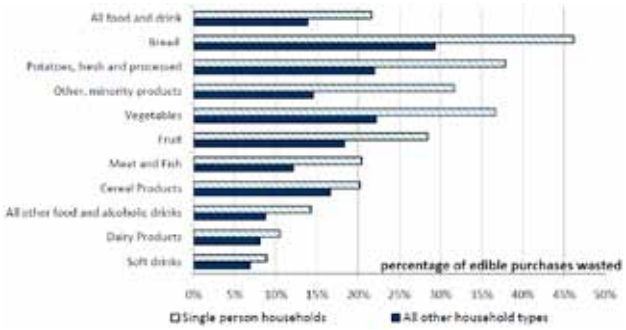
Source: Defra (2013). Food Statistics Pocketbook 2012

Household food waste

In contrast, patterns of food waste within UK households are well documented. Collectively, 38Mt of food and drink enter UK homes each year, of which nearly one fifth is discarded. This translates into a £12bn annual food surplus, costing £480 per average household[66 i] and £680 for family households[67]. On average, households amass over 5kg total food waste weekly with nearly two thirds being avoidable waste[68], from cooking, preparing or serving too much or more commonly by food not eaten in time (following definitions ascribed in Figure 1)[13], the characteristics of which, are: Cooking, preparing or serving too much food; or over-portioning, contributes to over 40% of household food waste which often reflects excessive pack sizes of goods especially for smaller households. Whilst smaller pack sizes are available at a premium, price is the prevailing driver in purchasing decisions[69]. Similarly, shoppers are highly influenced by in-store promotions and because many of these products are perishable. If they are not frozen for storage, many households experience increased pressure to consume more food within a shorter period of time.

Food not used in time is linked to modern lifestyles, which do not promote prior planning of when food should be bought and eaten. Furthermore, research has indicated that product date-labelling is a prominent factor in food disposal decisions[70 71]. Over recent years, product date formats have been simplified and consumer awareness grown; although the benefits of product packaging and optimum storage conditions remain common household barriers contributing to unnecessary food waste[70 72].

Figure 5: Percentage of edible purchases wasted by single person households compared to average households.



Source: Defra (2013). Food Statistics Pocketbook 2012.

These channels of waste may also be aligned to distinct population sub-groups[68]. Households which typically generate the least food waste are the elderly and professional social classes. Possible reasons why the elderly generate the least waste individually include a 'wartime mentality' towards food[73] and the effect of inflation on savings and pensions. Households which generate more waste per person are often those of families with children, younger households or lower social class households; whilst single-person households generate the most waste (Figure 5)[68 74]. The current economic climate is also providing all households with an incentive for avoiding food waste and making purchases go further.

[i] Office for National Statistics data (derived from 2011 Census) calculated national average UK household size as 2.35 people (Ref: 66).

Younger -person households appear unprepared and inexperienced in managing food within their homes. Individuals are less likely to check stocks prior to shopping and are less familiar with food storage. Single person households are also challenged by pack sizes and BOGOF retail promotions, which are frequently less suited to individual meal preparation compared to multiple households and families[73]. These combined factors culminate in high levels of food waste, making younger and single-person households a desired sub-group to explore behavioural changes towards better food management. Consideration should be given to ensuring that smaller sizes of products are made consistently cheaper (per unit mass or volume), than larger-volume products.

Not only does Figure 5 illustrate the scale of food waste, but it also provides a snapshot of the types of foodstuffs being wasted by all households. Typically, products most prone to waste are the short shelf-life chilled products (perishable and delicate goods) especially bakery goods[75] and fruits & vegetables[13 38 56 74]. In addition, large quantities of drinks which are disposed of down the drain are often not readily associated with food waste[76]. Whilst ready meals are not discarded at such excessive levels, their high economic value contributes to one fifth of wasted food budgets. Single person households are the largest consumers of chilled pre-prepared foods, such as ready meals which frequently have short expiry dates and are thus, highly prone to wastage. Within these waste-streams, there is a reciprocal trend of commodity prices against waste levels; whereby cheap staple foods (bread, cereals) are discarded and replaced much more readily than premium goods such as meats and fish, perhaps valued as an affordability-for-freshness[75].

Likewise, relating to personal affordability is the temptation and influence of retail promotions. In-store promotions are a highly persuasive driver of consumer overspend; accounting for one third of total food sales. However, against popular belief the 'BOGOF' bargains account for just 2% of sales compared to other marketing tools[i]. In fact, consumers hold strong opinions that in-store marketing is the major cause of overspend and food waste production[77]. Whilst the evidence as to whether promotions directly encourage wastefulness remains unproven, it is anticipated that single person households would be most prone to additional wastage with their typical household routine and domestic practice[73 78].Within a wider context, waste may be viewed as a by-product of lifestyles, information overloads, social norms[79] and retailers' policies on package sizes.

As a final aside from the food waste debate per se, it is also important to at least highlight the parallel economic and environmental costs accrued from food waste. In fact, food waste incurs a double economic burden, the largest of which being from initial financial and energy costs of food production, the smallest of which being from additional fiscal penalties for waste disposal and the generation of deleterious greenhouse gas emissions (e.g. from landfill). These costs are not equally distributed throughout the supply chain. The environmental impact for every tonne of avoidable food waste produces an equivalent of 4.2 tonnes of CO_2; nationally this is comparable to the emissions of one in five cars on the UK roads[67]. Furthermore, the water used to produce food and drink that is then wasted, represents 6% of the UK's water requirements, a quarter of which originates in the UK[80]. An environmental cost will always be associated with food, however reducing food waste and consumption can help minimise this cost. Towards this goal, the Government, in association with WRAP have developed a series of measures to help move society up the waste hierarchy.

[i] Various sales tools exist, most commonly used are the Temporary Price Reduction (TPR) and the buy x for £y -accounting for 18% and 12% of total sales respectively. Other tools include buy x% free and multi-buy purchases accounting for just 2% and 3% of total sales respectively (WRAP, 2011)[77].

Summary of food waste within the UK

It is clear that the food and drinks industry is highly competitive, yet perhaps not as technologically advanced as envisaged, with major investment barriers for many supply-chain businesses. Consequently, the retail supply-chain has existed on principles of high throughput goods, process inefficiencies and an acceptance of waste as a by-product. However, it is also evident that the majority of food waste occurs during initial production and final consumption, attributed to both technological limitations and behavioural influences resonating throughout the supply chain. It is also acknowledged that supply-chain inefficiencies and food waste both contribute to associated economic losses and environmental impacts; these combined aspects all serve as an initial framework in which research priorities and opportunities may be positioned, as discussed in Part three.

Part three: Research priorities and needs

The evidence-base summarised in Part two is further supported by survey analyses and stakeholder consultations to forge a consensus on proposed areas of priority research. Influential guiding documents are cited in Annex 2 for the stages of primary production (Table 3), post-production supply-chain (Table 4) and consumption stages (Table 5). The collective findings for developed countries are summarised below and expanded in Table. This is followed by an outline of proposed approaches for developing countries (Pgs 19-20). The impacts of these findings are drawn together in the final conclusion (Part four).

