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ORIGINAL PAPER

Priority research questions for the UK food system

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Abstract The rise of food security up international political, societal and academic agendas has led to increasing interest in novel means of improving primary food production and reducing waste. There are however, also many 'post-farm gate' activities that are critical to food security, including processing, packaging, distributing, retailing, cooking and consuming. These activities all affect a range of important food security elements, notably availability, affordability and other

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aspects of access, nutrition and safety. Addressing the challenge of universal food security, in the context of a number of other policy goals (e.g. social, economic and environmental sustainability), is of keen interest to a range of UK stakeholders but requires an up-to-date evidence base and continuous innovation. An exercise was therefore conducted, under the auspices of the UK Global Food Security Programme, to identify priority research questions with a focus on the UK food system (though the outcomes may be broadly applicable to other developed nations). Emphasis was placed on incorporating a wide range of perspectives ('world views') from different stakeholder groups: policy, private sector, non-governmental organisations, advocacy groups and academia. A total of 456 individuals submitted 820 questions from which 100 were selected by a process of online voting and a three-stage workshop voting exercise. These 100 final questions were sorted into 10 themes and the 'top' question for each theme identified by a further voting exercise. This step also allowed four different stakeholder groups to select the top 7–8 questions from their perspectives. Results of these voting exercises are presented. It is clear from the wide range of questions prioritised in this exercise that the different stakeholder groups identified specific research needs on a range of post-farm gate activities and food security outcomes. Evidence needs related to food affordability, nutrition and food safety (all key elements of food security) featured highly in the exercise. While there were some questions relating to climate impacts on production, other important topics for food security (e.g. trade, transport, preference and cultural needs) were not viewed as strongly by the participants.

Keywords Food security · UK food system · Post-farm gate activities · Stakeholder world views · Priority setting · Evidence gaps

Introduction

Food is a fundamental human need and access to food is a universal human right (UN General Assembly 1966). The UK Government's Foresight report (2011) on 'The Future of Food and Farming: Challenges and Choices for Global Sustainability' recognises the importance of food security and highlights five key challenges: balancing future supply and demand; ensuring adequate stability in food supplies; achieving global access to food and ending hunger; managing the contribution of the food system to the mitigation of climate change; and maintaining biodiversity and ecosystem services while feeding the world.

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Driven by the requirement to feed ever increasing human demand, major scientific and technical advances have been made in crop production, most notably, the 'green revolution'. This was based on a series of research, development, and technology transfer initiatives that occurred between 1966 and 1985, bringing about crop yield increases of 208 % for wheat, 109 % for rice, 157 % for maize, 78 % for potatoes and 36 % for cassava in developing countries in the period 1960–2000 (Pingali 2012). In industrialised countries, wheat and maize yield increases of *c.* 250 % and >500 %, respectively, have been seen over a similar period, although there have been marked regional differences (Ray et al. 2012). This, coupled with the many innovations in animal sciences, fisheries and more recently aquaculture, has meant that overall global food production has kept ahead of overall demand for many years (Lang and Ingram 2013).

Despite this productivity growth, about 1 billion people had insufficient calories and about a further billion were undernourished in 2010–2012 (FAO et al. 2012); huge inequalities with regard to access to food mean that hunger and poor nutrition are a continuing problem around the world, violating the human right to food of many. In contrast, the access to highly calorific food has been so easy for many others that the levels of overeating and obesity have become another global problem (Dyson 1996). Around a quarter of UK adults were classified as obese in 2011 (Gray and Leyland 2012; Health & Social Care Information Centre 2013) although, in addition to increasing accessibility of supply, the problem also relates to many interacting factors including differential changes in energy expenditure, sources of energy intake and types of food consumed (Butler and Dixon 2012; Dixon and Broom 2007; Institute of Medicine 2011). Nutritional quality is as important for food security as calorific content and FAO estimates of undernourishment overlook some aspects of food insecurity such as micro- and macronutrient deficiencies (Pinstrup-Andersen 2009).

The last few years have seen a growing realisation of the scale of future requirements: without substantial changes to dietary patterns and significant reductions in food waste, it has been estimated that 70 to 100 % more food will be needed by 2050 (Godfray et al. 2010). To achieve this, greater yields of crops, vegetables and products from livestock species will be required, with predicted increases in per capita meat consumption (kg/person/year) from 37 kg at present to around 52 kg in 2050 (26–44 kg in developing countries; Bruinsma 2009). However, climate change and decline of natural resources alongside population growth suggest that supply will not cope with growing demand, and innovative ways to manage food security more effectively are required (Schellnhuber et al. 2013; HM Government 2013). The recognition of future need, coupled with the 2007–2008 food price spike which sharply increased the number of hungry between 2006 and 2009 (FAO 2010), drove renewed concerns about hunger; the notion of

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food security rapidly ascended science, policy and societal agendas in many countries, as noted by Ingram (2011).

Despite the high-level political agreement at the 1996 World Food Summit that food security is essentially about stability of access to food rather than production per se (it is a condition whereby "*all people, at all times, have physical and economic access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active and healthy life*" (FAO 1996)), scientific and policy attention has again mainly focussed on increasing total production through increases in yield. This arguably risks ignoring people's anxieties about sustaining access to food (Maxwell 1996) and the other nutritional, social and economic aspects of food security emphasised by the FAO definition.

The notion of food systems

Food security is underpinned by food systems. These include complex sets of activities from producing to consuming food (often referred to as the food chain), which involve multiple interconnections. They have been modelled as food cycles, food webs and food contexts, but Sobal et al. (1998) noted that few existing models broadly describe the system, with most focussing on one disciplinary perspective or one segment.

Traditional food system and food security literatures have been somewhat separated, so recognising the need to consider not only the food chain, but also the food security outcomes defined by the FAO (1996) and the context of global environmental change, Ericksen (2008) drew together the extensive (yet relatively distinct) literatures in these areas. This approach provides a checklist of factors and issues that need to be considered in food security discussions (Fig. 1) and has proved valuable as a framework in a wide range of analyses (Ingram 2011). It is particularly useful in explaining how food insecurity arises when biophysical, economic and social stresses act – either singly, or in combination – on different aspects of the food system.

The methods by which food is produced, processed, packaged, marketed and consumed (food system activities in Fig. 1) affect all nine elements of the food security outcomes (bullets within circles, Fig. 1). In addition to health and wellbeing, food system activities also have outcomes related to, and are impacted upon by, socioeconomic (e.g. livelihoods of those working in the food system), and environmental sustainability goals (Fig. 1). Increasingly, these outcomes are related to the consumer preference aspect of food security (e.g. certification schemes such as fair trade or Marine Stewardship Council), which also brings in moral, religious and ethical aspects (e.g. animal welfare). A general research goal is therefore to understand how food system activities (and changes in the way they are undertaken) affect their outcomes on this diverse range of goals.

A focus on the UK food system

The recent emergence of food security as a priority in many policy forums is noticeable not just internationally but also within the UK specifically; several major government documents have been published in recent years (Defra 2009; 2008; HM Government 2010; Foresight 2011; Scottish Government 2009a, b). In critiquing these documents, MacMillan and Dowler (2012) acknowledge the shifts in UK policy discourse in the context of international research, policy and initiatives to promote food security. Food safety, consumer choice, nutrition, and authenticity are particularly prominent within policy and media (with the press devoting considerable space to recent food scares and diet), as are reducing waste and increasing productivity whilst reducing environmental impacts. There has also been increasing attention towards affordability (i.e. food cost in relation to the amount of disposable income available to spend on food) and inequality (Unwin 2012; Institute for Fiscal Studies 2013; Centre for Economics and Business Research 2013; Padley and Hirsch 2013).

