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The climatic impact of food consumption in a representative sample of Irish adults and implications for food and nutrition policy

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Abstract

Objective: To evaluate the greenhouse gas emissions (GHGE) associated with the diet of Irish adults.

Design: GHGE were estimated by applying conversion factors to habitual food consumption data taken from the National Adult Nutrition Survey, which was representative of the population. Descriptive analyses were undertaken for GHGE for the total population, as well as accounting for energy misreporting and across categories of sociodemographic and socio-economic factors and tertiles of emissions.

Setting: Republic of Ireland.

Subjects: Adults aged 18–87 years (*n* 1500).

Results: The GHGE derived from daily dietary intakes was estimated as 6·5 kg of CO_2 equivalents (CO_2eq) per person. Males, younger consumers, those with secondary education and student employment status were associated with significantly higher GHGE. Red meat was the highest contributor to GHGE with 1646 g CO_2eq arising from a mean intake of 47 g/d. Dairy and starchy staples were the next largest dietary GHGE sources, with mean daily emissions of 732 g CO_2eq and 647 g CO_2eq, respectively. The lowest emissions were associated with consumption of vegetables, fruits and legumes/pulses/nuts.

Conclusions: Based on profiling using actual food consumption data, it is evident that one single measure is not sufficient and a range of evidence-based mitigation measures with potential to lower emissions throughout the food chain should be considered. The research contributes towards an improved understanding of the climatic impact of the dietary intakes of Irish adults and can serve to inform a sustainability framework to guide action in food and nutrition policy development.

Keywords
Dietary greenhouse gas emissions
Sustainable diets
Food consumption

The production and consumption of food have direct impacts on both human health and the environment[1]. Agricultural production is ultimately driven by food consumption demands and represents a substantial source of anthropogenic greenhouse gases[2,3]. In Ireland, the agricultural sector is one of the largest indigenous industries, with approximately 90 % of the food produced exported to the UK, the EU and other markets. Thus, relative to many other European countries, Ireland is somewhat unusual in that the agricultural sector constitutes the largest proportion (32·3 %) of national greenhouse gas emissions (GHGE)[4]. Ireland has its own climate change legislation and is also subject to EU emission reduction targets[5–7]. Considering that food consumption strongly influences the climatic impact of the food system[8], achieving mitigation targets may prove challenging without significant changes to diets[9]. However, altering diet for climatic reasons may have implications from a public health and nutrition perspective. Unsurprisingly therefore, the FAO recommends giving due consideration to climatic impacts when developing dietary guidelines and policies[10].

The climatic impact of food consumption is measured based on the global warming potential of greenhouse gases generated throughout the food chain. A global warming potential is a relative measure of how much heat, relative to CO_2, a greenhouse gas traps in the atmosphere and is expressed in terms of CO_2 equivalents (CO_2eq)[11]. Both activity data (i.e. food consumed) and emission factors (multipliers that convert quantity of foods consumed to GHGE) are required to calculate a carbon footprint of one's diet. Generally, a carbon footprint is

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based on life cycle assessment (LCA), which reflects total CO_2eq generated throughout each stage of the food system[12]. Each stage is defined by a system boundary which indicates the point along the food chain at which emissions are assessed and aggregated[13]. From this, the final carbon footprint is expressed by a functional unit which can be used to reflect the way in which a product is consumed[14]. For instance, emissions associated with dietary patterns are typically expressed in terms of weight of food consumed (i.e. quantity of GHGE per quantity of food consumed)[15].

The largest proportion of the GHGE from food products is generated on-farm, with markedly lower emissions from reprocessing, retail, preparation, consumption and waste[11]. The contribution of ruminants towards anthropogenic-induced climate change is particularly relevant as methane, a potent greenhouse gas with a global warming potential twenty-five times that of CO_2, is generated on-farm[16–18]. For this reason, the carbon footprint of beef and lamb can be as much as forty times greater than that of many fruits and vegetables per gram of food eaten[8,19–22].

Dietary emissions

The concept of 'sustainable diets' was coined in light of recognition of the need for food to be both nutritious and environmentally considerate. The FAO has defined sustainable diets as 'diets with low environmental impacts which contribute to food and nutrition security and to healthy life for present and future generations. Sustainable diets are protective and respectful of biodiversity and ecosystems, culturally acceptable, accessible, economically fair and affordable; nutritionally adequate, safe and healthy; while optimizing natural and human resources'[23]. Therefore, diets should not only adhere to nutritional adequacy principles but also environmental and ethical concerns. This represents challenges all along the food chain and especially to those involved in formulating nutritional guidelines[24]. The concept of sustainable diets represents an opportunity to successfully advance commitments to achieving emissions targets by reducing dietary emissions[25]. To date a range of studies have been undertaken to quantify the GHGE associated with differing dietary patterns and propose recommendations for changes in consumption that are both nutritious and sustainable[1,15,26].