Priorities within developed countries

To ensure a sustainable future, there is a need to boost the capability of UK food production (crop, livestock, dairy and fisheries), with an urgency for industry and ecosystem services to be re-invigorated through modernisation and advanced technology adoption. Consumers and industry need to be upskilled and educated within a pro-environmental framework. The Government is currently considering UK food production capabilities in the Agri-Tech Strategy. Priorities for the food supply-chain include:

Production priorities (Table 3) seek to advance farming competitiveness and reduce in-field yield losses and consumer acceptance, especially in challenging the social norm of out-grading practices. Agri-engineering is entering a phase of high automation which can directly reduce harvesting losses and alleviate environmental burdens by reducing inputs whilst maximising productivity (i.e. sustainable intensification). Genetic research and breeding programmes are core biological tools with the potential to improve the productivity and resilience of crops, livestock and fish; however the lab to field lag times of such techniques can often be measured in decades. The scope of crop improvements includes genetic yield potential (F1 vigour) or modification of photosynthetic apparatus, but also extends to resilience, weather extremes, soil interactions, mineral nutrition, use of non-food parts as by-products, postharvest shelf life, food safety and nutritional quality (e.g. biofortification). These approaches can contribute directly to food waste prevention and provide opportunities for environmental mitigation, throughout the entire food system.

Post-production priorities (Table 4) are focused on supply-chain efficiencies and product enhancement through retaining freshness, extending shelf-life and improving nutritional quality. Supply-chain efficiencies rely largely on engineering technology adoptions (de novo or external) focusing on refrigeration and manufacturing processes. Options to provide highly flexible and modular processing capabilities and automation and robotics are viewed as long-term goals for larger-scale producers and early adopters.

Product enhancement (freshness/shelf-life) can be approached through innovative storage, preservation, reformulation or packaging solutions; or through biological control of crop maturation to exploit ripening properties of biological pathways. In fact by its very nature, many product enhancing approaches facilitate supply-chain efficiencies (in duration and monitoring). Sensing technologies (e.g. photo-electronics or biosensors) offer an array of potential real-time waste reduction applications, whilst packaging technologies have proven effective in microbial control along with the use of new materials. Moreover, further research is required to provide a better understanding of microbial biology (interactions and processes) to develop new anti-bacterial surfaces and environments to diminish spoilage throughout the food and drinks industry. As an example, the recent revelations of fresh 'two week sandwiches'[81 82] and '60 day bread'[83] provide insights into potential future possibilities through multi-disciplinary research. It is important to recognise that such research applications also raise further questions surrounding consumer acceptance and behaviours of novel technologies and novel foods.

Work by WRAP and FSA to underpin "Love Food, Hate Waste" is currently tackling safe-food practices via labelling. For household consumption, the Department of Health (DH) has undertaken much work to help

improve domestic food management skills, e.g. the "Food Bus" which toured schools. Private sector initiatives have also occurred in this space e.g. supermarkets that encourage children to cook. Similarly, for post-consumption, WRAP have been encouraging take-up of anaerobic digestion, though this is now being scaled back (Table: 2). At the retail-consumer interface, increasing product shelf-life without compromising food safety offers the opportunity for retailers to manage product flows better and to respond to demand-pull rather than supply-push, and thereby diminish food waste. WRAP's 'Fresher for Longer' campaign is attempting to get consumers to use food packaging to extend the life of food in the home[84]. However, modern lifestyles, shopping patterns and behaviours have developed strong social norms towards consumer engagement with food; these are explored below.

Consumption priorities (Table 5) centre on retailer-consumer relationships, consumer behaviours within the home and wider social norms. As summarised in Part two, there is evidence to support waste reduction by perhaps focusing on the retail-consumer interface, to elicit change in shopping patterns and influences. At the wider commercial level, the growing market segment of hospitality and food service needs investigation, to better understand consumption behaviours and waste generation. There is a need to link good consumer behaviours and attitudes in the home with those that occur when eating out (particularly around portion sizes and plate waste). Finally, household consumption trends are in radical need of change across society; with preliminary focus on lower social groups, younger households, families and single-person households, as previously highlighted in Part two.

It is widely reported within consumer research studies, that consumers are largely unaware of the levels of food waste generated. In part, this is complicated by individuals' perceptions (and language used) to convey waste in terms of down the drain, pre-plate losses or leftover scraps[13 70 73 76]. Moreover, consumer behaviours are identified as being complex, inter-linked and self-reinforcing where self-awareness can be a powerful trigger to alter behavioural outcomes and levels of waste generation, especially where cost is perceived as the primary driver for change.

Nudging has been used as a tool to influence consumer choice towards a desired trajectory, as observed for social agendas, including: alcohol consumption, teen pregnancy, diabetes and even organ donation[85]. This approach has also been used successfully in a number of food-oriented initiatives, including salt reduction, nutrition labelling and television advertising, either through nudging consumer choice (nutrition education) or by changing market environments (fiscal, regulatory)[86].

As with other countries, the UK Government[87] and Scottish Government[88] have issued guidelines for dietary change; with priority goals to reduce food waste and to lower consumption of low nutritional foods, meat and dairy products. The desired approach to nudge consumers into eating the right choice of foods and without excessive consumption is applied through the principles of a low impact diet[89 90], executed through a pro-environmental behaviours framework[91], largely within local contexts [58 92 93 94 95]. WRAPs[96] and Zero Waste Scotland's[97] "Love Food, Hate Waste" campaign is working to raise awareness of the financial and environmental impact of food waste. Scotland Food and Drink aims to provide support and leadership for the food and drink industry, to improve its sustainability in Scotland[98].

Whilst the development and understanding of a pro-environmental framework is becoming more well-established in nudging behaviours, there is a 'ceiling' of change within individual lifestyles even for the most receptive members of society[99]. In fact, as interventions go, there is no real benchmark to draw upon where radical shifts towards eating desired and healthy food choices have been successful[86]. In light of this, studying the (national) cost-effectiveness of policy effectiveness, preliminary recommendations are in favour of pre-emptive interventions within the dietary health agenda, albeit as being socially intrusive[100 101].

Whilst the technological (codified) priorities have been explicitly presented within Table: 2, the tacit behavioural priorities affecting both primary production and consumption stages are not so well suited to this reductionism. As behavioural change is absolutely central to this food waste debate, the impacts of consumer behaviours and consumerism are briefly discussed in a worldview perspective in Part four.

Table 2: Contributory factors for waste reduction in developed countries: Issues and priority areas.

