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Impact of a reduced red and processed meat dietary pattern on disease risks and greenhouse gas emissions in the UK: A modelling study

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Article Summary

Article focus

- Consumption of red and processed meat is a leading contributor to greenhouse gas emissions
- High intakes of red and processed meats increase the risks of several leading chronic diseases
- This research identifies a low red and processed meat dietary pattern that is already followed by a substantial fraction of the UK population and estimates health and environmental benefits that would result from its general adoption

Key messages

- Habitual red and processed meat intakes are 2.5 times higher in the top compared with the bottom fifth of UK consumers
- Sustained dietary intakes at a counterfactual reduced level in the UK population would materially reduce incidence of coronary heart disease, diabetes mellitus and colorectal cancer, by 3-12%
- The predicted reduction in UK food and drink associated greenhouse gas emissions would equate to almost 28 million tonnes per year across the population

Strengths and limitations of the study

- This research uses a food-based approach, taking intake-risk associations from meta-analyses rather than assuming the mechanisms via which the foods influence disease risk
- The dietary data was collected a decade ago, however the headline results from a more recent national dietary survey reveal that intakes of all meat categories were broadly similar although slightly higher in 2008/9 than in 2000/1

Abstract

Objectives Consumption of red and processed meat (RPM) is a leading contributor to greenhouse gas (GHG) emissions and high intakes of these foods increase the risks of several leading chronic diseases. The aim was to use newly-derived estimates of habitual meat intakes in UK adults to assess potential co-benefits to health and the climate from reduced RPM consumption.

Design Modelling study using dietary intake data from the National Diet and Nutrition Survey of British Adults.

Setting British general population

Methods Respondents were divided into fifths by energy-adjusted RPM intakes, with vegetarians constituting a sixth stratum. GHG emitted in supplying the diets of each stratum were estimated using data from life cycle analyses. A feasible counterfactual UK population was specified, in which the proportion of vegetarians measured in the survey population doubled, and the remainder adopted the dietary pattern of the lowest fifth of RPM consumers.

Outcome measures Reductions in disease risks and GHG emissions under the counterfactual.

Results Habitual RPM intakes were 2·5 times higher in the top compared with the bottom fifth of consumers. Risks of coronary heart disease, diabetes and colorectal cancer were associated with processed meat intakes and colorectal cancer was also associated with intakes of unprocessed red meat. Under the counterfactual, reductions in population aggregate risks ranged from 3·2% (95% CI 1·9, 4·7) for diabetes in females to 12·1% (6·4, 17·8) for colorectal cancer in males, with those moving from the highest to low consumption levels gaining about twice these averages. The expected reduction in GHG emissions was 0·45 tonnes CO2-e/person/year, about 3% of the current total, giving a reduction across the UK population of 27·8 million tonnes/year.

Conclusions Reduced consumption of RPM would bring multiple benefits to health and the environment. Current high consumers would gain most, illustrating the potential to reduce health inequalities.

Introduction

Climate change is 'the biggest global health threat of the 21st century'[1] and appropriately chosen mitigation policies could 'bring significant immediate co-benefits for population health and well-being'.[2] Health benefits provide near-term rewards for climate-friendly changes, whereas the benefits accruing as climate change mitigation apply to anonymous populations distant in time. Health co-benefits may thus 'nudge' humanity towards a sustainable future.

Food and drink account for around one-third of total greenhouse gas (GHG) emissions attributable to UK consumers (when contributions from land use changes for agriculture are included). Around half of these emissions are 'embedded' in imports. [3] Livestock products are particularly GHG intensive, with the Food and Agriculture Organization attributing 18% of total global GHG emissions to these (when contributions from land use and land use change are included).[4] Although emissions can be reduced by changing production methods, savings will not be sufficient to offset the effects of rising global demand, and radical departures from 'business as usual' trajectories will be needed to prevent global GHG emissions from livestock production rising unsustainably.[5,6] Even when food imports to the UK are ignored, failure to reduce domestic agricultural emissions will risk making the government's 2050 target for an 80% reduction in total UK-based GHG emissions 'unattainable'.[7] Considering only the final product, the UK has approximately 50 to 90% self-sufficiency in production of different livestock (see web appendix). However the distribution of GHG emissions between the UK and overseas differs substantially from these figures due to major imports of cereals and soy for animal feed.

Here we estimate co-benefits to health and climate change mitigation if, in the UK, high consumers of red and processed meat were to adopt the diets of low consumers. We predict reduced incidence of coronary heart disease, diabetes mellitus and colorectal cancer.[8–10] Together, these diseases accounted for almost 12% of the total disease burden in the UK in 2004. [11]

Methods

Dietary measurements

Meat intakes have been estimated from the 2000/1 British National Diet and Nutrition Survey (NDNS), which collected 7 days of weighed dietary records from a sample of 1,724 respondents aged 19-64y.[12] As previous reports from this source had not separately identified the meat content of composite meat-containing dishes, we derived new estimates by systematically recoding the original records.[13] Meats were classified as (unprocessed) red, processed or white, and all foods were allocated to 1 of 45 food categories, designed to be relatively homogeneous in both their nutritional characteristics and in the GHG emissions arising from their supply (Table 1, which also includes the operational definitions of red, white and processed meat).

Intakes of each type of meat were adjusted for total energy intake (g/MJ). The NDNS sample was then split by sex, and stratified on the basis of average daily intakes of red plus processed meat (RPM). Self-declared vegetarians (2% of males, 7% of females) were allocated to their own stratum.[14] Remaining respondents were then ranked by average daily RPM intake and divided into fifths (F1 being lowest consumers, F5 highest). Mean RPM intakes for each of the resulting 6 sex-specific strata were standardised to the sex-specific mean energy intake in the total sample. To correct for classifying individuals on intakes recorded over just 7 days, habitual intakes were estimated for strata F1 to F5 using ratios of between-person to total variance in daily intakes. Mean energy-standardised intakes of all 45 food categories were then calculated for each stratum. Stratum F1 was taken to exemplify a 'climate-friendly' low RPM dietary pattern. Key food and nutrient intakes plus health, behavioural and socio-demographic variables across these strata are described elsewhere.[13]

Assignment of greenhouse gas emissions to food categories

Emissions (given in table 1) are expressed as kg of CO_2-equivalent (CO_2-e) GHG resulting from all steps involved in making a given weight of food available for human consumption. Published values determined by life cycle analyses were identified and used to estimate average emissions for each of the 45 food categories.[15,16] Because emissions vary with system and country of production, weighted averages were calculated for meats according to proportions imported or produced in the UK under various systems. In the absence of data, processed meats were ascribed the values of equivalent unprocessed meats. Values for similar foods were interpolated where data was lacking. For the residual 'miscellaneous' category, the mean of all non-meat, non-beverage categories was applied. (Further details in Web Appendix: Assumptions and methods used to estimate greenhouse gas emissions from producing foods for UK consumers.)

Specification of a counterfactual diet

A 'feasible alternative'[17] counterfactual distribution of diets was specified as one in which the proportions of vegetarians in each sex doubled and the remainder of the population adopted the average dietary pattern of F1. All else was assumed to remain equal. Calculations were based on data for persons aged 19-64y. Estimates for Britain in 2000/1 were assumed to be generalizable to the UK over the following decade to the present day.

Changes in meat-related disease risks with the counterfactual intakes

Risk relationships for red and processed meat intakes and coronary heart disease (CHD), diabetes mellitus and colorectal cancer were taken from published meta-analyses, described in Table 2.[8–10] The log of the relative risks was assumed to be linearly related to absolute intakes across the full range of exposures in the dataset, including the low (but not null) RPM intakes reported by self-declared vegetarians. Stratum-specific relative risks were used to estimate proportional changes in aggregated population risks. These 'potential impact fractions' (PIF) were estimated separately for each sex, using the following equation:[18]

$$\text{PIF} = \frac{\text{current aggregate risk} - \text{aggregate risk under counterfactual}}{\text{current aggregate risk}}$$

$$= \frac{\sum p_{1i}RR_i - \sum p_{2i}RR_i}{\sum p_{1i}RR_i}$$

Where p refers to the proportion of the population in a given stratum; i identifies the stratum, and 1 and 2 identify the current and counterfactual intakes respectively. An overall PIF for each disease was calculated as the simple average of the values for males and females. Effects of reduced intakes of red and processed meat on colorectal cancer risk were assumed to be independent so that, for a given disease, the combined effect of both changes was estimated as: $((1\text{-PIF}_1) \times (1\text{-PIF}_2))$. This proportional change was then applied to WHO estimates for disease burdens in the UK for 2004.[11]

Proportional risk reductions were also estimated for the hypothetical scenario of reducing RPM from the mean level for F5 to a sustained intake at the mean for F1.

Estimation of GHG emissions

Diet-attributable GHG emissions were estimated for each stratum by multiplying mean intakes of each of the 45 food categories by their average emission value (Table 1), and summing resulting values. Estimated habitual intakes were used for red and processed meats, however as the proportional changes to other food categories (after adjustment of meat intakes from measured to estimated habitual) were negligible (less than 3%), values derived from reported intakes were used for these. Resulting dietary emissions estimates were energy-adjusted using the mean energy intake in the stratum, and standardised to the mean sex-specific energy intake in the overall sample.

Diet-attributable GHG emissions under the counterfactual were calculated for each sex as weighted means of strata V and F1 (proportions in V doubling and F1 intake applied to all non-vegetarians). The overall value was calculated as the simple average of means for each sex. The difference between counterfactual and current emissions values gave the expected average reduction in emissions from the specified changes in measured dietary *intakes* at 19-64y. These were then adjusted for average energy requirements in the total population relative to the study sample (which was restricted to ages 19 to 64). This adjustment factor was estimated at 0·93.[19] Finally, the change in emissions based on measured intakes was rescaled to the level of the food supply supporting the measured intakes. This was based on the FAO Food Balance Sheet estimates, which give total meat available for consumption in Britain as 219 g/person/d, compared with the measured intakes of 104 g/person/d. This ratio for meats was used as an estimate for inflation of total dietary GHG emissions, although it is accepted that wastage varies between food groups. No attempt was made to model the effects of reducing waste.

