Greenhouse gas emissions from UK food and drink consumption by systems LCA: current and possible futures

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ABSTRACT

This work determined the potential to reduce greenhouse gas (GHG) emissions from the UK food system by 70% from a 2005 baseline. A food consumption-orientated inventory was produced including primary agricultural production, food processing, distribution, preparation and disposal. Land use change (LUC) used a top-down approach. The inventory used many sources of data ranging from LCA studies to national level reporting of energy use by sectors of the economy and household surveys. The inventory was created with systems models to compare scenarios for emission reduction. The inventory for the baseline was 250 Mt CO_2e including 100 Mt CO_2e from LUC. Emissions without LUC from the UK food consumption system are about 20% of the current total consumption emissions. Several measures to reduce emissions were investigated, including dietary change, technical efficiency improvement, reducing waste and using non-fossil energy. Only a combination of measures achieved the 70% target reduction, but required major societal changes.

Keywords: agriculture, food, distribution, processing, consumption

1. Introduction

There are pressures to reduce greenhouse gas (GHG) emissions from human activities in order to meet national and international agreements on climate change. The agri-food sector is no exception. Before the UK Government formally set targets for each sector of the economy, the question was posed by WWF and Food Climate Research Network (FCRN): how low can we go in reducing emissions from the complete UK food system by 2050 compared with a baseline of 2005? A target of 70% was tested. (Audsley et al., 2010)

2. Methods

2.1. Inventory construction

The consumption inventory was created to represent as closely as possible the food commodities consumed in the UK as opposed to what is produced in the UK for domestic consumption or export. Data on domestic production, imports and exports were taken from FAOSTAT, UK Government statistics (Defra, 2009) and some trade data. This together with the animal feeds needed for animal products defined our 110 primary commodity production demands and the proportion imported (Table 1).

The UK Government's household food survey was used to estimate the partitioning of commodities into those passing through manufacturing stages together with those being consumed after retail or preparation in the food service sector (Defra, 2007). Data on food waste arisings (WRAP, 2008) was also used for the estimation of domestic food wastage.

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Table 1: Annual consumption of top 45 food commodities in the UK (see Audsley *et al*., 2010)

Commodity	Weight, kt	Commodity	Weight, kt	Commodity	Weight, kt
Milk	14,441	Bananas	658	Groundnuts	247
Sugar cane	8,066	Onions	621	Misc. cereals	237
Potatoes	6,843	Maize	606	Peas, green	226
Wheat	6,073	Bird eggs	559	Turkey meat	207
Sugar beet	4,901	Carrots and turnips	537	Pears and quinces	205
Grapes	3,623	Rice, paddy	531	Mushrooms and truffles	199
Chicken meat	1,598	Olives	406	Edible offal	180
Tomatoes	1,441	Pineapples	353	Grapefruit and pomelo	174
Rape and mustard seed	1,345	Sheep and goat meat	351	Peas, dry	169
Pig meat	1,228	Tangerines etc.	312	Cucumbers and gherkins	161
Oranges	1,178	Lettuce and chicory	300	Other melons	145
Bovine meat	1,041	Sunflower seed	284	Peaches and nectarines	145
Apples	1,026	Brassicas	268	Plums and sloes	135
Barley	708	Cauliflower/broccoli	252	Tea and Maté	129
Palm oil	706	Soy oil	252	Chillies and peppers	123

Primary production was represented, where possible, by commodities already analysed using Cranfield systems-LCA modelling (Williams et al., 2006; Williams et al., 2009). The Cranfield systems modelling approach to agricultural LCA ensures changes result in coherent systematic changes in inputs per unit output. For example, if milk yield increases, cow feed energy must increase to meet the cow's metabolic needs (as must manure outputs).

Other data were taken from the literature and proxies were used where necessary (e.g. Milà i Canals et al., 2007). All GWPs and emission factors were those from the IPCC (2007a). Emissions from food processing and distribution were a combination of process-based and high level industry inventory data (e.g. DECC, 2008), retailers' corporate social responsibility reports, e.g. Tesco (2009) and scientific studies (e.g. Tassou et al, 2009). Domestic and service sector food consumption rates came from government survey data (Defra, 2007), while cooking and refrigeration data were a combination of process-based and high level government and industry data (James et al., 2009; BERR, 2009).

Table 2: Steps in 'top-down' method to estimate land use change greenhouse gas emissions

Step 1. Estimate total LUC emissions per year
Step 2. Estimate the proportion of total LUC caused by commercial agriculture, including ranching.
Step 3. Divide LUC emissions attributable to agriculture (derived from Steps 1 and 2) by total commercial agricultural land area to derive **LUC emissions/ha**
Step 4. Calculate land required for each commodity consumed in the UK (**ha/unit of commodity**)
Step 5. Multiply **LUC emissions/ha** by **ha/unit of commodity** = **LUC emissions/t of commodity**
Step 6. Multiply **LUC factor/t of commodity** by total quantity of each commodity consumed in the UK per year = **LUC emissions per commodity**
Step 7. Sum **LUC emissions per commodity** = LUC emissions due to UK food consumption

Land use change (LUC) emissions were quantified with a top down approach. Central to the approach is the consideration that agricultural commodity markets are global and interconnected. Thus, all demand for agricultural land via the consumption of agricultural commodities contributes to LUC pressures (either directly or indirectly), and therefore should be allocated a share of LUC emissions. (Tipper et al., 2009) It should be noted that this approach does not divide emissions into emissions arising from LUC directly connected to crops consumed (direct emissions) and indirect emissions arising from the effect of land use for consumed crops displacing other crops to agricultural land obtained by LUC (indirect emissions). The steps are set out in Table 2.