While most attention about food insecurity is focussed on the developing world (where high food insecurity is widespread), the problem – albeit often to a considerably lesser degree – also exists in the UK. In 2007 the Food Standards Agency found that 29 % of materially deprived people sampled were mildly, moderately or severely food insecure, with 36 % of this group unable to maintain a balanced, nutritionally adequate diet (Nelson et al. 2007). More recently, Cooper and Dumpleton (2013) estimated that at least 500,000 people in the UK are food-insecure. Inequality is an increasing issue for the UK: while there is a high prevalence of overweight and obese children, up to 21 % of children admitted into hospitals nevertheless suffer from under-nutrition (Carey et al. 2012).

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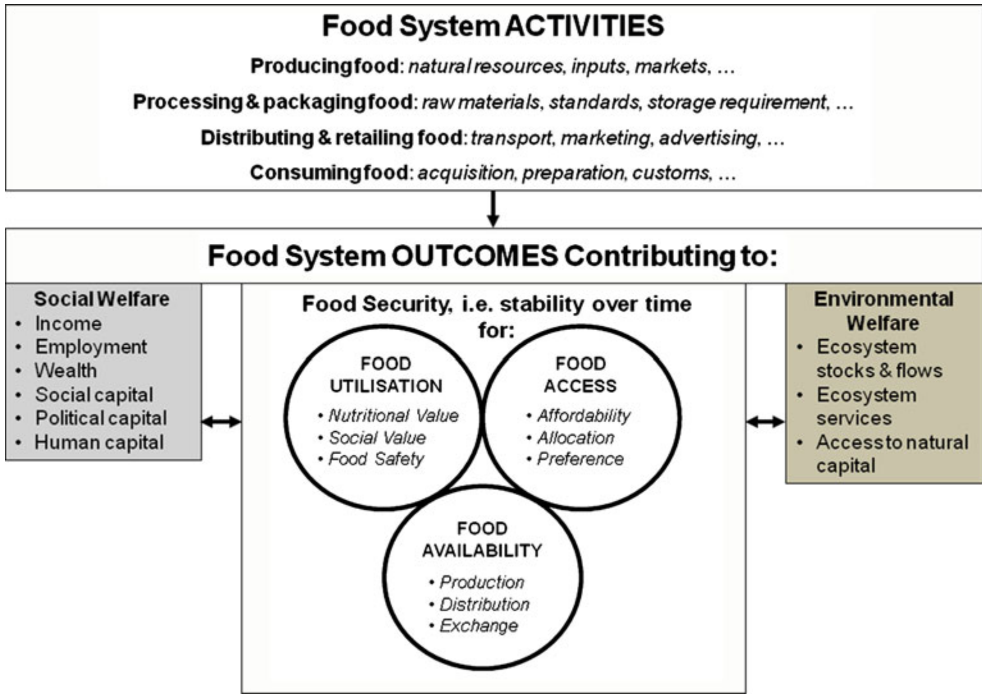

Fig. 1 The range of food system *activities* (with example determinants); and their *outcomes* in relation to nine food security elements (*bullet points in the circles*) all of which underpin food security. All nine elements are derived from the FAO World Food Summit definition. Food system activities also have other socioeconomic and environmental outcomes, and all contribute to waste production (Ericksen 2008; Ingram 2011)

This situation is accentuated due to the 'financial downturn' and related social welfare reforms and the UK has recently seen a rapid rise in the demand for food aid via food banks: the year to April 2013 saw *c*. 350,000 people (37 % of whom were children) receiving a minimum of three days emergency food from Trussell Trust foodbanks alone, 170 % more than in the preceding year and considerably more than the 26,000 people in 2008–2009 (Lambie-Mumford 2013; Trussell Trust 2013).

Setting research priorities

There have been several research prioritisation exercises addressing the primary production aspects of food security. Pretty et al. (2010) presented a set of questions which, if addressed, would have "a significant impact on global agriculture worldwide, while improving the synergy between agricultural policy, practise and research". The paper addressed the food system from an agriculture viewpoint, set within a complex landscape of production, rural development, environmental and social justice outcomes, and was not specific for the UK. More recently, Dicks et al. (2013) presented a set of priority research questions for enhancing the environmental sustainability of UK agriculture.

With a view to addressing the broader UK food security challenge, while in the context of other policy goals (e.g. social, economic and environmental sustainability) of keen interest to a range of UK stakeholders, an exercise was conducted to identify priority research questions for the UK food system as a whole. This encompassed all food chain activities, plus the food security outcomes relating to availability, access and utilisation of food. So as to complement earlier prioritisation studies, we emphasised 'post-farm gate' activities, but included food production (from land and water) as needed in relation to other food system activities and outcomes. The exercise, conducted under the auspices of the UK Global Food Security Programme, considered food consumed within the UK (whatever the origin), with a time horizon of 10–15 years. Particular emphasis was placed on incorporating a wide range of 'world views' from different stakeholder communities: governmental policy, private sector, non-governmental organisations, advocacy groups and academia.

Methods

The method for identifying priority research questions followed an iterative voting process previously applied in agricultural (Pretty et al. 2010), conservation (Sutherland et al. 2009), ecological (Sutherland et al. 2013) and science-policy (Sutherland et al. 2012) settings, and described by Sutherland et al. (2011). An initial long list of suggested research questions was reduced to 100 top priorities in four voting stages, and subsequently further refined to select the top priorities by theme and major stakeholder group (Table 1).

Participants

Participants were selected with the aim of representing all parts of the current UK food system, but with a focus on

Table 1 The five voting stages used for narrowing down the initial suggested questions into a refined list of research priorities. Right-hand column gives the stage's format. Stages 2–4 also included removing duplicate questions, rephrasing questions and highlighting important subject areas that had been overlooked in the process thus far

1. Voting on 811 questions to provide an initial ranking within 12 themes. 9 additional questions included.	Email survey
2. Removing *c.* 75 % of the 820 initial questions in 12 sessions (one theme per session) by discussion and voting. Ranking remaining questions as 'gold' (35 %), 'silver' (33 %) or 'bronze' (30 %).	Four rounds of three parallel workshop sessions (each 2–2.5 h)
3. Removing *c.* 30 % of 202 remaining questions in 4 sessions (three themes per session) by discussion and voting. Ranking remaining questions as 'gold' (59 %), 'silver' (14 %), 'bronze' (14 %) or 'nickel' (14 %).	Two rounds of two parallel workshop sessions (each 1.75 h)
4. Selecting the top 100 from the 140 remaining questions by discussion, championing of lower-ranked questions and voting.	One plenary workshop session (2 h)
5. Voting on the top 100 questions to identify the top priorities per stakeholder group (four shortlists of 7–8 questions).	Online survey

post-farm gate activities in particular. Sixty-one people ('participants') identified and prioritised the top 100 questions, 59 of which suggested questions and/or participated in the first voting stage and 48 (included here as authors) participated in the latter voting stages. Non-academics directly involved in the food system (henceforth 'practitioners') brought an understanding of practical knowledge needs and represented four major stakeholder groups. 'Primary production' (4 people) included two producer groups, one advisory body and a consultancy, ranging from small enterprise cooperatives to large, nationwide producer organisations. This relatively small number of farming representatives was deemed sufficient as priorities for primary production have already been addressed (Pretty et al. 2010) and we focus mainly on the post-farm gate food system. 'Food industry and retail' (10 people) included food processors, retailers, industry associations and private-sector research. 'Governmental policy' (11 people) included representatives from government and government agencies. 'Non-governmental organisations (NGOs) and advocacy' (8 people) included organisations, charities and foundations working across the food system on waste, consumer choice, nutrition, fair trade and other issues of security and sustainability. Of the 36 practitioner companies and organisations invited, 25 participated.

