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Greenhouse gases emissions from the diet and risk of death and chronic diseases in the EPIC-Spain cohort

Carlos A. González[1], Catalina Bonet[1], Miguel de Pablo[1], María José Sanchez[2,3], Elena Salamanca-Fernandez[2], Miren Dorronsoro[4,5], Pilar Amiano[4,5,6], Jose María Huerta[3,7,8], María Dolores Chirlaque[3,7,8], Eva Ardanaz[3,9,10], Aurelio Barricarte[3,9,10], Jose Ramón Quirós[11], Antonio Agudo[1], Marta Guadalupe Rivera Ferrer[12]

1 Unit of Nutrition and Cancer, Cancer Epidemiology Research Program, Catalan Institute of Oncology (ICO)-IDIBELL, Barcelona, Spain
2 Escuela Andaluza de Salud Pública, Instituto de Investigación Biosanitaria ibs, Hospitales Universitarios de Granada/Universidad de Granada, Granada, Spain
3 CIBER Epidemiology and Public Health (CIBERESP), Madrid, Spain
4 BioDonostia Research Institute, San Sebastian, Spain
5 Public Health Department of Gipuzkoa, Government of the Basque Country, San Sebastian, Spain
6 Subdireccion de Salud Pública de Gipuzkoa, Gobierno Vasco, San Sebastian, Spain
7 Department of Epidemiology, Murcia Regional Health Council, IMIB-Arrixaca, Murcia, Spain
8 Department of Health and Social Sciences, Universidad de Murcia, Murcia, Spain
9 Navarra Public Health Institute, Pamplona, Spain
10 Navarra Institute for Health Research (IdiSNA), Pamplona, Spain
11 EPIC Asturias, Public Health Directorate, Asturias, Spain
12 Agroecology and Food Systems Chair, University of Vic-Central University of Catalonia, Vic, Spain

Correspondence: Carlos A. González, Instituto Catalán de Oncología, Avda Gran Vía 199-203, 08907 Hospitalet de Llobregat, Barcelona, España, Tel: +34 (636) 822 705, email: cagonzalez@iconcologia.net

Background: Evidence from the scientific literature shows a significant variation in greenhouse gas (GHG) emissions from the diet, according to the type of food consumed. We aim to analyze the relationship between the daily dietary GHG emissions according to red meat, fruit and vegetables consumption and their relationship with risk of total mortality, and incident risk of chronic diseases. **Methods:** We examined data on the EPIC-Spain prospective study, with a sample of 40 621 participants. Dietary GHG emission values were calculated for 57 food items of the EPIC study using mean emission data from a systematic review of 369 published studies. **Results:** Dietary GHG emissions (kgCO_2eq/day), per 2000 kcal, were 4.7 times higher in those with high red-meat consumption (>140 g/day) than those with low consumption (<70 g/day). The average dietary GHG emissions were similar in males and females, but it was significantly higher in youngest people and in those individuals with lower educational level, as well as for northern EPIC centers of Spain. We found a significant association with the risk of mortality comparing the third vs. the first tertile of dietary GHG emissions [hazard ratio (HR) 1.095; 95% confidence interval (CI) 1.007–1.19; trend test 0.037]. Risk of coronary heart disease (HR 1.26; 95% CI 1.08–1.48; trend test 0.003) and risk of type 2 diabetes (HR 1.24; 95% CI 1.11–1.38; trend test 0.002) showed significant association as well. **Conclusions:** Decreasing red-meat consumption would lead to reduce GHG emissions from diet and would reduce risk of mortality, coronary heart disease and type 2 diabetes.

Introduction

Feeding 9–10 billion people by 2050 with healthy food while reducing global greenhouse gas (GHG) emissions are considered two of the most important challenges faced by humanity.[1,2] Currently, it is estimated that half of the global population suffers some kind of malnutrition (undernutrition, over nutrition and micronutrient deficiency).[3] Besides, food systems, including all the activities, actors and institutions from the production to the consumption of food, generate between 21% and 37% of total GHG emissions.[2] The IPCC in the Special Report on Climate Change and Land noted that reducing GHG emissions from food systems requires interventions both in the production (supply) and consumption (demand) components of food system.[4]

Evidence from scientific literature shows that there is a significant variability in GHG emissions from the diet, according to the type of food consumed: diets based on meat consumption release higher amounts of GHG than vegetable-based diets.[3,5–9] The causes of these differences depend on GHG emissions associated to livestock, deforestation for grazing, production of feed crops, methane emissions from the digestive system of ruminants and manure, among others.[6,7] Thus, the available data suggest that changes in consumption patterns are essential to reduce the impact of food system on global warming.

