**Working title: Rethinking the food system for human health in the Anthropocene:**

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There are increasing concerns about the current global food system and especially how it effects environmental and human health. The need to rethink and design a new system is at the heart of many reviews, which suggests there is considerable agreement that the current system is in need of radical change, as it is unsustainable and not good for planetary or human health. Amongst the most alarming of these reports is the "Food in the Anthropocene: the EAT-lancet Commission on healthy diets from sustainable food systems", which received global attention around its suggested “healthy reference” diet [1]. The commissioned report title page quotes "Food in the Anthropocene represents one of the greatest health and environmental challenges of the 21st Century". One of the lead authors, Johan Rockstrom, has been at the forefront of thinking about planetary boundaries [2] and the necessity to stay within them in order for humans to continue to thrive or perhaps even survive. During our current geological age, often termed the Anthropocene, many of these planetary boundaries are being exceeded and the food system is linked to so many of the boundaries either directly or indirectly. For example, the Anthropocene is significantly influenced by man’s increasing desire for more meat/dairy in their diets [3]. We face a significant planetary/environmental “health” issue but in this article we will be focusing on the direct effects on human health, as we know that the challenges of a meat/dairy based diet is driving greenhouse gases, affecting air quality and water pollution, land degradation and biodiversity loss.In the Anthropocene *the* major focus for the food sector is on macro/energy consumption, and not on micronutrient levels, which requires more investigation and resourcing. More people are now obese than underweight and it is estimated that 2 billion people consume diets lacking key micronutrients [4]. The WHO estimated that almost 2/3rd (62%) of adults in Europe were overweight, including 25% obese.

There has also been commentary about the challenges of offering a socially just level of dietary access/resource to the many, whilst not exceeding the boundaries, leading to the emerging field of doughnut economics – the conceptual framework of social and planetary boundaries providing a pathway for humanity’s progress in the Anthropocene [5]. The linking of these boundaries is complicated due to spatial differences, which was tackled in an important Chinese case study [6], which attempted to link across the different scales used for planetary versus social challenges. This highlights that there needs to be more attention paid to understanding how the food system needs to change both spatially and temporally to act within a safe and just operating space.

One significant attempt to address the planetary and social challenges across the world has been UN Member states designing a set of 17 Sustainable Development Goals (associated with 169 targets) based on the three pillars of sustainability (economic, environmental and social, including health) [7]. The food system is affected by and affects all of these goals either directly or indirectly [8,9] and is thus an area which is receiving much attention. It therefore requires disruptive thinking and a systems approach to ensure that the food system doesn't continue to create the environmental effects that are driving the Anthropocene which in turn indirectly affects human health alongside the direct human health effects caused by poor nutrition and food. In order to achieve this change, it is important to move towards “sufficient” diets where we don’t have too much or too little of the “right” stuff. Such a redesigned food system, placing humans and human health at the centre, is the best way for delivering for the environment as it would result in environmental conditions being radically improved.