'Academics' (28 people) formed a supplementary stakeholder group and included crop and livestock scientists, food technologists, logistics experts, engineers, environmental scientists, economists, social scientists, nutritionists and knowledge exchange specialists. Selected in approximately equal numbers to practitioners, academics brought a detailed knowledge of existing science and knowledge gaps from across the food system. Academics were selected based on having multiple, relevant publications in the scientific literature and were leading researchers in their fields. Of the 24 academic institutions invited, 22 agreed to participate. Across all stakeholder groups we attempted even representation of the different food system perspectives, but some bias is inevitable and the priority questions could only reflect the views of those participating.

Initial list of questions

Participants were invited to submit up to 10 research questions on any aspect of the UK food system. Throughout the prioritisation process we aimed to solicit questions that were answerable by a small research team or programme working within a limited timeframe (e.g. 3–5 years). Very broad or general questions summarising whole research agendas were therefore discouraged. We also strongly encouraged questions that would yield practicable answers, with priorities strictly limited to key existing and emerging issues relevant to food security that would benefit specifically from a stronger evidence/research base. Primary production questions were included, but to avoid duplicating other prioritisation exercises related to food (Pretty et al. 2010) participants were asked to tailor these from the perspective of post-farm gate activities. Participants engaged with their colleagues or group members and were asked to record the number they consulted (this included being present in a meeting but not simply being sent an email to which they did not respond). This resulted in consultation with 456 people and produced an initial list of 811 questions.

The initial list of questions was divided into 12 themes (Table 2; ranging 29–124 questions per theme), guided by the GECAFS (Global Environmental Change and Food Systems) framework (Ericksen 2008; Ingram 2011) of food system activities and food security outcomes (Fig. 1). For the first voting stage each participant was asked (via email) to choose the most important questions in two or more themes most relevant to their position or expertise in the food system. Participants selected 4–15 questions (*c.* 12 %) per theme and also suggested edits or provided examples of existing knowledge where they felt it useful to do so. Questions were then ranked and sorted within each theme by the tally of votes, but with very similar questions positioned consecutively. The wording of questions was not edited at this stage to maintain transparency in the process and to prevent misinterpretation of original meanings. Some additional questions were suggested during this voting stage, creating 820 initial questions in total.

Table 2 The number and percentage breakdown of initial questions into 12 themes. These data represent the list of questions following voting stage one (Table 1). Totals for each question type (i.e. 'food system activities', 'food security outcomes' or 'food system management') are shown in bold. Parentheses show the percentage of questions per theme per question type. Percentages are rounded to integers

	Number of questions	% of total
Food system activities	**466**	**57**
Producing - yields [a]	84	10 (18)
Producing - context [a]	85	10 (18)
Processing	76	9 (16)
Logistics and packaging	47	6 (10)
Retailing	50	6 (11)
Consuming	124	15 (27)
Food security outcomes	**150**	**18**
Affordability [b]	29	4 (19)
Nutrition	70	9 (47)
Safety [b]	51	6 (34)
Food system management	**204**	**25**
Whole system – environmental context	56	7 (27)
Whole system – policy context	76	9 (37)
Waste	72	9 (35)
TOTAL	820	

[a] Following voting stage four (Table 1) the remaining 'producing' questions were re-classified into two themes representing (A) environment and resources and (B) innovation and wider context. These are the themes presented in the Results section

[b] In later voting stages the remaining safety questions were grouped with those in logistics and packaging, and the remaining affordability questions were grouped with those in consuming. Although safety and affordability are key food security outcomes rather than food system activities, these merges were necessary to create approximately equal-sized themes for use in the final voting stage

Prioritising the top 100 questions

A two-day workshop was held in Birmingham, UK, on 27–28 February 2013 for the second to fourth voting stages (Table 1). Participants iteratively excluded, merged, edited, selected and ranked the questions, narrowing down the initial list to define the top 100. This sequential process ensured that early decisions were influential in latter stages, but could nonetheless be overruled if participants deemed this necessary. It also allowed comparison of questions from separate themes, thereby ensuring that questions were of equivalent importance and that overlaps were resolved. Voting stages two and three involved parallel workshop sessions and participants were free to attend the themed sessions that best met their expertise. Sessions were facilitated by an impartial chairperson who ensured that discussions represented all relevant viewpoints and that decisions were democratic. While many decisions were made unanimously, some decisions and all ranking exercises relied on voting using a show of hands. Parallel sessions contained a roughly equal number of participants and chairs checked that the number of practitioners and academics was not strongly imbalanced.

Each stage of the process was guided by the votes or ranks ('gold', 'silver', 'bronze' and 'nickel') allocated to questions in the preceding voting stage. Questions that received few votes in voting stage one were the first to be examined in voting stage two, and those unlikely to reach the final 100 were quickly excluded. However, low-ranking questions were supported by participants if their exclusion risked omitting an overlooked yet important issue, or if questions had simply been poorly phrased. Questions receiving strong support were assigned gold status, and remaining questions were assigned to silver or bronze (or excluded) through further discussion or voting. Multiple rounds of voting took place to resolve any tied vote counts. In voting stage three, questions previously ranked as gold were examined first, removing duplicates, improving wording, clarifying meanings and demoting less important questions to silver. Lower-ranking questions were then assessed to make further exclusions or consider promoting some questions to gold. Participants voted on remaining silver and bronze questions to set rankings between silver, bronze and nickel.

Voting stage four combined all themes and was attended by all participants. Gold and silver questions were examined first, checking for further overlaps or rephrasing where necessary, before attention turned to nickel questions to see if any of these deserved bronze status. Participants were asked to consider which key issues were not adequately covered by gold and silver questions, and were encouraged to argue in support of the lower-ranked questions that could fill these gaps. The final 100 questions comprised the remaining gold and silver questions, plus the five most popular bronze questions determined in a final show of hands. Following the workshop, the 100 questions were reclassified and grouped into 10 themes of approximately equal size (again following the GECAFS framework).

Prioritising the top questions per stakeholder group

The fifth and final voting stage (Table 1) used an online survey to identify the top research priorities by stakeholder group, asking respondents to choose their 10 most important questions from the list of 100. Again we aimed to represent the full breadth of food system perspectives, and so the survey was sent to all participants from earlier voting stages (who forwarded the survey to colleagues and group members) and to wider food system contacts encountered opportunistically. A total of 156 people responded (44 of which had previously engaged in the process) comprising 20 in primary production, 11 in the food industry and retail, 25 in governmental policy, 16 in NGOs and advocacy and 84 in academia. Respondents were asked to choose one 'favourite' theme most relevant to their self-selected stakeholder group, then select five questions from this theme and one question from each of five other themes. This design sought a compromise between capturing respondents' specialist knowledge and encouraging them to consider a wide range of food system activities and food security outcomes. The survey was built using Qualtrics Research Suite (Qualtrics 2013), providing each respondent with a randomly ordered list of research questions under each theme.

Votes from all 156 respondents were counted to determine the top research question in each of the 10 themes. Votes were then separated to compile a shortlist of top five priorities for each of the four practitioner-based stakeholder groups. Shortlists comprised the three most popular questions from the most frequently selected favourite theme and the two most popular questions from across the nine other themes. The academics' top priorities were used to supplement those of the practitioner groups. We identified the academics' most popular 2–3 questions (the exact number depended on vote ties) for each of the themes encompassed within the practitioners' shortlists. Where academics' top questions did not overlap with those already selected by practitioners, the former were added to the latter to create four combined shortlists of 7–8 priority questions.

To assess the overlap between academics' and practitioners' priorities we calculated the percentage of questions chosen by both groups in their respective subsets of the *c.* 3 most popular questions per theme (identified by vote counts). The actual number of questions compared within each theme varied from 2–4, depending on ties in vote counts; a total of 33 selections from each group were compared overall.