Estimations by international organizations indicate that the world population will increase by the year 2050 and also will have a higher per capita income that will contribute to a stronger demand for protein of animal origin (73% more meat and 58% more dairy products), compared to 2010, which is considered environmentally unsustainable.[2] The 2030 agenda of the United Nations for Sustainable Development shows that combating climate change, protecting natural resources and ensuring sustainable food and agriculture are at the center of global concern.[2] However, measures to reduce GHGs are mainly focused on reducing the production of energy from fossil fuels and an insufficient importance is given yet to food pattern intake.

Furthermore, there is solid scientific evidence, based on epidemiological studies and systematic reviews, showing that diet patterns based on a high consumption of plant foods [such as Mediterranean diet (MD), flexitarian or vegetarian] are associated with a lower risk of non-communicable diseases (NCD), such as obesity, type 2 diabetes, cardiovascular disease and some types of cancer.[10–15]

Several studies were developed with the aim to estimate the environmental impact of different patterns of diet, such as Vegetarian,[9] Vegans and high meat eaters,[7] MD,[16–18] Atlantic diet in Northwestern Spain[19] or the Swedish dietary pattern using different methodologies.[20] Those results show that daily GHG emission per capita in MD were between 2.19 and 2.86 kgCO_2eq, Atlantic diet released 2.78 kgCO_2eq, while high meat eaters in UK released 7.19 and 5.21 kgCO_2eq were emitted for the Swedish dietary pattern.[9]

There are however few studies that link both health and environmental dimensions of diets. It is claimed that vegetable-based diets are both healthier and more sustainable. Chronic diseases, such as myocardial infarction, type 2diabetes and cancer, are often associated with a high red meat intake.[13] Therefore, it is expected to observe a relationship between the risk of NCD and a higher dietary GHG emissions. However, when the link between dietary GHG emissions and mortality was assessed previously in a cohort study no association was found. We are not aware of other studies that have explored this association.[21]

The aim of this study is to estimate dietary GHG emissions from individuals in the European Prospective Investigation into Cancer and Nutrition (EPIC) Spain cohort according to sex, age, educational level, Spanish region, food items and the consumption amount of red meat, fruit and vegetables.[22] Moreover, in this article, we aim to advance on the association between sustainable and healthy diets by analyzing the daily dietary GHG emissions and the incident risk of myocardial infarction, type 2diabetes, cancer and general mortality in EPIC-Spain cohort.

Methods

Study population

The EPIC study is a large, ongoing prospective cohort study involving 23 centers in 10 European countries (Denmark, France, Germany, Greece, Holland, Italy, Norway, UK, Spain and Sweden) designed to study the role of dietary, lifestyle, environment and genetic factors in the development of cancer and other chronic diseases.[23] The EPIC cohort consist overall of more than 500 000 subjects (70% women), mostly age 30–70 years, recruited mostly between 1992 and 1998, usually from different social sectors and from both urban and rural areas.

The EPIC-Spain prospective cohort, includes 40 621 participants (38% men and 62% women), recruited from five regions of Spain (Asturias, Granada, Guipuzkoa, Murcia and Navarra), where Population base Cancer Registry exist.[22] Each participant's usual food intake was obtained through individual interviews at recruitment by using a validated electronic dietary history questionnaire.[24] The EPIC-Spain dietary questionnaire included a list of 662 registered foods that were grouped and reduced to 240 food items used in EPIC Europe studies.[23]

Classification of diet groups

Red meat consumption data was divided into three groups: high red meat consumers (>140 g/day), medium red meat consumers (70 and 140 g/day) and low red meat consumers (<70 g/day), based on recommendation to eat no more than 70 g/day of red meat.[25] For the GHG release estimation from red meat, consumption of fresh beef, veal, pork, lamb, horse and goat, was considered. To assess processed meat consumption (not included in the list from Clune et al.),[8] we considered, according to EPIC data, that in Spain, 50% of the consumption comes from pork meat, 25% from beef and 25% from chicken.

