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Adherence to the Healthy Eating Guidelines in the MyPlanetDiet study is associated with healthier and more sustainable diets

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Abstract

Environmental impacts of food systems have stimulated research to examine how to create healthy diets that will be more sustainable while meeting nutrient requirements. Increasing compliance with existing food-based dietary guidelines in most jurisdictions could be a first step to improve health and reduce environmental impact. MyPlanetDiet was an all-Ireland 12-week randomised controlled trial designed to inform sustainable healthy dietary guidelines. Healthy adults (n=355) aged 18-64 years with moderate-to-high greenhouse gas emitting (GHGE) diets were recruited from three study sites on the island of Ireland. The aim of this research is to assess the relationship between dietary intakes, diet-related environmental impacts, and metabolic health using baseline data collected during the MyPlanetDiet study. Dietary assessments collected using Foodbook24 were used to calculate diet-related GHGE, adherence to Healthy Eating Guidelines (HEG), and Healthy Eating Index (HEI) score. Anthropometrics and metabolic health markers (e.g. lipids, glucose and insulin) were included. Overall HEG adherence was low, with 43% meeting zero or one HEG food group recommendations. Adherence to 4+ HEG food group targets was associated with 31% lower diet-related GHGE compared to those with lowest adherence. Higher HEG adherence was associated with lower BMI and waist circumference and higher HEI scores. While our findings suggest HEG adherence is associated with positive health and environmental impacts, substantial behaviour change will be needed to meet existing HEGs. Further research is needed to assess response and acceptability to HEG. However, adherence to HEG may be an important first step to reducing the environmental impact of food consumption.

Clinical Trials registration: NCT05253547

Keywords: sustainable healthy diets; food-based dietary guidelines; healthy eating guidelines; metabolic health

Abbreviations: BMI: Body Mass Index; CRP: C-Reactive Protein; FAO: Food and Agriculture Organisation; FBDG: Food-Based Dietary Guidelines; GHGE: Greenhouse Gas Emissions; HDL-C: High Density Lipoprotein Cholesterol; HEG: Healthy Eating Guidelines; HEI: Healthy Eating Index; LDL-C: Low Density Lipoprotein Cholesterol; %TE: percent of Total Energy; Total-C: Total Cholesterol; TAGs: Triglycerides; UK: United KingdomWHO: World Health Organisation

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1. Introduction

Sustainable and healthy diets are a prominent theme in food and nutrition research today[1; 2; 3]. The need to reduce environmental impacts across all sectors is well documented in research and media, leading to changes in the food and agriculture sector[4; 5; 6]. The planetary impacts of food production can be quantified through environmental metrics including greenhouse gas emissions (GHGE), water footprint, energy use, and more[7]. It is through these metrics that researchers can estimate and model how to create diets with lower environmental impacts, or more sustainable diets. There are various definitions of a sustainable diet, including conceptual and overarching definitions like from World Health Organisation (WHO) and United Nations Food and Agriculture Organisation (FAO) which states such diets should have low environmental impact, support health and wellbeing, be accessible, and be acceptable [8]. Others have described a sustainable diet more granularly, offering quantifiable recommendations with respect to individual food groups with the purpose of reducing environmental impacts[3; 9; 10]. However, some recommendations such as the Eat-Lancet Commission's Planetary Health Diet have been criticised for lack of nutritional adequacy, prompting health concerns[11]. A recent systematic review of dietary modelling studies has demonstrated the increased risk of inadequate micronutrient intakes with increased adherence to sustainable diets, particularly nutritionally vulnerable groups[12]. Nonetheless, different definitions have similarities, such as the importance for a sustainable diet to have high amounts of plant-based foods, including fruits, vegetables, pulses, and whole grains with low-moderate animal-based foods like meats and dairy[3; 8]. These recommendations are comparable to other examples healthy diets, prompting researchers to examine whether existing guidelines can support a sustainable and healthy diet[13; 14; 15].