Results

RPM intakes show marked heterogeneity across the British population, with habitual intakes around 2·5 times higher in the top (F5) than in the bottom (F1) fifth of non-vegetarians. Under our counterfactual, 4·7% of males and 12·3% of females were vegetarian and the remainder adopted the sex-specific dietary pattern of F1. Average RPM intakes were reduced from 91 to 53 g/d in males and from 54 to 30 g/d in females (42% and 44% reductions respectively), as shown in Figure 1.

Changes in disease risks

Assuming epidemiologically observed risk associations are causal and independent, risk reductions for the 3 diseases of interest would range from 3·2 to 12·1% under the counterfactual scenario (see Table 3). Benefits would be greatest in those with the highest current intakes (F5; see Table 4).

Changes in greenhouse gas emissions

Total daily GHG emissions attributable to measured dietary intakes were estimated at 4·58 kg CO_2-e in males and 3·34 kg CO_2-e in females (unweighted mean 3·96 kg CO_2-e). The sex difference disappeared when emissions were expressed per MJ of dietary energy (0·47 kg CO_2-e/MJ in males, 0·49 kg CO_2-e/MJ in females). Red meat intake accounted for 31% of dietary CO_2-e emissions in males and 27% in females, with processed meat accounting for an additional 10% and 8% in males and females respectively.

CO_2-e emissions attributable to diet are shown for each stratum in Figure 2. Emissions for males increased by one third from F1 to F5 and for females by one quarter. Emissions attributable to dietary constituents other than red and processed meat were relatively constant across strata.

Diet-related emissions, calculated on the basis of intakes, were reduced by 0·47 kg CO_2-e/person/d (or 12%) to 3·96 kg CO_2-e/person/d in males and 3·02 kg CO_2-e/person/d in females. Scaling this estimate up to the food supplies supporting these intakes increases the expected reduction to 1·23 kg CO_2-e/person/d or 0·45 tonnes/person/y. For the 2009 UK population of 61,792,000 this amounts to a total GHG reduction of 27·8 m tonnes/y.

Discussion

We have identified a low red and processed meat dietary pattern that is already followed by a substantial fraction of the UK population, and estimated health and environmental benefits that would result from its general adoption. This is a deliberately heuristic exercise, intended to inform policy over the decadal timeframes familiar in climate change deliberations.

We estimate that sustained dietary intakes at our counterfactual levels would materially reduce incidence of coronary heart disease, diabetes mellitus and colorectal cancer. These estimates are approximate, and our method of calculation could not allow for confounding on the outcome.[20] Although the dietary intake data used here was collected 10 years ago, the headline results from a more recent NDNS (fieldwork carried out 2008/9) reveal that intakes of all meat categories were broadly similar although slightly higher than in 2000/1.[21] This indicates that our estimates remain relevant and may even be conservative, and highlights the need for action to prevent further increases in intake in the UK population. We have not considered beneficial effects from compensatory increases in other dietary components, especially fruit and vegetables and dietary fibre. Other assessments of the health effects of broadly similar dietary changes have found these beneficial effects to be of even greater magnitude that the reductions in harms.[22] We only considered a limited range of diseases: the incidence of stroke and a wider range of cancers could also be expected to decline.[23]

We use meta-analyses of a limited number of reports of the association between intakes of different types of meat and the risks of vascular disease and diabetes, rather than simply regarding meat as a vehicle for dietary fats and assuming all associated risks to be mediated via effects on blood lipids. [23] This food-based approach to assessing the health effects of meat is supported by the failure of epidemiological studies to confirm expected associations between intakes of unprocessed red meat and risk of coronary heart disease, by the differing patterns of epidemiological association with unprocessed and processed red meat, and by the evidence that red and processed meat intakes are associated with other vascular risk factors, notably blood pressure.[24,25]

Using 2004 Global Burden of Disease estimates for the UK[26] and assuming effects on incidence-based disease burdens are proportional to effects on incidence, the reduction in health losses under the counterfactual would be 50,960 disability-adjusted life years (DALYs) per year for ischemic heart disease, 5,421 DALYs per year for diabetes and 13,761 DALYs per year for colorectal cancer. If effects on these diseases were independent of each other, total reduction in DALYs would be 70,142/y, equivalent to almost 1% of health losses from all causes in the UK in 2004.

The predicted reduction in GHG emissions would equate to a total saving in UK food and drink associated emissions of 27·8 million tonnes CO_2-e/y across the 2009 UK population. To put this into context, the UK GHG 'footprint' has been estimated (using production-based accounts) at 10·16 tonnes CO_2-e/person/y.[27,28] Total emissions attributable to UK consumers will exceed this by perhaps 30 to 40% due to large net imports of embedded GHG.[29] This implies that *consumption*-based emissions are over 14 tonnes CO_2-e/person/y. Emissions reductions under the counterfactual therefore represent a saving of over 3% of this figure, a worthwhile amount given that addressing climate change mitigation is going to require the adding up of contributions from diverse sources.

We found that around one-quarter of the UK population had habitual intakes of red and processed meat below 55 g/d and 27g/d for men and women respectively, representing around two-thirds (62%) and one-half (51%) of their sex-specific means. Examination of the rest of the diet revealed that some, but far from all, of this reduction was offset by increased white meat intake, and remaining dietary substitution for RPM came from a wide variety of other sources.[10] When considering both health and environmental effects of reducing RPM consumption, substitute foods are important, and clear advice should be given regarding these in order that benefits are maximised.

Intakes of RPM are socially patterned, especially in females. Forty-five percent of low (F1) but only 29% of high (F5) RPM strata for females, were in social class I or II and 41% versus 19% had formal education beyond A level.[12] Given that inequalities in health outcomes are produced by inequalities in health determinants, a downward convergence of RPM intakes would yield a third benefit: a reduction in health inequalities. This is illustrated by the large potential risk reductions available to high consumers were they to converge down to the intakes of the low consumers.

Dietary recommendations should no longer be based on direct health effects alone. Whilst the UK Government has acknowledged the environmental impact of livestock production and is taking action with the industry to improve efficiency, [30] changes in production will be insufficient alone to meet challenging emission reduction targets. Joint producer and consumer responsibility is needed, supported by the use of both production- and consumption-based GHG accounts. Averting dangerous climate change will require multiple changes at all levels of society, and the potential contribution of reduced red and processed meat consumption should be addressed.

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Table 1: Greenhouse gas emissions, expressed as CO_2-equivalents/kg food produced for consumption in the UK*

	Food Category	GHG emissions (kg CO_2-e/kg)	Inclusions/Notes	Source
	Unprocessed Meat			
1	Beef	30·00		DEFRA[15]
2	Lamb	50·00		DEFRA[15]
3	Pork	10·00		DEFRA[15]
4	Other red meat [i]	30·00	Venison, Goat	Mean beef/pork/lamb
5	White meat [ii]	4·00	Chicken, turkey, game birds	DEFRA[15]
6	Other birds	5·32	Duck, goose	DEFRA[15]
	Processed Meat [iii]			
7	Processed beef	30·00		= beef
8	Processed pork	10·00	Sausagemeat, bacon, ham	= pork
9	Processed white meat	4·00		= white meat
	Fish			
10	Fresh fish/shellfish	2·60		Wallen et al[16]
11	Frozen fish	6·50		Wallen et al[16]
	Dairy/Eggs			
12	Milk	1·30	Yoghurt, cream, custard	DEFRA[15]
13	Cheese	9·80		Wallen et al[16]
14	Ice cream	0·64		Wallen et al[16]
15	Egg	3·00		DEFRA[15]
	Starchy Staples			
16	Bread	0·73		DEFRA[15]
17	Breakfast cereal	1·00		Wallen et al[16]
18	Pasta	0·81		Wallen et al[16]
19	Rice	1·68		Wallen et al[16]
20	Unprocessed potato	0·16		DEFRA[15]
21	Frozen potato	0·57		Wallen et al[16]
22	Other potato products	2·37		Wallen et al[16]
23	Flour/other grains	1·00		Wallen et al[16]
	Fruit & Vegetables			
24	Vegetables (1)	0·50	Roots, onions, brassicas	Wallen et al[16]
25	Vegetables (2)	3·30	All other, including salad	Wallen et al[16]
26	Pulses	0·64	Dried/tinned	Wallen et al[16]
27	Tomato [g]	2·00	Including tinned	DEFRA[15]
28	Fruit	0·40	All	Wallen et al[16]
	Fats			
29	Butter	0·98		Wallen et al[16]
30	Margarine	2·12		Wallen et al[16]
31	Cooking oil	3·53		Wallen et al[16]
	Other			
32	Crispbread/biscuits	2·65		Wallen et al[16]
33	Buns/cakes	0·91		Wallen et al[16]
34	Chocolate/sweets	1·80		Wallen et al[16]
35	Sugar/honey/treacle	4·18		Wallen et al[16]
36	Jam/marmalade	0·81	Including chutneys	Wallen et al[16]
	Beverages			
37	Soft beverages	0·56		Wallen et al[16]
38	Mineral water	0·56		= soft beverages
39	Alcoholic beverages	0·56		= soft beverages
40	Fruit juice/syrup	0·99	Including cordials	Wallen et al[16]
41	Coffee	33·00		DEFRA[15]
42	Tea	4·10	Including herbal tea	DEFRA[15]
43	Cocoa	210·00	Including hot chocolate	DEFRA[15]
44	Tap water	0·00	Including that in foods	No data
45	**Miscellaneous**	1·85	All other	Mean of all

* Emission estimates are preferentially based on life cycle analyses. Where emissions vary by production system within and beyond the UK, values are averages weighted on contributions to the UK food supply.