The key outcomes from this exercise together with a brief discussion of the implications for the UK food system research are summarised below.

Results

Overview

Of the original 820 questions submitted by participants, over half related to food system activities, with a quarter going to whole systems questions, and less than a fifth on food security outcomes (Table 2). This might be due to the recent re-emergence of food security as a UK priority and the likelihood that research and practitioner communities may not yet be thinking in terms of the complete set of elements involved in food security outcomes.

Within the questions on food systems activities, over a third related to producing food, while a quarter related to consuming food. Reference to "producing" and "farming" refers to both land-based and aquatic production, unless otherwise specified. Other food system activities received relatively few questions. Questions regarding food security outcomes were unevenly distributed across the nine elements (bullet points, Fig. 1), with the majority relating to nutrition, safety receiving over a third and affordability receiving a fifth. Issues regarding waste and the environmental and policy contexts of the whole food system (food system management questions), drew approximately equal proportions of questions (Table 2).

The top 100 questions are here presented grouped within 10 major themes (A–J), but are not presented in a rank order. Asterisks (*) indicate the highest priority questions in each theme (across stakeholders). Emboldened acronyms indicate the top questions identified by stakeholder groups, combining practitioners' and academics' priorities (see also supplementary material, Table S1–S4):

PP primary production
IR food industry and retail
GP governmental policy
OA NGOs and advocacy

Producing – environment and resources

It is well recognised that the environmental impacts of food production are significant as farming and fishing are, by their very nature, modifications of natural ecosystem functioning. They often use non-renewable resources (fuel, fertiliser) while pollution and unintended side-effects of agricultural, aquacultural and fishing practices can be substantial. The total external environmental damage costs (to air, water and soil) from agriculture in the UK have been estimated to range from £1–3 billion per year (O'Neil 2007; Jacobs 2008). As about 50 % of the UK's food comes from abroad, the environmental impact of the UK's food system is felt also in the 184 countries that supply goods to the UK (K. Evans 2012).

The questions (see below) covered a range of evidence needs around three major issues: optimising the farming environment for production (noting that often this applies equally to terrestrial and aquatic systems); building resilience to shocks, especially those from changing climate and weather extremes (see also Knox et al. 2010); and, balancing environmental impacts and production needs: Q2 highlights the need for a better understanding of how to manage farms differently according to the geographic or local environmental context; Q4 addresses the need to consider a wider range of protein sources for both human and animal consumption. The increasingly evident change in weather patterns requires the development of more resilient farming systems and identification and management of risks for handling disruption to food supplies by extreme events (Qs 1, 3, 8).

Given that the environment provides both food and other multifunctional ecosystem services of societal value (UK National Ecosystems Assessment 2011), a major challenge is how to balance the needs of food production against other societal needs including environmental aspects. In England for example, over 70 % of land is farmed (Defra 2011). This means that the viability of ecosystems, maintenance of biodiversity and delivery of wide ecosystem services are directly affected by the way agricultural land is used and managed. A balance is needed at a local or landscape level, where there is increasing competition for a range of resources for farming (including water; Q3), and also at larger (regional and global) scales. Q5, for instance, covers the question whether manure should be moved from the over-supplied west of the UK to the undersupplied east; and Q6 is about avoiding the export of the UK's food demand-related environmental costs overseas via importing food. The balancing applies equally to marine (Q7) as to terrestrial systems, although at present a relatively small proportion of coastal waters are used for cultivation, thus providing potential for controlled expansion in this sector.

1. How can UK food supply and primary production adapt to more extreme weather events? **PP GP**
2. How should UK soils be managed for optimum productivity and environmental protection in field vegetable, arable and grassland livestock systems in the long term? **PP**
3. Given the UK's geographical imbalance between limited and excess water supplies, how can water resources be better managed to improve water-use efficiency for food production? **PP**
4. How can the domestic supply of high quality proteins be sustainably diversified?
5. How can improved integration be ensured, especially in the efficient use of nutrient resources (e.g. fertilisers), between geographically dispersed UK farming systems?
6. How can the sustainability of UK primary production be improved without expanding our social and environmental footprint overseas? * **PP GP**
7. How should the efficient capture and processing of seafood be maximised while harvesting resources within sustainable limits and maintaining good marine ecological function?
8. Which crop sectors and regions of the world constitute the greatest risks (now and in the future) in terms of the UK's security of supply of fresh produce?

Producing—innovation and context

Over the past 60 years agricultural yields have improved as a result of innovations in breeding, crop protection, soil drainage, crop rotations, fertiliser production, crop and animal nutrition, livestock husbandry, and aquaculture systems. However, since the 1990s, there has been a plateau in yield for many major UK crops (NIAB 2012). At the same time, there is increasing pressure on water, soil, land, marine areas and energy resources, and changing climatic conditions (Foresight 2011). Increasing urbanisation, overeating, waste and a shift towards a more varied diet in developing countries add further pressure on global food chains.

In most cases, the challenge for agriculture and aquaculture (both UK and global) has been articulated as one of sustainable intensification (Foresight 2011; Global Food Security Programme 2013; Garnett 2013). This means simultaneously increasing food production, improving nutritional value, reducing negative environmental impacts and enhancing the wide range of interlinked ecosystem services that society needs from the land and sea.

To achieve this, there are three main areas for innovation, which are reflected in the priority questions below. These are: (i) improving the productivity and resilience of production systems to meet human nutritional needs with fewer inputs, less waste and reduced negative environmental impacts (Q10, 11, 14, 16, 17), (ii) helping farmers and fishermen to implement existing innovations, bringing them closer to the optimal level of sustainable intensification for their system (Q13, 18, 19), and (iii) exploring novel production systems and food sources (Q9, 12, 15).

9. How can a sustainable supply of the fatty eicosapentaenoic (EPA) and docosahexaenoic (DHA) acids for the UK be ensured (e.g. without further damage to fish stocks)?
10. How can food supply be maintained as the functionality or use of pesticides, anti-microbials, antibiotics and biocides decreases? * **PP**
11. How can primary food production be sustainably intensified whilst maintaining or enhancing the nutritional value of those food items? **PP**
12. What are the opportunities for farming algae as a raw material for food production in the UK, including as a source of long chain polyunsaturated fatty acids and protein?
13. What are the barriers to the further development and uptake of precision technologies, smart engineering and automation by producers to enhance the efficiency and sustainability of the food system, and how can they be overcome? **PP**
14. How could grassland agriculture in the UK better contribute to food security?
15. What would it take for the UK to be more secure in animal feed and what would be the consequences for the rest of UK food production?
16. How can pre-harvest management and selective breeding influence post-harvest quality (including nutritional quality) and waste?
17. How can the growth of domestic aquaculture be encouraged and supported to sustainably meet long-term demand?
18. How might engineering solutions help to improve existing, and develop new, food production systems?

19. How to make agriculture, aquaculture and fishing an attractive career for younger, enterprising people with the vision and ideas to put new ways of producing sustainable food into practice?

Processing

As the population grows and world resources decline one of the most important challenges for modern manufacturing industries is to produce more and better with less (Dobbs et al. 2011). Nowhere is this more relevant than in food processing due to its importance to ensuring long term availability, quality and security of food resources. This challenge of improving quality, quantity and efficiency needs to be addressed through a simultaneous consideration of food raw materials and products, processing methods, supply chain systems, retail policies and consumption patterns. To be successful, the UK food industry needs to deliver sustainable growth by providing foods that the consumer needs and prefers (Q22, 27, 30) which are produced competitively with more efficient use of resources, while being proactive in addressing key societal challenges such as public health and climate change (Q23, 28).