Computation of dietary GHG emission

Data on food GHG emission in kgCO_2eq/kg for 57 food items of EPIC-Spain were obtained from a systematic review from life cycle assessment (LCA) studies.[8] This meta-analysis reviewed 369 published studies that provided 1718 global warming potential values (GWP) for 168 varieties of fresh food products. Most of the food GWP values collected in this database comes from Europe, UK and EEUU, but there are also values from Asia, South America and Africa.

The GHG emission mean value for 133 food items from this systematic review (expressed in kgCO_2eq/kg of food) was applied to the same food items of the 240 food list of EPIC-Spain. The corresponding selected GHG emission value for the 240 Spanish food list is presented in Supplementary table S1. The item corresponding to the group or the subgroup of the Spanish list was not considered to avoid duplication, if the single components of the group or subgroup were taken. For 118 foods items of the Spanish list, there were no similar food items in the Clune review, therefore, they were classified as not applicable. They belong mainly to the group of fat (22 items), sugar and confectionary (13 items), non-alcoholic beverages (26 items), alcoholic beverages (16 items), condiments and sauces (14 items) and soup and bouillons (12 items). Final GHG emission value of 57 food items from EPIC (representing 68% of the mean of total calories intake of the participants), expressed in daily dietary kgCO_2eq/g of food are shown in table 1.

Other variables

Age was grouped in three categories (<45 years; 45–60 years and >60 years). Spanish regions were classified as the five regions of Asturias, Granada, Guipuzkoa, Murcia and Navarra, where the Spanish EPIC cohort is being conducted. Asturias, Guipuzkoa and Navarra are in the north and Murcia and Granada on the Mediterranean coast. Educational level was classified in six categories according to the highest completed level at recruitment: none; primary school; technical school; secondary school; university; and not specified.

Total mortality and incidence of chronic diseases

Identification of events or endpoints was done at different time of the follow-up according the aims of different studies performed in the EPIC cohort regarding these end-points. Assessment of the number of deaths within the cohort was performed by a record linkage of the EPIC-Spain database with the Spanish National Registry of Death from the National Institute of Statistic.[26] During 18 years of follow-up 3561 deaths were identified. Confirmed first event of incidence of fatal and non-fatal coronary heart disease (CHD) and unstable angina requiring revascularization were ascertained by means of self-reported questionnaires, hospital morbidity, mortality registries and population CHD registries available in some regions.[27] A total of 1007 participants had a fatal or non-fatal confirmed acute myocardial infarction or unstable angina requiring revascularization after a mean follow-up of 10.4 years. Incidence of first event of type 2 diabetes was ascertained by means of several sources of information: self-report, linkage with primary care registers, drugs registers, hospital admission and mortality data.[28] During 12.1 years of follow-up, 2025 incidence cases of type 2 diabetes were identified. The identification of first incidence cancer cases was done through periodic record linkage between the EPIC data base and the Population Cancer Registry in each of the included regions. Until 2015, 4457 incident cancer cases were identified.

Table 1 Dietary mean GHG emissions ($kgCO_2eq$/g of food by 2000 cal by day) estimated for the EPIC-Spain cohort