# Mismatch between supply, demand and requirements

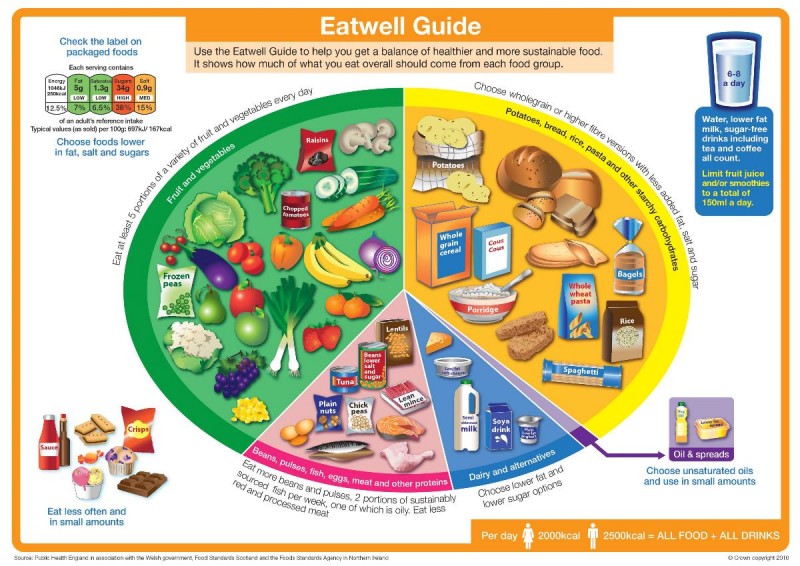
# In order to maintain health it will be essential to deliver future food systems and diets in the realm of nutritional security and not just the dominant focus on agricultural/farming high energy yields to feed our populations at the national and global scale. The editorial for the EAT-lancet commission [10] opens with "Civilisation is in crisis. We can no longer feed our population a healthy diet while balancing planetary resources. For the first time in 200,000 years of human history, we are severely out of synchronisation with the planet and nature". This is a global issue which affects every country albeit the exact picture being shaped by a range of socio-economic and biophysical factors. For example, in the UK we have to address a number of key issues for the future food supply as nearly half of the food consumed in the UK is imported from the EU [11]. This and future trade relationships might be quite different after Brexit [12, 3] which will require the government to arrange new agreements to maintain markets and labour associated with food production. Food security exists when people have “at all times, have physical, social and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life” [13]. There will be a new requirement to source alternative imports from other trading partners [12]. Globally the UK is the 5th biggest importer of meat, which also provides key macro and micronutrients e.g. vitamin B12, which need to be sourced from different food types if less meat is available. DEFRA developed an agricultural policy [14] which has developed into the Agriculture Bill 2017-19 [15] and Environment 25 year plan 2018 [16]. In 2019, Henry Dimbleby, as non-executive board member for DEFRA, is leading a group tasked with developing a National Food Strategy which must address the complex challenges of increasing production and supply alongside addressing current consumption patterns, managing consumer expectations and behaviour change including minimising waste and achieving balanced food distribution. Although the above national strategy and trade-flow analysis focusses on the UK food, the concepts apply to countries across the globe due to the globalised food system, which has been important in addressing food security but has had impacts on human and planetary health as outlined in the Lancet Commissions [1].

# The Lancet Commission on the Global Syndemic of obesity, undernutrition and climate change [17] states that economic losses attributable to undernutrition are equivalent to 11% of the GDP in Africa and Asia or $3.5 trillion annually. Whilst there might be a perception that food security is an issue for low and middle income countries, when considering the four pillars of food security it is clear that we must also look at high income nations. In the US, for example, in the period 2013-2015 the state of Mississippi had a prevalence rate of 20.8 percent of households as food insecure (7.9 % very low food security) [18]. This has been a consistent pattern for the state since 2004-2006 data collection. In the last 40 years, the rise of the obesity pandemic (estimated as 2 billion people globally) has resulted in a significant rise in preventable major non-communicable disease (NCDs) [19] and no nation has had success in reversing increasing obesity. In the UK, 1 in 5 children are leaving primary school obese and it appears that socio-economic status exacerbates obesity levels in this age group; at the adult level almost two-thirds of people in the UK population are overweight or obese [20]. Data from the Food Foundation “Broken Plate” report [20] shows that to eat the desired balance and level of the Eatwell plate [21] the proportion of disposable income (after housing costs) in those with the lowest incomes is not sustainable. It is estimated that the NHS spends about £10 billion on diabetes every year (around 10 per cent of the NHS budget) [22]. Of course we are not reaching low food security levels seen in the developing world, however, the descent into these conditions in the UK as the 5th largest global economy (IMF figures 2018) which is predicted to fall to 7th in 2019 [23] is notable. There is now a plan by the government to introduce an official measure of food security [24].

# Global Food security – the need to integrate nutrition into the environment and production

# A Royal Society discussion meeting in 2012 focussed on achieving food and environmental security: new approaches to close the gap [25]. These discussions helped inform the growing interests across the globe on Sustainable Intensification and/or Climate Smart Agriculture. This led to the development of The Kavli declaration for 2050, which proposed as a way of linking the environment with production but this was not linked to nutrition, thus illustrating the complexity of the issue and the challenge to link several components let alone all of the food system. An important approach presented at the meeting was to use an ecosystem services approach to offer the sustainable intensification frequently proposed as a way of increasing agricultural production whilst minimising environmental impact [26]. However, this needs to be linked throughout the food chain including food processing and retailing in order to link with the other end of the food system, ie nutrition, and especially the micronutrients which are often ignored, especially if we are to put human health at the centre of the food system. There has been important research on farming and the environment [25], as well as research linking food, nutrition and health [27], but we need to bring it all together in recognition of the diversity of food systems worldwide, to ensure human health alongside planetary health continues to thrive in the Anthropocene.

