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Modelling food demand in the 21st century

Susan Lee *and* ***Ruth Wood*** *of the University of Manchester's Tyndall Centre for Climate Change* *explain what we can potentially learn from modelling future food and diets consistent with limiting warming to no more than 1.5°C.*

Introduction

The global agricultural sector together with forestry and other land use (AFOLU) is responsible for 23% of global greenhouse gas (GHG) emissions[1]. As a result, food and diet are increasingly coming under the spotlight as both a cause and part-solution to climate change. There are a plethora of studies examining how dietary change can reduce GHG emissions and how farming practices can not only reduce GHG emissions but also enable CO_2 storage. There is good agreement within the literature that there needs to be a reduction in meat and dairy consumption to mitigate climate change, though studies differ in the scale of the reduction[2],[3],[4]. Here we outline how the global integrated assessment models used to inform international negotiations consider agricultural emissions and what they can tell us about the role of dietary change in delivering the Paris Agreement.

Climate negotiations require information on how to deliver the global emission reductions needed to avoid greater than 1.5°C or 2°C global warming. To do this they must have a robust way to determine the effects of their actions. Modelling, particularly global Integrated Assessment Models (IAM) such as IMAGE, provides the tools to do this as it has a cross-sectoral view and a global long-term perspective. There are 10 main global IAMs, which have been compared to assess their performance under set conditions and understand their responses[5]. IAMs represent the interactions between human and natural systems quantitatively, including the greenhouse gas emissions associated with agricultural production, land use change, transport, buildings, industry and energy supply. They can be used to explore how to reach defined carbon reduction targets, depending on future technology and resource availability, Gross Domestic Product (GDP), population and policy preferences. IMAGE[6] is a well-established and widely cited IAM and includes a robust and relatively detailed representation of land use. For this reason, the alternative pathways to 1.5 and 2°C it generates can provide a useful contribution to our understanding of the role of agriculture and dietary change under both strong climate mitigation policies and a changing climate.

The Centre for Climate Change and Social Transformations[7] is using insights from IMAGE to inform its research on low carbon living. The CAST vision is to be a global hub for understanding the systemic and society-wide transformations that are required to address climate change focusing on four areas: thermal comfort, mobility, food and diet, and material consumption. The aim of the

modelling research in CAST is to interpret the outputs of the IMAGE model, in order to provide meaningful insights of what living in a 1.5°C world could look like.

The IMAGE model

The IMAGE model can be used to explore global greenhouse gas emission pathways that are consistent with different levels of global warming. It projects developments in technology, population, economy, lifestyle, policies and resources that impact energy and land sectors, contributing to emission pathways over time and across regions. To understand the role of agriculture and diet in delivering greenhouse gas emission savings, the agro-economic MAGNET model[8], part of the IMAGE framework, projects the demand for agricultural commodities. This includes food demand based on available income, preference shift and the commodity prices arising from changes in resource availability, technological progress and trade and transport costs. A vegetation and land use model is used to quantify the emissions associated with the supply of food demand. The vegetation model assesses future crop growth depending on future climate, soil nutrients and fertiliser use. It includes 16 different crop types, which cover the main food crops of the world as well as spices, plant-based fibres and bioenergy crops. The livestock component differentiates between beef and other ruminant meats, dairy cattle (grass and crop-fed) and other animals (e.g. chickens and pigs)[9]. By combining how future agricultural productivity and thus yields could change with potential future food demand, IMAGE illustrates the role that dietary change plays within holistic, global, emission reduction scenarios.

To illustrate the type and utility of the results produced from IMAGE, we present a methodology to derive future food consumption from a specific scenario called Lifestyle Change (LiStCh). This scenario is used in combination with climate policy to deliver total global greenhouse gas emission reductions across all emission sources – not just agriculture and food - which are consistent with avoiding more than a 1.5 °C temperature increase[10]. In this scenario consumers have changed their lifestyle to lower GHG emissions, including a shift to a less meat intensive Willett's diet (also conforming to health recommendations), substituted with plant based proteins by 2050[11]. If, globally, countries and sectors were to follow the emission reductions and mitigation measures set out in the scenario, we can use the outputs to illustrate the dietary changes that can significantly aid individual nations to avoid 1.5°C.

Table 1 shows the assumptions made in the Lifestyle Change scenario for diet and food waste. IMAGE provides outputs in terms of kcal per capita food consumption for crops (plant-based kcal) and livestock (animal-based kcal) for 26 world regions, including Western Europe. To interpret the implications for dietary change in the UK and other individual nations in the interim years to 2050, the outputs first need downscaling from Western Europe to the UK, and then translating into their implications for diet.

Category	Scenario Inputs
Diet	Introduction of the Willett's diet[11]. The diet is introduced from 2020, by 2050 it is assumed 100% of the global population follow it.
Food Waste	Household food waste as a fraction of food demand is reduced: 10% less avoidable waste per year starting in 2011, reaching 98% reduction in 2050.
	Food waste as a fraction of demand is also reduced in storage and distribution systems: 5% less waste per year starting in 2011, reaching 86% in 2050.*

Table 1 The Lifestyle Change for Diet and food

(details extracted from Table 1, Van Vuuren et al.[10]) (van Vuuren et al., 2018) (van Vuuren et al., 2018) (van Vuuren et al., 2018) (van Vuuren et al., 2018) (van Vuuren et al., 2018)

*Note that the absolute amount of food waste will decrease less quickly than this waste fraction, since total demand increases with population size and affluence.