Other dietary patterns for healthy lifestyles, such as food-based dietary guidelines (FBDGs) or Mediterranean diets, are expected to lead to healthier diets with lower environmental impact [13;14;16]. FBDGs provide detailed guidance on healthy diets, taking into consideration regional or local dietary acceptability and food availability. FBDGs, like sustainable dietary advice, recommend high intakes of plant-based foods such as fruits, vegetables, and whole grains and moderate intakes of protein from diverse sources[15; 17; 18]. Large modelling analysis suggests adhering to FBDGs could offer reductions in global diet-related environmental impacts, especially in Europe and North America[13]. Similar research from the United Kingdom (UK) concluded greater adherence to their FBDGs, the Eatwell Guide, is associated with improvements for both human and environmental health[14]. Some countries have gone a step further and have incorporated sustainability into their FBDGs, like Germany, Denmark, and Canada[19; 20; 21]. Current FBDGs on the island of Ireland, the Healthy Eating Guidelines (HEG), do not yet address concurrent recommendations for both sustainable and healthy diets[18]. Assessing the environmental impact of adhering to the HEG on the island of Ireland can help to develop sustainable dietary guidelines. To date, some research has been published analysing diet-related environmental metrics on the island of Ireland, and have linked certain dietary patterns, including intakes of red meat, discretionary foods or alcohol to high environmental impact [22; 23;24]. Globally, there is a lack of randomised controlled trials examining the impact of sustainable healthy guidelines on both population and planetary health[25]. The MyPlanetDiet study ran from 2022-2023 with the primary outcome of reducing diet-related GHGE. The study collected current dietary intakes of meat eaters on the island of Ireland and was the first intervention study to test the effectiveness, safety, nutritional adequacy and acceptability of a whole diet approach for sustainable diets. The aim of this manuscript is to describe the MyPlanetDiet sample population, to assess the cohort's baseline diets including food group intakes and macro- and micro-nutrient intakes, and measure dietary adherence to the HEG, diet-related environmental impacts, anthropometry, and clinical chemistry biomarkers.

2. Methods

Study overview and participants

MyPlanetDiet was a multicentre randomised controlled trial providing personalised nutrition advice for more healthy and sustainable diets. Healthy adults aged 18-64 years were recruited at three study sites on the island of Ireland: University College Dublin, University College Cork, and Queens University Belfast. Ethical approval was granted by the Human Research Ethics Committee in University College Dublin (LS-21-51-Davies-OSullivan) (affirmed by Faculty of Medicine, Health and Life Sciences Research Ethics Committee, Queen's University Belfast MHLS_21_109) and the Clinical Research Ethics Committee of the Cork Teaching Hospitals in University College Cork (ECM 4 (cc) 10/8/2021 & ECM 3 (f) 19/10/2021). The study was

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registered with ClinicalTrials.gov (NCT05253547) and was carried out in line with the Declaration of Helsinki principles. Eligibility criteria included being in general good health and following a moderate-to-high GHG-emitting diet (self-reported red meat intake of ≥3 portions per week). Exclusion criteria included taking high dose vitamin or mineral supplements, taking medications that may impact study outcomes, alcohol intake of ≥28 units per week, or blood pressure ≥140/90 (mmHg). Prior to beginning the study, participants gave informed consent to participate. Participants were randomised using site-specific block randomisation lists to receive either sustainable and healthy personalised nutrition feedback (intervention) or personalised nutrition feedback based on HEG from the island of Ireland (control). The study aimed for a sample size of 360 participants based on achieving 20% difference in diet-related GHGE between intervention and control diets (80% power, 5% significance). Further details of the MyPlanetDiet study are included in the study protocol[26]. The baseline data from the MyPlanetDiet sample such as dietary assessments, anthropometry, and biomarkers of metabolic health were used in the present analysis.

Dietary intake assessment and diet-related environmental metrics

Participants completed a health and lifestyle questionnaire and baseline dietary assessments before beginning the intervention period. The health and lifestyle questionnaire included questions on age, sex, self-reported anthropometry, living locations, educational attainment, and health-related behaviours (smoking use and alcohol intake). Dietary assessments included 3x 24-hour online recalls using a validated online 24hr recall tool, Foodbook24[27]. The validation and development of Foodbook24 and the tool's corresponding food list have been previously reported[27; 28]. Participants were asked to complete recalls on 3 non-consecutive days over 7-10 days, including two weekdays and one weekend day. Participants were screened for adequate reporting after their baseline recalls were completed. Per study protocol, participants who reported mean daily energy intakes below their resting metabolic rate (assessed via Mifflin St Jeor) were asked to repeat their baseline dietary assessment prior to receiving their intervention dietary advice and starting the study[26; 29]. Of those who were requested to repeat their dietary assessment, none were later excluded for misreporting.

Using the reported food intake data, each individual food reported to be consumed was categorised into one of 24 food groups (e.g. whole grains, starchy vegetables, dark green vegetables). For composite dishes with mixed food items (e.g. Lasagne), a recipe database was created and used to disaggregate different food items within each recipe in a standardised manner. Ingredients of composite dishes were then mapped to their relevant food groups. Food group intakes determined whether individuals were adhering to HEG recommendations for the following food groups: fruit and vegetables, whole grains, total meat, red meat, fish, and dairy. Participants were grouped based on how many HEG they adhered to ranging from zero to six possible guidelines met. Table 1 describes the food group targets used to assess adherence to HEGs. Nutrient intakes were calculated using Foodbook24 data which was derived from McCance and Widdowson's Composition of Foods Integrated Dataset (CoFID)[30]. A select set of relevant micronutrient values were included in the present analysis.