Evidence points to many inherent contradictions which should be considered when developing and implementing sustainable dietary recommendations. In certain studies, modelling scenarios have been used which show that reducing dietary GHGE while ensuring nutritional adequacy is theoretically feasible[27–29]. Such studies are theoretical in nature and do not take into consideration the prevailing food consumption patterns of a population or inherent difficulties in changing consumer behaviour. Conversely, research derived from the French national food consumption data demonstrated that self-selecting diets which are lower in dietary emissions were also lower in nutritional quality when assessed on a nutrient density score rather than per gram of food consumed[30–32]. Vieux *et al.* observed that those who consumed a healthy diet, defined by low energy density, and low intakes of saturated fat, sugar and salt but high nutrient density, had higher GHGE[31]. Meanwhile, Masset *et al.* also showed that diets with lower than average GHGE tended to be less healthy based on nutrient density scores[32]. The relationship of higher intakes of fruits and vegetables with lower GHGE and better health outcomes has also been demonstrated. Scarborough *et al.* showed a positive relationship between GHGE and the quantity of animal-based foods in a standardised 8368 kJ (2000 kcal) diet[33]. Furthermore, that study found that as the quantity of animal-based foods decreased the intake of fruits and vegetables increased; this resulted in higher consumption of fibre and lower consumption of saturated fat[33].

Internationally, there have been numerous assessments of GHGE based on consumption surveys[19,30,34,35]. Consumption surveys tend to be favoured as they are often more representative of food intake than other methods which use commodity data to derive consumption[26]. However, inherent shortcomings in these data can occur as respondents can be inclined to change their food habits when consumption is recorded or others may not report consumption of various foods[36]. 'Energy misreporters' refers to individuals whose food intake is insufficient to sustain their BMR[37,38]. Only in some instances are outliers or misreporters in consumption data accounted for when reporting dietary emissions[30]. However, interpreting dietary emissions using consumption data is not without other challenges. For example, per capita dietary emissions in the UK have been estimated to range between 5·7 and 8·8 kg CO_2eq/d[19,22,34]. Deviations between reported UK dietary emissions are primarily a result of methodological differences, most notably the distinct system boundaries adopted, emission factors used and food consumption data assessed by each respective study. Methodological issues can consequently make direct comparisons between studies difficult. It is therefore important that the methods used to attain dietary emissions are explicitly stated as contrasting approaches can greatly influence overall findings.

To date no detailed analysis has been undertaken to determine the GHGE associated with food consumption in a national representative sample of Irish adults. Therefore, the aim of the present study was to take account of the aforementioned methodological considerations to determine the levels of and contributors to GHGE in the Irish diet. This was achieved by identifying a range of previously estimated emission factors from the literature which were applicable to an Irish context. The study adds to the current literature in that it uses representative food

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consumption data, accounts for energy misreporters, while also adopting emission factors that include emissions induced post-retail. It is hoped that in doing so a best possible estimate of Irish dietary emissions can be calculated. Determining the GHGE of nationally representative dietary patterns can serve to inform a framework to guide action in public health nutrition towards sustainable diets. Thus, the findings of the present study can assist in developing policies and practices that address dietary factors contributing to climate change.

Methodology

Food consumption data

Food consumption data from the National Adult Nutrition Survey (NANS) of Ireland were used[39]. The survey has been described previously in detail by Naughton *et al.*[40]. In brief, NANS was conducted from 2008 to 2010 on 1500 Irish adults ranging in age from 18 to 87 years and is representative of the Irish population with respect to age, gender, geographic location, marital status and social class when compared with the national census data from 2006, as illustrated in Table 1. The demographic features of the NANS have been shown to be representative of Irish adults with respect to age, gender, social class and geographical location when compared to census data[39].

Ethical approval for the survey was granted by the University College Cork Clinical Research Ethics Committee of the Cork Teaching Hospitals and written informed consent was obtained from study participants. A semi-weighed food diary was used to collect data on food and beverage intake on four consecutive days. The days of data collection were different for each participant to ensure that all weekdays and weekend days were equally recorded. Participants were instructed to provide detailed information on the amount and types of all foods and beverages consumed over the recording period and where applicable, the cooking methods, brand names of the foods, and details of recipes and leftovers. The Weighted Intake Software Program (WISP; Tinuviel Software, Warrington, UK) was used to analyse the food intake data to generate nutrient intakes. Each of the 2552 different foods consumed during the survey was assigned to one of sixty-seven food groups.

Allocating emission factors

At the time of the present study a comprehensive GHGE profile of the foods consumed in Ireland was unavailable. Therefore, GHGE factors from multiple sources in the literature were reviewed and those most applicable to an Irish context were used as detailed in online 'Supplementary material 1'. The emission factors assigned to the food groups from the NANS are drawn primarily from studies in the UK[22] and the USA[41], where both carried out extensive meta-analyses of GHGE associated with food consumption. The system boundary at which emission factors are assessed is defined to include emissions associated with food production, packing, distribution, storage/refrigeration, transportation, food handling/preparation and consumer waste[22,41,42]. Emission factors related exclusively to Irish dairy produce were previously generated. These factors were used for the present study as the vast majority of dairy produce consumed in Ireland is produced domestically[43]. However, the available emission factors relating to Irish dairy did not include emissions associated with the LCA system boundaries from retail to waste. Therefore, the same approach as in Green *et al.* was adopted when accounting for these post-retail emissions[22]. Emissions to include these boundaries were subsequently estimated to be an additional 18% for milk and milk products, and 14% for butter; with 9% added to all dairy products to account for travel and

Table 1 The sociodemographic profile of National Adult Nutrition Survey (NANS) participants in comparison with national Irish census of population data (*n* 1500 denotes full NANS sample; *n* 960 denotes the NANS sample with energy misreporters removed)

		2006 Census*	NANS (*n* 1500)	NANS (*n* 960)
Gender (%)	Men	50	49	49
	Women	50	51	51
Age group (%)	18–35 years	35	35	38
	26–50 years	29	29	31
	51–64 years	21	20	20
	65+ years	15	15	11
Marital status (%)	Single	38	32	35
	Married/living with partner	51	58	58
	Widowed/separated/divorced	11	9	7
Location (%)	Rural	39	30	29
	Urban	61	70	71
Social class (%)	Professional/managerial	33	46	49
	Non-manual	17	18	17
	Un/semi/skilled/manual	32	21	19
	Occupation unknown/students	18	15	15

*Irish Census data freely available from the Central Statistics Office, Ireland.