Further details in Web Appendix: Assumptions and methods used in the derivation of greenhouse gas emissions from food produced for UK consumers.

The following definitions were used, consistent those used in the meta-analyses of intake-risk associations:
[i] ***Red meat*** as beef, veal, pork, lamb, mutton and goat, either fresh, minced (including hamburgers) or frozen, but unprocessed other than by cooking with heat. Although processed meats were primarily red meats, the term 'red meat' has been used in this report to refer to 'unprocessed red meat', unless otherwise specified.
[ii] ***White meat*** as meat from poultry, fresh, minced or frozen, but unprocessed other than by cooking with heat.
[iii]***Processed meat*** as meat preserved by smoking, curing, salting or addition of nitrates, nitrites or other preservatives. Under this definition, processed meats were primarily red, but included white meats, and included ham, bacon, pastrami, salami, sausages and processed deli or luncheon meats.

Table 2: Relative risks of incident coronary heart disease, diabetes mellitus and colorectal cancer for differences of 100 g/d usual intakes of red and 50 g/d of usual intakes of processed meat from two meta-analyses

Exposure	Disease	Relative Risk (95% CI)	Meta-analysis	Comments
Red meat* (RR per 100 g/d)	Coronary heart disease	1·00 (0·81, 1·23)	Micha et al[10]	Based on 4 estimates; most controlled for total energy intake. No between-study heterogeneity or publication bias was evident. The range of exposures across all included studies (means in lowest/highest categories) was 15.7–118.6 g/d.
	Diabetes mellitus	1·16 (0·92, 1·46)	Micha et al[10]	Based on 5 estimates; most controlled for total energy intake. No between-study heterogeneity or publication bias was evident. The range of exposures across all included studies (means in lowest/highest categories) was 15.7–118.6 g/d.
	Colorectal cancer	1·17 (1·05, 1·31)	WCRF/AICR[9]	Based on 8 cohort studies; most controlled for total energy intake. There was no evidence of heterogeneity was present and a random-effects model was used. There were insufficient studies to check for publication bias. Intakes per category spanned the range 1 – >200g/d.
Processed meat* (RR per 50 g/d)	Coronary heart disease	1·42 (1·07, 1·89)	Micha et al[10]	Based on 6 estimates; most controlled for total energy intake. Between-study heterogeneity and publication bias were evident; sensitivity analysis did not significantly change the outcome, and a random-effects model was used. The range of exposures across all included studies (means in lowest/highest categories) was 2.9 – 40.7 g/d.
	Diabetes mellitus	1·19 (1·11, 1·27)	Micha et al[10]	Based on 6 estimates; most controlled for total dietary energy. Some heterogeneity was evident, but publication bias was not; sensitivity analysis did not significantly change the outcome, and a random-effects model was used. The range of exposures across all studies (means in lowest/highest categories) was 2.9 – 40.7 g/d.
	Colorectal cancer	1·18 (1·10, 1·28)	WCRF/AICR[9]	Based on 9 cohort studies; most controlled for total energy intake. Low heterogeneity was present and a random-effects model was used. Publication bias was not evident. Intakes per category spanned the range 1 – >100 g/d.

* For definitions see text

Table 3: Predicted reductions (%) in population risks of coronary heart disease, diabetes and colorectal cancer from sustained exposure at counterfactual intakes of red and processed meat and both (assuming independence of effects)

	Red meat		Processed meat		Red plus processed meat	
	% risk change	(95% CI*)	% risk change	(95% CI*)	% risk change	(95% CI*)
Coronary heart disease						
Males	NS	-	-9·6	(-1·8, -18·0)	N/A	-
Females	NS	-	-6·4	(-1·2, -11·8)	N/A	-
Diabetes mellitus						
Males	NS	-	-4·6	(-2·8, -7·3)	N/A	-
Females	NS	-	-3·2	(-1·9, -4·7)	N/A	-
Colorectal cancer						
Males	-7·9	(-2·4, -13·5)	-4·5	(-2·4, -7·2)	-12·1	(-6·4, -17·8)
Females	-4·8	(-1·4, -8·3)	-3·0	(-1·6, -4·7)	-7·7	(-4·0, -11·3)

* Estimated by Monte Carlo simulation, using @Risk software (Palisade, New York)

NS=Non-significant; N/A=Not applicable (as for processed meat)

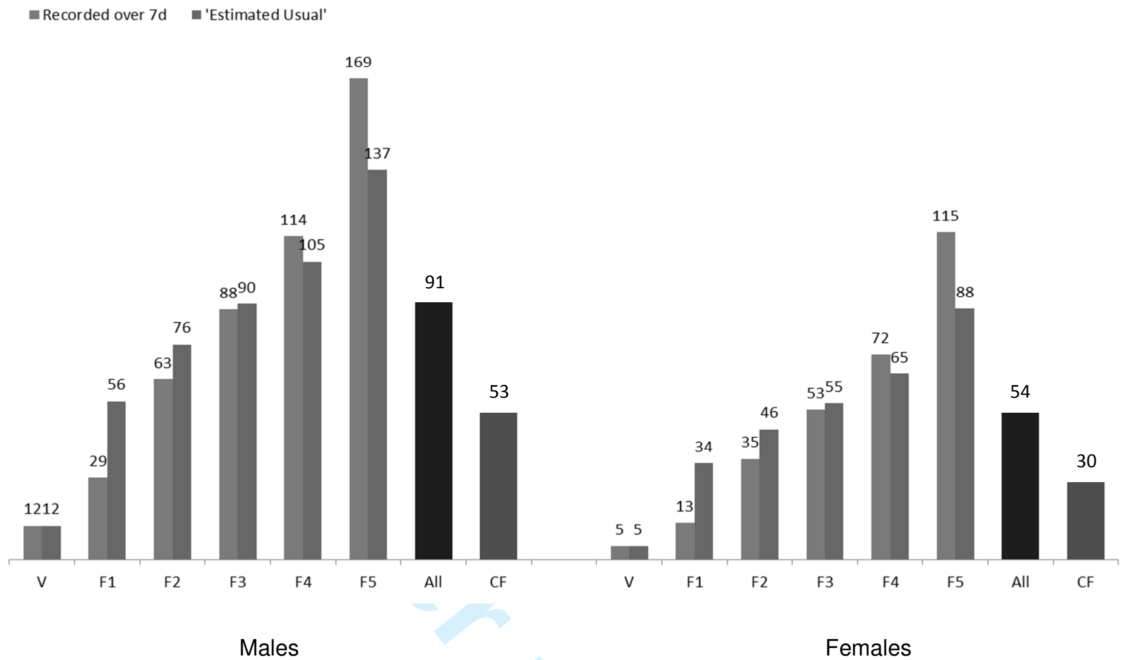
Table 4: Predicted reductions (%) in risks of coronary heart disease, diabetes and colorectal cancer for persons with usual intakes at the mean levels for F5 had they had sustained exposure at usual intakes for F1 of red and processed meat and both (assuming independence of effects)

	Red meat		Processed meat		Red plus processed meat	
	% risk change	(95% CI*)	% risk change	(95% CI*)	% risk change	(95% CI*)
Coronary heart disease						
Males	NS	-	-20·2	(-4·1, -35·3)	N/A	-
Females	NS	-	-11·0	(-2·2, -20·0)	N/A	-
Diabetes mellitus						
Males	NS	-	-10·5	(-6·4, -15·7)	N/A	-
Females	NS	-	-5·7	(-3·3, -8·4)	N/A	-
Colorectal cancer						
Males	-15·5	(-4·9, -25·6)	-10·3	(-5·5, -15·5)	-24·2	(-13·6, -34·1)
Females	-11·3	(-3·4, -19·0)	-5·4	(-2·8, -8·4)	-16·1	(-8·4, -23·7)

* Estimated by Monte Carlo simulation, using @Risk software (Palisade, New York)

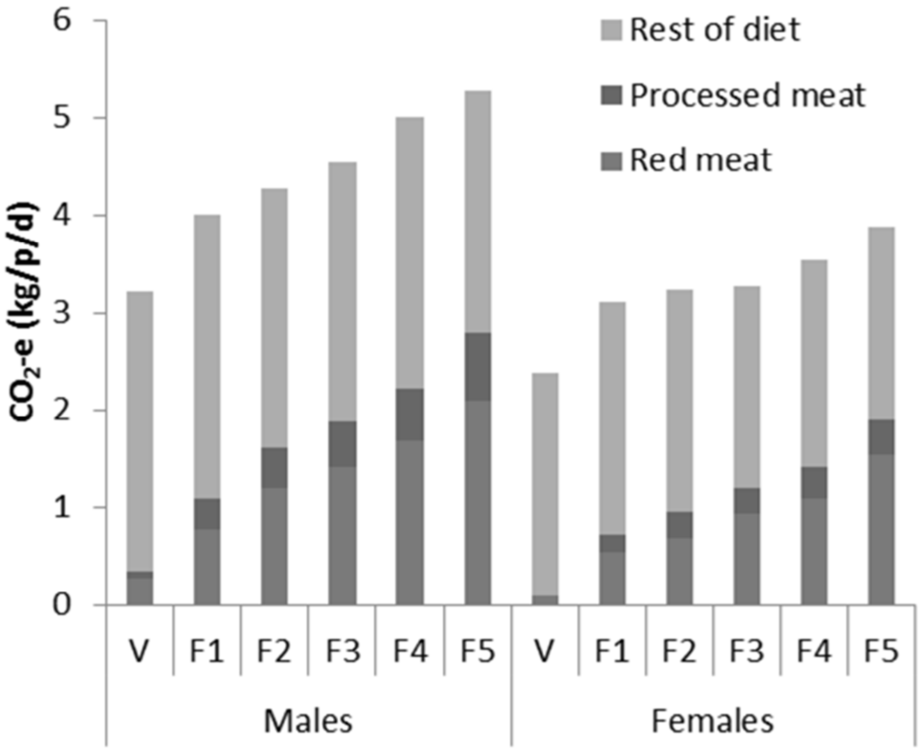
NS=Non-significant; N/A=Not applicable (as for processed meat)

Figure 1: Reported and estimated habitual intakes of red plus processed meat across strata based on energy-adjusted red and processed meat intake (mean and 95% confidence interval). Intakes in mean g/d following energy-adjustment and standardisation to sex-specific mean total reported energy intake. Overall factual and counterfactual (CF) mean intakes are also shown.