In the past few decades, incremental improvements have occurred in the processing aspects between 'the farm gate and the supermarket shelf'. However, due to mounting pressures from the cost of input materials and energy, changes in consumer preference and a need to reduce water usage, most of the current approaches to food processing need to change (Q24) (The Royal Society of Chemistry 2009). A continued climate of innovation in the food processing industry will be a key component of ensuring the secure supply of safe, affordable food and such innovation must be integrated with the development of more sustainable and nutritionally healthier products (Q21, 26, 29). There is an additional challenge that has arisen from recent changes in the use of land and crops, e.g. for the generation of biofuels. Increasingly crops are being grown on land not previously used for food production and novel resources harvested from the sea (Q20, 25). The conversion of these novel raw materials into food for human consumption is not straightforward, and new processing technologies and food formats are required.

20. What are the implications for food manufacturing of changes in available raw materials due to climate change? **IR**
21. In a world where many need to eat fewer calories, how can the density of nutrients (i.e. vitamins, minerals, essential fatty acids and essential amino acids) be improved in foods and in the overall diet?
22. How can the bioavailability of key dietary components be retained, enhanced and generated using the physical structure of food (e.g. colloids)?
23. How can efficiency be improved and greenhouse gas emissions reduced with respect to water and energy inputs in food processing (e.g. reduction of heating then cooling or wetting then subsequent drying steps across the food chain)?
24. What new engineering technologies (e.g. lotus leaf-effect surfaces) can be adopted for the conservation, reuse and inclusion of water in food processing without compromising food safety?
25. How can raw materials from aquaculture (e.g. hydrocolloids, proteins, fats) be better used?
26. How can foods be built that target nutrients to different regions of the digestive tract?
27. How can the fat, sugar, preservative and salt content of foods be reduced while ensuring that palatability is maintained, waste is minimised, and food remains safe and does not spoil? * **IR**
28. How can food hygiene and safety be ensured as chemistry and chemical engineering in manufacturing processes (e.g. cold plasma, high pressure processing, non-compressor refrigeration) change to meet future economic, social and environmental drivers? **IR**
29. How can foods be created with the benefits of eating fruit and vegetables (e.g. structure, bioactives, nutritional value), but with extended shelf life and consumer appeal?
30. How can the structure of food be used to create products with a low glycaemic index?

Logistics, packaging and safety

Transport and packaging are two aspects of the food system which greatly impact on food sustainability and security. Packaging and storage play a particularly crucial role in preventing waste and maintaining food safety. Making more efficient use of our resources can include 'lean production' (making foods that require less materials at the outset); 'waste reduction' (reducing the amount of waste created at all stages of manufacturing and retailing); and 'lifetime optimisation' (reducing the amount of food we throw away due to spoilage) (Parfitt et al. 2010). Extending product shelf life has the potential to reduce food waste (WRAP 2013) (although short shelf life does not always mean more waste, especially when demand is predictable; (Mena et al. 2008). It also offers consumers more flexibility and convenience in deciding when to use foods. Extending shelf life, whilst reducing energy consumption and still minimising the potential for food spoilage or food poisoning, is very challenging. These challenges are reflected in the key research questions below.

Shortening the food chain could improve resource efficiency and reduce waste (Qs 31, 32, 35) but may have an adverse impact on energy use on the retail side (Q39). Q33 seeks novel technologies to control pathogenic food poisoning organisms whilst Q34 addresses the possible losses in nutrient and taste properties of the food during extended storage. Preservatives are an effective method to extend shelf life, but increasingly consumers look for products without any additives, preferring those with 'clean labels' (Q36). Foods can also be heat-treated for preservation, but this often results in a different taste or texture, and may also alter nutritional quality. Developments in packaging technology, including smart labels that indicate when foods exceed their 'use by' dates can help the consumer better decide when products should be eaten or thrown away (Q38). Finally, Q37 tackles the big issues of climate change and its impact on food safety (see for example Miraglia et al. 2009).

31. How could resource efficiency of food processing be improved by moving some aspects of the manufacturing process physically closer to the consumer?
32. How can food distribution methods be improved to increase resource efficiency?
33. How will novel, emerging and re-emerging pathogens be prevented, detected and controlled rapidly and accurately to enhance food security? * **IR**
34. How can packaging innovation be used to extend shelf life while maintaining taste and/or nutritional quality?
35. What efficient technological innovations and practices are required to extend storage of domestically grown produce?
36. To what extent are reductions in preservative use and consumer preference for 'clean labels' (e.g. fewer E numbers) influencing shelf life and food waste?
37. Which aspects of food safety are most likely to be affected by climate change and/or by climate change mitigation and adaptation in the food system, and how?
38. How can smart packaging be used to reduce food waste and maintain or enhance food safety? **IR**
39. What impact does diversification of emerging shopping habits (e.g. online, farmers shops, markets) have on fuel consumption and traffic congestion (e.g. by consumers, delivery vans) compared with standard weekly supermarket shopping?

Retailing, trade and investment

Food retailers are an important part of the food supply chain and greatly influence food security and sustainability in terms of ensuring the resilience, integrity and safety of food supply and informing choice. Food retailing may well continue to evolve rapidly, as a consequence of changes in the way consumers obtain information about food and food suppliers, shop, cook and eat (internet food sales in the UK are expected to grow to £11 billion by 2017) (Institute of Grocery Distribution 2012). Affordability, stresses on the supply chain from increasing population and shifting demographics, climate change and continuous changes in the food supply system will also have a great impact (Roeder et al. 2011; Food Ethics Council 2013). The questions raised identify some of the key issues: how choices are made in the future (Qs 40, 45); how the supply chain will cope with increased challenges of social, economic and environmental pressures (Qs 41, 42, 47); and what responsibilities different actors in the food system have for sourcing food sustainably and equitably (Qs 43, 44, 46, 48, 50).

40. What food information systems would allow UK consumers to make an informed choice about each product's impact on different aspects of sustainability (environmental, economic, health and social)? * **IR**
41. How can volatility in food supply be better predicted and mitigated?
42. Which parts of the major supply chains in the retail (including food service) sector are susceptible to major disruptions such as crop failure, fuel supply etc. and how can strategies be developed to improve resilience?
43. What strategies would overcome the main barriers for UK food manufacturers, retailers and the food service sector to incorporate more smallholders and small and medium enterprises in their supply chains? **IR**
44. How can buyers and suppliers develop more trustworthy, equitable and collaborative relationships to improve supply chain practices? **IR**
45. How does digital media change purchasing choice behaviour?
46. What are the trends in the distribution of economic value across the food chain for key products sold in the UK, and what are the implications for investment and innovation?
47. How can precursors to extreme events that impact the food system be better identified (forecasting conflict, weather anomalies, etc.) and how can mitigation against them be enhanced?
48. Given the highly concentrated and rapidly evolving international commodity trading arena, how could agricultural commodities be traded in ways that increase transparency and contribute to enhanced sustainability and UK food security?
49. What is the impact of changing structures of ownership and investment across different parts of the food system on food security?
50. What are the best measures for assessing the contribution of the food system to a local area or local economy?

Affordability and consumption

It is essential that food meets consumers' needs and preferences, now and in the future. The food supply has to meet nutritional and other health needs, as well as wider social, economic, environmental and cultural expectations, and yet food has to remain affordable, accessible and safe to all. If a food product is not acceptable to consumers for any reason, it will not sell (Q60). It is therefore essential that consumer concerns (including those around the use of new technologies) are understood and addressed (Qs 58, 59). For example, the Foodlinks network (Foodlinks 2013) proposed that closer links between production and consumption may increase consumer understanding of food origin and improve trust and equality in the food system.