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refrigeration[22,38]. For the purpose of the present study dietary emissions can be defined as the quantity of daily GHGE generated by the consumption of food by an individual.

Analyses

The conversion factors for emissions were applied to the disaggregated sixty-seven NANS food groups and these were then further aggregated into sixteen food groups of similar food type characteristics. For instance, the food group labelled 'Red meat' comprised 'beef and veal', 'lamb', 'burgers', 'offal and offal dishes' derived from ruminants, the ruminant proportion of 'red meat dishes', along with the ruminant proportion of 'lamb, pork, and bacon dishes' from the NANS. Details of how each of the groups was aggregated are presented in online 'Supplementary material 1'. Of the 1500 participants, 540 were classified as energy misreporters as they had a ratio of energy intake to BMR that was either missing or did not fit into the recommended range of confidence limits of 1·02–2·35[37,38]. To highlight the impact of energy misreporting on dietary emissions, some analyses focused on dietary emissions associated with food groups included the whole sample (*n* 1500) as well as some which only included representative energy reporters (*n* 960). Emissions intensity was calculated as the quantity of GHGE in kilograms generated per energy provided in megajoules (kg CO_2eq/MJ)[44]. Three sensitivity analyses were carried out (see online 'Supplementary material 2'). First, the proportion of the meat component of composite dishes was increased from 35 to 50 %. Second, US emission factors were favoured where possible over those adopted from the UK. Third, emission factors for animal products were reduced by 20 %.

Statistical analyses were carried out using the statistical software package PASW Statistics Version 18.0. The size of the data set was sufficiently large to apply the Central Limit Theorem so that normality could be assumed[45]. Independent *t* tests and ANOVA tests were used to determine significant differences. Levene's test of homogeneity was used to inspect equality of variance for parametric tests. If homogeneity was confirmed, ANOVA was carried out with Bonferroni corrections; otherwise ANOVA was performed using the Welch test followed by the Games–Howell *post hoc* test. An α level of <0·05 was used to determine statistical significance.

Sociodemographic profiles of food consumption, dietary emissions and emissions intensity patterns were first assessed. Subsequent analysis was carried out to determine the relationship between GHGE and food consumption for the total population and excluding energy misreporters. Thereafter, dietary emissions and energy for each of the food groups were evaluated based on their relative (percentage) daily contribution towards total daily GHGE and energy intake. Participants were also classified into gender-specific groups of low, moderate and high emitters in terms of total dietary emissions. To account for gender differences in food intake and associated GHGE, tertile values were calculated specifically for men and for women separately and then combined into the gender-specific tertiles. Hence each tertile contained an equal proportion of males and females.

Results

Sociodemographic and socio-economic profiles of food consumption and dietary emissions

Table 2 presents differences in dietary GHGE, food intake, energy intake and emissions intensity of food consumption across sociodemographic and socio-economic categories. With the exception of location, significant differences in dietary emissions were observed for all categories. Males, younger consumers, those with secondary education and student employment status were associated with significantly higher GHGE. Similar patterns were also observed for food and energy intakes, except for education where no significant differences were observed. However, when emissions were expressed as intensity (CO_2eq/MJ per d), significant differences were observed only for gender whereby men had significantly higher emissions intensity compared with women. Many of these differences were explained by differences in food intakes; for example, men consumed significantly more meat than women, and younger groups consumed significantly more burgers and alcohol (data not shown).

Relationship between food consumption and emissions

Food consumption and its associated dietary GHGE are shown in Table 3 for both the total population and a sample excluding misreporters (*n* 960). Mean daily GHGE associated with food consumption was 6532 g CO_2eq for representative energy reporters and 5992 g CO_2eq for the total population when energy misreporters were included in the analysis. The inclusion of energy misreporters in the sample resulted in lower daily emissions from all of the food groups. Representative energy reporters consumed a daily total mean food intake of 3005 g. The food group with the highest intake was starchy staples with 387 g consumed daily, which accounted for 647 g CO_2eq. The highest beverage group intake was 1234 g/d for 'other beverages' which include tea, coffee, water, etc. and accounted for 402 g CO_2eq/d. The highest daily contributor to GHGE at 1646 g CO_2eq was red meat, arising from a mean intake of 47 g/d. Dairy (289 g/d) and starchy staples (387 g/d) were the next largest dietary GHGE sources, with mean daily emissions of 732 g CO_2eq and 647 g CO_2eq, respectively. The lowest emissions were associated with consumption of vegetables, fruits and legumes/pulses/nuts.