V=Vegetarian; F1-5= Fifths of energy-adjusted red + processed meat intake (F1=lowest intake); CF=counterfactual

Figure 2: Diet-related standardised energy-adjusted CO_2-e emissions according to dietary component across sex-specific categories of energy-adjusted red plus processed meat intake (based on estimated habitual intake of red and processed meats)



V=Vegetarian; F1-5=Fifths of energy-adjusted red plus processed meat intake (F1=lowest intake)

Web Appendix: Assumptions and methods used to estimate greenhouse gas emissions from producing foods for UK consumers

Beef

Values for beef varied 4-fold according to the production system, with the value for Brazilian beef reflecting transport emissions. Values from DEFRA[i] were as follows:

UK Intensive Dairy	10 kg CO_2-e/kg hung carcass
UK Extensive Suckler	30 kg CO_2-e/kg hung carcass
UK Organic Suckler	32 kg CO_2-e/kg hung carcass
Brazil Suckler	40 kg CO_2-e/kg hung carcass

The UK has 80% self sufficiency in beef production,[ii] with equal quantities of UK beef coming from dairy and suckler herds.[iii,iv] Consumption of organic beef is negligible, at around 1%.[v] This was therefore ignored, particularly since emissions were similar to those for suckler cattle. 65% of beef imports to the UK come from Ireland and other EU countries, which were assumed to have the UK average value of 20 kg CO_2-e/kg hung carcass. A further 21% of UK beef comes from South America, for which the Brazil value was assumed, and the final 14% from 'other' countries, for which the average of UK and Brazilian beef was assumed (30 kg CO_2-e/kg hung carcass). 1 kg of hung carcass produces 0.7 kg bone-free meat.[vi] According to this information, a weighted average CO_2-e value was calculated to be 30 kg CO_2-e/kg, using the following equation:

$$((0.40 \times 10) + (0.40 \times 30) + (0.13 \times 20) + (0.042 \times 40) + (0.028 \times 30)) / 0.7 = 30 \text{ kg } CO_2\text{-e/kg}$$

Lamb

Values for UK-consumed lamb were obtained from DEFRA,[i] as follows:

UK Intensive Lowland	28 kg CO_2-e/kg hung carcass
UK Extensive Upland	39 kg CO_2-e/kg hung carcass
UK Organic Lowland	27 kg CO_2-e/kg hung carcass
New Zealand	33 kg CO_2-e/kg hung carcass

The UK is 85% self-sufficient in lamb production,[iv] with around 70% of this being upland lamb and the remaining 30% lowland.[iii] As for beef, organic was assumed to be negligible. 90% of UK imports originate from New Zealand, Australia or South America, for which the New Zealand value was assumed. The remaining 10% originate from Ireland or other EU countries, for which the UK average of 36 kg CO_2-e/kg was assumed. 1 kg of hung carcass produces 0.7 kg bone-free meat (personal communication with EBLEX). A weighted average value for lamb was therefore calculated to be 50 kg CO_2-e/kg:

$$((0.60 \times 39) + (0.25 \times 28) + (0.135 \times 33) + (0.015 \times 36)) / 0.7 = 50 \text{ kg } CO_2\text{-e/kg}$$

Pork

GHG emissions from pork produced under different systems were obtained from DEFRA:[i]

UK Intensive Indoor	5.5 kg CO_2-e/kg hung carcass
UK Extensive Outdoor	8.9 kg CO_2-e/kg hung carcass
UK Organic Outdoor	9.9 kg CO_2-e/kg hung carcass

The UK is 47% self-sufficient in pork production, with 70% being indoor reared.[vii] As above, organic production was assumed as negligible. Imports to the UK come entirely from the EU. This production was assumed to be intensive and the figure for UK intensive production was adopted and rounded to 6 to allow a small amount for road transport. 1 kg hung pork carcass produces 0.6 kg bone-free meat.[vi] A weighted average for pork was calculated as 10 kg CO_2-e/kg: $((0.33 \times 5.5) + (0.14 \times 8.9) + (0.53 \times 6)) / 0.6 = 10$ kg CO_2-e/kg

Chicken

Values for chicken were obtained from DEFRA:[i]

UK Intensive Indoor	3.1 kg CO_2-e/kg hung carcass
UK Extensive Outdoor	3.7 kg CO_2-e/kg hung carcass
UK Organic Outdoor	4.1 kg CO_2-e/kg hung carcass

The UK is 90% self sufficient in chicken production, with 20% being outdoor or organically reared.[viii] As the value for organic production was close to that for outdoor, the value for outdoor was used for both. Imports to the UK are mainly from the EU, Brazil and Thailand, with much being shipped frozen from the non-EU countries. The UK intensive value was rounded to 3.5 to reflect road and ship transport. 1 kg hung carcass produces 0.77 kg bone-free meat.[vi] A weighted average was calculated as 4 kg CO_2-e/kg:

$$((0.72 \times 3.1) + (0.18 \times 3.7) + (0.10 \times 3.5)) / 0.77 = 4 \text{ kg } CO_2\text{-e/kg}$$

This value was also applied to turkey, for which no data existed, and to game birds such as pheasant and quail.

Duck

The same edible proportion was assumed as for chicken (0.77 kg/kg hung carcass). Therefore, the GHG emissions per kg edible portion was calculated as 5.32 kg CO_2-e/kg from the DEFRA[i] figure for hung carcass: $4.1 / 0.77 = 5.32$ kg CO_2-e/kg. This figure was also applied to goose.

Egg

The DEFRA[i] value for a dozen eggs was 1.8 kg CO_2-e. The shell-free weight of 1 average egg is 50 g, therefore 12 eggs weigh 0.6 kg, and the value for 1 kg egg was calculated as 3.0 kg CO_2-e/kg.

Tomato

The following values for tomatoes were given by DEFRA:[i]

Oil heated UK	2.3 kg CO_2-e/kg
Waste heated UK	0.39 kg CO_2-e/kg
Spanish	1.8 kg CO_2-e/kg

The average of oil-heated UK and Spanish was calculated, then lowered slightly to represent a small proportion from waste heated production, to give a value of 2 kg CO_2-e/kg.

Mineral water and alcoholic beverages

In the absence of any data, the value for soft beverages was applied on the assumption that much of the impact would be due to bottling, packaging and transport, common to all of these.

Miscellaneous

In the absence of any data or knowledge of food group, the average of all non-meat foods (excluding beverages) was calculated as 1.85 kg CO_2-e/kg and applied to the proportion of foods classified as miscellaneous due to lack of information about the food or the GHG emissions.

[i] Department for Environment Food and Rural Affairs. Scenario building to test and inform the development of a BSI method for assessing GHG emissions from food. Research project final report FO0404. London: DEFRA; 2009.
[ii] House of Commons. Note SN/SC-01363. 2009.
[iii] EBLEX. Change in the air: The English beef and sheep production roadmap. Kenilworth: EBLEX; 2009.
[iv] Spedding A. RuSource Briefing 814: Feeding Britain - beef and sheep meat. London: Arthur Rank Centre; 2009.
[v] Red Meat Industry Forum. Introduction to beef production in UK. RMIF; 2007.
[vi] Cederberg C, Meyer D, Flysjo A. Life cycle inventory of greenhouse gas emissions and use of land and energy in Brazilian beef production. Sweden: SIK; 2009.
[vii] Spedding A. RuSource Briefing 815: Feeding Britain - pig meat. London; 2009.
[viii] Spedding A. RuSource Briefing 650: Poultry production. London: Arthur Rank Centre; 2008.

Impact of a reduced red and processed meat dietary pattern on disease risks and greenhouse gas emissions in the UK: A modelling study

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Impact of a reduced red and processed meat dietary pattern on disease risks and greenhouse gas emissions in the UK: A modeling study

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Article Summary

Article focus

- Consumption of red and processed meat is a leading contributor to greenhouse gas emissions
- High intakes of red and processed meats increase the risks of several leading chronic diseases
- This research identifies a low red and processed meat dietary pattern that is already followed by a substantial fraction of the UK population and estimates health and environmental benefits that would result from its general adoption

Key messages

- Habitual red and processed meat intakes are 2.5 times higher in the top compared with the bottom fifth of UK consumers
- Sustained dietary intakes at a counterfactual reduced level in the UK population would materially reduce incidence of coronary heart disease, diabetes mellitus and colorectal cancer, by 3-12%
- The predicted reduction in UK food and drink associated greenhouse gas emissions would equate to almost 28 million tonnes of CO_2 equivalent per year across the population

Strengths and limitations of the study

- This research uses a food-based approach, taking intake-risk associations from meta-analyses rather than assuming the mechanisms via which the foods influence disease risk
- The dietary data was collected a decade ago, however the headline results from a more recent national dietary survey reveal that intakes of all meat categories were broadly similar although slightly higher in 2008/9 than in 2000/1

Abstract

Objectives Consumption of red and processed meat (RPM) is a leading contributor to greenhouse gas (GHG) emissions and high intakes of these foods increase the risks of several leading chronic diseases. The aim was to use newly-derived estimates of habitual meat intakes in UK adults to assess potential co-benefits to health and the climate from reduced RPM consumption.

Design Modelling study using dietary intake data from the National Diet and Nutrition Survey of British Adults.