	Challenges	Context and future priorities
Farm production - agri & aqua-culture & livestock	Product standards and uniformity including food safety Pest and disease pressure, extreme weather conditions Sustainable ecosystem services – mitigate environment impacts by lower inputs Sustainable crop production – Higher crop productivity and greater resource efficiency Sustainable livestock – Higher animal welfare & productivity. Potential GHG mitigation and impact of diversion from food crop yields. Environmental impact of restricting feeding food waste to animals. Sustainable aquaculture welfare/productivity Farm machinery efficiencies - reduce losses in handling, transportation and storage. Forecasting – meeting retail demands Frequency of food spikes.	**Agricultural losses** are largely derived from product specifications (e.g. out-gradings) and contractual agreements excesses. Seed and crop development research along with agronomy and agricultural engineering advances (e.g. precision farming) are anticipated to provide more uniform produce and greater harvesting efficiencies. In parallel, adoption of a food systems approach enables waste reductions to be researched within context of sustaining ecosystems. **Future priorities:** + Agile automated harvesting technologies + Good seasonal weather prediction to allow "adaptive" planing and management + Economic forecasting to alleviate social costs of low availability - high demand ('food spikes') + Novel control of pests, disease and weeds + Research into changing consumer perceptions and acceptance of food + Plant breeding programmes to focus on nutrient uptake and energy use (e.g. CO_2, NOx) + Alternative approaches to pesticide and herbicide regimes + Animal or fish breeding programmes to enhance productivity & welfare + Animal feedstuffs and methane emissions + Engineering energy consumption and emissions.
Storage	Post-gate spoilage/shelf-life extension – reduce waste through handling, transportation & storage. Additional benefits derived from seed/crop enhancement Microbial spoilage of produce - better understanding of food spoilage processes Cold-chain faster, development of deep chill technologies, efficient preservation processes, temperature stability, reduce energy inputs, emissions & hardware failure Monitoring product integrity, need accurate, faster detection and greater containment of spoilage or microbial contamination	**Post-farm gate storage** losses primarily occur through produce handling and limitations in storage capabilities. Storage is crucial as a stage-gate between supply and demand. The supply-chain could become exposed to greater waste if temperature-time indicators were introduced; therefore technology adoption and transfer are crucial. A key priority is to minimise temperature fluctuations throughout supply-chains. The long-term need is to gain a fuller understanding of plant maturation and ripening pathways, ultimately to extend storage life, taste and shelf-life. Novel sensors (e.g. photo-electronics or biosensors) provide future opportunities for real-time monitoring to enable immediate intervention in rescuing potentially wasted produce. **Future priorities:** + Plant research into biological pathways of maturation and ripening + Microbial research into modes of action and interactions with food + Investigation into the potential of existing technologies (e.g. ethylene management, modified atmosphere packaging) or emerging technologies (e.g. nano-technology) to help manage ethylene and microbial spoilage. + Engineering cold-chain - temperature fluctuation and stabilisation + Novel sensors to monitor product integrity and microbial containment + Advanced cold-chain - Novel refrigerants (non-GHG).

	Challenges	Context and future priorities
Processing	Technology adoption & transfer - Low levels of automation, robotics or flexible processing systems Food preservation – microbial management of food products and clean-air environments Resource efficiency – reduce wastewater & energy inputs Monitoring – reducing process inefficiencies, and increasing QC measures for processed foods & drinks Supply-chain models – meeting consumer affordability, demands and values	**Processing** in the food sector comprises a few Multi-national corporations (MNCs), but is dominated by thousands of Small and medium enterprises (SMEs). This stage of food manufacturing provides the greatest scope for re-engineering to meet the demands of multiple short-runs and frequent switchovers. Whilst many business solutions may be addressed by existing technology adoption or transfer, there is potential to push the early adopters towards more advanced automation and robotics to extend boundaries of competitive advantage. Throughout this business chain, there is also a recognised priority need to reduce water utilisation, especially through advanced engineering of processes and development of alternative solutions. **Future priorities:** + Process innovation through existing technology transfer and adoption + Process innovation through novel engineering process run efficiencies: • 'Agile' automation and robotics • Flexible, modular systems for product changeovers + Economic analysis of supply-chains and alternative business models + Reduced water utilisation - novel hygiene/decontamination processes + Novel sensors to monitor Quality Control processes Low impact heating & cooling technologies + Optimising resource efficiency (e.g. energy, water etc.), which is linked to developing processing, engineering and automation technologies.
Packaging	Shelf-life extension – minimise microbial contamination/product spoilage; extending product life within retail and consumer premises (households/food-service sector) Information and tracking systems – direct microbial control of products and indirectly through innovative packaging Consumer acceptance –new packaging and labelling technologies, and extended shelf-lives	**Packaging** technologies have provided significant advances in minimising spoilage and microbial contamination, thereby extending shelf-life and reducing waste concurrently. There still exists significant potential in utilising new materials and processes to further extend product integrity, and in providing supplementary retailer and consumer information. The popularity/ need of product traceability and authenticity is likely to expand in the future. **Future priorities:** + Extension of active packaging technologies and applications + Extension of intelligent packaging technologies and applications + Consumer awareness of packaging benefits within the home + Extension in clean-room environments (anti-bacterial surfaces) and anti-microbial applications.
Retail	The 'final 50 yards': Forecasting & inventory management to minimise surplus whilst maximising shelf replenishment and in-store shelf-life times Cold-chain (as above for 'Storage') Consumer choice: Provision of high value, quality & safe food. Purchasing needs versus wants (promotions) Date labelling – consumer confusion and potential to extend maximum product life?	**Retail** environments are highly complex and dynamic, commanding established IT-systems capabilities to co-ordinate the flow of goods through stage-gate processes of the supply-chain. Retailers also serve as a technological hub throughout the supply-chain including innovations in packaging and data-labelling. However, dense environments and fast-flow of goods in backroom retail warehousing remains highly challenging. There is a priority need to understand consumer choice: using alternative providers (e.g. local markets or boxed vegetable deliveries) or food ethics (e.g. food miles or in-season) to consider the social impacts of future food provision models. **Future priorities:** + Advanced integrated supply-chain tracking systems + Flexible warehousing processes + Consumer engagement in food management skills + Retailer – consumer relationship - Corporate social responsibility + Adoption of refillables and re-usables + Optimising resource efficiency (e.g. washing vegetables before sale).

	Challenges	Context and future priorities
Consumption	Food management and consumer waste – Individual behaviours, attitudes, habits & values. New social norms & centrality of food. A better understanding of the base psychology around food and food waste.	**Household consumption** in developed countries is the primary source of food waste. Combinational factors contribute to this situation, including changes in affordability, family dynamics, working patterns, meal routines and domestic food management skills. **Future priorities:** + Social research into: • Alternative models of eating habits (including hospitality research) • Domestic food management practices(from preparation, cooking, & storage to date labelling), noting the work undertaken by DH on the "Food Bus" which toured schools. • Campaign design and intervention to embed hardest-to-reach groups • Co-embedding health, nutrition and sustainability messages.
	Health messages – Portion sizes, balanced nutrition and food safety guidelines	
	Hospitality sector – Consumer expectations for menu choice, nutritional standard in cost sector, complex environment in which to set food waste reduction priorities.	
	Consumer and supermarket campaigns - Effective social engagement and embedding practices	
Post-consumption	Greenhouse gas emissions	**Post-consumption** destinations of food-waste are pivotal in securing highest value-added and alleviation of landfill environmental impacts. **Future priorities:** + Retaining highest value-added - Social norms of sharing food: domestic and retail environments + Retaining highest value-added - Scientific research into biomolecule recovery + Anaerobic digestion + Implications for future models (on-farm, local hub, networks) + Biopolymer research.
	Diversion from landfill – best alternative uses for value-added (including energy generation)	
	Anaerobic digestion – nascent technology and adoption. Advances in early stage technology for energy production, digestate applications & networking systems	

Priorities within developing countries

Over 98% of the 868 million undernourished people live in developing countries, predominantly within Sub-Saharan regions and Southern and Eastern Asia, and it is typically these regions which will also witness the greatest population growth rates towards 2050. It is clearly appreciated that significant and persistent capital investment is required within these least developed countries along with engagement with political powers and NGOs on the ground, education and policy reform. Food insecurity within developing countries provides an opportunity to focus on specific research priorities, although a model based on a bottom-up regional approach in priority setting and implementation towards national (and global) priorities may provide an appropriate framework to signal successful initiatives[104]. The strength of this approach is through attracting resources (priority-pull) rather than allocating resources (priority-push) facilitating greater community and organisational engagement, and therefore greater potential for such projects to succeed.