Mean food group and nutrient intakes from baseline dietary recalls were used to calculate a Healthy Eating Index (HEI) score. The HEI is made up of 13 food group or nutrient components ranging from 0-5 or 0-10 points for a possible total score of 0-100[31]. There are eight food group components scored for adequacy (target gram intake per day) including total fruits; whole fruits; total vegetables; greens and beans; whole grains; dairy; total protein foods; and seafood and plant protein. Adequacy components refer to a positively correlated scoring system (i.e. higher intake of the components leads to higher scores). There is one adequacy component for nutrient intake which measures the ratio of fatty acids consumed (higher ratio of unsaturated fats to saturated fats). There are four HEI moderation components (i.e. lower intakes of the component leads to higher scores) which includes grams per day or percent of total energy for intakes of refined grains, sodium, added sugar and saturated fats. Dietary intake data for added sugar was not available, therefore, a score of 5 (0-10 scoring potential) was allocated to all participants.

All individual foods reported to be consumed were assigned GHGE and water footprint factors per 100g of food. The factors were derived from previously published data by Colombo and colleagues in the UK[32]. Where possible, foods were assigned the factor in the published database[32]. For composite dishes, the same recipe database described above was used to assign environmental factors to individual food items. The factors for each food or dish were multiplied by the weight in grams that was eaten to calculate GHGE and water footprint for each eating occasion, and then summed to determine a daily amount. The mean daily diet-related GHGE and water footprint were calculated for the three recall days.

Anthropometry

All participants attended an onsite baseline visit on commencing the study. Fasting anthropometric measurements were taken in duplicate, in accordance with standardised protocols. Freestanding Leicester stadiometers (Seca, Birmingham, UK) were used to measure height to the nearest millimetre. Weight and body composition were measured using bioimpedance body composition analysers (Tanita BC-420MA, Tanita Ltd., Manchester, UK). Waist and hip circumference were measured with participants standing with their arms down. Blood pressure readings were taken using Omron M6 Comfort HEM-7360-E (Omron Healthcare Ltd, Brighton UK). Blood pressure was measured while participants were seated, with feet on the floor, in their non dominant arm. Mean values of the duplicate anthropometry readings were recorded.

Sample collection

Trained phlebotomists collected 12 millilitres (2x 6 millilitres collection tubes) of fasted blood from participants. Blood samples were inverted five times and then stored at room temperature for 30 minutes before centrifugation at 4 degrees Celsius and 1500 RCF for 15 minutes. Serum was aliquoted into 2 millilitre microtubes and placed in -80-degree Celsius freezer until analysis.

Biochemistry data

Serum samples were analysed for total cholesterol (Total-C), LDL cholesterol (LDL-C), HDL cholesterol (HDL-C), triglycerides (TAGs), insulin, glucose, and C-reactive protein (CRP) at the Mater Misericordiae University Hospital in Dublin, Ireland. Samples were analysed according to hospital standard operating procedures using standard reagent kits for the Alinity c Clinical

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Chemistry Analyser (Abbott Laboratories, Illinois, USA). For samples with TAGs <2.2 millimole per litre (mmol/L), LDL-C was calculated using the Friedewald equation per hospital protocol. Where TAGs were >2.2 mmol/L, the directly measured LDL values were used.

Statistical analysis

IBM SPSS Statistics for Macintosh, Version 29.0 (IBM Corp., Armonk NY, USA) was used for statistical analysis. Demographic data are presented as count and percent of total population. Nutrient, environmental impact and food group data are presented as mean and standard deviation (SD). Shapiro-Wilk tests and histograms were used to assess normality of continuous variables. Non-normally distributed variables were transformed to normality with logarithmic or square root functions. Univariate general linear model was used to compare means of nutrient intakes, environmental impact, and metabolic health of males and females. Pearson's correlation was used to determine the association between covariates and dependent variables. Energy intake (kilocalories), body mass index (BMI) (kg/m^2), and age were used as covariates in the general linear model. Food group data were used to determine the proportion of the population meeting HEG [18]. Participants were grouped based on how many HEG they met. Univariate general linear model was used to compare mean nutrient intakes, environmental impacts, and biomarkers of metabolic health across HEG groups. Based on Pearson's correlation, energy intake (kilocalories), sex (male/female), age, and BMI (kg/m^2) were used as covariates. Post-hoc power calculations were completed to ensure sufficient power in the presented analysis. The post-hoc power to detect a difference in diet-related GHGE, HEI, and waist circumference between the lowest and highest HEG adherence groups is 100%, 100%, and 93.3% respectively. Presented p-values were adjusted to account for the false discovery rate using the Benjamini-Hochberg method. P values of <0.05 were considered significant.