Setting British general population

Methods Respondents were divided into fifths by energy-adjusted RPM intakes, with vegetarians constituting a sixth stratum. GHG emitted in supplying the diets of each stratum were estimated using data from life cycle analyses. A feasible counterfactual UK population was specified, in which the proportion of vegetarians measured in the survey population doubled, and the remainder adopted the dietary pattern of the lowest fifth of RPM consumers.

Outcome measures Reductions in risks of coronary heart disease, diabetes and colorectal cancer and GHG emissions under the counterfactual.

Results Habitual RPM intakes were 2·5 times higher in the top compared with the bottom fifth of consumers. Under the counterfactual, statistically significant reductions in population aggregate risks ranged from 3·2% (95% CI 1·9, 4·7) for diabetes in females to 12·2% (6·4, 18·0) for colorectal cancer in males, with those moving from the highest to low consumption levels gaining about twice these averages. The expected reduction in GHG emissions was 0·45 tonnes CO_2-equivalent/person/year, about 3% of the current total, giving a reduction across the UK population of 27·8 million tonnes/year.

Conclusions Reduced consumption of RPM would bring multiple benefits to health and the environment.

Introduction

Climate change is 'the biggest global health threat of the 21st century'[1] and appropriately chosen mitigation policies could 'bring significant immediate co-benefits for population health and well-being'.[2]

Food and drink account for around one-third of total greenhouse gas (GHG) emissions attributable to UK consumers (when contributions from land use changes for agriculture are included). Around half of these emissions are 'embedded' in imports.[3] Livestock products are particularly GHG intensive, with the Food and Agriculture Organization attributing 18% of total global GHG emissions to these (when contributions from land use and land use change are included).[4] Although emissions can be reduced by changing production methods, savings achieved will not be sufficient to offset the effects of rising global demand, and radical departures from 'business as usual' trajectories will be needed to prevent global GHG emissions from livestock production rising unsustainably.[5,6] Even when food imports to the UK are ignored, failure to reduce domestic agricultural emissions will risk making the government's 2050 target for an 80% reduction in total UK-based GHG emissions 'unattainable'.[7] Considering only the final food products, the UK is approximately 50 to 90% self-sufficient in livestock production (see web appendix). However, total GHG emissions arising from the full life cycles of livestock food products are much bigger because of the overseas emissions associated with the large quantity of cereals and soy imported to feed animals raised in the UK.

Recent large meta-analyses[8–10] have found significant increases in risk of coronary heart disease, type 2 diabetes and colorectal cancer with increased intake of processed meat (increases of 42%, 19% and 18% respectively per 50g increase per day). A significant increase in colorectal cancer risk has also been shown with increased intake of red meat (17% per 100g increase per day).

Here we estimate co-benefits to health and climate change mitigation if, in the UK, high consumers of red and processed meat were to adopt the dietary patterns of current low consumers. We estimate GHG emissions reductions using published life-cycle analyses of different foods, and predict health benefits using published associations of red and processed meat intakes with incidence of coronary heart disease, diabetes mellitus and colorectal cancer from recent meta-analyses. Together, these diseases accounted for almost 12% of the total disease burden in the UK in 2004. [11]

Methods

Dietary measurements

Meat intakes have been estimated from the 2000/1 British National Diet and Nutrition Survey (NDNS), which collected 7 days of weighed dietary records from a sample of 1,724 respondents aged 19-64y.[12] As previous reports from this source had not separately identified the meat content of composite meat-containing dishes, we derived new estimates by systematically recoding the original records. [13] Meats were classified as (unprocessed) red, processed or white, and all foods were allocated to 1 of 45 food categories, designed to be relatively homogeneous in both their nutritional characteristics and in the GHG emissions arising from their supply (Table 1, which also includes the operational definitions of red, white and processed meat).

Intakes of each type of meat were adjusted for total energy intake (g/MJ). The NDNS sample was then split by sex, and stratified on the basis of average daily intakes of red plus processed meat (RPM). Self-declared vegetarians (2.3% of males, 6.2% of females) were allocated to their own stratum. [14] Remaining respondents were then ranked by average daily RPM intake and divided into fifths (F1 being lowest consumers, F5 highest). Mean RPM intakes for each of the resulting 6 sex-specific strata were standardised to the sex-specific mean energy intake in the total sample.

[COMMENT TO REVIEWER: Although it is common practice to refer to fractions of the distribution lying between quintiles as 'quintiles' this is in our view technically incorrect, hence we maintain our use of 'fifths']

Among non-vegetarians, marked within-person variability existed in daily intakes of RPM over the 7-day recording period. As a consequence, the differences between strata created on the basis of just 7 days of observation were substantially greater than the differences that would have resulted had it been possible to create strata using information on each individual's usual (long-term average) intake. A method for correcting this inflation of between stratum differences has been described elsewhere.[13] In brief, sex-specific ratios of between- and within-person variances for energy-adjusted RPM intakes (g/MJ) were used to derive sex-specific correction factors according to the following equation:

$$\frac{s^2_{between}}{s^2_{between} + \frac{s^2_{within}}{7}}$$

These correction factors (0.622 in males and 0.542 in females) were used to 'shrink' the differences between each stratum's initial estimated mean and the sex specific grand mean in order to estimate expected mean *usual* intakes for each stratum – as though they had been created on the basis of usual intakes rather than intakes observed over just 7 days. For self-reported vegetarians, recorded intakes of RPM (which were not all null) were taken as the best estimates of usual intakes.

Mean energy-standardised intakes of all 45 food categories were then calculated for each stratum. Stratum F1 was taken to exemplify a 'climate-friendly' low RPM dietary pattern. Key food and nutrient intakes plus health, behavioural and socio-demographic variables across these strata are described elsewhere.[13]

Assignment of greenhouse gas emissions to food categories

Emissions (given in table 1) are expressed as kg of CO_2-equivalent (CO_2-e) GHG resulting from all steps involved in making a given weight of food available for human consumption. Published values determined by life cycle analyses were identified and used to estimate average emissions for each of the 45 food categories.[15,16] Because emissions vary with system and country of production, weighted averages were calculated for meats according to proportions imported or produced in the UK under various systems. In the absence of data, processed meats were ascribed the values of equivalent unprocessed meats. Values for similar foods were interpolated where data was lacking. For the residual 'miscellaneous' category, the mean of all non-meat, non-beverage categories was applied (further details in Web Appendix).

Specification of a counterfactual diet

A 'feasible alternative'[17] counterfactual distribution of diets was specified as one in which the proportions of vegetarians in each sex doubled and the remainder of the population adopted the average dietary pattern of F1. All else was assumed to remain equal. Calculations were based on data for persons aged 19-64y. Estimates for Britain in 2000/1 were assumed to be generalizable to the UK over the following decade to the present day.

Changes in meat-related disease risks with the counterfactual intakes

Risk relationships for red and processed meat intakes and coronary heart disease (CHD), diabetes mellitus and colorectal cancer were taken from published meta-analyses, described in Table 2.[8–10] The log of the relative risks was assumed to be linearly related to absolute intakes across the full range of exposures in the dataset, including the low (but not null) RPM intakes reported by self-declared vegetarians. Stratum-specific relative risks were used to estimate proportional changes in aggregated population risks. These 'potential impact fractions' (PIF) were estimated separately for each sex, using the following equation:[18]

$$\text{PIF} = \frac{\text{current aggregate risk} - \text{aggregate risk under counterfactual}}{\text{current aggregate risk}}$$

$$= \frac{\sum p_{1i}`RR_i - \sum p_{2i}RR_i}{\sum p_{1i}RR_i}$$

Where p refers to the proportion of the population in a given stratum; i identifies the stratum, and 1 and 2 identify the current and counterfactual intakes respectively. An overall PIF for each disease was calculated as the simple average of the values for males and females. Effects of reduced intakes of red and processed meat on colorectal cancer risk were assumed to be independent so that, for a given disease, the combined effect of both changes was estimated as: $((1\text{-}PIF_1) \times (1\text{-}PIF_2))$. This proportional change was then applied to WHO estimates for disease burdens in the UK for 2004 to give a population aggregate risk reduction for the UK.[11] Proportional risk reductions were also estimated for the hypothetical scenario of reducing RPM from the mean level for F5 to a sustained intake at the mean for F1.

Estimation of GHG emissions

Diet-attributable GHG emissions were estimated for each stratum by multiplying mean intakes of each of the 45 food categories by their average emission value (Table 1), and summing resulting values. Estimated habitual intakes were used for red and processed meats, however as the proportional changes to other food categories (after adjustment of meat intakes from measured to estimated habitual) were negligible (less than 3%), values derived from reported intakes were used for these. Resulting dietary emissions estimates were energy-adjusted using the mean energy intake in the stratum, and standardised to the mean sex-specific energy intake in the overall sample.

Diet-attributable GHG emissions under the counterfactual were calculated for each sex as weighted means of strata V and F1 (proportions in V doubling and F1 intake applied to all non-vegetarians). The overall value was calculated as the simple average of means for each sex. The difference between counterfactual and current emissions values gave the expected average reduction in emissions from the specified changes in measured dietary *intakes* at 19-64y. These were then adjusted for average energy requirements in the total population relative to the study sample (which was restricted to ages 19 to 64). This adjustment factor was estimated at 0·93.[19] Finally, the change in emissions based on measured intakes was rescaled to the level of the food supply supporting the measured intakes. This was based on the FAO Food Balance Sheet estimates, which give total meat available for consumption in Britain as 219 g/person/d, compared with the measured intakes of 104 g/person/d. This ratio for meats was used as an estimate for inflation of total dietary GHG emissions, although it is accepted that wastage varies between food groups. No attempt was made to model the effects of reducing waste.

Results

RPM intakes show marked heterogeneity across the British population, with habitual intakes around 2·5 times higher in the top (F5) than in the bottom (F1) fifth of non-vegetarians. Under our counterfactual, 4·7% of males and 12·3% of females were vegetarian and the remainder adopted the sex-specific dietary pattern of F1. Average RPM intakes were reduced from 91 to 53 g/d in males and from 54 to 30 g/d in females (42% and 44% reductions respectively), as shown in Figure 1.