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Table 2 Mean daily greenhouse gas emissions (GHGE), food intakes, energy intakes and emissions intensities, across sociodemographic and socio-economic categories, for the sample of nationally representative Irish adults excluding energy misreporters (*n* 960)

		GHGE (g CO_2eq/d)		Food intake (g/d)		Energy intake (MJ/d)		Emissions intensity (kg CO_2eq/MJ per d)	
	n	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Total		6532	2337	3005	967	9	2	1	0
Gender									
Male	470	7850[a]	2345	3339[a]	1031	11[a]	2	1[a]	0
Female	490	5268[b]	1471	2685[b]	777	8[b]	1	1[b]	0
Age group									
18–35 years	364	7096[a]	2624	3166[a]	1095	10[a]	3	1	0
36–50 years	299	6299[b]	2228	2956[b]	930	9[b]	2	1	0
51–64 years	189	6147[b]	1889	2917[b]	766	9[b,c]	2	1	0
65+ years	108	5953[b]	1913	2751[b]	835	8[c]	2	1	0
Location									
Country/village	282	6465	2172	2927	896	9	2	1	0
Town	373	6633	2464	3064	1035	10	3	1	0
City	305	6472	2328	3005	942	9	2	1	0
Education									
Primary	65	6562[a,b]	2034	2853	1072	9[a,b]	2	1	0
Intermediate	184	6630[a,b]	2302	2933	905	9[a,b]	2	1	0
Secondary	227	7024[b]	2778	3057	1058	10[b]	3	1	0
Tertiary	475	6232[a]	2048	3029	932	9[a,c]	2	1	0
Employment status									
Working for payment	548	6508[a]	2197	3014[a]	923	9[a]	2	1	0
Working from home	86	5305[b]	1361	2647[b]	764	8[b]	2	1	0
Not working	197	6285[a]	2250	2944[a]	970	9[c]	2	1	0
Student	129	7832[c]	2913	3300[c]	1166	11[d]	3	1	0

CO_2eq, CO_2 equivalents.
[a,b,c,d]Mean values within a column (within sociodemographic and socio-economic categories) with unlike superscript letters were significantly different ($P < 0{\cdot}05$).

Table 3 Mean daily food intakes and associated dietary greenhouse gas emissions (GHGE) for the total sample of nationally representative Irish adults (*n* 1500) and excluding energy misreporters (*n* 960)

	Food intake (g/d)				GHGE (g CO_2eq/d)			
	n 960		*n* 1500		*n* 960		*n* 1500	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Total	3005	967	2753	1013	6532	2337	5992	2394
Starchy staples	387	147	360	147	647	229	599	233
Dairy	289	212	261	200	732	477	661	459
Vegetables	80	65	77	64	71	78	69	75
Fruit	105	118	97	114	75	83	68	79
Legumes/pulses/nuts	29	35	27	34	49	58	46	56
Red meat	47	44	45	43	1646	1539	1558	1509
Eggs/poultry/pork	85	55	81	54	584	383	555	374
Fish	26	37	26	36	249	347	244	341
Processed meat	33	41	29	39	303	380	274	361
Savoury snacks	44	61	37	56	221	330	189	302
High-sugar snacks	94	69	82	68	267	198	234	200
Fats/oils	22	17	20	17	281	319	259	311
Carbonated beverages	108	185	93	168	217	370	185	337
Other beverages	1234	659	1157	661	402	324	364	307
Alcoholic beverages	356	612	300	554	533	917	451	831
Miscellaneous	66	70	61	68	257	271	237	267

CO_2eq, CO_2 equivalents.

Table 4 profiles the percentage contribution and ranking of each of the food groups in terms of contribution to both emissions and energy intake, as well as the ratio of emissions generated relative to the energy intake derived from the food group. Red meat was consumed by more than three-quarters of the population and was associated with 22·3 % of daily GHGE while providing just over 4 % of daily energy intake (Table 4). Therefore, the red meat food group generated high daily dietary emissions while providing a relatively low proportion of dietary

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Table 4 Food groups' ranking in terms of contribution to daily dietary greenhouse gas emissions (GHGE), daily energy intake (MJ) and the ratio of daily emissions to energy provided by the food group (GHGE:MJ) for the nationally representative sample of Irish adults excluding energy misreporters (*n* 960)

Rank GHGE	Rank MJ	Food group	%GHGE	%MJ	GHGE:MJ	% Consumers
1	7	Red meat	22·3	4·4	5·1	77·8
2	3	Dairy	12·0	11·0	1·1	99·0
3	1	Starchy staples	10·6	29·7	0·4	100·0
4	4	Eggs/poultry/pork	9·5	6·9	1·4	97·6
5	5	Alcoholic beverages	6·9	6·2	1·1	64·0
6	15	Other beverages	6·5	1·4	4·6	100·0
7	8	Processed meat	4·6	3·9	1·2	64·2
8	2	High-sugar snacks	4·6	14·6	0·3	96·4
9	9	Fats/oils	4·5	3·6	1·3	95·1
10	12	Fish	4·2	2·1	2·0	53·1
11	10	Miscellaneous	4·2	3·0	1·4	97·1
12	6	Savoury snacks	3·5	5·4	0·6	71·5
13	14	Carbonated beverages	3·1	1·6	1·9	55·4
14	11	Fruit	1·3	2·8	0·5	76·7
15	16	Vegetables	1·2	1·3	0·9	92·3
16	13	Legumes/pulses/nuts	0·8	2·1	0·4	80·3

Table 5 Mean daily intake of each food group and associated greenhouse gas emissions (GHGE) across tertiles of low, moderate and high emitters for the nationally representative sample of Irish adults excluding energy misreporters (*n* 960)