3. Results

Baseline demographics

The MyPlanetDiet study recruited n=355 participants between March 2022-March 2023. The mean age of the sample population was 41.7±12.4 years. MyPlanetDiet participant demographics are presented in Table 2. Participants were most likely to live in a city (45%) with a partner and

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children (51%). Participants had high educational attainment, with 43% having received postgraduate level education.

Nutrient intakes

Mean daily nutrient intakes and diet-related environmental impacts of males and females are presented in Table 3. Males reported significantly ($p<0.001$) higher energy intakes (2354.8±685.4kcal) compared to females (2007.7±541.1kcal). There were no other significant differences in nutrient intakes between males and females. Mean daily diet-related GHGE were significantly ($p=0.01$) higher in males (7.7±3.4kg CO_2-eq) compared to females (6.2±2.34kg CO_2-eq). There were no significant differences between males and females for mean daily diet-related water footprint.

Anthropometry and health-related biomarkers

Mean BMI was comparable for males and females at 28.2±4.6 and 27.9±5.9 (kg/m^2) respectively ($p=0.65$) (Table 4). Females had higher fat mass (30.4±12.6kg) and body fat percentage (38.3±8.3%) than males ($p<0.001$). Males had higher muscle mass (63.4±7.0kg) and waist circumference (97.0±13.8cm) ($p<0.001$). HDL-C was significantly higher for females ($p<0.001$) while TAGs ($p=0.02$) and glucose ($p<0.001$) were higher in males. Males had lower CRP on average (1.7±2.6mg/L) compared to females (2.4±3.0mg/L) ($p=0.02$). Females had lower systolic blood pressure (115.4±13.4mmHg) than males (125.0±11.2mmHg) ($p<0.001$).

Food Intake relative to Healthy Eating Guidelines

There were no significant differences in mean daily food group intakes between males and females (Table 5). The mean daily intake of whole grains for males and females was 30.4±27.0g and 27.2±25.5g per day respectively. Mean daily total fruit and vegetable intake was 347.1±176.8g for males and 338.8±196.4g for females. Males consumed 247.3±178.8g of dairy per day on average while females had lower intakes of 205.4±142.5g on average. The proportion of males and females meeting HEG recommendations is shown in Table 5. Most participants reported mean daily intakes below HEG recommendations for fruit and vegetables, whole grains, fish, and dairy food groups. Females were more likely than males to be meeting recommendations for total meat ($p=0.001$) and red meat ($p<0.001$). No participant met all six recommendations. There was very low HEG adherence, with 43% of participants meeting 0-1 HEG recommendations. There was no statistical difference between males and females for the number of recommendations met.

Mean daily diet-related greenhouse gas emissions lowered in a stepwise manner as adherence to HEG increased ($p<0.001$) (Table 6). There were no significant differences in energy intakes across HEG adherence groups ($p=0.32$) but HEI was higher among higher adherence HEG groups ($p<0.001$). Mean weight ($p=0.01$), BMI ($p=0.009$), and waist circumference ($p=0.02$) lowered as adherence to HEG increased (Table 6). There were no significant relationships between blood lipids or glucose across HEG groups.

Discussion

This study demonstrates that higher adherence to HEG was associated with better health indicators for participants, including body weight indicators and was associated with 31% lower diet-related GHGE. Almost half of the study cohort met none or one HEG recommendation, compared with 10% who met four or more of the six total recommendations. While several modelling studies have described a theoretical ‘sustainable diet’, our work demonstrates that simply encouraging people to follow HEG will achieve substantial gains towards personal and planetary health. However, our data also show that there is very low HEG adherence, which demonstrates that change is needed to achieve more healthy and sustainable diets, especially if adherence to HEG are considered a first stepping stone.

Higher diet quality and better adherence to FBDGs have previously been linked to lower diet-related GHGE[13; 14; 33; 34]. Therefore, existing FBDGs may offer a solution to support consumers in the transition to more sustainable diets. The present analysis shows that diets with lower HEG adherence have higher diet-related GHGE while healthier diets, that follow more HEG, have both higher HEI scores and lower diet-related GHGE. These associations exist despite comparable energy intakes across HEG groups, suggesting that food choice is largely impacting diet-related GHGE. This is similar to findings from Strid and colleagues where energy adjusted diets with higher adherence to Swedish dietary guidelines were associated with lower diet-related GHGE[33]. Scheelbeck and colleagues also reported that intermediate-to-high adherence to the UK Eatwell Guide resulted in 30% lower diet-related GHGE compared to very low adherence[14]. Reductions in diet-related GHGE have been previously attributed to simply reducing intakes of high-GHGE foods, such as red meat [13; 34]. However, it is also important to note that lower-GHGE diets do not always result in higher diet quality, such as in a recent systematic review where some low-GHGE dietary patterns scored poorly on numerous diet quality metrics[1]. These findings emphasise that a whole-diet approach is needed to balance human and planetary health.