There exists a mass of literature which has hailed successive case-studies through local engagement, novel thinking and applied workings; yet there remain significant barriers to knowledge dissemination, technology adoption and best practices. There is therefore a need to better understand the social complexity of local contexts in establishing successful agri-tech schemes and how best practices may be more readily adopted universally. Taking a 'proof of concept' approach, actionable research may be prioritised at post-harvest to maximise and retain yield, either through existing 'local' and innovative re-

engineering solutions or accessible biological control approaches. In reality, there is an urgent need for multi-disciplinary research throughout the supply-chain from agricultural efficiencies, through to processing optimisation and economies of market structures.

The Foresight Workshop on Global Food Waste identified the overall sequencing of the economic and technological development of food supply chains to be a key consideration for the reduction of food waste[105]. The workshop highlighted that there is little point in greater agricultural productivity, unless the infrastructure can deliver food to the consumer e.g. adequate storage, good roads and availability of transport packaging. Storage capabilities provide a compelling economic and social benefit in serving as a buffer between sustaining longer-term self-provision, and increasing future market opportunities. Longer term self-provision provides greater food security, serves as a bartering tool and reduces external expenditure of alternative food goods. Similar buffering capacity may also alleviate adverse market conditions, providing a greater window of opportunity to access disconnected or sporadic markets. Storage capabilities and wider supply-chain benefits can be realised through economies of scale and the facilitation of farmers' groups and co-operatives in achieving purchasing power, agricultural efficiencies and greater access to markets. That said, it would be naïve to single out storage capabilities as a solution in isolation, but it is recognised as an important factor in conjunction with whole supply-chain and capital infrastructure investments[4 19 106 107 108].

Emergence of mobile technologies and social media approaches (e.g. peer to peer learning and information sharing amongst farmers and growers), has also recently gained momentum in reaching distant communities and is already proven to be a powerful agri-business tool in knowledge dissemination[106 107 109]. But the scope of its reach and best utilisation remains to be explored as a key driver in terms of economic, social benefits and poverty alleviation. Finally, additional social enhancements may be returned through engagement and practical support for women farmers, whereby educational and health impacts can lead to amongst other things, greater farming efficiencies, waste prevention, and reduction of food losses[1 108].

Research needs: evidence gaps

The global analysis of Gustavsson et al (2011) provides a clear perspective of supply-chain trends relating to food waste. This preliminary research should serve as a baseline for future analyses and success of policy developments to reduce food waste and alleviate global hunger. There is a need for future analyses to collect new 'on the ground' data, from crops, food types and world regions and research into the utilisation of food waste is also important (e.g. for energy generation).

The detailed analysis undertaken within the UK has provided key insights into food waste patterns and consumer behaviours. These sources of analysis have provided strong guidance in identifying the socio-economic pinch-points of food waste generation. Currently, evidence gaps exist around how to nurture a social environment where consumers are nudged towards sustainable and healthy food choice, within a resource-constrained environment.

Part four: Closing remarks

Behaviours and potential for change

Food is now a small fraction of disposable income in developed countries, leading to a decline in its perceived monetary value. In today's society, high-consumption, high standards and a throw-away culture exist[79]. When combined with the attractive ('addictive') nature of food-types (i.e. fats, salts and sugars) which some suggest as being hardwired into our body chemistry; then over-eating and food waste are perhaps inevitable outcomes, in the absence of intervention[110]. Recent research has also questioned the tendency to blame the consumer for food waste production and that individual policies and interventions would instead be useful to target[111]. Lessons may be taken from the behavioural changes that took place through the anti-smoking agenda[86], however unlike smoking, food is essential to sustain life so interventions and behavioural changes are therefore likely to be more modest and less effective over a similar period.

It is important to appreciate that this is a collective social imperative requiring government agencies, NGOs and the food & drinks industry to engage with consumers to raise awareness and elicit change. Whilst the exact mechanisms and environments to elicit such change may not be fully understood, it may be anticipated that current consumer awareness is highly acute (and receptive). Therefore, there may well be a window of greater opportunity in engaging dialogue, reinforcing the naturalness (appearance and provenance), health benefits and improving the sustainability of food.

Experiences from food campaigns have highlighted that 'marketing' is insufficient alone, but sustained activities which permeate deep into the household through a community-led collective can potentially cascade[112 113 114]. Evidence suggests that a tangible trigger of awareness and realisation can facilitate behavioural change[115], though again this scale of reach suggests a generational change. At the same time, it must be acknowledged that this is a continuation of an on-going process, where avoidable household waste has declined by nearly one fifth in a three year period[13 67]. A key question is whether a critical mass is being reached, which may embed such social behaviours more widely, or whether efforts will begin to stall as harder-to-reach communities do not respond quite so proactively. Future trends in household waste may serve as a metric as to whether a social (contract) intervention is sought, in climate change policy, the simple equation of attitude-behaviour-choice (the ABC of behaviour change) is being questioned[116]. Further research into the UK's position on food waste, health and sustainable societies requires continued investigation to unravel the complexities of human behaviours, perhaps over multiple generations.

Conclusion

The challenge of addressing food waste needs to take into consideration the whole supply chain; from food production, through to food processing and retail. There is also a need for research to be undertaken around patterns of consumer behaviour and choice. The causes of food waste are different between developed and developing countries, with the majority of losses in developing countries being at the early, post-harvest and processing stage, whilst in developed countries, major losses are at the retail and consumption stage. The research and policies required to reduce food waste, therefore need to be region specific.

To begin to address issues relating to global food security, primary production and manufacturing processes within the UK need to adapt to retain competitive advantage in the future. These priority areas are not blue sky research but respond to industry needs over the next decade(s); nor are they radical innovations, but rather incremental advances within the food & drinks sector. Typically, these research priorities have previously been explored and are often early-stage developments, with large potential, but the priority lies in accelerating the translational pipeline which will span perhaps decades in some instances. However, such technological futures must also be contextualised alongside their social dimensions.

Alternative consumption models must be explored, with a need for greater environmental sustainability where food is viewed as a finite resource. Society as a whole needs to consider the current mass commoditisation of global food in providing cheap and plentiful goods, but at high environmental cost. New options should be explored which truly appreciate food as a natural (non-uniform) resource and move towards high quality, nutritious and sustainable food intakes, albeit perhaps at higher financial costs for consumers. Such an approach would incorporate sustainable and healthy diets (e.g. reducing red meat consumption), which have major global environmental and health impacts. As such, the food waste agenda may also be practicably viewed where food waste prevention also becomes an integral component, derived from higher productivity and greater utilisation of finite ecosystem services in a food systems approach, framed in terms of the least environmental impact.

