Final Report: from the Science Council Working Group on Food System Risks and Horizon Scanning to the Food Standards Agency

May 2019

This report was prepared and endorsed by the Science Council Working Group on Food System Risks and Horizon Scanning (Working Group 3) May 2019.

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Interests Declaration:

In line with FSA Guidance on managing interests of its scientific advisers, the interests of members of the Working Group were assessed to identify any potential conflicts with the work of this Group. No such interests were identified.

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Abbreviations Used

BPA: Bisphenol A

EFSA: European Food Safety Authority

FAQs: Frequently Asked Questions

FSA: Food Standards Agency

FTE: Full Time Equivalent

HS: Horizon Scanning

NFCU: FSA's National Food Crime Unit

SACs: Scientific Advisory Committees

WG3: Working Group 3

Introduction

Science Council Working Group 3 (WG3) on Food System Risks and Horizon Scanning was established to address the challenge set to the Science Council by the FSA Chairman on the 16 June 2017:

"What should the FSA do to improve its horizon scanning and its understanding of global food systems risks (and opportunities)?"

Drivers for this question are set out in the WG3 Terms of Reference[1], arising in part from one of the goals in the Regulating our Future programme: to anticipate future risks, harness innovation and be active rather than reactive.

It was felt that the FSA's current approach to horizon scanning and surveillance do not sufficiently consider longer-term Departmental and food system resilience; they identify and act in relation to current and near or medium-term risks and opportunities and do not deliver a longer-term strategic view. A long-term strategic position, informed by an integrated view of the global food system and of systemic risks and issues over the next five to ten years would deliver benefits to Food Standards Agency (FSA) business planning, and support consumer trust in a safe and authentic UK food system. The Science Council noted that changes to the operating environment ahead of the FSA underlines the importance of developing good, well supported horizon scanning (HS) capability.

Approach Taken by Working Group 3

WG3 worked with the FSA to design a tender commissioned by FSA for a desk study, carried out by RAND Europe (Smith *et al.* 2019; see attached) to help better understand the current global food system context and its emerging issues, aligning the FSA's place within it, aiding the development of a function capable of identifying gaps which exist in the FSA's ability to respond to potential risks.

The RAND project delivered a systematic framing and scanning exercise followed by prioritization, to help identify the key emergent features of the global food system, building a simplified food system map and a connectivity heat map. A key input to the final RAND report was the success of a FSA-led expert stakeholder workshop (see Annex 1).

WG3 further distilled issues identified in the RAND study in a Discussion Paper (Annex 2), adding insights from the experience of Working Group members, and from relevant horizon scanning activity elsewhere. Outputs combine in the delivery of HS recommendations to the FSA.

[1] https://science-council.food.gov.uk/sites/default/files/wg3tor.pdf

Working Group 3 Horizon Scanning Recommendations to the Food Standards Agency

1. Horizon Scanning Operationalisation

The FSA should take advantage of several pathways as outlined below to introduce an enhanced HS function. A systematic gathering of signals is necessary, linked to FSA operations, activities of the independent Scientific Advisory Committees (SACs) and an annual expert workshop event.

Timeline to Horizon

In consideration of the rapid pace of change in the global food system, a suitable horizon is 5-10 years as recommended in the RAND report. That timeframe corresponds to the longer end of the current industrial innovation cycle (e.g. for crop protection, and totally novel foods/ingredients/additives). Importantly, it overlaps with the five-year timeline commonly used in strategic planning: near enough to be of political relevance and allows capitalization of necessary preventative measures. Finally, it allows the FSA to focus on signals that can be tracked and acted upon over a realistic number of business cycles without being distracted by longer-term weaker signals.

Human Resources

In agreement with the experience from the UK Government Office for Science, WG3 suggests a minimum critical mass of 2 people (not necessarily both Full Time Equivalent (FTE)) for an effective HS function. The most appropriate location of the resources is a matter for FSA leadership but should take into account the additional recommendations below.

Integration of Horizon Scanning with FSA Business

WG3 recommends the following principles to support the introduction of a successful HS programme within the FSA:

i. **Clear identification of internal client(s)**. This could, for example, be a senior leader or an "Horizon Scanning Governance Board" drawn from senior staff in key units. This would support a culture of sharing and the distributed senior "buy-in" necessary for the success of such activities.

ii. **Identification of the business processes informed by HS**. This is closely aligned with the identified client(s). WG3 recognises the work of the FSA on Risk Governance[2], which should be used as a reference to guide appropriate action(s) following risk identification. While it is important to anchor HS in terms of today's business processes, flexibility should also be maintained to allow for continuous evolution and to be able to focus on developments outside of the scope of current strategy, challenging thinking and assumptions as appropriate.

iii. **Regular cycle of information exchange.** As the focus is on an ultimate horizon of up to 10 years, it is appropriate to select a suitable timeline for meetings to share insights gained. Based on the experience of WG3 members, one meeting per month is a suitable frequency.

[2] https://www.food.gov.uk/sites/default/files/media/document/fsa-18-12-11-risk-analysis-final.pdf

Inputs from Current Business Activities. It is recognized that there is a continuum from the identification of current risks, emerging risks and the HS of future risk scenarios. The FSA should harness existing data at its disposal to build an effective horizon scanning system:

i. Current and emerging risks can offer insights into drivers of future risks. Therefore, ongoing food surveillance data should be used as a source of insights (e.g. statistical trends in surveillance data, systematic root-cause analysis of previous food safety/authenticity incidents).
ii. Reinforce the use of social science insights, including the advice of the Advisory Committee for Social Science, to analyse trends in consumer behaviour impacting diet and food safety risks.
iii. Formalize collection of insights (solicited and unsolicited) at SAC level. A dedicated HS workshop as proposed in (2) below would offer the opportunity for SAC inputs to be considered collectively.

Inputs from Horizon Scanning Activities Elsewhere: The FSA should also avail of data available from HS systems in place in other government agencies/departments (e.g. DEFRA, HMRC, Environment Agency, etc) (see Annex 3).

Inputs from Technology Foresight: The unprecedented pace of technological development, consumer demands and business innovation argue for deeper understanding of the drivers of change and more agility in responding to them. FSA should avail of abundant data available elsewhere as detailed in the RAND report and WG3 Discussion Paper (Annex 2). A summary of new technology developments should be prepared and added to a "watch list" as pre-reading material in advance of each stakeholder expert HS workshop (see Recommendation 2).