Estimates of land use change emissions have high uncertainty, and perhaps the highest uncertainty of any emissions source (IPCC, 2007b). There is also high uncertainty associated with the estimate of the proportion of total LUC emissions attributable to commercial agriculture, which is based on the FAO's State of the World's Forests Report 2009. LUC is driven by the interaction of numerous proximate and underlying causes, and attributing a proportion to a single cause will be approximate.

2.2. Scenarios, themes and mitigation measures

The main aim of the study was to consider potential scenarios for reducing human-induced GHG emissions attributable to the UK food system by 70% by 2050. To examine reductions in the region of 70%, scenarios require several mitigation measures to be implemented together and over time. We identified 21 production and technical measures together with eight behavioural measures – mainly diet change (Table 3 and Table 4). Modelling was used to combine measures where possible (remembering that some are mutually exclusive and others synergistic).

Table 3: Details of technical mitigation measures

Primary production	Energy, processing, distribution, retail, preparation
Zero fossil fuels (electricity and other energy carriers)	Low carbon energy for cooking
No enteric methane emissions from ruminants	Low carbon energy for supply chain chilling
N_2O inhibitor with fertiliser (no N_2O from soils)	50% saving in energy inputs into food processing
Anaerobic digestion (AD) of manure	Low GWP potential refrigerants
50% yield increase in crops	Low carbon transport in processing and distribution
Zero N_2O from nitrate fertiliser production	Energy recovery from food waste using AD
25% improvement in feed conversion efficiency	Low energy use in consumer transport
N use efficiency in crop production increased by 50%	95% reduction in GWP of packaging
Livestock production based on by-products and grass	75% reduction in GWP from shopping bags
Minimum tillage (where possible)	Low GWP refrigerants for end users
Organic production	

Mitigation measures were grouped into six mitigation themes:

1. "**Non-mobile energy**" Reducing GWP from the fuel for processes such as ventilation, heating and cooking. This substitutes fossil fuels by renewable energy or nuclear power for electricity, with a shift from gas to electricity in food preparation.
2. "**Mobile energy**" Reducing GWP from the fuel for mobile equipment such as tractors, trucks, ships and cars and from fertiliser production. This replaces fossil fuels with hydrogen or electric engines, coupled with producing N fertiliser from electricity.
3. "**Direct GHG emissions**" Reducing direct emissions to the atmosphere such as methane, nitrous oxide and refrigerants. This requires techniques for reducing: enteric emissions, nitrous oxide from soils and low GHG refrigerant gases.
4. "**Production efficiency**" Reducing GWP by: reducing waste in all stages of the supply chain, increasing food conversion efficiency in livestock, increased crop yields and reducing energy usage in food and drink processing.
5. "**Consumption**" Changing consumption patterns by eating less meat, milk, eggs and rice. (Table 4)
6. "**Conservation**" Increased recycling and avoiding wasteful use: anaerobic digestion of manures, unavoidable food wastes, reducing wastage in the supply chain.

Scenarios were developed in which these themes were implemented over time up to 2100. Rates of implementation were estimated by expert judgment allowing for the technical, economic and social challenges associated with each measure. Several scenarios were investigated by Audsley et al. (2010), but only the most effective one is presented here.

Table 4: Details of consumption mitigation measures

Measure	**Consumption Details**
No meat	Meat is replaced by fungal protein, tofu and pulses
66% reduction in livestock products	Livestock products are reduced and other food increased by 29%
50% reduction in livestock products	Livestock products are reduced and other food increased by 21%
Red to white meat	Red meat replaced by white meat with more vegetables (NB still some shortage of vitamins, but these have small production burdens)
No dairy milk	Dairy milk and products are replaced by soy based milk products
No rice	Rice is replaced by wheat and potatoes
No eggs	Eggs are replaced by "soy synthetic egg"

3. Results

3.1. The UK food consumption inventory

The annual total emissions from primary production were 85 Mt CO_2e (CI 70-100): 66% in the UK, 18% in Europe and 16% in the rest of the world. Livestock product components accounted for 61% of direct primary production emissions. The contributions of gases to GWP at this stage were 54% carbon dioxide, 24% nitrous oxide and 22% methane.