Whilst we did see an alignment with HEG and dietary GHGE, there was no relationship between HEG adherence and water footprint, which is similar to work published in the UK[14]. Adherence to the Eatwell Guide was not associated with lower water footprint in an analysis by Scheelbeck and colleagues, though it is worth noting that regardless of Eatwell Guide adherence, their analysis had lower water footprints than in any HEG group from the present analysis[14]. Other studies have also reported inconsistent relationships with diet quality, FBDGs, and diet-related water footprint[1; 13; 35]. This may be related to the variability in water footprint across all foods regardless of food group and differences in water use across different countries[36]. Springmann and colleagues report adherence to European FBDGs would not reduce water footprint, largely due to higher intakes of fruits and vegetables, nuts and seeds, legumes, and milk which would attenuate any predicted decreases in water footprint through lower intakes of meat and starchy staples[13]. In this regard, water footprint is similar to diet-related GHGE where a balanced approach looking at diets as a whole is needed to improve sustainability.

Our findings can be an important motivator for public health bodies to incorporate additional sustainability considerations into FBDGs and may even provide motivation for consumers to adhere to such recommendations, when recognising the impact on both personal and planetary health. However, recent research from Ireland has found a lack of public awareness of

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sustainable dietary behaviours and has called for new strategies to support the transition to more sustainable diets[37; 38]. To date several countries have considered sustainability in their FBDGs with countries such as Canada, Germany and Denmark, producing recent amendments to existing FBDGs to support a more favourable diet-related environmental impact[19; 20; 21]. For example, Canada incorporated sustainability messaging into their FBDGs in 2019, and a recent analysis shows adherence to the new FBDGs aligns with scoring of the Eat-Lancet Commission Planetary Health Diet, suggesting the new guidelines have potential to reduce diet-related environmental impact[3; 21; 39]. However, the nutrition or health-related impacts of these changes are not yet known, nor do we know if Canadians will adhere to the new FBDGs. Nonetheless, the evidence to date would suggest that FBDGs, especially when updated to incorporate sustainability targets, could play a transformative role in creating more sustainable diets[39].

Adherence to FBDGs is associated with reduced mortality[13; 14]. Within the present study, better adherence to HEG was associated with better anthropometric measurements including body weight, BMI, and waist circumference. However, there were no differences in clinical chemistry biomarkers between HEG adherence groups. Previous studies, including those from the Netherlands and Denmark, have found that better adherence to FBDGs is associated with better anthropometry[40; 41]. While there was stepwise reduction in BMI with higher HEG adherence, mean BMIs were all in the overweight category for all HEG adherence groups. It is likely that the overweight status across HEG groups explains why we reported no differences in circulating blood lipid concentrations between groups. Other studies that have reported associations between HEG adherence blood lipid concentrations, such as total-C, LDL-C, or TAGs, have also reported lower or more variable BMIs[42; 43]. MyPlanetDiet specifically recruited those with moderate to high red meat intakes, which has been previously shown to contribute to high cholesterol and LDL-C[44; 45; 46]. Furthermore, mean energy intake suggests that participants were in energy balance. It is possible that if participants were to reduce energy intake to achieve a BMI in the healthy range (18.5-<25 kg/m^2), that we might begin to see the effects of HEG adherence. In other research, Tande and colleagues examined the relationship between food groups recommended in the FBDGs in the United States and blood lipid concentrations and found that fruit, grains, meat, and dairy were associated with blood lipids[42]. Using LDL-C as an example,

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fruit intake was significantly associated with lower LDL-C concentrations while meat and dairy were associated with higher LDL-C concentrations[42]. While no such association was found here, there were clear associations between HEG adherence and more favourable anthropometry in the MyPlanetDiet baseline cohort.