Inputs from Trade Data: The FSA should make more use of publicly available data on trade. This necessitates the analysis of data on trade to visualize vulnerabilities (domestic and imported streams). In consideration of the high volume of food imported into the UK, we recommend that HS is designed such that it can maintain awareness of risks arising overseas. This should operate in parallel with and avoid duplication of analysis by the FSA Surveillance Team and the National Food Crime Unit (NFCU).

Data Science: Reliable data is at the heart of a successful Horizon Scanning process. WG3 recognizes that the recommendations of the Science Council Working Group on Data Usage and Digital Technology[3], will influence the identification of emerging and future threats to food systems. WG3 recommends that introduction of predictive tools is supported by a thorough understanding of the business process being analysed and validated by understanding of the biological/food safety problem addressed.

2. Stakeholder Expert Workshop

WG3 strongly recommends the establishment of a regular (annual) workshop of stakeholder experts, modelled upon the successful event of 2018 (Annex 1), addressing drivers/trends under the four themes: Consumer, Industry, Technology and Environment, to inform and challenge FSA HS thinking.

Workshop minutes should be shared within the FSA community and identified issues assigned an appropriate level of priority for timely follow-up action. A graphical heat map (i.e. Figure 1) should be developed to support internal communication and priority setting. The stakeholder expert workshop

[3] https://science-council.food.gov.uk/science-council-subgroups/science-council-working-group-on-food-system-risks-and-horizon-scanning

could help pinpoint where value-chain partners can work better together to improve consumer confidence and deliver safer foods.

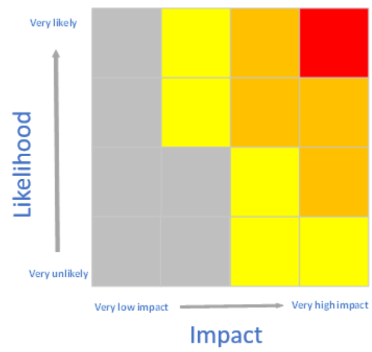

Figure 1: Heat map representation providing a prioritisation tool based on scenario likelihood and potential impact.

3. Horizon Scanning Follow-up

A system should be put in place to track prioritized topics and expected outcomes over time.

The Strategic Evidence Fund enables rapid short-term projects on simple research questions. This should be used on a targeted basis to deepen understanding where HS signals indicate a potential risk.

FSA should ensure that external research funding bodies are provided with timely information of gaps in understanding of food systems in relation to food safety and authenticity.

4. Implementation

A period of one year is a suitable timeline for the establishment of a formal HS activity at the FSA. It is recommended that a post implementation review be conducted to determine the performance of the programme. We recommend a review after the first year and thereafter a biennial review. This timeframe would permit the incorporation of new tools in the programme in addition to evaluating intended outcomes.

5. Research Opportunities to Develop New Tools.

The goal of a programme to better understand food systems driven risks is the development of preventive action(s) addressing the drivers of risks, resulting in more resilient systems. Historical food safety events demonstrate that early signals were frequently available in the past that could have predicted major food safety incidents. Such signals were often weak, ignored or misunderstood, missing the opportunity for a proactive response. As those cases demonstrate, the weak link in the causal chain was not signal detection but understanding.

Such understanding requires expertise and experience. While FSA can benefit from the establishment of systems and processes as described above, there is an opportunity to better codify how expert insight works in relation to spotting potential vulnerabilities. This could be addressed, for example, by an epistemological project designed to standardise and improve the efficacy of analysis of food systems risks. We recommend that such a project be designed with advanced analytical tools such as artificial intelligence in mind that could be used to better process the enormous amount of food system data now available.

Annex 1. Review of Workshop and Expert Interviews

Summary

A one-day workshop of diverse stakeholder experts (including internal FSA expertise) was organized to support the RAND Europe project. The workshop on 12 September 2018 was deemed to be a successful and efficient way of bringing expertise together to draw conclusions on the main trends in food safety and authenticity. In particular, the following contributed to the success and should be taken into consideration during the design of future workshop events:

i. High-quality, well-organised, pre-reading materials were sent in advance to all participants.
ii. Structured expert interviews had been completed and the outputs incorporated in the reading material.
iii. Participants were asked to share, in writing, in advance of the workshop their identified single greatest challenges facing the UK food system and proposed ways of responding to this challenge.
iv. Participants were asked to consider a simple set of five questions in preparation for the meeting.
v. Chairs of the break-out discussion groups were selected from external stakeholder organisations, were well briefed on the goals, constraints and challenges of the workshop and, in addition to the materials shared with all participants, received an additional set of more detailed questions prepared by FSA to guide/focus discussions.
vi. Science Council WG3 members acted as Rapporteurs for the break-out discussion groups ensuring a focused and consistent approach across the different discussions.

There was strong consensus that such an event should be repeated annually with follow-up action by the FSA on the output. It was noted that not every topic in the food systems map has direct food safety and food authenticity relevance. However, as several different systems are interacting, a perturbation in one system can lead to impact on other connected systems.

Feedback was solicited in written form before the workshop and also via structured interviews with selected key experts. A summary of the expert feedback is presented in Box 1. One of the takeaway messages from the interview process was the difficulty experts had in assigning a ranking or priority to the issues identified. This is an opportunity for the future as the Working Group wished to see a heatmap of issues as a useable output of the interviews and workshop. Such a heatmap would be envisaged to present a limited selection of topics to facilitate FSA choices for deeper analysis.

The four themes used for discussion (Consumer, Industry, Technology and Environment) helped both to align with the RAND report and to assign stakeholder experts to the discussion groups. Overall, the issues identified were in line with expectations which was seen as reassuring. This raised the question of whether there is a risk of missing weak signals. Some of the data collected during the expert interviews and workshop are anecdotal, but merit further analysis. Future horizon scanning activities in the area of food safety will need to maintain awareness of formal and informal data sources in order to pinpoint possible impacts on food safety and food authenticity.

Expert Workshop Discussion Group Output

Consumers

Consumers have high expectations and there is an expectation that food standards will continue to increase. Price is important and there is the built-in assumption that safety and authenticity is taken care of. Innovation and new technology introduction is possible with caveats about explaining the benefits, alternatives and assurance on oversight/regulation. Some of the red lines are not safety related but influenced by values. There is a need to see consumers as drivers of change - eating as voting and the strong concentration of retail as an opportunity. Social media is an opportunity to shape and manage the conversation on food safety and authenticity which FAQs cannot do. Some consumers wish to be recognized as food citizens.