These findings may be carried forward within the context of underpinning Global Food Security Programme objectives, and in supporting the UK government's Agri-Tech Strategy.

Appendices for this report can be found online:
www.foodsecurity.ac.uk/assets/pdfs/food-waste-report.pdf

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Produced by RCUK's internal service provider on 100% recycled post consumer waste

Annex 1: Global food waste

The Swedish Institute for Food and Biotechnology (SIK) undertook two research studies on behalf of the FAO to compare global food losses for (1) high/medium-income countries, and (2) low income countries. These findings were published in Gustavsson *et al* (2011)[11] and included a global breakdown of food loss and waste along the supply-chain for different commodity food groups. This dataset below is reproduced herein to serve as a handy reference, in order to contribute directly to the food waste debate for the Global Security Programme. Graphical outputs are also provided for the food groups: cereals (Figure 6) as also presented in the main body of text, and fruit & vegetables (Figure 7), roots & tubers (Figure 8), oilseed & pulses (Figure 9), meat (Figure 10), fish & seafood (Figure 11) and dairy products (Figure 12).

Estimated/assumed waste percentages for each commodity group in each step of the FSC for **Europe incl. Russia.**

	Agricultural production	Postharvest handling and storage	Processing and packaging	Distribution: Supermarket Retail	Consumption
Cereals	2%	4%	0.5%, 10%	2%	25%
Roots & Tubers	20%	9%	15%	7%	17%
Oilseeds & Pulses	10%	1%	5%	1%	4%
Fruit & Vegetables	20%	5%	2%	10%	19%
Meat	3.1%	0.7%	5%	4%	11%
Fish & Seafood	9.4%	0.5%	6%	9%	11%
Milk	3.5%	0.5%	1.2%	0.5%	7%

Estimated/assumed waste percentages for each commodity group in each step of the FSC for **North America & Oceania.**

	Agricultural production	Postharvest handling and storage	Processing and packaging	Distribution: Supermarket Retail	Consumption
Cereals	2%	2%	0.5%, 10%	2%	27%
Roots & Tubers	20%	10%	15%	7%	30%
Oilseeds & Pulses	12%	0%	5%	1%	4%
Fruit & Vegetables	20%	4%	2%	12%	28%
Meat	3.5%	1.0%	5%	4%	11%
Fish & Seafood	12%	0.5%	6%	9%	33%
Milk	3.5%	0.5%	1.2%	0.5%	15%

Estimated/assumed waste percentages for each commodity group in each step of the FSC for **Industrialized Asia.**

	Agricultural production	Postharvest handling and storage	Processing and packaging	Distribution	Consumption
Cereals	2%	10%	0.5%, 10%	2%	20%
Roots & Tubers	20%	7%	15%	9%	10%
Oilseeds & Pulses	6%	3%	5%	1%	4%
Fruit & Vegetables	10%	8%	2%	8%	15%
Meat	2.9%	0.6%	5%	6%	8%
Fish & Seafood	15%	2%	6%	11%	8%
Milk	3.5%	1%	1.2%	0.5%	5%

C

Estimated/assumed waste percentages for each commodity group in each step of the FSC for **sub-Saharan Africa.**

	Agricultural Production	Postharvest handling and storage	Processing and packaging	Distribution	Consumption
Cereals	6%	8%	3.5%	2%	1%
Roots & Tubers	14%	18%	15%	5%	2%
Oilseeds & Pulses	12%	8%	8%	2%	1%
Fruits & Vegetables	10%	9%	25%	17%	5%
Meat	15%	0.7%	5%	7%	2%
Fish & Seafood	5.7%	6%	9%	15%	2%
Milk	6%	11%	0.1%	10%	0.1%

Estimated/assumed waste percentages for each commodity group in each step of the FSC for **North Africa, West&Central Asia.**

	Agricultural production	Postharvest handling and storage	Processing and packaging	Distribution	Consumption
Cereals	6%	8%	2%, 7%	4%	12%
Roots & Tubers	6%	10%	12%	4%	6%
Oilseeds & Pulses	15%	6%	8%	2%	2%
Fruits & Vegetables	17%	10%	20%	15%	12%
Meat	6.6%	0.2%	5%	5%	8%
Fish & Seafood	6.6%	5%	9%	10%	4%
Milk	3.5%	6%	2%	8%	2%

Estimated/assumed waste percentages for each commodity group in each step of the FSC for **South & Southeast Asia.**

	Agricultural production	Postharvest handling and storage	Processing and packaging	Distribution	Consumption
Cereals	6%	7%	3.5%	2%	3%
Roots & Tubers	6%	19%	10%	11%	3%
Oilseeds & Pulses	7%	12%	8%	2%	1%
Fruits & Vegetables	15%	9%	25%	10%	7%
Meat	5.1%	0.3%	5%	7%	4%
Fish & Seafood	8.2%	6%	9%	15%	2%
Milk	3.5%	6%	2%	10%	1%

Estimated/assumed waste percentages for each commodity group in each step of the FSC for **Latin America.**

	Agricultural production	Postharvest handling and storage	Processing and packaging	Distribution	Consumption at household level
Cereals	6%	4%	2%, 7%	4%	10%
Roots & Tubers	14%	14%	12%	3%	4%
Oilseeds & Pulses	6%	3%	8%	2%	2%
Fruits & Vegetables	20%	10%	20%	12%	10%
Meat	5.3%	1.1%	5%	5%	6%
Fish & Seafood	5.7%	5%	9%	10%	4%
Milk	3.5%	6%	2%	8%	4%

Part of the initial production lost or wasted, at different supply-chain stages in different regions

Figure 6: Supply-chain losses - Cereals

Source: Gustavsson et al (2011)