Despite the potential for better human and planetary health, poor adherence to FBDGs remains a problem, which is well documented in literature and aligns with the findings presented here[13; 14; 47]. In the present analysis, 43% of the 355 participants met one or none of the recommendations from the HEG, and no one met all six recommendations. Food-based dietary guidelines are meant to be culturally appropriate healthy diets developed by local authorities to support a population's health and wellbeing. Yet, achieving adherence to FBDGs (or other generic population-based nutrition advice) is often ineffective[47; 48; 49]. One-size-fits-all nutrition advice aimed at the general population does not consider individual factors that impact dietary behaviour, like food preferences or acceptability which are crucial components of healthy and sustainable diets. On the other hand, a personalised nutrition approach, where individuals are provided with actionable feedback tailored to their dietary intake and nutrient needs, has been shown to lead to longer-lasting and larger dietary change when compared to standard nutrition advice [48; 49]. Personalised nutrition feedback can be developed to be standardised and reproducible through decision-making processes such as decision trees[50]. Decision trees can consider individual factors, including barriers or enablers for dietary change, as well as aspects of an individual's phenotype and provide clear actionable guidance [51]. To our knowledge, no other study has tested how a personalised nutrition approach can affect both human and planetary health. Personalised nutrition feedback was created as part of the MyPlanetDiet randomised controlled trial described here. The study provided individuals in the control group with the content of the HEG but in a new manner of personalisation. While following HEG adherence is likely to improve health markers for people and planet, it remains unclear whether people are willing–or able–to follow the HEG in Ireland. Future findings from the MyPlanetDiet study will examine the interpersonal response to more healthy and sustainable diets.

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Strengths and limitations

The present analysis uses baseline data from the MyPlanetDiet randomised controlled trial, which recruited healthy adult meat consumers between 2022 and 2023. Using a cohort of omnivores, free of food avoidance or allergies, our analysis can accurately compare dietary intakes to the HEG as all study participants were able to eat all the presented food groups. No other research has been published examining the adherence to HEG in Ireland to our knowledge. The recruitment sites for MyPlanetDiet were spread across the island of Ireland, which is beneficial for updating dietary patterns and preferences across the island. The data presented here relies on observational analysis, and caution must be taken when interpreting the relationships between dietary intake and markers of planetary and human health. Similarly, while the dietary assessment method is robust and validated, intake data was self-reported(27). Dietary assessment methods have flaws, but the study operating procedures were designed to minimise rates of underreporting. Individuals with low energy intakes were asked to repeat their dietary assessments prior to beginning the study. Environmental data for diet-related GHGE and water footprint was matched to foods reported in Foodbook24. The data used for GHGE and water footprint were previously published in a UK study(32). While food production practices are similar between the UK and Ireland, we acknowledge the limitation of using data from outside Ireland. There are inherent limitations to measuring the environmental impacts of food, but conducting new life cycle assessments was beyond the scope of the project. Our study recruited those following moderate-to-high GHG-emitting diets, which relied on individuals being meat consumers and eating red meat three or more times per week. Although meat intakes in the MyPlanetDiet baseline cohort are similar to the latest intake data in Ireland, we were not able to include all individuals in the present study, such as those who already follow more sustainable diets(52).

Conclusion

Food-based dietary guidelines are designed to be a benchmark for healthy lifestyles and recent research has also shown adherence to FBDGs can reduce diet-related environmental impacts(13; 14; 33). Our findings align with these concepts and show higher adherence to HEG is associated with better diet quality, lower diet-related GHGE, and healthier anthropometry. Yet, overall adherence to HEG remains a problem, with nearly half the cohort meeting zero or one HEG recommendation. Substantial behaviour change would be needed to increase adherence to HEGs. Achieving behaviour and dietary change is likely to act as a barrier to improving adherence to FBDGs and diet-related sustainability. Future research should examine novel strategies and interventions, including through a personalised nutrition lens, to improve FBDG adherence and transition to more sustainable diets. HEG adherence, including the impact on health and planetary indicators, will be assessed as part of the MyPlanetDiet randomised controlled trial results and will be disseminated in the coming months.

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Table 1: Food group targets in the Healthy Eating Guidelines used to assess adherence

Food group	Healthy Eating Guidelines recommendation
Fruit and vegetables	≥5 servings per day
Whole grains	≥50g per day
Total meat	≤2 servings per day
Red meat	≤1 serving per day
Fish	≥2 servings per week
Dairy (milk, cheese, yoghurt)	≥3 servings per day

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Table 2: Baseline demographics of the MyPlanetDiet sample population (n=355)

	n	**%**
Sex		
Male	151	42.5
Female	204	57.5
Age group		
18-40	156	43.9
41-64	199	56.1
Living arrangements		
Living alone	31	8.7
Living with a partner	69	19.4
Living with a partner and children	183	51.3
Living with family members	43	12.1
Living in shared accommodation	29	8.2
Living location		
Open country/village (less than 1,500 residents)	81	22.8
Small town (between 1,500-10,000 residents)	57	16.1
Large town (greater than 10,000 residents)	56	15.8
City	161	45.4
Education		
Secondary	42	11.8
Third level non degree	55	15.5
Third level degree	106	29.9
Postgraduate	152	42.8
Smoking history		
Current smoker	21	5.9
Past smoker	106	29.9
Never smoker	228	64.2
Alcohol units (per week)*		
0	79	22.3
1-11	207	58.3
12-17	41	11.5
≥18	28	7.9