There is a generational change in expectations. Food is not just fuel but part of a lifestyle; e.g. the adoption of veganism to protect the planet. As some shifts in consumption are driven by perception, it is important to have evidence available to support claims made in marketing products. Consumer expectations may generate conflict due to demands to reduce plastic packaging while keeping food free of pathogens. Equally the demand for more fresh food may have the unintended consequence of increasing food waste and the incidence of foodborne infections. The tipping point that led to millions of consumers recognizing the impact of plastics on the environment (particularly ocean plastics) was the BBC series Blue Planet. The Discussion Group asked how can we spot the next "Blue Planet" moment?

The facilitation of consumer choice is seen as important. Increase in out-of-home consumption has implications for safety, nutrition and authenticity. Consumer demand is seen as a system driver but perhaps less so in UK compared with other European countries. Some of the changes in consumer demands were not foreseen, taking value chain actors by surprise (e.g. free-from categories, vegan, plastics). While there is a need for better understanding of consumer perceptions, consumer perceptions may not always be valid. The consumption of ready-to-eat products is increasing; including fresh produce (potential for increased microbiological risks e.g. due to *Listeria* spp). There is remarkable growth of online sales (grocery and food service). As stated above, some consumer demands may generate conflicting pressures. For example, less plastic AND less food waste. Less plastic AND more food safety, etc. Thus, there are challenges of understanding consumer values and behaviour and communicating with consumer in a rapidly changing society.

Industry

The food manufacturing industry is fragmented and diverse, ranging from SMEs with a few staff to transnationals with tens of thousands of staff. Consolidation and fragmentation is happening side-by-side; contrast the merger & acquisition activity of big companies and investment in start-ups offering a multitude of new offerings.

It is not a level playing field, neither in terms of available capital nor in terms of technical capability. Capital investment by the UK food industry is low compared with the rest of the world. Coupled with low margins, downward pressure on prices, high labour turnover, and the high proportion of imported foods, this creates pressures on the UK domestic food system that could impact business sustainability, potential for food fraud, and the propagation of errors leading to food safety incidents. In addition, the operational complexity of the UK food system is increasing and will be likely to increase due to new trade arrangements and the need for UK to define its own future food standards driven by evidence and aligned with future trade requirements. Industry infrastructure is in need of updating but is hampered by access and affordability. There is still a need to address standards equivalency and mutual recognition of regulatory agencies in the context of international trade.

Underinvestment in training and human capital was recognized as a risk for the UK food industry. In particular, high staff turnover and loss of technical expertise has led to a loss of corporate memory of past failures and learnings. There is a need for joined-up thinking, e.g. chemical vs microbiological vs nutrition risk, coupled with better prioritization and targeting for more impact.

As digital supply chains and manufacturing become more important, data standards will be needed. Because of the diversity of manufacturing systems, interoperability will be a major constraint. Verification, quality and security of data is important as data underpins food authenticity and safety.

There are opportunities for precision processing with higher food safety and quality standards and improved efficiency.

Technology

There was strong consensus in this discussion group that technology would impact food systems in the short term. However, while technology solutions may exist, scarcity of capital may hinder further development.

The potential impact of technology on food safety and authenticity is quite broad and covers a multitude of tools that were not developed with food safety in mind. For example, blockchains in banking, and a range of technologies designed to mitigate climate change (e.g. crop protection and crop nutrition products; water treatment). Such technologies may carry benefits and risks for food safety. The discussion group identified several opportunities for technology in the areas of food safety and authenticity:

- To better predict events impacting food safety and authenticity
- Technology to support more transparency, authenticity and trust
- Technology to minimize food loss and waste
- Low-cost mitigation opportunities
- Technology to improve and transform the current infrastructure

Data science is seen as a major opportunity, but work is needed to turn data into actionable insights. Digital connectivity would enable more use of data (e.g. Internet of Things, household appliances, retail Points of Sale, online sales, transport and industry). However, data are fragmented across companies and sectors. It was recognized that a critical success factor would be data interoperability, which in the current food industry might be a challenge due to the existence of multiple legacy systems. Data standards are necessary. Similarly, questions about data access and ownership need to be addressed.

The group underlined the hazard of the technology-policy gap whereby technology matures more quickly than policy development, meaning that policy always lags behind. The group posed some questions that may help to frame future analysis and discussion:

- Is digital ledger technology and Blockchain the regulator's friend?
- Should regulators be passive or active with respect to technology?
- How early should a regulator act? For example, could a regulator act based on predictive analytics?
- Should the ensuing regulation be light or heavy touch?

- How much industry investment would be needed to generate the improvements in data quality and interoperability needed?

Environment

The impact of interacting complex adaptive systems is greater when considering the impact of environment on food and *vice versa*. Several systems such as energy, water, crop protection and crop nutrition are involved. It was considered that the most significant environmental issues for FSA were microbiological contamination and the associated problem of AMR; extreme weather; and plastics (note many of the risks are interconnected and it is not easy or appropriate to try to separate them). It was noted that a model of sustainable consumption would be a useful tool to complement sustainable production. However, the topic cuts across several government departments and agencies, making it difficult to identify where responsibility might lie. The growth of the circular economy is a dominant factor with the expectation that more streams, today designated as “waste”, will be used in future food manufacture. Such changes in value chains require safeguards to avoid new food safety, authenticity or communication/perception issues. Equally, the growth in diverse bio-economies may lead to competition for raw materials affecting food prices and standards. The loss of biodiversity might impact on risk to food security and safety due to decreased resilience.

Extreme weather events and related impacts on food systems need to be anticipated and a framework put in place to manage food safety and authenticity risks. Predictive tools could be used to anticipate where extreme weather might affect the UK food supply and help direct targeted surveillance of food imports. Plastics (particularly non-biodegradable types) are of concern due to the role of food packaging in contamination of the environment. There is also concern due to the potential contamination of food with chemical from plastic materials at multiple points along the food chain. Agricultural practices and environmental factors influence AMR in human health care. There is an opportunity to influence trade deals and to increase safety and the improvement of international standards. FSA can leverage its position as an influencer of international governance to advance protection of the environment through food standards. As the issues cross the boundaries of departmental responsibility, it would be useful to map responsibilities and topic leaders; AMR was cited as an example of a successful joint response with positive outcomes.