Increased food prices and prices spikes have been an important spur to improve our understanding of food insecurity in the UK. The role of prices on food choice is complex and not particularly well understood. Price elasticities for broad food groups indicate that price responsiveness of the consumer is small. At the level of individual brands however responsiveness is much larger. What is beyond doubt is that the poorest are challenged by high food prices and that dietary quality may consequently be compromised. Research with UK householders at risk of food insecurity conducted before the recent austerity measures showed people were very concerned about food quality if they had to 'trade down' and buy cheaper food as prices rose (Dowler et al. 2011; Kneafsey et al. 2012). It is therefore important to understand much better the likely impact of reduced access to food due to rising prices, particularly for the most vulnerable and how this can be mitigated (Qs 55, 57, 60, 61). This includes understanding the main drivers of the increases in price and the true cost of our food choices in the longer-term (Q56) (Food Ethics Council 2010).

At the moment, many of the food choices consumers make are unhealthy and/or nutritionally unbalanced and/or not sustainably produced. Knowledge of what constitutes a healthy diet is widely disseminated but many fail to apply this in practice, partly because people believe experts are always "changing their minds". As well as physical and financial access (Q53), the ways in which environmental and cultural contexts (Lang and Rayner 2012; Bestwick et al. 2013) influence food choice need to be better understood (Q54). Information about what to eat to optimally balance nutritional, environmental, social and economic impacts as well as address ethical and cultural aspects needs to be further developed beyond simply the impact on health and greenhouse gas (GHG) emissions (Macdiarmid et al. 2012; Sutton and Dibb 2013); so too do the actions needed to help people achieve this in practice (Qs 51, 52, 54).

51. What dietary choices would UK consumers make if their intake of meat and dairy products was reduced, and what impact would this have on health and sustainability? **OA GP**
52. What influences an individual's consumption of plant-derived foods?
53. What are the structural and market factors that affect UK individuals and households in terms of access to, and affordability of, a healthy balanced diet, and what policies and interventions are effective in managing these?
54. Which intervention (or combination of interventions) would be most effective in achieving changes in consumption decisions and which types of intervention (e.g. awareness raising campaigns, choice editing, education, legislation or regulatory) are most appropriate for specific contexts and decisions? * **OA GP**
55. Which UK groups (e.g. socioeconomic, regional) are, or are likely to become, food insecure in the near future, and why? **GP**
56. How can food prices or other financial mechanisms account for the environmental and health externalities in food production and consumption? **OA**
57. What factors influence the allocation of food within UK households, and what are the implications for health? **GP**
58. How can mismatches between formal risk assessments and public perception be resolved when assessing the use of different technologies that could improve the efficiency and resilience of the food system? **OA GP**
59. How does civil society, enabled by information and communication technologies, impact on the structure and governance of the UK food industry?
60. What are the effects of prices, income and other socio-economic variables on the diet choice of different segments of the UK society, and how will that impact on nutritional quality and sustainability?
61. To what extent do 'grow your own', and community growing and purchasing schemes, increase individual food security in the UK's low income groups?

Nutrition

A key aspect to the food security challenge is to produce and supply enough safe and nutritious food to meet population dietary needs and to maximize health and wellbeing throughout the life-course (Buttriss 2009). Many modern processed foods are calorie dense and rich in sugars, starch and fats. They are made from a limited selection of crops – 50 % of global calories consumed are from wheat, maize and rice (Edmeades et al. 2010). Because ingredients used by food manufacturers are often refined, the concentration of plant-derived phytochemicals in processed foods is generally low. The presence of these biologically active phytochemicals may have positive health consequences (Terry 2011; Jaganalth and Crozier 2008). A desirable goal is to increase availability of raw materials lower in sugar and starch, but richer in fibre, minerals and bioactive phytochemicals. In respect of healthy eating, "one size does not fit all" (Joost et al. 2007) and there is a need for fundamental research on interactions between food, genetics and the epigenome (Q66) to provide the basis for personalised (or stratified) dietary advice (Gibney and Walsh 2013). This will include understanding of the optimal balance between different types of fatty acids (Q70) and the development of food-based strategies, which deliver improved nutrition for vulnerable groups (Q63). In addition, evidence is emerging that there are interactions between food and the gut microbiome with profound implications for health (Claesson et al. 2012; McCartney 2013); such evidence offers considerable opportunities for new food-based routes to improved health (Q67).

Worldwide, the major population challenges include prevention and management of obesity and the management of ageing. Overconsumption of energy leading to high body fat stores is a major risk factor for common diseases and for premature death (Prospective Studies Collaboration et al. 2009). Reducing energy intake would bring health and wellbeing advantages whilst reducing the pressures on food security and the environment (Q62). We need to investigate how maternal nutrition and eating patterns during childhood and early adulthood influence how we age (Buttriss 2013) and to develop dietary strategies for promoting healthy ageing (Q69). For older people per se, there are major gaps in our knowledge of nutrient requirements (Q64) and of how to ensure that food products available to them supply their nutritional needs (Q69). All of this will be underpinned by understanding the effects of climate change (Gornall et al. 2010) on the nutritional composition of primary food products (Q68) to secure optimal nutritional supply.

62. How can existing understanding of overconsumption drivers be used to reduce the impact of overconsumption on food security?
63. Which integrated food-based strategies are best to improve nutrition and health in vulnerable population groups without negatively affecting other groups?
64. What are the nutrient needs of an ageing UK population?
65. How can the supply of nutrient-dense, easily ingested and easily assimilated foods for the elderly be developed and ensured?
66. How can nutrition be improved based on understanding of the interactions between genetics, epigenetics, environment and diet? *
67. How can the human gut microbiome be modulated by diet for improved health?
68. How does seasonality, extreme weather and climate change affect the nutrient composition of primary food products?
69. What is the contribution of foods eaten or diets taken throughout life towards healthy ageing (i.e. quality of life, physical and mental agility)?
70. What is the optimal balance between different types of fatty acids for health?

Whole system—environmental context

There is increasing concern about the impact that food systems are having on the environment. The literature is strongest in terms of primary production aspects and some impacts are reasonably well understood, including GHG emissions (Vermeulen et al. 2012), altered land cover (MEA 2005), nitrogen fixation (Vitousek et al. 1997), and extensive water use (Wallace 2000). Other, more indirect aspects, such as implications of atmospheric levels of reactive nitrogen compounds for human health (Hertel et al. 2012), are now also receiving attention. Post-farm gate food system activities also have significant environmental impact, with such activities accounting for 10 % of all industrial use of the public water supply, 10 % of the industrial and commercial waste stream, and 25 % of all heavy goods vehicle kilometres in the UK (Defra 2006). The latest estimates indicate around 195 Mt of CO_2 equivalent (CO_2-e) GHGs were emitted within the UK from domestic food chain activities in 2010, excluding emissions from non-fertiliser pre-farm production, extended cold storage, food packaging, food waste and land use change (Defra 2013a); GHG emissions by UK households in 2010 from food shopping, storage and preparation were about 18.8 Mt CO_2-e (Defra 2013b, 2013c).

While a key issue is still how to reduce GHG emissions (Qs 74, 79), there is also a clear need for research on the more complex environmental sustainability issues (Gill and Johnston 2010), and especially in the area of changing lifestyles and habits related to food (Qs 71, 72, 80). Concern about the impact that changing environmental conditions will have on the UK's food system have also been highlighted (Garnett 2008; K. Evans 2012; Global Food Security Programme 2012; Bows et al. 2012) but there are still significant evidence needs in relation to determining economic opportunities in the adaptation and mitigation agendas (Qs 73, 78) including extreme weather events.