Food item	$kgCO_{2eq}$/g	SD
Potatoes	0.0148	0.0087
Leafy vegetables	0.0261	0.0244
Fruiting vegetables	0.0741	0.0580
Root vegetables	0.0017	0.0032
Cabbages	0.0031	0.0075
Mushrooms	0.0005	0.0016
Onion, garlic	0.0044	0.0033
Stalk vegetables, sprouts	0.0047	0.0113
Legumes	0.0320	0.0212
Fruit n.s.	0.0001	0.0013
Citrus fruits	0.0347	0.0373
Apple and pear	0.0325	0.0470
Grape	0.0016	0.0058
Stone fruits	0.0141	0.0264
Berries	0.0015	0.0058
Banana	0.0040	0.0134
Kiwi	0.0036	0.0155
Non-citrus fruits n.s.	0.0507	0.0871
Tree nuts	0.0018	0.0067
Peanuts	0.0003	0.0017
Seeds	0.0006	0.0050
Coconut, chestnut	0.0000	0.0005
Olives	0.0020	0.0043
Milk	0.3224	0.2540
Yoghurt, thick fermented milk	0.0531	0.0958
Cheese	0.2210	0.2808
Cream desserts, puddings	0.0086	0.0249
Dairy creams	0.0009	0.0093
Milk for coffee and creamers	0.0000	0.0000
Flour, flakes, starches	0.0003	0.0014
Pasta, rice, other grains	0.0000	0.0000
Pasta	0.0118	0.0103
Rice	0.0968	0.0657
Other grains (100% cereal)	0.0000	0.0000
Pasta-like cereal-based	0.0000	0.0000
Bread	0.0667	0.0354
Breakfast cereals	0.0007	0.0047
Salty biscuits, aperitif biscuits	0.0003	0.0015
Pastry	0.0000	0.0000
Bread/pizza dough	0.0004	0.0017
Beef	0.0622	0.3189
Veal	0.7011	0.7913
Pork	0.0553	0.0728
Mutton/lamb	0.1115	0.2759
Horse	0.0049	0.0843
Goat	0.0017	0.0436
Chicken, hen	0.1301	0.1121
Turkey	0.0046	0.0322
Duck	0.0000	0.0011
Rabbit (domestic)	0.0147	0.0324
Processed meat	0.3787	0.3072
Offal	0.0604	0.1641
Fish	0.2389	0.1747
Crustaceans, mollusks	0.0654	0.0892
Egg and egg products	0.0821	0.0604
Butter	0.0048	0.0275
Soya products	0.0001	0.0021

Statistical analysis

The arithmetic mean and standard deviation (SD) has been used as descriptive statistics for continuous variables. Categorical variables were described using absolute and relative frequencies. Comparisons for total emissions between food groups or baseline variables were examined by the T-Test (for two group comparisons) or analysis of variance (ANOVA) (for more than two groups).

The average daily consumption of selected foods and macronutrients of the three groups of red meat consumers were estimated by a linear regression model adjusting by sex, age and calorie intake. Tests for linear trend across the three groups were performed.

Table 2 Mean dietary GHG emissions ($kgCO_2eq$ by 2000 cal/day per capita) for the main food groups in the EPIC-Spain cohort

Food group	Mean (kgCO2eq/day)	SD
Fruit	0.14	0.11
Vegetables	0.12	0.77
Cereals	0.08	0.04
Legumes	0.03	0.02
Dairy products	0.61	0.39
Fish and mollusks	0.30	0.20
Chicken	0.13	0.31
Processed meat	0.38	0.31
Total red meat	0.99	0.85
Red meat <70 g/day	0.69	0.58
Red meat 70–140 g/day	1.95	0.80
Red meat >140 g/day	3.25	1.39

The Cox regression model was used to assess the association between daily dietary GHG emissions and end-points of the cohort study: total mortality, and incidence of CHD, diabetes and total cancer. Age was used as the time-scale, and the models were stratified by center and age at recruitment, and adjusted by sex. The effect of other potential confounders, such as smoking, alcohol intake and BMI, were assessed in a sensitivity analyses. Categorical analysis was performed comparing high (third tertile) and medium (second tertile) vs. low (first tertile) of the distribution of GHG emissions, and continuous analysis for 1-unit (1 $kgCO_2eq$) increase in the level of dietary GHG emissions.

Statistical significance was established at the 5% level and all analyzes were performed using STATA statistical package.