*Data are presented as count (n) and percent (%). *Alcohol units represent self-reported standard alcohol intake per week in standard drink units (e.g. one pub measure of spirits, half pint of lager, etc.)*

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Table 3: Mean daily nutrient intakes and environmental impacts for males and females.

	Male (n=151)		Female (n=204)		
	Mean	**SD**	**Mean**	**SD**	**p-value**
Energy (kcal)	2354.8	685.4	2007.7	541.1	<0.001
Carbohydrate (%TE)	45.3	7.3	44.0	7.6	0.21
Dietary fibre (g)	19.8	7.5	17.6	6.7	0.63
Fat (%TE)	36.1	5.8	37.8	6.2	0.11
Saturated fat (%TE)	13.8	3.2	14.7	3.6	0.13
Protein (%TE)	17.5	4.3	16.7	3.8	0.21
Protein (g/kg)	1.2	0.4	1.1	0.4	0.18
Sodium (mg)	2557.3	1004.2	2196.7	769.3	0.76
Calcium (mg)	963.5	371.9	807.5	269.5	0.74
Iron (mg)	13.7	4.8	11.6	3.5	0.60
Zinc (mg)	11.4	4.0	9.5	3.2	0.11
Iodine (µg)	176.1	271.7	131.9	55.1	0.81
Vitamin B12 (µg)	5.2	3.0	4.2	2.1	0.63
Vitamin A (µg RE)	871.3	668.9	794.6	458.5	0.19
Vitamin C (mg)	76.9	58.0	72.1	55.3	0.67
HEI	43.5	8.1	43.2	8.1	0.78
GHGE (kg CO_2-eq)	7.7	3.4	6.2	2.3	0.02
Water footprint (L H_2O)	768.2	547.6	764.9	574.6	0.45

SD, standard deviation. %TE, percent of total energy. RE retinol equivalent. HEI, Healthy Eating Index. GHGE (kg CO_2-eq), greenhouse gas emissions (kilogram of carbon dioxide equivalent). Univariate general linear model analysis of covariance, controlled for energy intake (kcal); p-values were adjusted for false discovery rate using Benjamini-Hochberg; p-values <0.05 considered significant.

Table 4: Baseline anthropometry and biomarkers of metabolic health for males and females

	Male (n=151)		Female (n=204)		
	Mean	SD	Mean	SD	p-value
Height (cm)	178.5	6.3	165.3	6.0	<0.001
Weight (kg)	90.1	16.8	76.3	16.6	<0.001
BMI (kg/m^2)	28.2	4.6	27.9	5.9	0.65
Fat mass (kg)	24.2	11.3	30.4	12.6	<0.001
Body fat (%)	25.8	7.2	38.3	8.3	<0.001
Fat free mass (kg)	65.9	7.5	46.0	5.3	<0.001
Muscle mass (kg)	63.4	7.0	44.3	4.9	<0.001
Waist circumference (cm)	97.0	13.8	88.1	14.5	<0.001
Hip circumference (cm)	107.2	8.7	107.7	11.6	0.28
Total-C (mmol/L)	5.1	1.0	5.3	1.1	0.37
HDL-C (mmol/L)	1.3	0.3	1.7	0.4	<0.001
LDL-C (mmol/L)	3.3	0.9	3.2	0.9	0.14
TAG (mmol/L)	1.2	0.6	1.1	0.6	0.02
Glucose (mmol/L)	5.4	0.7	5.2	0.7	<0.001
Insulin (pmol/L)	56.6	44.6	53.3	34.8	0.43
CRP (mg/L)	1.7	2.6	2.4	3.0	0.02
Systolic BP (mm Hg)	125.0	11.2	115.4	13.4	<0.001
Diastolic BP (mm Hg)	79.8	8.0	78.8	9.1	0.12

SD, standard deviation. BMI, body mass index. Total-C, total cholesterol. HDL-C, high density lipoprotein cholesterol. LDL-C, low density lipoprotein cholesterol. TAGs, triacylglycerols. CRP, C-reactive protein. Systolic BP, systolic blood pressure. Diastolic BP, diastolic blood pressure. Univariate general linear model analysis of covariance, controlled for age, BMI and energy intake (kcal); p-values were adjusted for false discovery rate using Benjamini-Hochberg; p-values <0.05 considered significant.