	Food intake (g)						GHGE (g CO_2eq/g)					
	Low (*n* 320)		Moderate (*n* 321)		High (*n* 319)		Low (*n* 320)		Moderate (*n* 321)		High (*n* 319)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Total	2601[a]	743	2944[b]	856	3471[c]	1069	4676[a]	1074	6262[b]	1295	8667[c]	2348
Starchy staples	373	159	388	142	399	141	600[a]	214	650[b]	232	690[b]	232
Dairy	262[a]	179	284[a,b]	197	323[b]	249	659[a]	401	724[a,b]	465	815[b]	542
Vegetables	77	61	83	70	80	63	70	71	70	80	73	82
Fruit	114[a]	123	114[a]	124	87[b]	102	80[a]	81	84[a]	93	61[b]	71
Legumes/pulses/nuts	28	33	30	34	29	37	48	55	52	57	48	61
Red meat	17[a]	21	41[b]	31	84[c]	46	598[a]	732	1410[b]	1070	2934[c]	1619
Eggs/poultry/pork	83	54	88	53	85	59	571	382	597	366	582	401
Fish	24	32	29	37	27	41	226	301	269	352	251	382
Processed meat	26[a]	37	31[a]	38	41[b]	45	241[a]	344	289[a]	358	378[b]	423
Savoury snacks	36[a]	50	44[a,b]	63	51[b,c]	69	182[a]	271	222[a,b]	334	258[b]	374
High sugar snacks	99[a]	65	103[a]	79	81[b]	59	278[a]	185	292[a]	227	231[b]	174
Fats/oils	20[a]	15	22[a,b]	17	24[b]	18	274	310	272	324	296	323
Carbonated beverages	52[a]	102	101[b]	173	172[c]	235	105[a]	205	201[b]	347	344[c]	471
Other beverages	1198	614	1222	654	1283	704	333[a]	262	410[b]	328	465[b]	361
Alcoholic beverages	140[a]	252	295[b]	445	632[c]	859	211[a]	378	443[b]	668	948[c]	1289
Miscellaneous	51[a]	57	71[b]	75	75[b]	73	201[a]	223	277[b]	291	293[b]	286

CO_2eq, CO_2 equivalents.
[a,b,c]Mean values within a row (across food intake or GHGE tertiles) with unlike superscript letters were significantly different ($P<0·05$).

energy, with a GHGE:MJ of 5·1:1. Dairy followed as being the next largest GHGE source but, unlike red meat, its GHGE:MJ was nearly proportionate (1·1:1). Starchy staples were the highest energy source, providing almost 30 % of overall energy intake; they were also the third highest contributor to GHGE at 10·6 %. High-sugar snacks were the second highest source of energy intake at 14·6 % but scored lowest in terms of their GHGE:MJ (0·3:1).

Classification of low, moderate and high emitters

To further profile the differences in GHGE, tertile analysis was undertaken to determine low, moderate and high dietary emissions. Men and women were categorised separately to account for gender differences in food intake and subsequent dietary emissions. The total sample was then classified into three equal groups of low, moderate and high emitters in terms of their total dietary emissions. Table 5 presents the contribution of each food group in respect of GHGE and daily intake across the tertiles of low, medium and high GHGE emitters.

Total dietary emissions and total food intake increased significantly across increasing tertile ($P<0·05$). Those categorised as high emitters had almost twice the GHGE associated with food consumption than their low emitter peers. Dairy, followed by starchy staples, were the largest contributors to emissions for the low emitter tertile.

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Red meat followed by alcoholic beverages were the largest sources of GHGE for moderate and high emitters. Significant differences were observed across all three groups in both dietary emissions and intakes of red meat, carbonated beverages and alcoholic beverages. No significant differences in dietary emissions were observed between emitters for many food groups; namely, vegetables, legumes/pulses/nuts, eggs/poultry/pork, fish and fats/oils.

Discussion

Research concerning the deleterious climatic impact of the food system generally relies on typified diets or diets based on average food consumption patterns, thereby not capturing the diversity observed across a representative sample of the population[26]. In many studies, dietary emissions are based on consumption-level data from published data (food consumed)[21,29–31,46–48] or GHGE from agricultural commodities[49–52]. It has been argued that food consumption surveys provide a more realistic distribution of dietary intakes across societal demographics[26]. However, when possible, energy misreporters should be accounted for in analyses to allow for a more realistic interpretation of results[30]. This is frequently overlooked in many studies and may result in less accurate and lower reported emission levels. The considerations outlined highlight the notable challenges in making direct and meaningful comparisons between studies as no agreed methodology exists to determine GHGE associated with food consumption. It also highlights the need for harmonisation of national population analysis of dietary GHGE outputs, with the need to be consistent in data type (commodity *v.* consumption), accounting for energy misreporting, as well as using conversion factors with the same system boundaries.

Dietary emissions were estimated in the present study to be 6·5 kg CO_2eq/d for a representative sample of the Irish population. Every attempt has been made to calculate as accurately as possible the GHGE associated with food consumption by using full LCA while also accounting for misreporters. Tukker *et al.*[28] used food balance sheets from the FAO to estimate 7·1 kg CO_2eq/d as the average GHGE associated with food consumption in the EU. Although the method used by Tukker *et al.* overestimates per capita consumption, it is an accurate procedure for calculating food-related environmental impacts such as dietary emissions[26]. Therefore, it would be reasonable to conclude that at the very least emissions related to food consumption in Ireland are comparable to those across the EU.