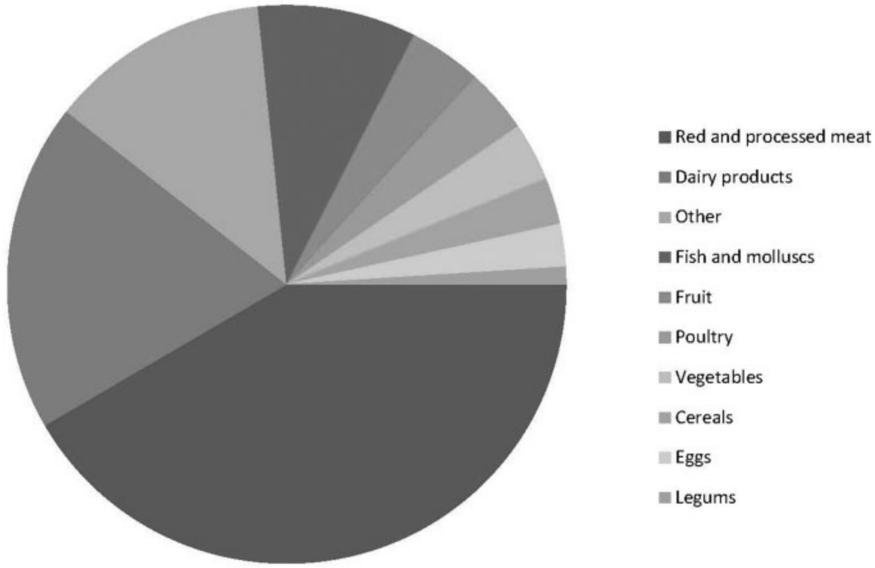
Results

Our analysis included 40 621 participants of the EPIC-Spain cohort, 62.3% were females and the average age was 49.3 years. The mean dietary GHG emissions in $kgCO_2eq$ of food estimated for the cohort was 3.01 (SD 0.94) per day and per capita. The highest contributions were from veal and processed meat (table 1). When single foods items were gathered in main food groups (table 2 and figure 1), we could observe that 41.59% of dietary GHG emissions from our cohort came from red and processed meat; 19.02% from dairy products and 9.15% from fish and mollusks. The lowest contribution (only 11%) was from fruits, vegetables, legumes and cereals.

In our cohort, 33 446 (82.3%) participants had a low red meat consumption (<70 g/day); 6452 (15.9%) a medium consumption (70–140 g/day); and only 723 (1.8%) a high red meat consumption (>140 g/day) (table 2). Comparing dietary GHG emissions among those individuals with low daily red meat consumption (<70 g/day) vs. those with medium (70–140 g/day) daily red consumption (table 2), it was observed that the level of dietary GHG emissions was 2.8 times higher, and 4.7 times higher than those with high red meat consumption (>140 g/day).

Supplementary table S2 shows the means of daily dietary GHG emissions ($kgCO_2eq$) for different variables. The average dietary GHG emissions was similar (*P*-values of difference 0.3341) for males and females. GHG emissions were slightly higher in the youngest age group as well as in individuals with an education up to primary or technical school (most probably belonging to low socioeconomic level), and in northern EPIC centers (Asturias, Guipuzkoa and Navarra).

Table 3 shows the associations of dietary GHG emissions with the risk of overall death and the risk of chronic diseases. We found a significant association with the risk of general mortality (trend test 0.037) when we compared the third against the first tertile of the distribution of dietary GHG emissions [hazard ratio (HR) 1.095; 95% confidence interval (CI): 1.007–1.19]. This means that it was



Diet	% of the median
Red and processed meat	41,5937
Dairy products	19,0203
Other	12,7425
Fish and mol·luscs	9,1534
Fruit	4,1974
Poultry	3,732
Vegetables	3.3974
Cereals	2,6915
Eggs	2,4781
Legums	0,9937

Figure 1 Proportion of the mean greenhouse emissions (kgCO2eq/g of food by 2000 cal/day) for main foods groups estimated for the EPIC-Spain cohort

Table 3 Risk (hazard ratio and 95% CI) of total death and incidence of selected chronic disease according to daily mean dietary greenhouse emissions (kgCO_2eq/per capita/day)[a] in the EPIC-Spain cohort, adjusted by sex and stratified by Spanish center and age at recruitment