Changes in disease risks

Assuming epidemiologically observed risk associations are causal and independent, statistically significant risk reductions for the 3 diseases of interest would range from 3·2 to 12·2% under the counterfactual scenario (see Table 3). Benefits would be greatest in those with the highest current intakes (F5; see Table 4).

Changes in greenhouse gas emissions

Total daily GHG emissions attributable to measured dietary intakes were estimated at 4·58 kg CO_2-e in males and 3·34 kg CO_2-e in females (unweighted mean 3·96 kg CO_2-e). The sex difference disappeared when emissions were expressed per MJ of dietary energy (0·47 kg CO_2-e/MJ in males, 0·49 kg CO_2-e/MJ in females). Red meat intake accounted for 31% of dietary CO_2-e emissions in males and 27% in females, with processed meat accounting for an additional 10% and 8% in males and females respectively.

CO_2-e emissions attributable to diet are shown for each stratum in Figure 2. Emissions for males increased by one third from F1 to F5 and for females by one quarter. Emissions attributable to dietary constituents other than red and processed meat were relatively constant across strata.

Diet-related emissions, calculated on the basis of intakes, were reduced by 0·47 kg CO_2-e/person/d (or 12%) to 3·96 kg CO_2-e/person/d in males and 3·02 kg CO_2-e/person/d in females. Scaling this estimate up to the food supplies supporting these intakes increases the expected reduction to 1·23 kg CO_2-e/person/d or 0·45 tonnes/person/y. For the 2009 UK population of 61,792,000 this amounts to a total GHG reduction of 27·8 m tonnes/y.

Discussion

We have identified a low red and processed meat dietary pattern that is already followed by a substantial fraction of the UK population, and estimated the health and environmental benefits that would result from its general adoption. Although the dietary intake data used here was collected a decade ago, the headline results from a more recent NDNS (fieldwork carried out 2008/9) reveal that intakes of all meat categories were broadly similar although slightly higher than in 2000/1.[20] This indicates that our estimates remain relevant and may even be conservative, and highlights the need for action to prevent further increases in intake in the UK population.

We estimate that sustained dietary intakes at our counterfactual levels would materially reduce incidence of coronary heart disease, diabetes mellitus and colorectal cancer. Our method for calculating changes in population aggregate risks could not allow for confounding on the outcome.[21] Our point estimates for these reductions have associated uncertainties, which we have estimated using Monte Carlo simulation, although the relative risk estimates may still be more uncertain than we have assumed. Our estimates have been based on meta-analyses of a limited number of reports of the association between intakes of different types of meat and the chronic diseases of interest, and are therefore highly dependent on these results. A more recent meta-analysis indicates that our results may be conservative for diabetes.[22] This research, including over 440,000 individuals, found a similar but statistically significant increase in risk of type 2 diabetes with unprocessed red meat intake (RR 1.19 (95% CI 1.04 – 1.37) per 100g unprocessed red meat per day) but a far stronger association with processed meat than that used here (RR 1.51 (95% CI 1.25 – 1.83) per 50g processed meat per day). A recent update of the WCRF/AICR meta-analysis does not change the relative risk estimates given in that report and used in our analyses.[23]

Using meta-analyses of the association between intakes of different types of meat and the risks of vascular disease and diabetes, we have avoided simply regarding meat as a vehicle for dietary fats and assuming all associated risks to be mediated via effects on blood lipids.[24] This food-based approach to assessing the health effects of meat is supported by the failure of epidemiological studies to confirm expected associations between intakes of unprocessed red meat and risk of coronary heart disease, by the differing patterns of epidemiological association with unprocessed and processed red meat, and by the evidence that red and processed meat intakes are associated with other vascular risk factors, notably blood pressure.[25,26] Whilst we have only considered a limited range of diseases here, the incidence of stroke and a wider range of cancers could also be expected to decline.[27]

Using 2004 Global Burden of Disease estimates for the UK,[11] the reduction in health losses under the counterfactual would be 50,960 disability-adjusted life years (DALYs) per year for ischaemic heart disease, 5,421 DALYs per year for diabetes and 13,761 DALYs per year for colorectal cancer. If effects on these diseases were independent of each other, total reduction in DALYs would be 70,142/y, equivalent to almost 1% of health losses from all causes in the UK in 2004. These calculations are based on the assumptions that effects on incidence-based disease burdens are proportional to effects on incidence, and that the results based on the diets of 19-64 year olds are applicable to the over-65 population, where the majority of the disease burden lies.

The predicted reduction in GHG emissions would equate to a total saving in UK food and drink associated emissions of 27·8 million tonnes CO_2-e/y across the 2009 UK population. To put this into context, the UK GHG 'footprint' has been estimated (using production-based accounts) at 10·16 tonnes CO_2-e/person/y.[28,29] Total emissions attributable to UK consumers will exceed this by perhaps 30 to 40% due to large net imports of embedded GHG.[30] This implies that *consumption*-based emissions are over 14 tonnes CO_2-e/person/y. Emissions reductions under the counterfactual therefore represent a saving of over 3% of this figure, a worthwhile amount given that climate change mitigation is going to require contributions from diverse sources.

Recent work for the UK Committee on Climate Change (CCC) has modelled the reductions in GHG emissions both in the UK and overseas resulting from three specified dietary change scenarios.[7,31] Under a scenario in which UK intake of livestock products was reduced by 50% (with a two-thirds reduction in all meat and the deficit replaced with plant-based foods), the reduction in GHG emissions was estimated to be 15.0 million tonnes CO_2-e/y. In a second scenario, beef and sheep meat were replaced with pig and poultry, with no overall reduction in total meat intake, resulting in a reduction in GHG emissions of 6.3 million tonnes CO_2-e/y. The dietary changes in the CCC scenarios were more extreme than the counterfactual dietary pattern taken here, with either a greater total reduction in meat, or total elimination of beef and sheep meat. However, the GHG reductions estimated in this work were greater due to inflation to account for wasted food. Whilst we made no attempt to model the impact of a reduction in waste, this demonstrates the great potential to make GHG savings even without major dietary changes through reducing waste. This approach however would not bring co-benefits to health.

We found that around one-quarter of the UK population had habitual intakes of red and processed meat below 55 g/d and 27g/d for men and women respectively, representing around two-thirds (62%) and one-half (51%) of their sex-specific means. Examination of the rest of the diet revealed that some, but far from all, of this reduction was offset by increased white meat intake, and remaining dietary substitution for RPM came from a wide variety of other sources.[10] We have not considered beneficial effects from compensatory increases in other dietary components, especially fruit and vegetables and dietary fibre. Other assessments of the health effects of broadly similar dietary changes have found these beneficial effects to be of even greater magnitude than the reductions in harms.[24] Recent estimation of the health effects of the CCC dietary scenarios has found that the greatest health gains were achieved when meat was replaced by fruits and vegetables.[32] The influence of increases in these foods was far greater than health benefits attributable to reductions in salt consumption or changes in the fatty acid profile of the diets. When considering both the health and environmental effects of reducing RPM consumption therefore, substitute foods are important, and clear advice should be given regarding these in order that benefits are maximised.

Intakes of RPM are socially patterned, especially in females. Forty-five percent of low (F1) but only 29% of high (F5) RPM strata for females, were in social class I or II and 41% versus 19% had formal education beyond A level.[12] Although mainly outside the scope of this paper it may also be noted that inequalities in health outcomes are produced by inequalities in health determinants, so a downward convergence of RPM intakes would be expected to yield a third benefit: a reduction in health inequalities. This is illustrated by the large potential risk reductions available to high consumers were they to converge down to the intakes of the low consumers.

Climate change mitigation is a far-future benefit that may not directly affect those who must make lifestyle changes now. It is therefore unlikely to be a strong motivator for change. In contrast, health benefits provide near-term rewards to individuals for climate-friendly changes, and may thus 'nudge' humanity towards a sustainable future. Dietary recommendations should no longer be based on direct health effects alone. Whilst the UK Government has acknowledged the environmental impact of livestock production and is taking action with the industry to improve efficiency,[33] changes in production will be insufficient alone to meet challenging emission reduction targets. Joint producer and consumer responsibility is needed, supported by the use of both production- and consumption-based GHG accounts. Averting dangerous climate change will require multiple changes at all levels of society, and the potential contribution of reduced red and processed meat consumption should be addressed.