Greenhouse gas emissions from processing, distribution and retail, consumption and disposal amounted to 65 Mt CO_2e (CI 57-76). The three largest terms accounted roughly equally for 66%: cooking, food manufacture and food storage energy. 80% of emissions came from home consumption and 20% from the food service sector. The contributions of gases to GWP at this stage were 85% carbon dioxide, 6% methane and 9% refrigerants: almost all from retail units and road transport rather than domestic or industrial cooling.

LUC emissions amounted to 100 Mt CO_2e (CI 71-130) of which 90% were from livestock production. This was dominated by red meat at 84% of all livestock emissions and is in turn driven largely by the land requirements for extensive beef in countries outside the UK coupled with deforestation in the Amazon.

3.2. Mitigation scenarios to achieve a 70% reduction

The 70% reduction target was applied only to the supply chain emissions because they align more closely with the UK's own targets than the total consumption orientated inventory. The single most-effective measure was behavioural: "no meat", with the technical measure of "no fossil fuels" the next most effective (Figure 1). Note that this assumes 100% implementation, which is unlikely for most measures. The least effective measures were improved refrigerants by end users (0.1%) and improved shopping bags (0.2%).

No single measure or theme was capable of reducing emissions by more than about half. For example, the decarbonisation of the wider economy sought now by government policy by 2050 will reduce food supply chain emissions by about 50%. Measures such as adopting a vegetarian diet (with milk and eggs), a 66% reduction in livestock product consumption, and the adoption of technologies to reduce nitrous oxide emissions from soils and methane from ruminants each have the potential to reduce direct supply chain emissions by only 15-20%.

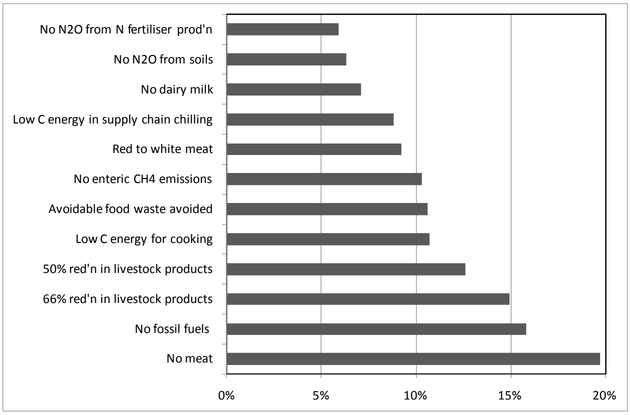

Figure 1: Effectiveness of top 12 mitigation measures in reducing emissions from the supply chain (excluding LUC emissions) if each was fully implemented.

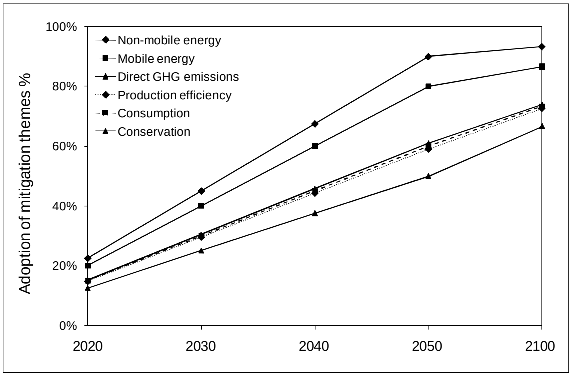

Figure 2: Rates of implementation of themes in the scenario

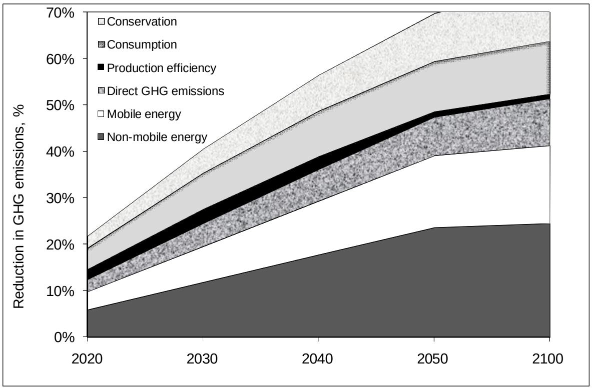

Figure 3: Expected effectiveness of mitigation themes in reducing supply chain GHG emissions from the UK food system (excluding LUC) compared with the 2005 baseline.

Figure 2 shows one scenario of rates of implementation of themes, ranging from 50% to 90% by 2050, with production efficiencies being most easy to implement and conservation being the lowest. High levels of implementation of all themes was the only way to achieve a 70% reduction in food related GHG emissions by 2050 (Figure 3).

4. Concluding discussion

The inventory indicates that for the UK food system, primary production, post farm gate activities and land use change are of similar magnitudes and total about 250 kt CO_2e annually. Technical measures to reduce emissions in the supply chain are clearly feasible, but large changes in technology are required. Dietary change away from livestock products can help reduce emissions further, although this alone would not enable the 70% reduction target to be reached. Decarbonising the energy system had a large effect on the food chain, but has yet greater effects in the wider economy than specifically food-related measures.

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