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Table 5: Mean daily intakes of Healthy Eating Guidelines food groups and count and percent of individuals meeting recommendations, for males and females

	Mean daily intake (g)					Meeting HEG				
	Males		Females			Males		Females		
Food group	**Mean**	**SD**	**Mean**	**SD**	**p-value**	**n**	**%**	**n**	**%**	**p-value**
Fruit and vegetables	347.1	176.8	338.8	196.4	0.76	50	33	60	29	0.46
Whole grains	30.4	27.0	27.2	25.5	0.69	28	19	37	18	0.92
Total meat	204.5	124.6	159.6	82.2	0.14	46	31	97	48	0.001
Red meat	95.6	66.3	72.8	52.5	0.11	59	39	121	59	<0.001
Fish	18.9	27.4	20.1	26.8	0.81	46	31	63	31	0.93
Dairy	247.3	178.8	205.4	142.5	0.67	19	13	22	11	0.60
HEG met										0.11
0-1						74	49	76	37	
2						42	28	67	33	
3						25	16	37	18	
4+						10	7	24	12	

HEG, Healthy Eating Guidelines. SD, standard deviation. Differences in food group intake compared using univariate general linear model analysis of covariance controlled for energy intake (kcal); differences in HEG groups compared using chi-square test; p-values were adjusted for false discovery rate using Benjamini-Hochberg; p-values <0.05 considered significant.

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Table 6: Mean daily food group intakes, environmental metrics and health biomarkers split by HEG met

	# HEG recommendations met								
	0-1 (n=150)		2 (n=109)		3 (n=62)		4+ (n=34)		
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	p value
Fruits and vegetables (g)	296.7	174.4	323.4	173.8	417.3	185.1	467.2	467.2	<0.001
Whole grains (g)	24.4	23.3	29.2	27.3	29.7	25.1	42.9	31.2	0.019
Total meat (g)	231.5	91.3	159.4	98.5	128.8	105.7	98.2	45.2	<0.001
Red meat (g)	115.7	60.2	69.4	51.0	49.7	40.7	37.9	25.4	<0.001
Fish (g)	9.0	16.7	16.4	23.2	33.3	33.0	51.9	28.8	<0.001
Dairy (g)	198.5	148.3	207.5	140.9	261.9	296.9	312.2	156.2	<0.001
GHGE (kg CO2-eq)	7.8	3.2	6.2	2.6	6.2	2.5	5.4	1.1	<0.001
Water footprint (L H_20)	804.6	613.4	774.9	576.1	700.2	478.1	690.3	406.6	0.99
Energy (kcal)	2236.6	657.3	2106.3	662.7	2086.8	592.2	2079.3	405.4	0.32
Healthy Eating Index	41.0	6.9	42.9	8.4	45.1	7.8	51.6	6.4	<0.001
Weight (kg)	85.3	16.2	82.1	20.4	78.8	17.0	74.9	16.4	0.01
BMI (kg/m^2)	28.8	5.3	28.2	5.7	26.9	5.0	26.4	4.7	0.009
Waist circumference (cm)	94.4	14.4	91.7	16.0	89.5	13.9	85.9	12.6	0.02
Total-C (mmol/L)	5.3	1.1	5.1	1.0	5.2	1.0	5.3	1.0	0.46
LDL-C (mmol/L)	3.4	0.9	3.1	0.9	3.2	0.9	3.3	0.9	0.84
HDL-C (mmol/L)	1.5	0.4	1.5	0.4	1.5	0.4	1.6	0.4	0.63
TAG (mmol/L)	1.1	0.6	1.1	0.6	1.2	0.7	0.9	0.5	0.33
Glucose (mmol/L)	5.2	0.5	5.3	0.8	5.3	0.9	5.1	0.5	0.60
Insulin (pmol/L)	56.1	39.3	57.5	42.3	53.3	38.0	43.0	30.6	0.44
CRP (mg/L)	2.0	2.8	2.2	3.3	1.9	2.1	2.3	3.1	0.38

HEG, Healthy Eating Guidelines. SD, standard deviation. GHGE (kg CO_2-eq), greenhouse gas emissions (kilogram of carbon dioxide equivalent). BMI, body mass index. Total-C, total cholesterol. HDL-C, high density lipoprotein cholesterol. LDL-C, low density lipoprotein cholesterol. TAG, triacylglycerols. CRP, C-reactive protein. Univariate general linear model analysis of covariance, controlled for sex, age, and energy intake (kcal); p-values were adjusted for false discovery rate using Benjamini-Hochberg; p-values <0.05 considered significant.