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Table 1: Greenhouse gas emissions, expressed as CO_2-equivalents/kg food produced for consumption in the UK*

	Food Category	GHG emissions (kg CO_2-e/kg)	Inclusions/Notes	Source
	Unprocessed Meat			
1	Beef	30·00		DEFRA[15]
2	Lamb	50·00		DEFRA[15]
3	Pork	10·00		DEFRA[15]
4	Other red meat [i]	30·00	Venison, Goat	Mean beef/pork/lamb
5	White meat [ii]	4·00	Chicken, turkey, game birds	DEFRA[15]
6	Other birds	5·32	Duck, goose	DEFRA[15]
	Processed Meat [iii]			
7	Processed beef	30·00		= beef
8	Processed pork	10·00	Sausagemeat, bacon, ham	= pork
9	Processed white meat	4·00		= white meat
	Fish			
10	Fresh fish/shellfish	2·60		Wallen et al[16]
11	Frozen fish	6·50		Wallen et al[16]
	Dairy/Eggs			
12	Milk	1·30	Yoghurt, cream, custard	DEFRA[15]
13	Cheese	9·80		Wallen et al[16]
14	Ice cream	0·64		Wallen et al[16]
15	Egg	3·00		DEFRA[15]
	Starchy Staples			
16	Bread	0·73		DEFRA[15]
17	Breakfast cereal	1·00		Wallen et al[16]
18	Pasta	0·81		Wallen et al[16]
19	Rice	1·68		Wallen et al[16]
20	Unprocessed potato	0·16		DEFRA[15]
21	Frozen potato	0·57		Wallen et al[16]
22	Other potato products	2·37		Wallen et al[16]
23	Flour/other grains	1·00		Wallen et al[16]
	Fruit & Vegetables			
24	Vegetables (1)	0·50	Roots, onions, brassicas	Wallen et al[16]
25	Vegetables (2)	3·30	All other, including salad	Wallen et al[16]
26	Pulses	0·64	Dried/tinned	Wallen et al[16]
27	Tomato [g]	2·00	Including tinned	DEFRA[15]
28	Fruit	0·40	All	Wallen et al[16]
	Fats			
29	Butter	0·98		Wallen et al[16]
30	Margarine	2·12		Wallen et al[16]
31	Cooking oil	3·53		Wallen et al[16]
	Other			
32	Crispbread/biscuits	2·65		Wallen et al[16]
33	Buns/cakes	0·91		Wallen et al[16]
34	Chocolate/sweets	1·80		Wallen et al[16]
35	Sugar/honey/treacle	4·18		Wallen et al[16]
36	Jam/marmalade	0·81	Including chutneys	Wallen et al[16]
	Beverages			
37	Soft beverages	0·56		Wallen et al[16]
38	Mineral water	0·56		= soft beverages
39	Alcoholic beverages	0·56		= soft beverages
40	Fruit juice/syrup	0·99	Including cordials	Wallen et al[16]
41	Coffee	33·00		DEFRA[15]
42	Tea	4·10	Including herbal tea	DEFRA[15]
43	Cocoa	210·00	Including hot chocolate	DEFRA[15]
44	Tap water	0·00	Including that in foods	No data
45	**Miscellaneous**	1·85	All other	Mean of all

* Emission estimates are preferentially based on life cycle analyses. Where emissions vary by production system within and beyond the UK, values are averages weighted on contributions to the UK food supply.

Further details in Web Appendix: Assumptions and methods used in the derivation of greenhouse gas emissions from food produced for UK consumers.

The following definitions were used, consistent those used in the meta-analyses of intake-risk associations:
[i] ***Red meat*** as beef, veal, pork, lamb, mutton and goat, either fresh, minced (including hamburgers) or frozen, but unprocessed other than by cooking with heat. Although processed meats were primarily red meats, the term 'red meat' has been used in this report to refer to 'unprocessed red meat', unless otherwise specified.
[ii] ***White meat*** as meat from poultry, fresh, minced or frozen, but unprocessed other than by cooking with heat.
[iii] ***Processed meat*** as meat preserved by smoking, curing, salting or addition of nitrates, nitrites or other preservatives. Under this definition, processed meats were primarily red, but included white meats, and included ham, bacon, pastrami, salami, sausages and processed deli or luncheon meats.

Table 2: Relative risks of incident coronary heart disease, diabetes mellitus and colorectal cancer for differences of 100 g/d usual intakes of red and 50 g/d of usual intakes of processed meat from two meta-analyses

Exposure	Disease	Relative Risk (95% CI)	Meta-analysis	Comments
Red meat* (RR per 100 g/d)	Coronary heart disease	1·00 (0·81, 1·23)	Micha et al[10]	Based on 4 estimates; most controlled for total energy intake. No between-study heterogeneity or publication bias was evident. The range of exposures across all included studies (means in lowest/highest categories) was 15.7–118.6 g/d.
	Diabetes mellitus	1·16 (0·92, 1·46)	Micha et al[10]	Based on 5 estimates; most controlled for total energy intake. No between-study heterogeneity or publication bias was evident. The range of exposures across all included studies (means in lowest/highest categories) was 15.7–118.6 g/d.
	Colorectal cancer	1·17 (1·05, 1·31)	WCRF/AICR[9]	Based on 8 cohort studies; most controlled for total energy intake. There was no evidence of heterogeneity was present and a random-effects model was used. There were insufficient studies to check for publication bias. Intakes per category spanned the range 1 – >200g/d.
Processed meat* (RR per 50 g/d)	Coronary heart disease	1·42 (1·07, 1·89)	Micha et al[10]	Based on 6 estimates; most controlled for total energy intake. Between-study heterogeneity and publication bias were evident; sensitivity analysis did not significantly change the outcome, and a random-effects model was used. The range of exposures across all included studies (means in lowest/highest categories) was 2.9 – 40.7 g/d.
	Diabetes mellitus	1·19 (1·11, 1·27)	Micha et al[10]	Based on 6 estimates; most controlled for total dietary energy. Some heterogeneity was evident, but publication bias was not; sensitivity analysis did not significantly change the outcome, and a random-effects model was used. The range of exposures across all studies (means in lowest/highest categories) was 2.9 – 40.7 g/d.
	Colorectal cancer	1·18 (1·10, 1·28)	WCRF/AICR[9]	Based on 9 cohort studies; most controlled for total energy intake. Low heterogeneity was present and a random-effects model was used. Publication bias was not evident. Intakes per category spanned the range 1 – >100 g/d.

* For definitions see text

Table 3: Predicted reductions (%) in population risks of coronary heart disease, diabetes and colorectal cancer from sustained exposure at counterfactual intakes of red and processed meat and both (assuming independence of effects)

	Red meat		Processed meat		Red plus processed meat	
	% risk change	(95% UI*)	% risk change	(95% UI*)	% risk change	(95% UI*)
Coronary heart disease						
Males	0.0†	(-10.4, 11.0)	-9·7	(-1·8, -18·1)	-9.7†	(3.6, -22.0)
Females	0.0†	(6.4, -6.2)	-6·4	(-1·2, -11·9)	-6.4†	(1.8, -14.3)
Diabetes mellitus						
Males	-7.5†	(4.2, -18.6)	-4·9	(-2·8, -7·3)	-12.0†	(4.5, -22.7)
Females	-4.5†	(2.5, -11.5)	-3·2	(-1·9, -4·7)	-7.5	(-0.5, -14.5)
Colorectal cancer						
Males	-7·9	(-2·4, -13·5)	-4·6	(-2·4, -7·2)	-12·2	(-6·4, -18.0)
Females	-4·8	(-1·4, -8·3)	-3·0	(-1·6, -4·7)	-7·7	(-4·0, -11·3)

* Uncertainty intervals estimated by Monte Carlo simulation, using @Risk software (Palisade, New York)

† Non-significant

Table 4: Predicted reductions (%) in risks of coronary heart disease, diabetes and colorectal cancer for persons with usual intakes at the mean levels for F5 had they had sustained exposure at usual intakes for F1 of red and processed meat and both (assuming independence of effects)

	Red meat		Processed meat		Red plus processed meat	
	% risk change	(95% UI*)	% risk change	(95% UI*)	% risk change	(95% UI*)
Coronary heart disease						
Males	0.0†	(25.7, -20.4)	-20·6	(-4·2, -35·1)	-20.6†	(1.3, -37.0)
Females	0.0†	(17.6, -14.7)	-11·0	(-2·2, -20·0)	-11.1†	(7.7, -26.7)
Diabetes mellitus						
Males	-14.9†	(9.2, -33.8)	-10·5	(-6·4, -15·7)	-24.1†	(1.6, -41.7)
Females	-10.8†	(6.6, -25.6)	-5·7	(-3·3, -8·4)	-15.9†	(0.9, -30.0)
Colorectal cancer						
Males	-15·7	(-4·9, -25·6)	-10·3	(-5·5, -15·5)	-24·4	(-13·6, -34·1)
Females	-11·4	(-3·4, -19·0)	-6·4	(-2·8, -8·4)	-16·2	(-8·4, -23·7)

* Uncertainty intervals estimated by Monte Carlo simulation, using @Risk software (Palisade, New York)

† Non-significant

Web Appendix: Assumptions and methods used to estimate greenhouse gas emissions from producing foods for UK consumers

Beef

Values for beef varied 4-fold according to the production system, with the value for Brazilian beef reflecting transport emissions. Values from DEFRA[i] were as follows:

UK Intensive Dairy	10 kg CO_2-e/kg hung carcass
UK Extensive Suckler	30 kg CO_2-e/kg hung carcass
UK Organic Suckler	32 kg CO_2-e/kg hung carcass
Brazil Suckler	40 kg CO_2-e/kg hung carcass

The UK has 80% self sufficiency in beef production,[ii] with equal quantities of UK beef coming from dairy and suckler herds.[iii,iv] Consumption of organic beef is negligible, at around 1%.[v] This was therefore ignored, particularly since emissions were similar to those for suckler cattle. 65% of beef imports to the UK come from Ireland and other EU countries, which were assumed to have the UK average value of 20 kg CO_2-e/kg hung carcass. A further 21% of UK beef comes from South America, for which the Brazil value was assumed, and the final 14% from 'other' countries, for which the average of UK and Brazilian beef was assumed (30 kg CO_2-e/kg hung carcass). 1 kg of hung carcass produces 0.7 kg bone-free meat.[vi] According to this information, a weighted average CO_2-e value was calculated to be 30 kg CO_2-e/kg, using the following equation:

$$((0.40 \times 10) + (0.40 \times 30) + (0.13 \times 20) + (0.042 \times 40) + (0.028 \times 30)) / 0.7 = 30 \text{ kg } CO_2\text{-e/kg}$$

Lamb

Values for UK-consumed lamb were obtained from DEFRA,[i] as follows:

UK Intensive Lowland	28 kg CO_2-e/kg hung carcass
UK Extensive Upland	39 kg CO_2-e/kg hung carcass
UK Organic Lowland	27 kg CO_2-e/kg hung carcass
New Zealand	33 kg CO_2-e/kg hung carcass