Local waste recycling is an unrealized opportunity but needs careful management due to potential waste stream contamination with microorganisms, chemical contaminants and plastics.

BOX 1. Workshop: summary of major challenges and opportunities

CHALLENGES

- Consumers more removed than ever from food production and manufacture; lack of knowledge or misperception on health claims and nutrition.
- Environmental sustainability and food security.
- Absence of policy and activities supporting sustainable consumption.
- Climate change will impact food systems at multiple levels. It will influence purchase/consumption (for example less meat and dairy, sustainable packaging, low carbon and water footprint options).
- Changing social expectations (risk from outside the food system).
- Non-replacement of food industry technical staff; knowledge leaving the food industry; complexity of food manufacturing and regulatory requirements beyond the current capability of many players in the field.
- Low productivity of food industry compared with other industries (especially concerning low efficiency of some UK domestic production versus imports).
- Prevalence of legacy technologies that are decades old.
- Downward pressure on prices leading to business sustainability risks.
- Food overconsumption.
- Food authenticity.
- Food value-chain imbalances.
- Lack of transparency.
- Maintaining trust in food.
- Increased regulatory/ inspection work-load due to EU exit.

OPPORTUNITIES

- Better education about food and nutrition at school level.
- Investment in training and education of workers in food production and manufacturing.
- Better detection and quantification of food contaminants (micro and chemical).
- Opportunity to improve resilience of UK food system. High level of imported food as a source of vulnerability.
- Need to manage consumer expectations.
- Dependence of food on energy, water and digital systems (risk of malicious cyber activities as part of food fraud or to disrupt supplies).
- Opportunity to improve crop protection practices.
- Move away from single use food contact materials.
- Increase in plant-based diets (including veganism).
- Improved joined-up approach to food across government agencies and departments.

Annex 2. Discussion Paper: Science Council Working Group on Food System Risks and Horizon Scanning

1. Introduction

The present paper builds on the analysis of the RAND report, the insights of the Expert Workshop and WG3, and selected additional sources reviewed below to make a series of recommendations to FSA in the area of food safety horizon scanning (as detailed in the main document). The additional reports cited herein are included to underline that the key conclusions are founded upon solid supporting evidence. While the Discussion Paper is not intended to be an exhaustive analysis, it attempts to identify the key trends and drivers of change in food systems of relevance to the FSA. As such, it can be used as a model for the organisation of information and the development of appropriate responses to signals captured from the activities of horizon scanning. The following summary of issues and drivers identifies opportunities for further analysis and makes recommendations where new developments may warrant further action. WG3 noted that some recommendations may concern topics outside of the remit of the FSA and/or may require action by several government departments/agencies.

2. Summary of Issues and Drivers

i) The past several decades have witnessed increased complexity and scale of global food systems, global food safety and authenticity crises, and increased consumer concerns. At the same time, there have been step changes in the impact of technology in food production, food manufacturing and delivery. It is recommended that tools such as HS and technology foresight be deployed to understand the systemic drivers of food safety and authenticity crises to avoid future incidents and to harness new opportunities. Future food control should depend less on classical product analysis and auditing and focus more on intelligence-led targeted checks.

ii) The recent acceleration of new product development, new business models and new technology is stretching the well-described gap between new technology introduction and the development of new food policy and regulation. This requires alternative flexible approaches to ensuring appropriate checks and balances between innovation and consumer protection during product innovation and renovation.

iii) New technology means that foods are increasingly reaching the consumer through new channels that may bypass traditional control points. For example, the double-digit growth in online shopping and a variety of new home and office delivery platforms. Analysis of such routes of food supply needs to assess potential vulnerabilities to fraud, safety implications and the adequacy of standards and risk management measures.

iv) Alternative methods of food production promise greener, safer more sustainable consumption. It is recommended that standardized measures of sustainable consumption be developed to protect consumers from misleading or unsubstantiated claims. This will necessitate collaboration among several government departments and agencies (e.g. DEFRA, FSA, Environment Agency, APHA).

v) New categories of food product aimed at health or environmentally conscious consumers may have radically different composition from conventional foods. Research is needed to avoid unintended nutritional and food safety consequences of rapidly changing diets.

vi) Consumers are demanding a new generation of "free-from" food categories and personalized diets. There is a need for more assurance on the efficacy and safety of such product offerings.

vii) New technology (e.g. "cellular agriculture" and insect culture) will drive a new generation of novel foods with more complexity than historical new products, necessitating multifaceted pre-market evaluation to protect the health and interests of consumers. The developments have the potential to straddle the remit of several regulators necessitating a cross-government joined-up approach (e.g. FSA, DEFRA).

viii) Reduction in food waste will drive the development of circular economies in food production and manufacturing. New standards and risk management measures should be developed to safeguard consumers during the introduction of new processes and products.

ix) Sustainable food packaging will drive the use of recycled materials in food packaging and the replacement of some single use packaging materials with biodegradable or recyclable alternatives. It is recommended to develop new safety evaluation approaches for the development of new food contact materials to avoid introducing new hazards during product development. It will be important to find an appropriate balance between environmental sustainability and chemical and microbiological food protection.

x) A high level of food recalls occurs despite incremental improvements in standards and quality management. It calls for a comprehensive rethink of the way food safety and authenticity is assessed and managed.

xi) The demand for fresh and ready to eat products is increasing. As recent reports demonstrate such shifts in consumption may be associated with an increased risk in some foodborne illnesses such as listeriosis. Research is recommended to devise ways of avoiding contamination at production level and to improve decontamination technologies.

xii) There have been step changes in analytical technology facilitating a new generation of tests in the laboratory, in-line and in the field. Development of new testing strategies is needed to realise the full potential of such tools in the field of consumer and business protection.

3. Food Systems Risks

Global risks are assessed as increasing during a period when multilateral cooperation is more difficult (World Economic Forum, 2019). While Food safety and authenticity risks do not appear in the top 10 global risks (World Economic Forum, 2018a) by likelihood, many of the risks that appear, such as failure to mitigate the effects of climate change, water crises, major weather events and man-made environmental damage, do impart directly on food safety and security and may generate pressures incentivising food fraud. In terms of impact, food and water crises are both in the top ten. Furthermore, lack of government agility generally is impeding responses to a range of issues. Greater international cooperation is demanded to address emergent transboundary food system threats such as pests and disease (FAO, 2017).