71. What are the interactions between potential demographic and future societal or lifestyle changes (e.g. changing leisure time, use of online shopping, 'smart' kitchens, etc.) and the food system, and what are their consequences for health and the environment?
72. What are the potential unintended consequences of efforts to drive healthier food choices in the UK on other outcomes (e.g. environmental impact)?
73. What are the opportunities and risks for UK food supply and primary production in responding to climate change? * **GP**
74. How can the food system adapt to reduce its dependence on non-renewable energy?
75. What criteria and acceptable rules-based system should be used to quantify and assess a gradient of sustainability in the UK food system?

76. What non-technological innovations (e.g. social, economic and ecological innovation) can enhance sustainability in the food chain, and how can they be integrated?
77. How can a closed loop production model be scaled to agricultural and food systems?
78. In what ways can the opportunities of increasing environmental and social sustainability in the food system create economic value?
79. What are the benefits and trade-offs between a sustainable food supply chain and one which is optimised to minimise long-term greenhouse gas emissions?
80. What are the impacts on UK food security and efficiency of the food system of processed or frozen food versus cooking from scratch in the home?

Whole system—policy context

Food security is a long-term challenge that the UK, along with EU and international partners, has a duty to address. The nation state is regarded as the primary locus of public policy making and governance of the food system, and the UK government (as for many other states) has adapted its role in policy making and implementation over recent decades. While one of the UK government's priorities is now to help enhance the competitiveness and resilience of the entire food system to help ensure a secure, environmentally-sustainable and healthy supply of food with improved standards of welfare for all, legal authority has to some extent been ceded both up- and downwards.

First, UK food policy was integrated within the European Union where single market regulation, rules and supports shape the operation of the food system and the provision of food (Lang et al. 2009). Also, legal authority has been ceded upwards to global facing international institutions and regimes, such as the World Trade Organisation agreements whose rules shape food trade and agricultural support regimes (Coleman et al. 2004; Swinbank and Daugbjerg 2006). Second, devolution of legal powers downwards to the Devolved Administrations of Scotland, Wales and Northern Ireland has led to an increasing diversification of food policy within the UK (Ambler Edwards et al. 2009). Also, there has been a shift from state controlled governing to other forms of governance where non-governmental public bodies, such as levy boards, and private actors, such as trading, manufacturing and retailing corporations, sector groups, such as farmer unions and civil society organisations, undertake the administration and implementation of policy (Schilpzand et al. 2010).

In these cases, the state takes an enabling role, steering rather than propelling, yet expanding its policy reach into a more fluid and networked series of governance arrangements that direct practices within the food system. Here, authority is more diffuse, involving private governance forms (Clapp and Fuchs 2009), and policy making and policy change are more extenuated and complex (Lang et al. 2009).

Identifying the governance relationships and their interdependencies (Qs 83, 88) and the effective use of available policy instruments (Q90) are essential in order to understand and assess the value of contemporary practices within the food system. Information and knowledge exchange are important for enabling future innovation (Q85), for example in addressing the UK food system's global footprint (Q87), and may be of value in transferring knowledge to other parts of the world (Q92). Innovations are needed in terms of building and maintaining resilient food supply (Q86) and addressing potential vulnerabilities to this supply and its access (Qs 81, 82, 84, 91), and may necessitate altering the judgements by which successful policy outcomes are measured (Qs 89, 87) (Jackson 2009).

81. How will changes in global availability of food impact UK food security?
82. In the context of global trade, how can UK production be optimised to maximise UK food security?
83. Which modes of food governance (voluntary, mandatory, and hybrid) are most effective in delivering food security under given conditions?
84. What are the socioeconomic consequences of the reduction in infrastructure to support alternative UK producers and distribution chains?
85. How can the accessibility and use of data be improved to characterise food supply chains and consumption?
86. What are the potential mechanisms through which agro-economic policies improve the efficiency, resilience and competitiveness of the food supply chain?
87. Where the UK food system has demand for, and command of, resources in other parts of the world, how can associated ethical, political and other impacts be addressed? *
88. What are the networks of influence and power that connect political, financial and corporate players in the food system and influence the regulatory regimes?
89. What would adopting metrics of prosperity other than gross domestic product mean for the structure, labour, food prices and consumption patterns of UK food and farming systems (e.g. numbers of people employed, skill set needs, research priorities etc.)?
90. How far will available government policy levers increase UK food security and sustainability?

91. How can the status and supply of skilled and unskilled labour be improved across the UK food system?
92. What are the major lessons learned in the UK food system that could help developing countries avoid the negative consequences of development?

Waste

Globally, approximately one-third of produce suitable for human consumption is lost, wasted, or used for other purposes, amounting to about 1.3 billion tons per year (Gustavsson et al. 2011; FAO 2012; Bond et al. 2013). Considerable resources – including land, minerals, energy and water – are consequently expended in growing and processing products that are not used as intended (i.e. eaten by humans). Given the increasing pressures on global resources, reducing food waste has the potential to impact significantly on increasing food security. Food waste is generated in all parts of the food supply chain, as well as at home and in catering (Gustavsson et al. 2011), and many promising ideas for waste prevention therefore involve multiple stages of the supply chain (Qs 93, 100).

For UK primary production, there is considerable uncertainty around estimates of food waste and losses; however, the existing evidence (Terry 2011) suggests that there may be considerable benefits from ensuring that harvesting, storage, processing, retailing and consumption practices minimise waste and resource use (Qs 94 and 97). Food and drink waste generated by UK households was approximately 7.2 million tonnes in 2010 (WRAP 2011), more than any single supply chain sector. Although much is known about why this waste is generated (e.g. D. Evans 2011; Quested et al. 2013), a key challenge remains understanding the most cost-effective way of influencing change in households (Q96). Although preventing food from being wasted usually leads to the greatest environmental benefit (Quested et al. 2011), using waste material in a way that maximises its value (Q98) or is treated most appropriately (Q95) also has the potential to deliver benefit to society.

93. How might developments in quantitative microbial risk assessment and predictive microbiology contribute to reducing food waste and spoilage, ensuring safety and setting of shelf life?
94. How can waste of primary production be minimised by ensuring efficient conversion to secondary products? **OA**
95. Under which circumstances are the various channels for using food waste (including anaerobic digestion, feeding it to animals, composting, land-spreading etc.) socially, environmentally and economically preferable? **OA**
96. How can ways of influencing behaviour be most cost-effectively designed and targeted to reduce food waste in UK homes? * **OA**
97. How can seafood trimmings, discards and non-commercial bycatch be minimised or best used?
98. How can the useful chemicals and co-products in food waste streams be extracted and commercialised (e.g. for health, dyes, food, drugs, polymer building blocks, bulk fibre, etc.)?
99. What are the wastages and losses that occur overseas in the supply of food for UK consumption?
100. What is the relationship between forecast patterns of demand for fresh produce and subsequent waste?

Discussion

Food security is undoubtedly amongst the most pressing of challenges confronting the world in the twenty-first century. As discussed above, the FAO definition (FAO 1996) highlights the importance of ensuring that all people have *access* to *safe*, *nutritious, preferred* food, rather than simply ensuring that sufficient food is produced. So as to complement similar exercises focussing on producing food (e.g. Pretty et al. 2010; Feeding the Future 2013), this exercise therefore aimed to cover the entire food system, i.e. all the activities encompassed by the food chain, plus the food security outcomes relating to availability, access and utilisation (Fig. 1). To this end, the effort to generate a large, broad-ranging list of initial questions was largely successful for food system activities, but considerably less successful regarding the nine elements of the food security outcomes (see Fig. 1), which attracted only 18 % of initial questions. This echoes the analysis by Wood et al. (2010) which shows how international assessments of food security are heavily biased towards food production (Fig. 2). One solution to this, and an important lesson for subsequent exercises aiming at a more balanced approach, is to ensure more participants with expertise and interests in food security outcomes are engaged, even if they represent a smaller part of the research or stakeholder community (relative to participants with interests in food system activities) at the time.