Methodology for downscaling food demand

Step 1 Data extraction

The methods used to downscale the IMAGE outputs to the UK are summarised in Figure 1. For the period 2020 to 2050, we extract food demand data consisting of 'Crops' , 'Livestock' and 'Total Demand' (in kcal/capita/day) from the IMAGE model's Lifestyle Change scenario for the Western Europe region (WEU). The WEU consists of 11 countries ranging from the very small Andorra and Lichtenstein up to France and Germany.

Step 2: Establish a baseline and separate out food waste from food demand to give truer indication of consumption

The WEU data for the baseline year (2020) is downscaled to the UK by population, assuming equal per capita food consumption across the WEU region and that the proportion of the UK population within WEU follows World Bank[12] population estimates. This is a preliminary assumption and further work will use food consumption by country in the baseline year to do this.

Food consumption, excluding fish, is included within IMAGE Food Demand as well as food waste (decrease in the quality or quantity of food due to retailers, food service providers and consumers) and food loss (decrease in the quality or quantity of food due to food suppliers). Part of establishing the baseline involves distinguishing between the actual food consumed and that lost. The FAO[13],[14] estimates that the current level of global food waste and loss is around 30% to 50%[14].

This particular model scenario gradually reduces waste over the 2011 to 2050 time-period to account for both wastage at the consumer level as well as losses in the supply chain. When losses have been taken into account, the resulting figures for food consumption for crop and livestock derived foods are established.

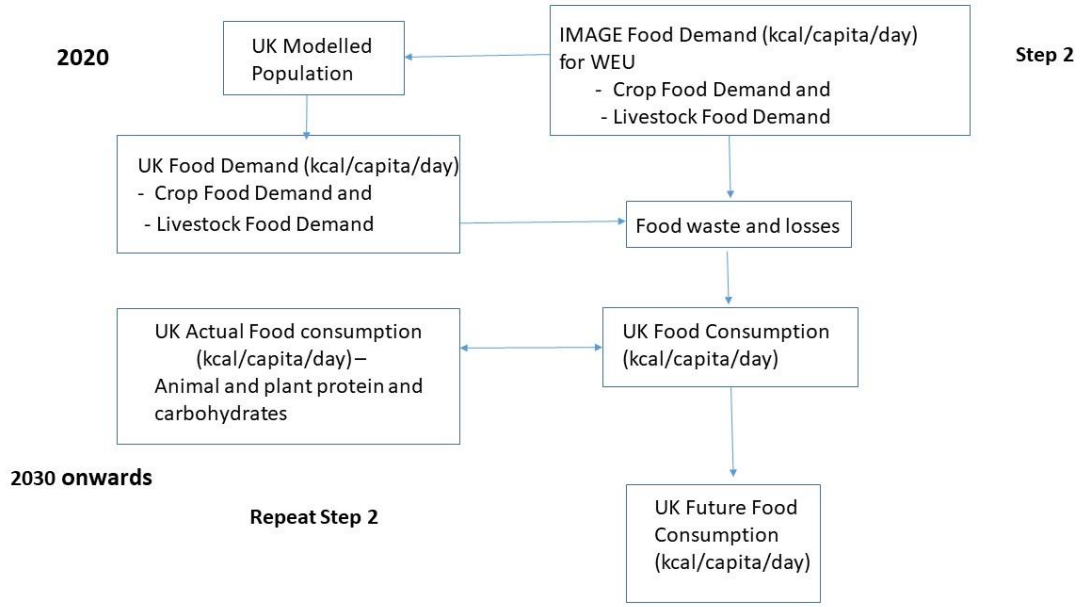

Figure 1 Downscaling of IMAGE Food Demand data to UK Food Consumption (Step 2)

Step 3: Develop a pathway for crop types and livestock groups

After establishing the UK's current split of kcal/capita/day for animal and plant based foods, these are changed on a decadal basis to meet the 2050 dietary figures from IMAGE. The assumption within the Lifestyle Scenario is that by 2050 the global population is following the Willett's Diet, represented by the resulting split between animal and plant based food consumption in 2050. To do this we assumed the following:

i) The UK average calorific intake per person will be 2175 kcal initially (based on the UK Food Survey, recognising this is an underestimate)[15] and this is changed proportionally in line with the IMAGE total food demand to 2050.

ii) The reduction in animal products and corresponding rise in plant-based products will change at a steady rate between 2020 and 2050 i.e. there will be no abrupt changes.

Figure 2 shows how the present day diet for the UK from the Family Food datasets on household and eating out nutrient intakes (converted to percentages of protein and fat and carbohydrate) compares with the 'healthy' diets proposed by UK Eatwell Guide[16] and the Willett Diet[17] used within the IMAGE scenario. It highlights the dominance of fat and protein in our diet - currently 60% of UK protein intake is animal protein. The current UK protein and fat intake needs to decrease by 8% to achieve 25% of total diet as recommended by Willett.