**Figure 1. The NHS Eatwell Guide**



Fortunately, there is increasing recognition of the need to take a food system approach. For example, the recent Global Food Security Programme’s Priority Research Questions expert group looked at food security game changing developments in detail using a food systems approach [11]. There needs to be more research undertaken on mitigation as illustrated in Figure 2 of the EAT-lancet commission paper [1]. Projections of global emissions to keep global warming to well below 2°C, aiming for 1·5°C and nudging large scale farming practices into more sustainable systems that promote biodiversity. Whilst it is important to focus on interdisciplinarity and systems thinking in order to offer disruption and not incremental change of business as usual it is essential that we really start to put human nutrition and wellbeing at the heart of the food system [28].

**Figure 2. The direct and indirect costs of agriculture on global and national health**



Micronutrients are becoming increasingly recognised as important to nutritional security and human health. This is particularly relevant and important to maternal and infant nutrition, as there is strong evidence that fetal and infant undernutrition are risk factors for obesity and subsequent NCDs in later life and the Developmental Origins of Health and Disease concept has emerged [35]. Included in this is the period around conception with parental lifestyle (preconception) influencing long term risks in the child [36] the first 1000 days (from conception to year 2).

**Global Drivers and Pressures in the Market and which Biological Responses might help?**

If one considers the global food system as a complex socio-ecological challenge, then the use of a DPSIR framework (*Drivers*, *Pressures*, *State*, *Impact* and *Response* model of intervention) might help frame some responses. Whilst some might believe that DPSIR is more appropriate for linear processes the concept is still useful in our thinking here.

Much of the current food system, especially in the industrialized agriculture countries, is largely *Driven* and *Pressured* by market forces which influence what farmers produce . For example, in countries across the world but especially within Europe, subsidies and economics mean they produce high yields of profitable goods which are often based on energy output (calories), etc. This has contributed to few crop species providing the significant share of calories in the world [37]. The supply chain tends to mean the processors in the supply chain maximise profits by adding value using cheap ingredients, further enhanced by retailers using market research to explore what consumers desire and/or can be influenced to buy and thus maximising their profits too. The consumer can influence the farmer directly, especially where there is a short supply chain but it is often the processor and retailer whom have most direct interaction with the consumer. Consumer trends driving retailer and processor practices can lead to making change happen e.g. in the UK, a rapid increase of convenience foods, which the Food Standards Agency (FSA) food futures report [38] flagged as responsible for loss of connection with food which has many unhealthy and unsustainable outcomes. The FSA’s work with RAND [39] on foresight of the global food system and what this means to a UK consumer and a UK standards and safety regulator, flags the important role of Industrial, Technological, Consumer and Environmental *Drivers* and *Pressures* on the system. One shouldn’t underestimate the disruptive power and influence of consumer trends such as the rapid rise of veganism particularly in the Generation Z [40] or disruptive business platforms such as online delivery providers shaping both consumer and business behaviour (Deliveroo, Just Eat, Amazon, etc). The rapidly growing economies of India and China (with almost 25% of worlds population) [41], coupled with the associated changing dietary preferences, are shaping food systems and contributing to the environmental and health issues at an even bigger scale, requiring an even more timely and significant *Response* before these *Drivers* and *Pressures* change the *State* and have *Impact*, which is beyond a planetary tipping point. This environmental tipping point is driven by the dynamics of human diets and the current food system, meaning a redesigned food system with human health at its centre will not only reduce the likelihood of a tipping point being reached but will also improve human health through healthier environmental parameters such as air and water quality.

To meet the EAT-lancet commission’s definition of a healthy reference diet, which can provide optimal health and wellbeing, reducing premature deaths by 19-23%, there needs to be a reduction in red meat (50%) and a 100% increase in legumes, nuts, fruit and vegetables. However, there is a very real challenge in changing the current food system to offer such a diet from the farming and food production system and facilitating consumer change to allow these diets become widespread and adopted across socio-economic divides and cultures/societies across the globe.