It is repeatedly observed that global food systems are becoming more complex and are changing rapidly (Machell *et al.*, 2018). There is currently a disconnection between our fragmentary knowledge of global food systems, notably relating to trade and material flows, and the study of exposure to chemicals in the diet (Ng & von Goetz, 2017). Published international food trade data have been used to generate models of global food commodity fluxes and have been proposed as tools to model contaminant distribution (Ercsey-Ravasz *et al*., 2012). Similarly trade data have been combined with local risk data (e.g. political, meteorological) to identify a finite number of global chokepoints affecting food commodities (Bailey & Wellesley, 2017). Most of the analyses to date have been retrospective, using historical data. There is an opportunity, however, to do such analyses using live data which may have more predictive value for food controls.

Food chain approaches to the management of food safety and integrity have existed for some time (Hoorfar *et al., 2011*). As the food manufacturing environment is becoming progressively more complex, there is also a recognition that systems thinking is necessary to better anticipate and prevent food safety and authenticity problems.

Many of the larger food corporations apply the concept of materiality to support their response to environmental, social and governance issues (WBSD, 2018). “Material” risks can be financial, reputational or social. Consumers are increasingly aware of issues such as child labour, slavery, animal welfare, deforestation, environmental footprints and demand food products that come from systems that address such concerns. There is growing awareness that many of the materiality risks are linked. This was highlighted by Brashares *et al.* (2014), who suggested complex linkages between local and global food systems and between fish stocks, food insecurity and child labour.

The scale of the impacts of agriculture on climate change, coupled with consequent changes in agricultural productivity in some regions plus changing consumer awareness/food choices has the potential to result in significant changes to global food demand. Such impacts may be more pronounced in some low- and medium-income countries where climate impacts may be greater and where there are fewer mitigation options.

4. Technology Developments

The pace of change in new technology is accelerating. There is potential for new technology to bring about transformational change in food systems with many benefits for consumers. The focus on such technologies are sometimes disproportionate in reports that neglect to see food systems in holistic terms. For example, without financial sustainability or appropriate training, new technology many not be a viable prospect. While a panoply of technical solutions exist, experience has shown that sometimes there are also cheaper simpler and more effective alternative low-tech fixes (e.g. (https://www.weforum.org/agenda/2015/04/why-food-safety-matters/).

Furthermore, new technology implementation can have unforeseen beneficial and adverse consequences, which argues for a broader impact assessment. For example, packaging materials designed to replace bisphenol A (BPA) might have other chemical migrants that give rise to safety concern.

Some technology developments will impact in multiple ways. For example, nanotechnology research has identified opportunities in food additives, food packaging, crop protection and health, crop nutrition, nutrient delivery, plant sanitation, water treatment, diagnostics and many more applications in food production, manufacturing and nutrition (e.g. Iavicoli *et al*., 2017; Jhong *et al*., 2018; Kaur & Liu, 2016).

The following are a selection of key areas of research in the agri-food industry (several more detailed reports on new agri-food technology are available elsewhere; for example, see FAO, 2017; Mylona *et al*., 2016; Santeromoa *et al*., 2018; WEF, 2017, 2018).

4.1. Agriculture

As reviewed in the RAND report, a new revolution in crop science is beginning. The new developments are largely based on technology:

- Gene editing (several gene edited plants have been produced with the possibility that gene edited crops may be ready for the market soon)
- New generation pesticides and integrated pest management tools
- Smart agriculture based on remote sensing drone and satellite technology, robotics, foliar fertilizers based on nanotechnology.
- Diagnostics and telemetry for animal and plant health

On the farm, smart agriculture systems are being implemented rapidly often based on existing technology platforms such as smart phone tools for farmers (Pretty, 2018). It has been recognized for many years that there are complex relationships been agriculture practices and both human health and environmental sustainability (Tilman and Clark, 2014).

4.2. Technologies to Support Food Reformulation

As products high in salt, sugar and fat are increasingly recognized as contributing to overnutrition and ill health, manufacturers are competing to produce healthier recipes that retain consumer preference. A huge amount of research has targeted the removal or reduction of sugar, sodium chloride and total and saturated fat in products. Some innovations have used developments in material science to change the microscopic structure of foods. Alternative, more traditional approaches have used non-caloric artificial sweeteners, alternative caloric sugars, other salts such potassium chloride, low-salt seasoning mixes, and protein or carbohydrate-based fat replacers. While hydrogenated fats are being avoided, alternative approaches using natural fats or enzymatically transesterified oils are finding more applications. The development of "clean" and "clear" labels has been a boom area for product developers for several years due to consumer's fears and perceptions about the presence of certain additives and ingredients. The alternatives are not always better than the products being replaced, as sometimes, there is a loss of transparency compared with the original labelled product. The appeal of the "clean" label is now generating fresh thinking in an effort to address topics like animal welfare, labour, sustainability issues.

4.3. Cultured Animal Cells

The topic of cultured meat was a major topic of food conferences in 2018. While it is scientifically possible to grow meat muscle cells in a laboratory culture, it is not yet economically feasible to do this commercially. Marketable products are still likely to be several years away. In this respect, the field is unique in food research in having an unprecedentedly long lead time and involves mainly start-ups rather than traditional food industry players. However, this field of endeavour, sometimes called cellular agriculture (or "clean meat" by some) has attracted millions in capital funding from high-profile investors. It has sought support from animal welfare advocates as well as environmentalists (Shapiro, 2018). There are multiple new start-up companies competing to develop the technology to bring a new generation of products to consumers. Perhaps the most famous of these is MosaMeat which set out to develop lab-cultured beef. However, cell-culture-derived food is now also targeting chicken meat, fish and dairy products. The regulations to cover the technology are not yet in place. In addition, there are significant technical challenges to overcome. For example, the co-factors needed to support the growth of cells are still derived from animals, so some work is needed before such products are truly "animal free".

4.4. Alternative Proteins

There is a growing gap between the supply and demand for protein. The land-energy-water footprints of animal proteins are increasingly unsustainable on a global scale. Consumers that eat meat are being encouraged to eat less (IPCC, 2018; Gu *et al*., 2019). In addition, the rapid growth of vegetarianism and veganism is demanding an expansion of consumer choices.