Nonetheless, there are several post-farm gate activities which are of clear interest to many UK stakeholders, with processing, packaging, retailing and consuming collectively drawing 64 % of food system activity questions in the initial list of questions (Table 2). Regarding food security outcomes, about half of these questions related to nutrition while affordability (arguably the main factor in access to food in the UK) drew only a fifth. Other key food security elements were

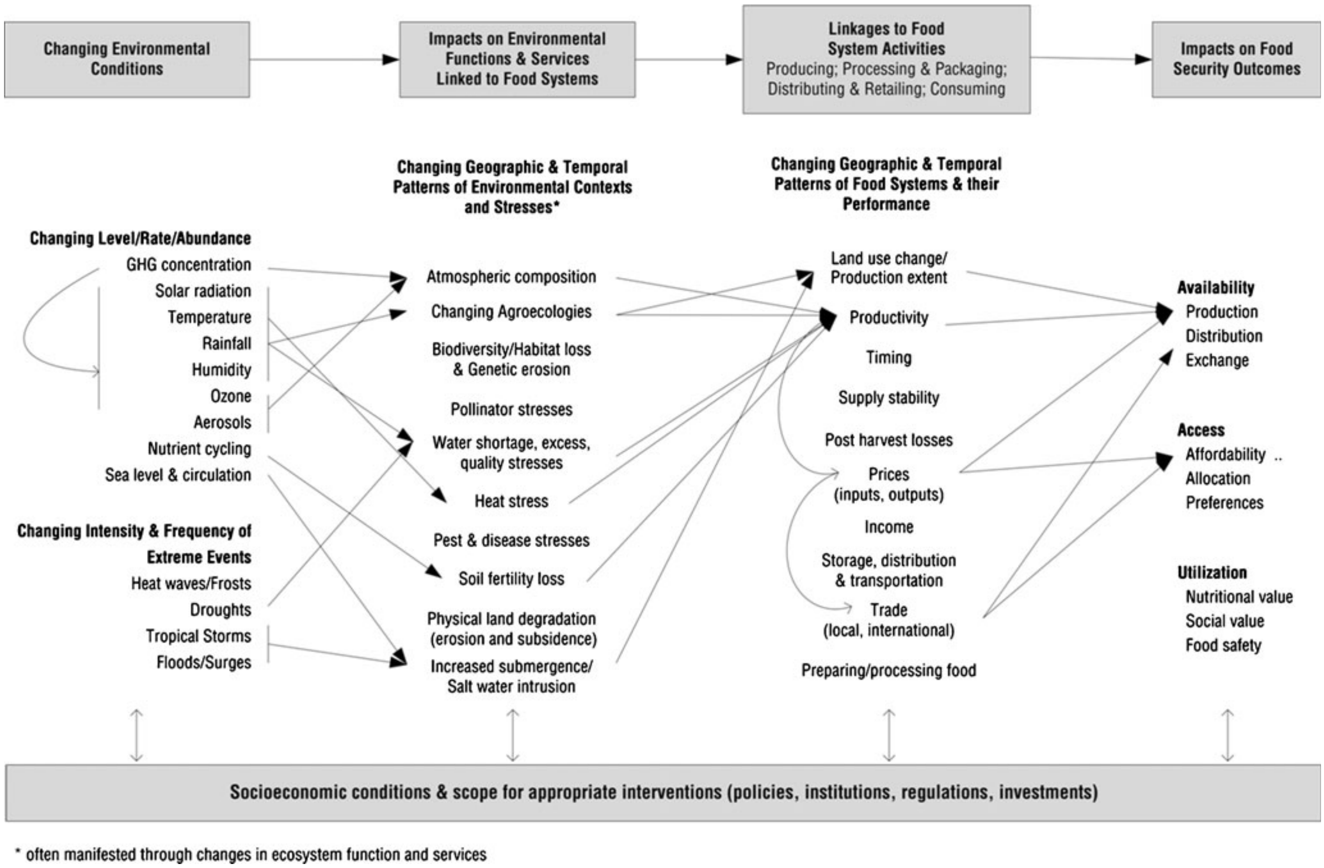

Fig. 2 Environmental change, food system, and food security outcome components and dynamics: highlighting concentration of issues and pathways addressed by assessments (from Wood et al. 2010)

covered to an even lesser extent (e.g. social value, preference, transport and trade). The imbalance between activity and outcome questions, and the uneven coverage of the nine food security elements, to a large extent reflected the individual interest areas of the participants. It is also possible that many of the elements considered important for food security (e.g. the social function of food) are not yet high enough on the policy and academic agendas to attract sufficient research investment or visibility.

The final selection of 'top' questions by stakeholder groups not surprisingly revealed significant differences. All five questions identified by the primary production (PP) group addressed issues of sustainability of the production base, with an important reference to also maintaining or enhancing the nutritional value of primary food products (Q11). The industry and retail (IR) group's selections ranged from reducing nutritionally-poor aspects of food, to food hygiene, safety, packaging and labelling. The NGOs and advocacy (OA) group were most interested in dietary choices, consumption patterns and reducing food waste. The governmental policy (GP) group was similarly interested in resilience and overall supplies given a changing climate; food consumption and accessibility to food. Academics and practitioners had a shared interest in many issues, with 61 % of the top questions per theme chosen by both these groups. Not surprisingly, however, academics also championed questions tackling 'bigger picture' issues relating, for example, to climate change, resilience and public perceptions.

Evidently, the questions identified by this type of prioritisation process will be shaped by the interests of the particular participants involved (Sutherland et al. 2011), so the fact that some elements of the food security outcomes were less prominent does not necessarily suggest these are not also important. Furthermore, while the exercise could arguably have been enhanced with greater participation from people directly involved in food retailing, consumer-focused charities and food anthropologists, the concerted effort to engage a wide variety of stakeholders and large number of consultees helped to define an extensive initial list of questions. Our list of 100 top priorities is therefore likely to represent a suitably broad representation of food system perspectives.

Conclusions

Taking a systems-based approach in addressing questions related to the UK's food security is important as the UK's food system is becoming increasingly globalised and has inherent complexities and multiple feedbacks among a range of activities and outcomes. This exercise has therefore proved useful in engaging the wide range of stakeholders involved, and has helped to establish a relatively well-balanced discussion across the complete set of food system activities and many key aspects of the food security outcomes. Our 100 questions can inform the UK research agenda both from public funders' and applied industry viewpoints, as well as mapping research needs onto international food security agendas. It is clear, from the wide range of questions, that individual stakeholder communities see the need for more research on a range of post-farm gate activities, thereby complementing many investments in food production research. New research can build on on-going efforts to improve food production and, as policy interest develops and researchers respond to stakeholders' information needs, this research can help to make comparatively overlooked elements of the food security agenda become more mainstream.

From the perspective of the food system activities, the need to take into account optimal allocation of natural resources to increase the efficiency with which inputs are used is emerging as a critical area for further research. This is not only important in production but also more generally along the whole food chain. Key elements of the food security outcomes (including nutrition, food safety and affordability) also emerged as priorities. By encompassing the whole food system, our list of priorities can help to identify opportunities for cross-sectoral collaboration between food system disciplines. It is important to integrate research on food system activities and food security outcomes more effectively, and to develop this with closer collaboration between different research communities, as well as between academics and practitioners. UK food system policy, governance, food-related economies and health will all be significantly enhanced when these key questions are answered and the UK's collaborative Global Food Security programme provides a useful vehicle to help take this agenda forward.

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