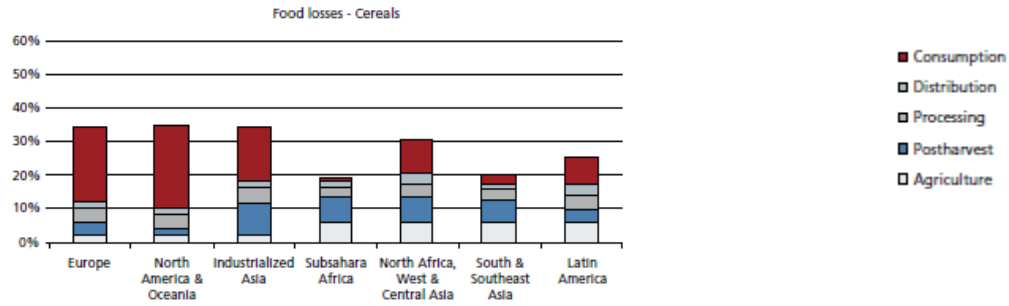


Figure 7: Supply-chain losses - Fruits & vegetables

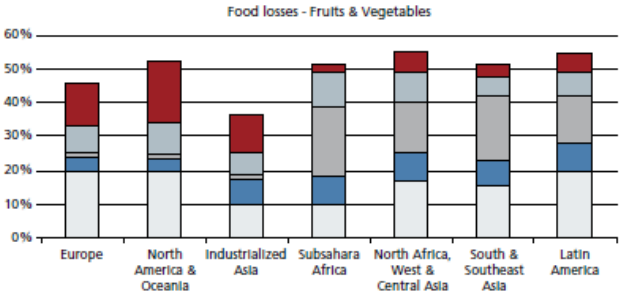


Figure 8: Supply-chain losses - Roots & tubers

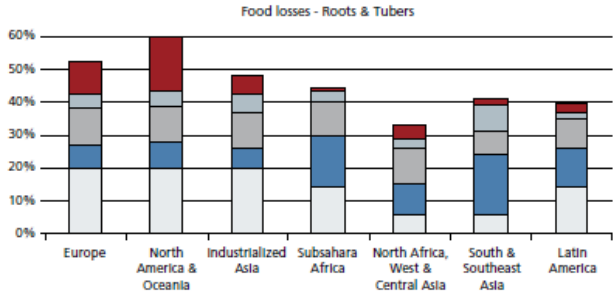


Figure 9: Supply-chain losses - Oilseeds & pulses

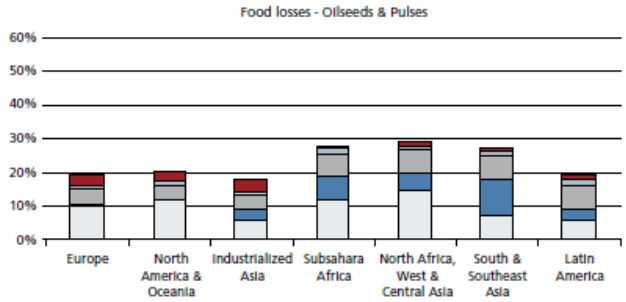


Figure 10: Supply-chain losses - Meat

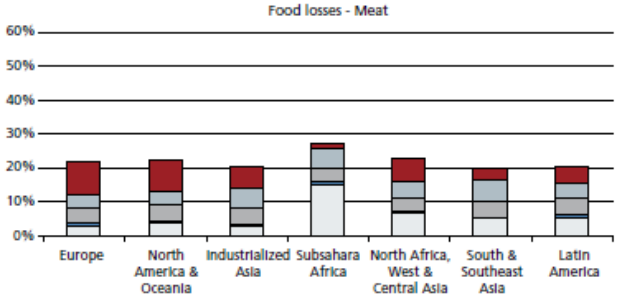


Figure 11: Supply-chain losses - Fish & seafood

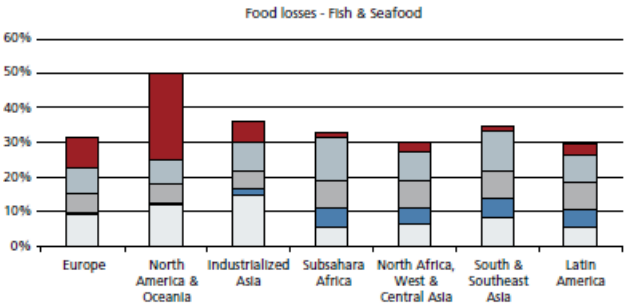
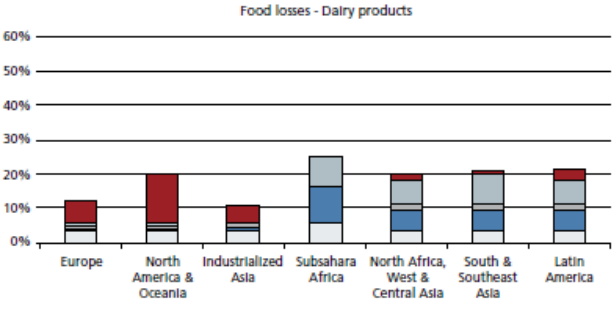


Figure 12: Supply-chain losses - Dairy products



Annex 2: Priority research literature

Table 3: Literature listings for future agricultural (pre-farm gate) research requirements

Source	Priorities
Consultation Draft: Feeding the Future – Innovation Requirements for Primary Food Production in the UK to 2030. Pollock, C. (2012)[117]	*Modern technologies:* • To improve precision and efficiency of key agricultural management practices, towards precision farming and sustainable intensification principles *Modern genetic and breeding approaches:* • To improve quality, sustainability, resilience and profitability of crops and farm animals, including 'Omics to better understand and exploit desired traits. *Systems-based approaches:* • To understand better and manage interactions between soil, water and crop/animal processes; including rhizosphere processes and carbon flows, and GHG mitigation *Integrated management:* • Develop approaches for crop and animal diseases within farming systems; including novel rotations, disease genetics, vaccines and welfare management *Evidence-based approaches:* • To value ecosystem service delivery by land users and incorporate these approaches into effective decision support systems at the enterprise or grouped enterprise level; towards a 'circular agricultural economy' *Extend the training and professional development:* • For researchers, practitioners and advisors to promote delivery of the targets above; working with HEIs, FEIs, RCUK and BIS to identify research and skills gaps, and to support extension activities *Social and economic science:* • To promote development, uptake and use of sustainable, resilient and profitable agricultural practice that can deliver affordable, safe and high-quality products; by developing and disseminating best practices.
The Green Food Project Defra (2012)[118]	Underpinning research into: • Soil science • Agronomy • Ecosystem services • Socio-economic research.
Agricultural Engineering: a key discipline enabling agriculture to deliver global food security. IAgrE (2012)[119] See Table 4 for post-gate research priorities and opportunities. [Framed around challenges within The Foresight Report. Ref: 3]	*Balancing future demand and supply sustainably:* • Enhanced crop productivity and quality - precision farming advances • Improved animal health and welfare – real time monitoring/ diagnostics • Better use of irrigation water to support production *Addressing the threat of future volatility in the food system:* • Impacts of changes using farm systems models • Improved commodity storage to stabilise supply and volatility *Ending hunger:* • Conservation agriculture – sustainability and mechanisation • Ergonomically-optimised engineering for women and communities • Reduction of wastage in food supply-chains – technology and education

Foresight Project on Global Food and Farming Futures. Workshop Report: W4 GOS (2011)[24]	*Growers:* • Information systems • technology & knowledge transfer • Improved post-harvest infrastructure
Knowledge transfer in agriculture Defra (2011)[120]	For arable farms: • Yield • Meeting market standards/quality • Nitrogen input costs. • Fixed costs management • Fungicide timing • Weed control • Cultivation costs
Sustainable Agriculture and Food Innovation Platform TSB (2011)[121]	• Crop productivity including protection and nutrition • Sustainable livestock production • Waste reduction and management • GHG Reduction Technologies and Methodologies
Technology and Innovation Futures: UK Growth Opportunities for the 2020s. GOS (2010)[122] Technology and Innovation Futures: UK Growth Opportunities for the 2020s – 2012 Refresh. GOS (2012)[123]	*Agricultural production:* • New agricultural technologies, farming techniques and third generation crops. • Bio-optimisation of production & processes - novel biomolecules, food safety processes • 2nd and 3rd generation industrial bio-refineries to process non-edible plant and other waste into high value biofuels. *Genetically modified crops (GMs):* • Input traits include herbicide and pesticide resistance or nutrient utilisation traits. • Output traits to mitigate climactic stresses (drought, salinity and temperature) or photosynthetic capacity, • Enhancing the value-chain for crops as a food good or by-product. *Carbon reduction:* • Utilisation of biowaste, including anaerobic digestion or low carbon transport • Other novel energy and low carbon technologies *Precision farming:* • Microclimate level farming with reduction of chemical inputs and run-offs and providing higher productivity agriculture *Technology convergence:* • e.g. genomics, micro-electronics and nanotechnologies in development of novel diagnostics sensors *Active packaging:* • From product tracking (e.g. RFID) to food safety and atmospheric control of packaging. *Intelligent sensor networks:* • To expand on the utilisation of RFID for future supply-chain applications *3D printing:* • 'Construction' of ready to cook, reducing packaging & food waste along with lower water utilisation *Analytical tools:* • Real-time stock controls or consumer behaviours *Robotics*: • Applications within agricultural surveying, manufacturing and logistics *Recycling technologies:* • For advanced mechanical sorting mixed waste