Thus, alternative proteins is a hot research topic. Technologists are challenges by the need to find proteins at sustainable scale that can deliver similar functional properties and nutritional value as the traditional counterparts. Plant proteins are attractive but require careful screening due to the potential to introduce new food allergens into the diet. Some protein sources may also need to address consumer acceptability issues (e.g. insect protein). Taste has been a barrier to success for some plant proteins necessitating additional processing to render them acceptable. Recent research on cultured animal products (see below) offers a potential alternative source of protein as well as an alternative to traditionally grown meat and dairy. Alternative proteins are perceived as more having lower GHG footprints than animal alternatives but, in most cases, there are few life-cycle data.

4.5. Vertical and Multi-Channel Agriculture

The idea for indoor farming was born about twenty years ago and was facilitated by the invention of LED lighting which makes them economically viable. Such facilities are mainly dedicated to leafy greens such as lettuce. They frequently use soil-free systems: hydroponic (water alone) or aeroponic (air or water mist). Vertical urban farm start-ups have attracted some of the biggest investments in the food industry in recent years. They have an advantage of co-location with large population centres and high productivity but have been criticized due to high energy consumption. Future facilities running on renewable energy will overcome this problem. Multi-channel agriculture systems harvest several products from one integrated system (e.g. farmed fish and watercress). Urban agriculture systems which would include insect culture (see below) are foreseen as an opportunity for a more efficient circular local economy for food (Ellen McArthur Foundation, 2019).

4.6. Insects

While insects are consumed by people in many regions of the world, they do not have a history of food use in the UK. Most insect species have been classified as novel foods since 1 Jan 2018 and several authorisations for food use are currently progressing to ensure they can be eaten safely.

The use of insect protein in aquaculture feeds is permitted in the EU. While insect protein is still relatively expensive as a source of animal feed, the price is likely to fall over time making its use possible for example in poultry feeding. The number of insect culture facilities worldwide is growing rapidly driven by the possibility of converting cheap biomass waste into an expensive protein source. This includes biomass that cannot be processed by alternative methods (e.g. Palm husks). There is still a need to determine consumer acceptability and to address potential allergy issues.

The rapid development of technologies such as insect culture, cellular agriculture and alternative protein sources highlights the regulatory challenge of keeping up with technology and industrial innovation.

4.7. Digital Supply Chain Technology, Data science, Blockchain, Artificial Intelligence and the Internet of Things

The advent of digital supply chain technology has supported the proliferation of food products associated with more customization to consumer tastes (MGI, 2019). More customization means more recipes, specifications, ingredients, suppliers, labels, etc. The task of sustainably managing that much complexity demands new tools. As digital supply chains become more important, the integrity of the food supply will be more and more underpinned by data integrity. This will necessitate measures to detect data fraud which might be used to cover up the supply of unsafe food or to mislead customers.

It is recognized that a huge amount of food data is currently generated that could provide useful food safety insights (Marvin *et al*., 2016). As suggested during our Expert Workshop (Annex1), there are challenges of access, ownership, quality, and data standards that need to be addressed before such data can be further exploited.

The use of permissioned or private Blockchains are already in use in agri-food chains and in the regulatory community. Trials conducted to date report a dramatic saving of time to do traceability studies. In the regulatory community, pilot studies demonstrated an improvement in the efficiency of document checks by inspectors resulting in significant time saving. Blockchains promise to improve the integrity of food supply chain data. However, there is a need not to overlook the quality of the raw data input. Blockchains require resources to implement and this may be a barrier for some enterprises.

4.8. Analytical Science and Diagnostics

New technical developments in analytical science are too numerous to detail here. While, product and raw material testing is only one tool of many needed to manage food safety, new technologies have led to the opportunity to capture data leading to deeper insights on the characteristics of food constituents and contaminants with potential for improved risk management. Four developments in food analysis deserve to be highlighted:

- Next generation sequencing
- Process analytical technology and sensor applications
- Various technologies for designed to produce chemical “fingerprints” of foods
- Improved performance of existing analytical technologies (e.g. resolution, precision, limits of detection, multiplexing, software, automation)

The application of next generation sequencing to bacterial whole genome sequencing is outlined below. The speed and decreasing cost of the technology is also making it attractive for metagenomic fingerprinting to gain insights on pathways of microbial contamination. Next generation sequencing tools have been applied successfully to determine the authenticity of a range of animal and plant-based foods.

The pace of application sensors and of process analytical technology (PAT) in the food industry is accelerating. The technologies can be used in-line and with a combination of other tools (e.g. AI) to improve process control and ultimately product safety and quality (Tamplin, 2018; O’Donnell *et al*., 2014).

Non-targeted fingerprinting technologies are being widely applied in the area of food adulteration and authenticity assessment. The technologies used range from infrared spectroscopic techniques, various chromatography-mass spectrometry applications and next generation sequencing. The more complex fingerprinting techniques require chemometric tools together with databases of historical data to interpret the raw data (Medina *et al.,* 2019). There is an opportunity for further research in this area, in particular to better standardize and validate the tools.

Food manufacturers would like to have more early supply chain analytical data captured, if possible, in the field or on the production line. Early data facilitate early decisions and have the potential to reduce, waste, increase efficiency and improve food safety and quality. Some companies are equipping staff with portable analytical devices (including hand-held smartphone enabled tools) to perform rapid measurements on raw material or ingredients. Several companies already market cheaper hand-held food-testing devices direct to consumers, but to date there is little evidence of large-scale benefits of using such technology.

Private and public analytical laboratories have explored the use of a variety of finger-printing technologies to perform untargeted analysis of food materials. The main technologies used to date have been based on FTIR, MALDI-ToF MS or high resolution MS.

4.9. Whole Genome Sequencing of Bacteria

The recent reduction in cost of whole genome sequencing makes the technology accessible as a routine tool for the characterisation of foodborne pathogens. It is also recognized as a valuable tool in the production environment with many applications, for example improve understanding of microbial ecology; more precise risk assessments and consequently better risk management measures; and the investigation of incidents (such as those seen during routine facility pathogen monitoring). Some regulatory agencies have adopted large scale sequencing of isolates both from food products and factory samples. For example, GenomTrakr network led by the US FDA has sequenced more than 280,000 isolates and is currently sequencing approximately 9,000 samples per month.

The large databases being developed will generate insights into the characteristics of foodborne infections not possible with conventional methods. There are still questions to be resolved concerning the quality management of routine sequencing and the standardisation of criteria for determining matches among sequence data.

At the clinical level, one of the consequences of an improved success rate in source attribution is likely to be the identification of more outbreaks. This will require proactive communication with key stakeholders to explain possible new trends as a successful application of a new technology rather than necessarily an increase in failure of risk management. A decrease in sporadic cases coupled with improvements in outbreak source attribution could also mean more resources dedicated to follow-up actions to prevent future cases.