Comparability between international and national studies can be difficult due to the varying types of data source used and/or differences such as system boundaries in the emission factors adopted. Researchers from the UK[19,22,34] , France[30] and the Netherlands[35] have obtained dietary data from similar national nutritional surveys as NANS and provide useful comparisons. What is more, Ireland, France, the Netherlands and the UK are comparable in that they share diets that are characterised by low ratio of vegetal to animal energy, high intake of animal fats, and relatively low intakes of cereals and vegetables[28]. Various studies have approximated UK dietary emissions as 5·7[22], 7·3[19] and 8·8 kg CO_2eq/d[34]. Some of the differences in UK estimates can be attributed to the differences in system boundaries, the particular wave of the UK national consumption survey used, emission factors adopted, and whether the study includes children as well as adults. French and Dutch adult dietary emissions have been reported as 4·2 kg CO_2eq/d[30] and 4·3 kg CO_2eq/d[35], respectively. The omission of post-retail emissions and emissions associated with waste may partially explain the higher emission profile of Ireland in comparison to France[30]. Furthermore, meat consumption for adults in the French dietary survey used to derive food consumption was 35 % lower than that of the NANS, which would have greatly influenced overall GHGE[53]. Dutch dietary emissions were also lower than those observed in Ireland; although Dutch emission factors considered GHGE associated with food waste, energy misreporters were not accounted for in the analysis[35]. Indeed, the authors suggested that dietary emissions were underestimated by a similar order of magnitude (15 %) to the proportion of energy under-reporters observed the study[35]. Additionally, Dutch meat consumption was 44 % lower than observed in Ireland[54]. However, the emission factors applied to meat were lower for both the French and Dutch studies, which may further contribute to their lower overall dietary emissions compared with those of Ireland.

The majority of emission factors used in the present study were those used by Green *et al.*; in their study, UK dietary emissions for adults were estimated at 5·7 kg CO_2eq/d[22]. However, the UK estimates did not account for energy misreporting; hence their findings were broadly similar to those observed herein of 6·0 kg CO_2eq/d when the total population including energy misreporters was considered. Meat consumption was 10 % higher in Ireland than observed by Green *et al.* and may be one of the many factors which may explain why their reported GHGE were slightly lower. A smaller number of emission factors were obtained from Heller and Keoleian and they estimated daily average GHGE in the USA at 5·0 kg CO_2eq/d using commodity data rather than habitual data[41]. A sensitivity analysis revealed that Irish dietary emissions were in line with US estimates when using as many of their emission factors as possible (see online 'Supplementary material 2', Table S1).

Differences in GHGE across sociodemographic and socio-economic groups were mostly influenced by the quantity of food consumed. With the exception of gender, the emission intensity of diets (GHGE/MJ) was not

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significantly different across the sociodemographic profiles. Previous research on adult Irish men has shown that they use dietary choices to express masculinity, which can influence a preference for certain foods such as meat[55]. Women, on the other hand, often restrict food intake, therefore not eating as much and not consuming meat in the same quantities as men[56]. Hence, male dietary preferences may explain the difference observed in both the emission intensity of diets and the variation in dietary emissions between genders. Significant differences in dietary emissions were also observed according to age. Those aged 18–35 years consumed higher quantities of unhealthy foods such as processed meats and alcohol, which leads to overall higher dietary emissions when compared with other age groups. Indeed, other studies have also noted the unhealthy eating patterns of young adults[57,58]. Therefore, those aged 18–35 years failed to adhere to both the environmental and nutritional aspects of a sustainable diet[23]. Foods of animal sources contributed most towards GHGE, with red meat responsible for the greatest proportion of Irish dietary emissions. Furthermore, red meat had the highest ratio of GHGE per MJ of energy provided. Higher intakes of animal-based foods were noted in high emitter tertiles. However, the tertiles were not indicative of the complexities and underlying structure of dietary patterns as only a single variable (total dietary emissions) was used for quantile classification.

Foods of animal origin provide many beneficial micronutrients and their high content of essential amino acids and micronutrients should not be overlooked when formulating dietary recommendations that consider both nutrition and GHGE[59]. Clearly, tensions exist in balancing the environmental and nutritional facets of food consumption. It is suggested that to achieve sustainability and public health objectives a transition to a less meat-based diet is required[24]. In an effort to address this issue many non-government organisations traditionally favoured climate change messages which ask for modest reductions of meat and encourage consumption of ruminant meat derived from grass-fed systems[60]. Recently non-government organisations such as the World Resource Institute and Chatham House have been more uncompromising and both have called for a reduction in consumption of animal-based foods[61,62]. Research from Tom *et al.*[63] suggests that per kilojoule, production of vegetables requires more water than meat. Attention should therefore be paid to the potential swapping of one environmental concern for another when developing recommendations to reduce dietary emissions[63]. However, the European food system is very different to that which exists in the USA. While Meier and Christen identified that blue water needs were higher for vegan and vegetarian diets in Germany[64], Vanham and co-workers found that the overall water footprint of vegetarian diets was lower than that of other dietary patterns in separate studies of the EU[65] and Austria[66]. Consideration is consequently advised when assessing the sustainability of diets as the climatic impact is only one facet of wider environmental concerns.