Reaping the benefits: Science and the sustainable intensification of global agriculture. London The Royal Society (2009)[124]	• Crop breeding and genomics programmes to better understand and enhance germplasm of priority crops: • For the UK; wheat, barley, oilseed rape, potato, vegetable brassicas and other horticultural crops • Of international importance are millet, sorghum and rice • Long-term research into genetic improvements into crops using genetic modification (GM) or conventional breeding programmes (e.g. by traditional hybridisation, phenotype analysis or marker-assisted selection, QTL)[xi] to: • reduce environmental impacts through greater fertiliser efficiencies/uptake, or to grow as perennials • increase yields and resistance to stress and disease • improve photosynthetic capacity and nitrogen fixation by GM approaches • Ecosystem-based approaches, agronomy and research into crop and soil management • Translational research and international collaborations (e.g. China, Brazil, India and South Africa)

A Research and Innovation Network Supporting Adaptation in Agriculture to Climate Change. Defra (2009)[125]	• Water application strategies
	• Water storage technology
	• New food crops
	• Drought resistant varieties
	• Opportunities, not priorities:
	  • water application technology
	  • soil structure and function
	  • Integrated Pest (Crop) Management
	  • crop scheduling

Potential to Increase Productivity of wheat & oilseed rape in the UK. BIS (2009)[126]	**Wheat** Sustainable protection against pests, disease and weeds Better water capture and conversion Better nutrient capture and conversion Improved light conversion Early canopy closure Early stem extension Delayed canopy senescence Increased partitioning of dry mass to grain **Oilseed Rape** Sustainable protection against pests, disease and weeds Improving rooting to exploit soil resources (nutrients and water) Better Nitrogen conversion Improved light conversion, especially post-flowering Improved pre-flowering assimilate production and storage Increased seed sink capacity Reducing harvest losses

[xi] Marker assisted selection (MAS) allows genetic identification of desired traits to be assigned to specific genes at a specific location on the DNA; this region is referred to at the quantitative trait loci (QTL). This QTL marker may then be 'tracked' through conventional plant breeding cycles to ensure the desired characteristic has been carried forward.

Table 4: Literature listings for future post-production research requirements

Source	Priorities and opportunities
Foresight Project on Global Food and Farming Futures. Workshop Report: W4 GOS (2011)[24]	*Storage & distribution:* • Infrastructure development • Shorter supply-chains • Reduced transit times • Cool/cold storage & dry storage • Manufacturing & retail • Accountability of food waste along food supply-chain • Clearer apportionment of costs for food waste • Fairer balancing risks along supply-chain (from growers to retail) *Post-consumer:* • Improved home economic skills • Make food waste socially unacceptable • Identification of who benefits from food waste reduction. Consumer vs Retailer
Food Technology Fund TSB (2012)[127]	• Sensor development as process (line) efficiencies quality control tools • Drying and preservation processes • Microbial management and waste reduction of produce • Packaging and labelling technologies • Shelf-life extensions • Value-adding waste (by-products)
'Nutrition for Life' TSB (2011)[128]	• Novel, healthier foods & processes • Food safety, authenticity & traceability
The seven biggest supply chain themes for 2013 IGD (2013) [129]	• Integrating the planning process • Understanding the online channel • Data integrity checks • In-store supply chain • Automating order picking • Shared resources – knowledge exchange
Scientific and technical needs of the food and drink industry Campden BRI (2011) [130]	*Manufacturing & supply:* • Efficient processes • Innovative processes • Sustainable practices and cost consumtion • Effective supply-chain management • Effective design and maintenance of capital assets • Protection of the health, safety and welfare of operatives
Agricultural Engineering: a key discipline enabling agriculture to deliver global food security. IAgrE (2012) [119] [Framed around challenges within The Foresight Report, Ref:3]	*Addressing the threat of future volatility in the food system:* • Improved commodity storage to stabilise supply and volatility *Ending hunger:* • Ergonomically-optimised engineering for women and communities • Reduction of wastage in food supply-chains – technology and education

Table 5: Literature listings for future consumption stage - social research requirements

Source	Priorities and opportunities
Food Statistics Pocketbook 2012 Defra (2013)[15]	• 15 million tonnes food wasted in UK, 7.2Mt/yr from households, equating to 15% of edible food and drink purchased and wasted, costing £480 to average households. • 4.4Mt household waste is avoidable – equivalent to 17Mt CO_2e • One third of all bread is wasted • Food and drink waste down 49% between 2002-03 and 2009 • 4 million households had food waste collection schemes in 2011
Consumer attitudes to food waste and packaging WRAP (2013)[72]	• Poor consumer understanding of role of packaging within the home, with the opposite generally perceived as true. Packaging seen as excessive and bad for the environment • Consumer awareness can change attitudes and behaviours to packaging and waste
The Milk Model: Simulating Food Waste in the Home. WRAP (2013)[78]	• Prior actions can influence waste levels, including stock-taking and shopping patterns - interactive and feedback loops which link purchasing decisions • Waste prevention involves trade-offs – e.g. additional packaging or shopping more often

Effectiveness of Policy Interventions to Promote Healthy Eating and Recommendations for Future Action: Evidence from the EATWELL Project
EU FP7 – Eatwell (2012)[86]
	• Benchmarking diet and health-related policy interventions of EU member states - most dietary interventions are recent, therefore weak evidence-base
	• Majority of policies are information measures – cost effective but small positive effects, and well-received by public
	• Most common market interventions are directed towards:
	  ◦ the nutritional composition of school meals
	  ◦ the private sector to improve diets (i.e. reformulation of processed foods)
	• Less common market interventions are fiscal incentives, nutritional standards and equity of food availability
	• Social marketing campaigns to sustain messages and behavioural influences
	• Member states should work towards introducing taxes aimed at promoting healthy eating and reinvest in further health programmes

Foresight Project on Global Food and Farming Futures: Changing consumption patterns. Synthesis Report C8 GOS (2011)	• Increased resource competition and dietary shifts leading to health and environmental impacts. Nutritionally balanced diet to reduce societal health costs • Pro-environmental and locally sourced foods • High priority – reduce food waste, reduce consumption of low nutritional foods, dairy and meat products • Medium priority – increase consumption of fruit & vegetable and sustainable fish, with a greater environmental consideration in the production of food stuffs. • Changing food consumption behaviours highly complex – may take decades. • Tools for change: taxes/subsidies, labelling, campaigns, targeting schools/workplace
Motivations for Pro-environmental behaviour. Defra (2010)[131]	• Motivations are complex and contested. Individuals have different motivations and interact in different ways leading to unique patterns of behaviour. • Potentially causal link between motivations and environmental behaviours • Pro-environmental behaviours becoming a social norm – especially recycling. • Balanced between self-identity, status and social environment • Individual ceilings (barriers) for change – *Positive greens* most receptive • Social circles (family, friends & colleagues etc) can influence to create new social norm • Economic downtime as lever for actual change • Policies to promote mainstream socially acceptable and self-rewarding activities • Positive indicators for pro-environmental change, but not a new social norm as yet.