4.10. Packaging

Food packaging R&D is currently receiving immense investment in response to widespread concerns about plastic pollution and food waste. Research will focus on achieving more recyclable and biodegradable packaging while maintaining the functional properties of the material that protect food from contamination while maintain quality through barriers to gas and moisture. In addition, many companies have committed to replacing packaging ingredients such as BPA due to consumer concerns. Packaging material has high chemical complexity with the potential presence of thousands of chemical substances. In addition, the supply chains can be complex and fragmented with many companies working in partnership. Care will be needed to support the development of a new generation of food packaging materials that addresses consumer and environmental concerns while ensuring alternatives materials are safer than traditional materials. In particular, there is a trend toward increasing the amount of recycled materials used in food packaging. This an opportunity to increase the sustainability of food packaging but generates a risk of food contamination with chemical migrants (Geueke *et al.,* 2018). The elimination of single use plastic packaging for food will necessitate a new generation of packaging materials with equivalent functional characteristics and safety.

4.11. New Agri-food Technologies

We can predict with confidence an acceleration in the development of novel foods. Such developments range from step changes in food and agriculture such as insects and cellular agriculture to targeted innovations such as alternative proteins, botanicals, or products of nanotechnology.

At industrial level, new processing technologies, such as high-pressure processing, pulsed electric fields, UV irradiation, are being introduced to address a series of food safety and quality challenges. New enzymes like transglutaminases are being used in many applications ranging from dairy gels to smoked salmon. The technology has the advantage of creating new textures supporting new product development. In some cases, it can help reduce food waste without compromising food quality and safety. Another recent innovation was the use of microbial asparaginases to remove asparagine during the processing of raw materials to avoid the formation of the carcinogen acrylamide during cooking. The search for novel food enzymes is particularly intense. Frequently, such enzymes are inactivated during production, but precaution is needed to avoid allergy issues.

The technology drivers associated with Industry 4.0 (Schawab, 2017) are now beginning to impact food production, manufacture and distribution, with profound economic and regulatory implications. Robotics has long been used in the food industry for packaging, distribution and warehousing. However, deployment of robot technology in food manufacturing lags other industries such as automotive manufacturing. Recently, the use of robotics has started to impact agriculture (e.g. autonomous vehicles; milking machines; fruit picking; weed removal; application of crop protection chemicals), meat processing (e.g. cutting) and food service (e.g. barista coffeemaking, hamburger and pizza making). Widespread global implementation of robotics in the agri-food industry would have the potential to displace thousands of human workers. In some of the above cited examples, there are opportunities for improvements in both food safety, traceability and productivity.

5. Retail and Consumption Trends

The shift to new business models is rapid: Walmart, the world's largest grocery retailer, saw a 40% increase in e-commerce activity in 2018 alone (Digiday, 2017). In addition, new players, such as Amazon, have entered the food retail market. One of the impacts of online food sales is a dramatic acceleration of the renovation cycle of food products. In line with other developments in the platform economy, a number of food delivery platforms have been set up; in some cases, standalone businesses and in others, such as Uber Eats, as secondary businesses using drivers and vehicles also used as taxis. These enterprises which are growing rapidly, offer more choice, but they are separate enterprises from food preparation.

Social and cultural factors are recognized as increasingly important drivers of consumer choice and demand. In some cases, shifts in consumer expectations have even taken leading manufacturers by surprise. The UK, USA and Germany are seeing huge growth in vegan and "free-from" products. Such changes in consumption are driving the development of new products, new formulations, and are influencing the diet of a generation of consumers. Sometimes such developments have unforeseen consequences. For example, a range of new natural products including herbal teas and alternative cereal grains have been associated with a higher risk of exposure to natural toxicants such as pyrrolizidine and tropane alkaloids caused by contamination with seeds from non-crop plants. An increase in listeriosis in Europe has been associated, *inter alia*, with the popularity of fresh and ready to eat foods. The nutritional, safety and long-terms health implications, good and bad, of the current wave of dietary changes are still not well understood.

Consumers have access to a multitude of information sources in addition to the on-pack data, including smartphone apps and industry-provided off-label information. However, there is undoubtedly also more confusion among consumers as the messages are changing rapidly and are often conflicting. As a means of scanning the horizon for future trends in consumption, FSA will benefit from input from social science.

6. Private Food Quality Schemes

Private food quality certification schemes have multiplied in recent years. Some apply internal (company-specific) standards and some use industry wide standards with external third-party certification. Such schemes have helped to build food safety capacity among food businesses across categories, especially where there are gaps in public standards. While there is evidence of increasing convergence among schemes dedicated to food safety, schemes dedicated to other quality parameters are numerous, proliferating and have had mixed success. Food safety inspections and audits are beginning to employ new technologies to produce a more comprehensive picture of compliance, such approaches are always limited (Powell *et al*., 2013; Turku *et al*., 2018) and need to be complemented by other measures such as corporate support for a strong food safety culture.

Consumers are concerned about a variety of material issues associated with food production. Manufacturers have attempted to respond by developing a variety of company-specific and industry standards. However, there have been high-profile differences in interpretation and leading to a fragmented approach that does not support consumer needs.

7. Food Fraud

Food fraud is still a major threat to food systems worldwide. Some commodities will be more vulnerable than others. However, fundamental to an effective programme to tackle food crime is a good understanding of the drivers of food crime (Elliott, 2014). Changing consumption trends will determine the raw materials, ingredients and processes used to manufacture a future generation of food products. Recipe changes may generate vulnerabilities to food fraud that do not exist today. It is therefore important that the changes observed in the food landscape are evaluated as potential drivers of food crime.

8. Lloyd's Register Foundation

Lloyds has been active in the analysis of food systems risks for a number of years. Previous reports were mainly concerned with food production and security (Lloyd's, 2013, 2015).

Lloyd's Register Foundation launched a foresight review in food safety in 2018. A series of workshops were convened (Paris, France; Seoul, South Korea; and San Diego, USA). The Paris workshop, attended by the Chair of Science Council Working Group 3, looked at food and food safety through the lens of data science, genomics and the social sciences. One of the technology developments explored was cultured meat, dairy and fish; the so-called cellular agriculture area was a major theme at several conferences during the past year. The science of cultured meat is already exploring how to move to products that better simulate steak including connective tissue and adipose tissue.