While vegan and vegetarian diets can substantially reduce dietary emissions, partial replacement of meat could potentially induce higher climatic effects if the substituted food groups are higher in GHGE than those being displaced (i.e. if chicken was substituted for cheese)[67]. Careful consideration is therefore required when formulating health recommendations based on environmental concerns. To provide more holistic assessments, it has been proposed that the sustainability of alternative diets is based upon nutrient and energy contents[32]. Hypothetically meat can be replaced by plant-based substitutes but an appreciation of the nutritional equivalency of the replacement food is necessary[68]. Replacing the energy and protein attained from average beef consumption could be compensated by the consumption of bean varieties, which leads to GHGE reductions (see online 'Supplementary material 2', Table S2). However, the size of the reduction in GHGE is dependent on the quality of meat being replaced. Moreover, replacing the energy induced by beef by instead consuming vegetables such as broccoli is difficult and requires large intakes which yield similarly high GHGE as beef (see online 'Supplementary material 2', Table S3). Thus, there are inherent difficulties in implementing dietary guidelines which adhere to all the principles of sustainable diets.

Typically, diets which are in accordance with health and nutrition guidelines for fruit and vegetables often conflate in reducing dietary GHGE[21,22]. Evidently, low dietary emissions were generated through the consumption of fruits and vegetables in the present study. High-sugar snacks were the second highest contributor to energy intake in the diet while also providing the least amount of GHGE per unit of energy provided. Indeed, many of the food groups which had the lowest emission factors are not conducive to good health if consumed excessively. Minimising dietary GHGE by only consuming foods low in GHGE therefore does not necessarily conform to maximising human health outcomes[31]. For instance, from a public heath perspective, increased and over-consumption of high-sugar foods may lead to negative health outcomes while concurrently resulting in lower GHGE[69]. In addition, meat was the highest source of dietary emissions but had a low energy profile. Recommendations to reduce red meat will result in reductions in GHGE but consideration must also be given to its health properties. In contrast, high-sugar snacks were low in GHGE but high in energy content; they also lack nutritional quality. Therefore, when devising low-carbon diets a balance is warranted as to both the nutritional and environmental impacts of certain food groups[70,71]. Green *et al.*[22] suggest that dietary emissions could be reduced

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by as much as 40 % through dietary changes. However, consumers are often unwilling or unsuccessful in altering dietary behaviour[72]. Indeed, campaigns over numerous decades calling for increased intakes of fruits and vegetables have been largely unsuccessful despite active targeting by government and health organisations[73]. The advocates of meat-free diets may therefore be met with resistance as consumers favour diets that contain some meat[74,75]. 'Less but better' and 'less and more varied' meat consumption have been subsequently proposed as a dietary mitigation strategy which may appeal to consumers[76]. Meat can be defined as 'better' if it achieves a spectrum of outcomes for climate change, the environment, animal welfare, human health, livelihoods, social justice and social values[77]. However, consumers often find ways of disengaging from many of the issues concerning meat consumption by 'explaining away' their behaviour through blame avoidance[75,78].

There are many alternative non-voluntary measures which could be enforced to lower dietary emissions. Decreasing dietary emissions can be achieved by using economic (e.g. Pigouvian tax), social (e.g. educational campaigns) and legal instruments. Many arguments have been made in favour of a meat consumption tax, rather than a meat production tax[79–81]. It has even been suggested by Chatham House that without government intervention consumers are unlikely to reduce their consumption of animal-based produce[62]. However, consumers generally respond unfavourably to such taxation measures and there is likely to be some public resistance to a meat tax[82]. Conversely, a Finnish Mandatory Vegetarian Day is an example of a legal instrument to stimulate reduced meat consumption. A weekly forced food restriction day is implemented in the Helsinki School District whereby meat and fish have been eliminated from the school menu. The effectiveness of the intervention is unclear however and may have unintended consequences such as increased food waste arising from a hedonic dislike of vegetarian food[83].

Sustainability can be an important motivator of behaviour and may be adopted in future campaigns to change dietary patterns and promote health[84]. Hence, policy makers, nutritionists and health professionals need to increase the public's awareness not only of health but also emphasise the environmental impact of dietary choices[85]. This may however prove challenging, considering the limited success that health organisations have had in changing consumers' behaviour towards fruit and vegetable consumption[73]. Although some subsets of individuals are motivated to eat less meat as it appeals to their psychological desires to protect the environment and promote good health, this motivation is not shared by all[86]. Nevertheless, de Boer *et al.*[85] found that consumers' willingness to eat less meat increased with its perceived effectiveness in reducing dietary emissions. This highlights the importance of social instruments such as education and consumer awareness campaigns. Improving understanding is difficult when one considers consumers lack of awareness of GHGE generated through diet[85]. Motivating people to change embedded and habitual food behaviour is compounded by a reluctance within government, industry and even non-government organisations to inform consumers of the climatic impact of diet[87]. Moreover, findings from a recent Eurobarometer study have shown that for consumers in Ireland climate change is not deemed as serious an issue as in other EU member states[88]. Asking individuals to trade perceived enjoyment and tradition for sustainability is challenging when the benefits of sustainability are poorly understood. Although 60 % of Irish adults perceive sustainability as being important in the food choices they make, only 34 % fully understand the concept[89].