The UK is 85% self-sufficient in lamb production,[iv] with around 70% of this being upland lamb and the remaining 30% lowland.[iii] As for beef, organic was assumed to be negligible. 90% of UK imports originate from New Zealand, Australia or South America, for which the New Zealand value was assumed. The remaining 10% originate from Ireland or other EU countries, for which the UK average of 36 kg CO_2-e/kg was assumed. 1 kg of hung carcass produces 0.7 kg bone-free meat (personal communication with EBLEX). A weighted average value for lamb was therefore calculated to be 50 kg CO_2-e/kg:

$$((0.60 \times 39) + (0.25 \times 28) + (0.135 \times 33) + (0.015 \times 36)) / 0.7 = 50 \text{ kg } CO_2\text{-e/kg}$$

Pork

GHG emissions from pork produced under different systems were obtained from DEFRA:[i]

UK Intensive Indoor	5.5 kg CO_2-e/kg hung carcass
UK Extensive Outdoor	8.9 kg CO_2-e/kg hung carcass
UK Organic Outdoor	9.9 kg CO_2-e/kg hung carcass

The UK is 47% self-sufficient in pork production, with 70% being indoor reared.[vii] As above, organic production was assumed as negligible. Imports to the UK come entirely from the EU. This production was assumed to be intensive and the figure for UK intensive production was adopted and rounded to 6 to allow a small amount for road transport. 1 kg hung pork carcass produces 0.6 kg bone-free meat.[vi] A weighted average for pork was calculated as 10 kg CO_2-e/kg: $((0.33 \times 5.5) + (0.14 \times 8.9) + (0.53 \times 6)) / 0.6 = 10$ kg CO_2-e/kg

Chicken

Values for chicken were obtained from DEFRA:[i]

UK Intensive Indoor	3.1 kg CO_2-e/kg hung carcass
UK Extensive Outdoor	3.7 kg CO_2-e/kg hung carcass
UK Organic Outdoor	4.1 kg CO_2-e/kg hung carcass

The UK is 90% self sufficient in chicken production, with 20% being outdoor or organically reared.[viii] As the value for organic production was close to that for outdoor, the value for outdoor was used for both. Imports to the UK are mainly from the EU, Brazil and Thailand, with much being shipped frozen from the non-EU countries. The UK intensive value was rounded to 3.5 to reflect road and ship transport. 1 kg hung carcass produces 0.77 kg bone-free meat.[vi] A weighted average was calculated as 4 kg CO_2-e/kg:

$$((0.72 \times 3.1) + (0.18 \times 3.7) + (0.10 \times 3.5)) / 0.77 = 4 \text{ kg } CO_2\text{-e/kg}$$

This value was also applied to turkey, for which no data existed, and to game birds such as pheasant and quail.

Duck

The same edible proportion was assumed as for chicken (0.77 kg/kg hung carcass). Therefore, the GHG emissions per kg edible portion was calculated as 5.32 kg CO_2-e/kg from the DEFRA[i] figure for hung carcass: $4.1 / 0.77 = 5.32$ kg CO_2-e/kg. This figure was also applied to goose.

Egg

The DEFRA[i] value for a dozen eggs was 1.8 kg CO_2-e. The shell-free weight of 1 average egg is 50 g, therefore 12 eggs weigh 0.6 kg, and the value for 1 kg egg was calculated as 3.0 kg CO_2-e/kg.

Tomato

The following values for tomatoes were given by DEFRA:[i]

Oil heated UK	2.3 kg CO_2-e/kg
Waste heated UK	0.39 kg CO_2-e/kg
Spanish	1.8 kg CO_2-e/kg

The average of oil-heated UK and Spanish was calculated, then lowered slightly to represent a small proportion from waste heated production, to give a value of 2 kg CO_2-e/kg.

Mineral water and alcoholic beverages

In the absence of any data, the value for soft beverages was applied on the assumption that much of the impact would be due to bottling, packaging and transport, common to all of these.

Miscellaneous

In the absence of any data or knowledge of food group, the average of all non-meat foods (excluding beverages) was calculated as 1.85 kg CO_2-e/kg and applied to the proportion of foods classified as miscellaneous due to lack of information about the food or the GHG emissions.

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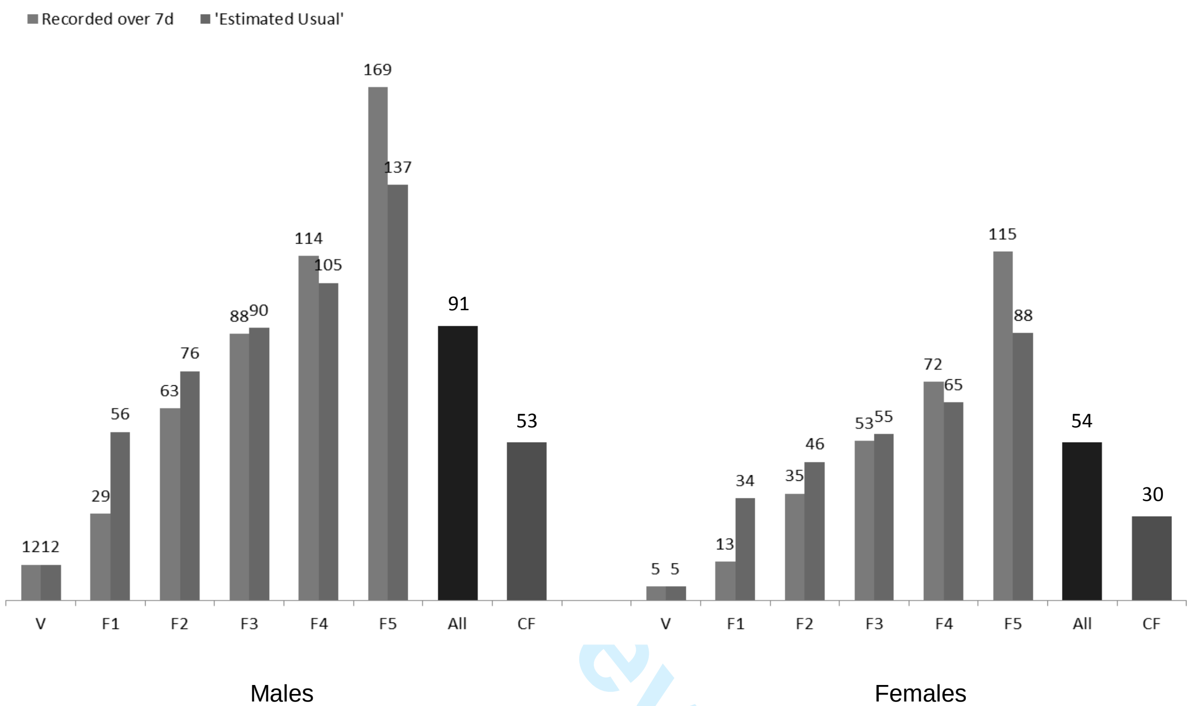
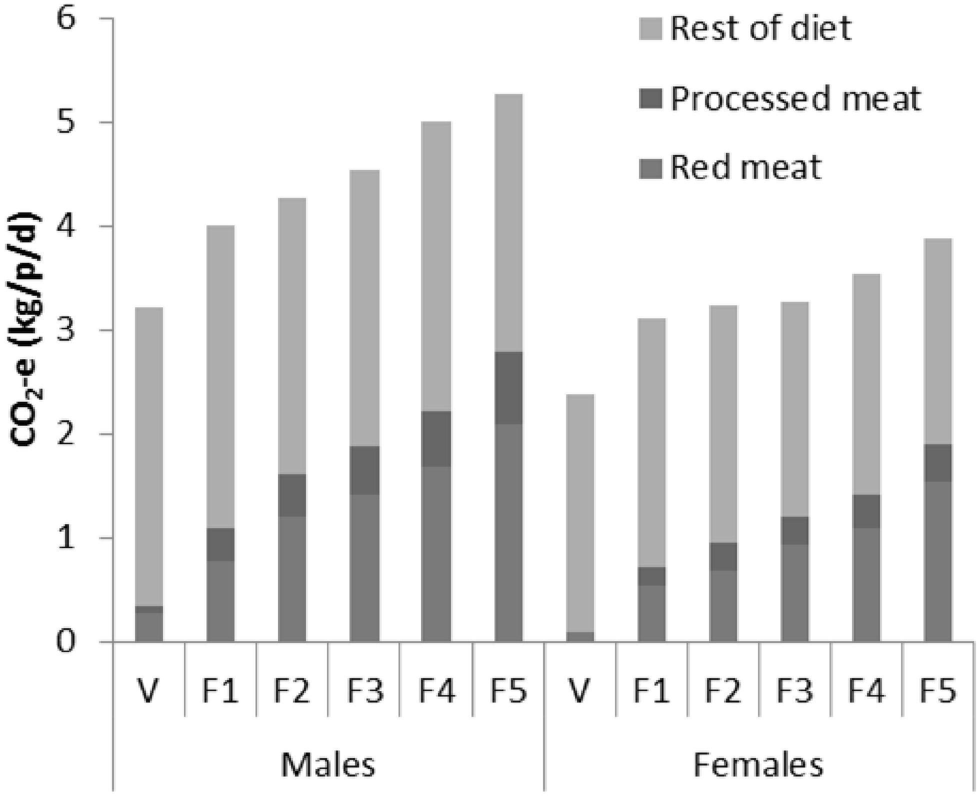
Figure 1: Reported and estimated habitual intakes of red plus processed meat across strata based on energy-adjusted red and processed meat intake (mean and 95% confidence interval). Intakes in mean g/d following energy-adjustment and standardisation to sex-specific mean total reported energy intake. Overall factual and counterfactual (CF) mean intakes are also shown.



V=Vegetarian; F1-5= Fifths of energy-adjusted red + processed meat intake (F1=lowest intake); CF=counterfactual

Figure 2: Diet-related standardised energy-adjusted CO_2-e emissions according to dietary component across sex-specific categories of energy-adjusted red plus processed meat intake (based on estimated habitual intake of red and processed meats)



V=Vegetarian; F1-5=Fifths of energy-adjusted red plus processed meat intake (F1=lowest intake)