Nutrition and the environment were major themes of this foresight project with a strong emphasis on the interlinkage of food production with the United Nations Sustainable Development Goals and the related challenges of food security and food sustainability.

Social-ethical and environmental aspects of food safety were particularly prominent. In parallel with new technologies, new business models are promising new consumer offerings based on local, ethical, traditional and sustainable production. To underline the conclusion that the food sector is undergoing a step change, the report highlights the changing role of investment in food production and manufacture, including a significant flow of investment into new food technology from non-food investors.

9. Food Emerging Risks and Horizon Scanning Activities

HS and food safety early warning systems are currently employed by private industry and some food agencies (FAO, 2014: EFSA, 2017; SwissRe, 2017). The European Food Safety Authority (EFSA) hosted a colloquium on emerging risks in 2010 which attempted to draw together the state of the art in the area of early warning approaches and foresight on area of food safety (EFSA, 2011). The EFSA

Stakeholders Consultative Group on Emerging Risks (StaCGER) has been meeting several times per year since 2010. Meetings are in a workshop style with a limited group of stakeholders drawn from the agri-food industry, professional bodies and non-governmental organisations. The EFSA StaCGER group produces an annual report of the major topics of discussion (EFSA, 2017). To date, the StaCGER meetings have focused more on the collection of data on possible emerging risks rather than horizon scanning *per se.* The identification of emerging food safety risks by EFSA was recently reviewed and a number of opportunities for improvement were identified, including the improvement of horizon scanning (Donoghue *et al*., 2018). The translation of StaCGER data collection to impact (food system resilience) remains to be determined.

The challenges of horizon scanning have been reviewed by several practitioners. The following drawbacks and opportunities are relevant (Sutherland and Woodroof, 2009):

1. Data gathering can to be backward looking unless suitable scenarios are built to interpret plausible consequences of change
2. Making sense of data in the form of scenario development and systems mapping can be expensive and time consuming
3. Detection of signals is of no value unless suitable action can be identified
4. It is not a predictive tool so caution is still needed to avoid complacency

The International Risk Governance Council (2010) emphasized the value of analysis of drivers of change and proposed 12 “generic contributing factors” of emerging risks. These can include unintended impacts of regulation which was a factor in the melamine crisis. The analysis of driving forces also forms part of the DPSIR framework (Drivers-Pressure-State-Impact-Responses) (RIVM, 2001).

For example, the presence of melamine in pet food, leading to widespread illness and mortality of dogs in particular, was well reported approximately a year before the first cases of illness in humans were reported. Clearly, a systemic connection was not made between the fraudulent use of melamine to influence the protein analysis of pet food ingredients and the potential for similar fraud in human food products. Early intelligence was also available in the case of other food safety crisis including the case of Sudan Red 1 and horsemeat. Therefore, history teaches that a successful horizon scanning system will depend not just on acquiring intelligence on new threats to food safety, but the formulation of appropriate and timely responses to that information. Routine root cause analysis of incidents can inform foresight of food safety issues and could, for example, be used with bow-tie analysis to anticipate potential additional scenarios.

Many recent HS activities have worked on the timescale to 2030, 2040 or even 2050. The RAND project highlighted the rapid and disruptive nature of developments in the global food system, which argues for a shorter timescale. We propose a timeframe of 5 to 10 years for future FSA activities. Not surprisingly, consumers express more concern about emerging risks that are the result of food fraud (EFSA, 2018). Therefore, foresight of potentially fraudulent activities is particularly important to maintaining consumer confidence and trust in the food system. Such events are generally on a shorter timescale.

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Annex 3. Examples of Useful Open Data Sources to Support Technology Foresight and Risk Governance in the Agri-food Area

Accenture	www.accenture.com/gb-en/insight-food-industry-trends
Animal and Plant Health Agency	https://www.gov.uk/government/organisations/animal-and-plant-health-agency
Bloomberg	www.bloomberg.com
BusinessWire	www.businesswire.com
Centre for Strategic Futures Singapore	www.csf.gov.sg/
DEFRA	www.gov.uk/government/organisations/department-for-environment-food-rural-affairs
Deloitte	www.deloitte.com
EFSA	http://www.efsa.europa.eu/
EMPRES (FAO)	http://www.fao.org/ag/empres.html
ERIS	www.tno.nl
EU Rapid Alert System For Food and Feed	https://webgate.ec.europa.eu/rasff-window/portal
Eureka Alert	www.eurekalert.org
Euromonitor	www.euromonitor.com
Fabian Society	www.fabians.org.uk
Feed Navigator	www.feednavigator.com
Feed Navigator	www.feednavigator.com
Food For Life	http://etp.fooddrinkeurope.eu/
Food Foundation	www.foodfoundation.org.uk
Food Navigator	www.foodnavigator.com
Foresight4Food	www.foresight4food.info
Forum for the Future	www.forumforthefuture.org
HorizonScan	https://www.fera.co.uk/food-safety
INFOSAN	http://www.fao.org/food/food-safety-quality/empres-food-safety/early-warning/en/
Innovate UK	https://www.gov.uk/government/organisations/innovate-uk
Institute of Food Science & Technology UK	www.ifst.org
Institute of Food Technologists (USA)	www.ift.org
International Risk Governance Council	www.irgc.org
Kantar WorldPanel	www.kantarworldpanel.com/en
Lloyd's Register Foundation	www.lrfoundation.org.uk/en/
McKinsey	www.mckinsey.com
McKinsey Global Institute	www.mckinsey.com/mgi/overview
nextBIGfuture	www.nextbigfuture.com
Nielsen	https://www.nielsen.com/uk/en.html
NutraIngredients	www.nutraingredients.com
Rabobank	https://research.rabobank.com/far/en/home/index.html
SingularityHub	www.singularityhub.com

Sustainable Food Trust	www.sustainablefoodtrust.org
Swiss Re SONAR	www.swissre.com/institute/research/
UK Government Office for Science	www.gov.uk/government/organisations/government-office-for-science
UK Ministry of Defence Global Strategic Trends	www.gov.uk/government/publications/global-strategic-trends
UK Research & Innovation	www.ukri.org
UN Food and Agriculture Organisation	www.fao.org
Waste and Resources Action Programme UK	www.wrap.org.uk
World Bank	www.worldbank.org
World Economic Forum	www.weforum.org/

Annex 4: Acknowledgements

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