The climatic burden that accumulates throughout the food system could be potentially lowered not only by altering dietary patterns but also through changing other consumer behaviours. Towards the end of the food chain, consumers throw away food, let it spoil or engage in behaviours which contribute to unnecessary food waste. In Europe, this translates to between 95 and 115 kg of food waste per capita annually[90]. Food loss, on the other hand, occurs earlier in the food system. Lowering food waste and food loss represents a potentially effective method to reduce dietary GHGE[42]. Approximately one-third of the food produced globally for human consumption is lost or wasted[90], with as much as 40 % of food lost and wasted in the industrialised world occurring at retail and consumer levels[91]. If food waste can be reduced the climatic impact of dietary patterns could be considerably lowered. Furthermore, mitigation measures which address food waste, rather than consumption, may receive less resistance from consumers than other actions[82].

Consumption of animal-based foods has been linked to both positive and negative health outcomes and there are many contrasting arguments both for and against the consumption of red meat[92]. While research has associated red meat consumption with negative health impacts[93], other studies suggest it can have many beneficial health outcomes[94,95]. Nevertheless, it is important to note that many of the micronutrients derived from meat can also be acquired from consumption of plant-based foods[96,97]. Yet consumers' reluctance to alter their behaviour with regard to meat consumption may hinder the potential environmental benefits of a more plant-based diet. Therefore, placing the onus on the supply chain to reduce GHGE is of particular importance. Mitigation strategies that occur before the farm gate could theoretically lower emissions associated with consumption of animal products. Reductions in the carbon footprint of red meat at farm level can be as high as 30 % if all producers in any given system, region and climate adopt the efficiency practices implemented by those with the

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lowest GHGE per unit of production[17,98]. Moreover, other on-farm mitigation measures could lower emissions further[99]. Ireland has implemented a sustainable food programme which enables farmers and producers to set and achieve sustainability targets by providing a framework to deliver long-term improvements in areas such as emissions mitigation with the aim of reducing GHGE associated with food production[100]. However, some research suggests that these production mitigation options alone are unlikely to be sufficient; changes in diets are also required to meet EU emission targets[101].

Emission factors should ideally account for where food was produced, processed, distributed, etc. Thus a full understanding of the source and supply chain for each food consumed in NANS would be necessary to give an absolute and accurate estimate of dietary emissions. Nevertheless, the methods used in the present study provide a good indicator of GHGE associated with food consumption in Ireland. Indeed, the primary method to appraise dietary emissions in this research area is through sourcing emission factors from the literature rather than ones which are country specific. However, this may be limiting when assigning emission factors to foods with a high carbon footprint that may not be fully applicable in an Irish context. Globally, animal-based foods have considerable variations in emission factor estimates due to differences in methods applied and variation in agricultural production systems[11]. This was highlighted in the dairy emission factors applied from Finnegan *et al.*[43], which were lower than those used in other studies. Indeed, a sensitivity analysis revealed that a 20 % decrease in the emission factors used for animal-based products would lead to a 10 % overall decrease in the dietary emissions elicited in the present study (see online 'Supplementary material 2', Table S1). It would not be unreasonable to assume other emission factors could also be lower than the ones found in the literature when one considers the highly competitive Irish agricultural sector and low food miles associated with Ireland's relatively small land area. Taking account of such factors in the future could result in lowering daily Irish dietary emissions.

Conclusion

Food consumption represents a substantial source of anthropogenic GHGE. Therefore it is important to quantify emissions associated with food consumption. Using detailed and reliable habitual food consumption data from a nationally representative sample of Irish adults and appropriate emission factors taken from the literature, the mean daily dietary emissions of the Irish population was calculated as 6·5 kg CO_2eq. Availability of socio-demographic and socio-economic variables supported further analysis. With the exception of education, those who had significantly higher dietary emissions per unit of energy also had significantly higher food intakes than their counterparts of similar sociodemographic and socio-economic profiles. Thus they contributed to higher GHGE as a result of both the volume and type of food they consumed. This indicates that strategies that change food consumption patterns as well as reduce consumption could be leveraged to reduce GHGE. In Ireland, the main contributors to daily emissions were foods of animal origin; most notably foods derived from ruminant animals. Red meat provided the greatest proportion of GHGE per energy intake while high-sugar snacks provided the lowest. From a policy perspective, however, it is not a question of simply reducing meat consumption and increasing high-sugar snacks, as overconsumption of high-sugar snacks while both under- and overconsumption red meat can lead to negative health outcomes. This highlights the complex relationship between diet, health and the environment. In addition, considerable challenges are involved in altering dietary behaviour as consumers are often reluctant to voluntarily alter their diets and many are unaware of the relationship between diet and climate change[75,85]. Policy interventions using economic, social and/or legal instruments targeted at consumers could however be considered in an effort to decrease dietary emissions[102]. A reduction in dietary emissions could also be realised through policy initiatives targeted at reducing food waste at the end of the chain and emissions at the start of the chain. Ireland thus has a range of voluntary, non-voluntary and alternative measures that it needs to evaluate in designing a sustainability framework to guide action in food and nutrition policy development while reducing dietary emissions from 6·5 kg CO_2eq/d per capita.

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involving human subjects were approved by the University of Nottingham Medical School Ethics Committee. Ethical approval for the survey was granted by the University College Cork Clinical Research Ethics Committee of the Cork Teaching Hospitals and written informed consent was obtained from study participants.

Supplementary material

To view supplementary material for this article, please visit http://dx.doi.org/10.1017/S1368980016002573

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