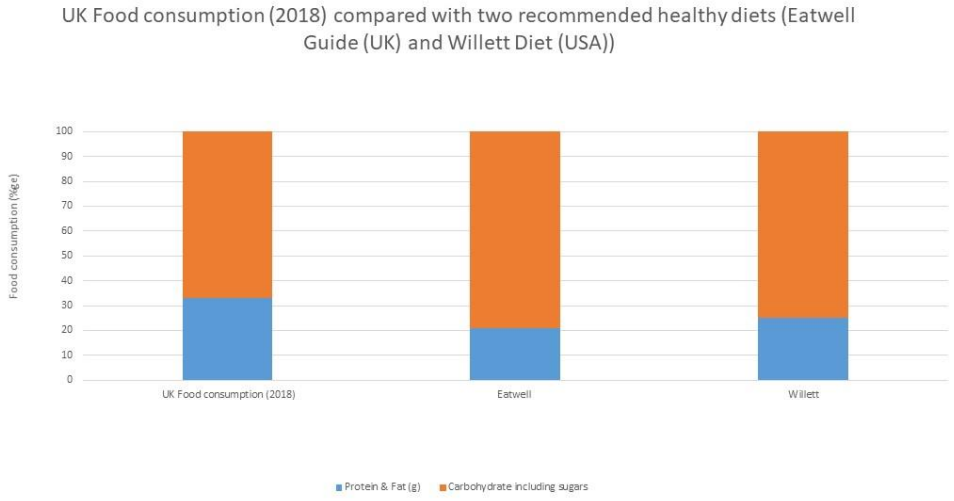

Figure 2 UK Food consumption (%ge) in terms of protein and fat, and carbohydrate compared with the UK Eatwell Guide (UK Government, 2018) and the Willet Diet (Willett, 2001)

Step 4: Interpret the results for dietary changes

Using the calorific data, the next step is to interpret the implications of the changes in calorie intake for everyday diet. This includes the breakdown of the animal products category into different types of meat and dairy together with further refinement of the plant based foods category. Following this breakdown we will use national studies to develop typical meal patterns reflecting regional diets, identifying where and with which alternatives animal products are replaced. Finally, where food is eaten and how it is prepared will be considered to reflect potential changes in eating out and cooking.

Potential outputs from modelling food demand

We have presented a simple demonstration of a downscaling technique taking regional food demand data for Western Europe from the IMAGE model and estimating UK dietary implications in terms of the kcal/capita/day for animal and plant based foods. The next stages in the process would be to interpret further the implications of the kcal data for what we eat every day and to use outputs from other IMAGE 1.5^{o}C consistent scenarios to see how dietary change varies across them. The outputs from IMAGE provide an indication of potential trends and the magnitude of future changes in daily per capita kcal consumption for both crops and livestock incorporating both stringent mitigation policies and the feedback from a changing climate. The lifestyle scenario exemplified here includes changes in diet with significant reductions in energy and transport use, along with wider transformations in the energy, industry and agricultural supply systems, which together provide an example pathway that avoids exceeding the 1.5 °C limit.

Currently IMAGE provides a broad overview for a large region and is not able to show the subtleties of local and regional diets – in particular the breakdown of food types within the broad 'crop' and 'livestock' categories. As part of our planned, more detailed work for the UK, as well as other countries (Sweden, Brazil and China), we will focus more on local and regional diets. This will enable us to better understand how the changes indicated by IMAGE could play out and to compare the final results with other international and national studies which explore the role of dietary change in climate change mitigation.

We recognise that there are issues with our understanding of current food consumption in the UK and that food survey data tend to underestimate actual consumption and are just a snapshot in time. The actual food consumed is likely to be around 25% higher due to individuals underestimating what they eat. However, a review on this issue in the UK estimates that household food purchase data is the closest to predicted current food energy intakes[15]. In addition, we have not shown any food waste data here, though the IMAGE model accounts for this. In the Lifestyle Change scenario presented, significant efforts are made to reduce household food waste to almost zero by 2050. The socio-economic changes within the Lifestyle scenario are only one representation of how these may change in the future. To understand the space within which diets could change as a result of both socio-economic factors as well as stringent mitigation, a wider set of scenarios will need to be used to better contribute to the discussion in this field.

Conclusions

Modelling studies (Tilman and Clark, 2014, Bajželj et al., 2014, Scarborough et al., 2014, Springmann et al., 2018) carried out to date on future diets have reached a general consensus that meat consumption needs to go down and plant-based diets to increase.

The present UK diet is significantly out of step with both the Government's Eatwell Guide and the Willett's 'healthy eating' diet used to develop scenarios based on a less meat-intensive diet in the study presented here. UK diets are dominated by fat and protein - currently 60% of UK protein intake is animal protein.

The IMAGE model is a useful tool that is able not only to assist in future decision making on mitigation steps to reduce greenhouse gas emissions within a changing climate at the global scale but also potentially at the household-level.

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