Applying behavioural insights to health. Behavioural Insights Team. Cabinet Office (2010)[85]	• Most important policy issues have a strong behavioural component • Adoption of MINSPACE behavioural model • Pre-emptive approach to healthy lives (rather than focus on ill-health) • Environmental effects on behaviour is strong influence
Tackling of unhealthy diets, physical inactivity, and obesity: health effects and cost-effectiveness, Cecchini M, Sassi F, Lauer JA, Lee YY, Guajardo-Barron V, Chisholm D (2010)[100]	• Cost-effective interventions to reduce obesity, increase health and activity collectively, for low and middle income countries • Price interventions and regulation can produce the largest health gains in the shortest timeframe • Multiple interventions to yield significantly larger health gains and cost-effectiveness • Interventions targeting children are long-term for return of benefits. • Private sector interventions may be useful, but is largely unproven
A Food synthesis Review summary Report (2009) [132]	• To minimise peoples' environmental impacts, must address entire food supply-chain • Most environmental impact during purchasing (e.g. transport), handling (e.g. storage or cooking) and disposal (e.g. transport, landfill) • Adopt 'Low Impact Diet' as the overarching framework • No evidence for low impact preparation, eating less meat & dairy or lower portion sizes
A framework for Pro-environmental behaviours Defra (2008)[91]	• To improve the environment by increasing contributions from individual and community actions • 7 population segments from most receptive *Positive greens* to the *Honestly disengaged* • 12 headline behaviours including; waste less food, eat more locally & in season and adopt a low impact diet • Spectrum of peoples' willingness and ability to change behaviours - motivations/barriers • Radical lifestyle changes highly unlikely
Understanding of Consumer Attitudes and Actual Purchasing Behaviour with Reference to Local and Regional Foods FO0312. Defra (2008) [133]	• Consumer-led demand for local & regional goods is increasing, less so for younger, poorer urban consumers • Positive attitudes but doesn't always translate into purchases with modern lifestyles • Significant behavioural, structural, and institutional factors that impede its wholesale expansion
A Synthesis Review of the Public Understanding Research Projects Defra (2007)[90]	• Public poor understanding of different behaviours and environmental impact • Pro-environmental behaviour frequently associated with sacrifice, lower quality and higher cost • High expectation for government to lead on environmental issues • Public mistrust of government, but less so for environmental issues • Motivation for some, can act as barriers for others • Radical lifestyle changes highly unlikely
We Don't Waste Food! A Householder Survey. WRAP (2007)[73]	• 14% households do not check stocks prior to shopping – single households least likely. • One quarter households do not pre-plan meals • Three-quarters of households buy unintended items at times, with promotions making up half of the unintended purchases • Main waste food past its best by or use by date, as well as cooking too much • No single message to enable behavioural change

Annex 3: research by the AD Little consultancy - Mapping current innovation and emerging R&D needs in the food and drink industry required for sustainable economic growth

This study has identified nine priority technological challenges, i.e. problems or opportunities that require technological innovation in order to be solved or exploited, which Defra could seek to address in order to further stimulate the production of environmentally sustainable and healthy food. The challenges are summarised in the graphic, below.

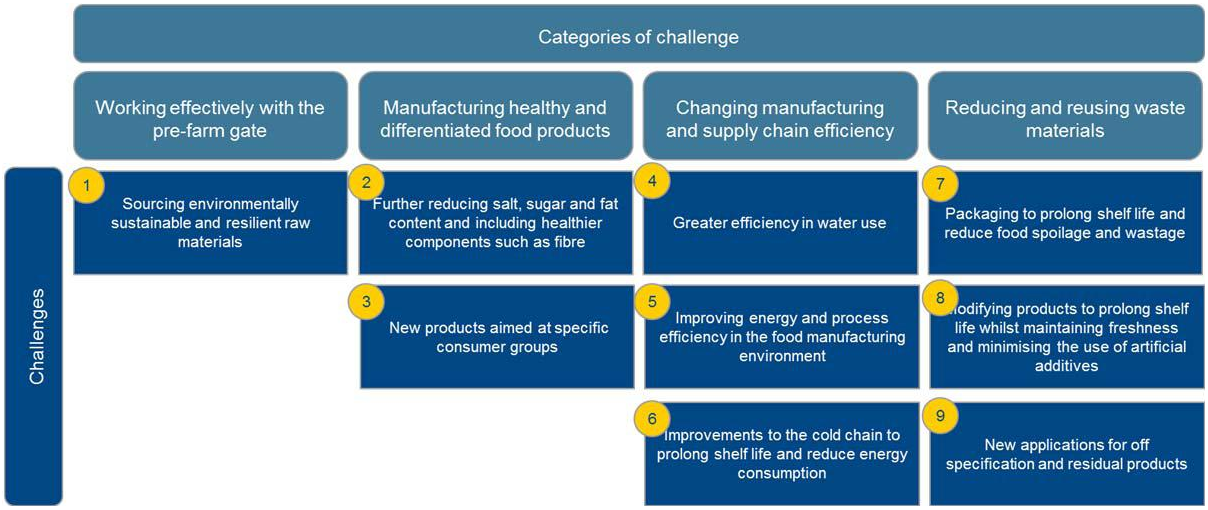
The challenges concern the sourcing of environmentally sustainable and resilient raw materials. This is an activity which requires close interaction with the farming and primary production sector and has strong implications for security of supply, both for the UK and for individual companies.

Manufacturing healthier and differentiated food products requires a continued focus on reducing salt, sugar and fat content of foods, especially those which are highly processed, and developing products which are bespoke to individuals within an ageing population with increasing incidence of nutrition related disease.

There are also opportunities to change manufacturing and supply chain efficiency by reducing water use, improving energy and process efficiency in the food manufacturing environment, and making improvements to the cold chain. Reducing and reusing waste is a further important topic, in terms of increasing the shelf life of foods whilst meeting consumer demand for freshness and innovating in packaging to reduce food spoilage and wastage.

There are further opportunities to reuse food waste as ingredients, materials and energy.

Challenges to be addressed through technological innovation – Summary



Source: Arthur D. Little analysis

Arthur D Little also make some suggestions for action to encourage innovation. Those that relate to research are:

- To create technology roadmaps to set R&D targets and address the “hot spot” technological challenges
- To build a better evidence base to support minimum temperature requirements for chilled and frozen products.

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** Denotes One day consultation meeting*