**Time to Act – what biological tools could we develop in our response toolbox**

The complexity of the response is likely to need to match the complexity of the *Drivers*, *Pressures*, *States* and *Impacts*. Here we focus on the major biological *Responses,*  which often have interaction with socio-economic or socio-ecological effects, we might use to ensure we keep human health central in our redesigning of the food system: these might include:

1. Investigating the intra- and inter-specific variations of micronutrients in plants through increasing the diversity of our agricultural systems. So are there “super veg” or “super fruit” present with very high levels of key micronutrients and fibre? Genetic advances that could rapidly develop crops with increased nutritional content may bring significant advantages in a world requiring food with a better nutrient content. Could a “5 A Day” recommendation be simplified to “1 A Day” of the right species or cultivar? Whilst “5 A Day” is a well developed and publicised policy recommendaton, it is rarely followed [42]. Understanding what makes micronutrients more bioavailable such that plant nutrients can be as bioavailable to humans as many animal micronutrients, and/or exploring other limiting factors in plants such as the presence of anti-nutrients [43].
2. Optimising farm to fork conditions: post-harvest and cooking. Storage, preparation and cooking are key variables in consumer practice – what do we know about how this affects micronutrients and how might this also affect 5 A Day advice including storing, processing and cooking practices? How much can the biological process of rotting and spoilage be altered so less food is wasted and its nutritional quality made more resilient to storage and handling conditions.
3. How nutrient secure are sectors of our society and what are the impacts of policies aiming to optimise nutrient intake in these sectors? There is not a single consumer: FSA social science has segemented consumers into seven groups [44], but even this requires generalisation. Understanding socio-economics and demographics on consumer behaviour and how to nudge such consumers becomes key in trying to address nutritional challenges across society as well as to address human and planetary health, both supply and demand and the human behavioural practices in the current and redesigned food system.
4. Environmental: optimisation of the microbiome and soil amendments. The gut microbiome is being linked to an ever increasing number of human health conditions [45]. There is a market for probiotics, as there are for supplements, but there needs to be much more disruption and redesign if we are to effect health through the microbiome. For example, understanding the role of different plant-based or other diets on the gut microbiome and how these establish and maintain the microbiome. In addition, the links between the gut microbiome diversity and how that relates to nutrient uptake needs to be a knowledge gap filled. Soil has recently become central to many discussons on agriculture [46] but the soil microbiome has great potential as it influences plant chemistry and thus micronutrients [47].
5. What might be the role of gene editing in future food production? For example the use of CRISPR-Cas9 [48] in gene editing to enhance micronutrients in preferred plants for consumption might be a way forward in the short term rather than major changes to the food production system, etc. For example, can key micronutrients from meat and dairy be engineered into bananas or key staple crops as was the case for edible vaccines in bananas or vitamin A in Golden rice.
6. Finally, we cannot forget cultural/behavioural issues, pricing and behavioural nudge. What are the influences on future generations and how do these play a part in food production strategies? Too often the food system is considered as a system requiring technical or biological intervention yet social and economic change can have a bigger effect. The Food Foundation is trying to increase the consumption of fruit and veg in the UK using a range of behavioural and political/media levers [49] without any change to the biological/technical inputs of these foods. The FSA is increasingly aware of how major disruption comes from cultural and business change and rather than worry how to regulate, perhaps we should think on how to use this disruption. Increasingly in sections of societythere are interesting shifts in tastes coming into play with the rise of veganism and a rising consciousness to eat a more plant based diet (Meatless Monday; Meat free Monday). Over the last century there have been national schemes to reduce consumption in times of need (ie wartime dietary change in the USA and UK).

The call to arms to redesign the global food system for human and planetary health is becoming louder as more evidence accumulates of a system in need of radical change. The Anthropocene has helped drive the current food system and in turn it drives the Anthropocene, yet importantly human health is not central in discussions and solutions. By starting with renewed focus on nutrition, there is an opportunity to redesign the global food system through the combined lenses of the SDG’s, ensuring that human health is directly and indirectly improved by a redesigned global food system.

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