Variable	*N* of events/*N*	HR (95% CI)		*P*-trend	HR (95% CI)
		GHG emissions categorical analysis[a]			GHG emissions: continuous 1-unit increase
		Second tertile	Third tertile		
Total death	3561/40 613	0.94 (0.86–1.02)	1.095 (1.007–1.20)	0.0368	1.057 (1.019–1.096)
CHD	1005/40 379	1.09 (0.93–1.28)	1.26 (1.08–1.48)	0.0039	1.125 (1.052–1.202)
Type II diabetes	2025/37 728	1.00 (0.90–1.12)	1.24 (1.11–1.38)	0.0002	1.099 (1.048–1.152)
Total cancer	4457/40 214	0.93 (0.86–1.00)	1.07 (0.99–1.15)	0.0662	1.031 (0.998–1.065)

a: Categorical analysis in tertiles of kgCO_2e/by g of food/day, cut-off: 2.53; 3.25. Reference category: first tertile.

almost 10% higher total mortality in individuals with the highest dietary GHG emissions vs. the lowest. HR was 1.057 (95% CI 1.019–1.096) for 1-unit (1 kgCO_2eq) increase when the emissions level was analyzed as continuous variable.

We also observed a significant association (trend test 0.003) with the risk of CHD (HR: 1.26; 95% CI 1.08–1.48). This risk was 26% higher in individuals with the highest vs. the lowest GHG emissions. Taking emissions levels as continuous variable the HR was 1.125 (95% CI 1.052–1.202) for 1-unit increase in the dietary emissions level. Moreover, there was a significant association (trend test 0.002) with the risk of diabetes type 2 (HR=1.24; 95% CI 1.11–1.38). The risk was 24% greater for the highest GHG emission category. As a continuous variable the HR was 1.099 (95% CI 1.048–1.152) for 1-unit increase. We found a borderline association with the risk of total cancer (HR=1.07; 95% CI 0.99–1.15; trend test 0.06) as categorical variable as well as a continuous variable (HR=1.031; 95% CI 0.998–1.065).

In a sensitivity analysis, we explored the potential confounding effect of smoking status (never, former, current and several duration and intensity categories), alcohol intake (never, former, current and several duration and intensity categories) and BMI on the association with total mortality. These risk factors are associated with the end-point of the study, but we do not have data about their association with the exposure of interest (GHG emissions levels). Both conditions are necessary to be a true confounder.

After adjusting for smoking, alcohol intake and BMI, HR for total mortality was 1.049 (95% CL 1.011–1.088) for 1-unit increase in the continuous analysis and 1.087 (0.999–1.184) when comparing highest vs. lowest emissions levels. The adjusted and not-adjusted results were very similar indicating that they are not important confounders.

Discussion

This study conducted in Spain on dietary GHG emissions has shown that the daily per capita mean GHG emissions in the EPIC cohort is 3.01 $kgCO_2eq$. This value is coherent with the results about the MD, Atlantic diet or Vegetarian diet found in other studies, and lower than what was observed in medium or high meat eaters.[9] This fact is expected given that 82.34% of the cohort has a low (<70 g/day) consumption of red meat and (more than 62%) has a high intake (>400 g/day) of fruit and vegetables. This means that our cohort follows a typical MD pattern. Different studies have shown that greater adherence to the MD pattern could reduce the risk of some types of cancer and the incidence of cardiovascular events and type 2 diabetes.[29–31]

After standardizing by 2000 kcal and adjusting for age and sex, diet associated to high red meat eaters (>140 g/day) have 4.7 times more GHG emissions than diets associated to low red meat eaters (<70 g/day). These results are also consistent with other studies conducted in Spain as well as in other countries.[7,9,16,18,19,21,32–34]

More than 41% of dietary GHG emissions in the Spanish EPIC cohort come from red and processed meat consumption, and only 11% are from plant foods (fruit, vegetables, cereals and legumes together). These results confirm that, to reduce dietary GHG emissions, it is necessary that high meat eaters reduce red meat consumption and substitute it by plants food in their diet.[10,15]

We found that the level of dietary GHG emissions is lower in older people that eat less meat. The level of dietary GHG emissions was lower for the EPIC participants in southern regions (Granada and Murcia) that eat more fruit and vegetables and less red meat than participants from the north (Asturias, Granada and Guipuzkoa).

In another EPIC study from The Netherlands[21] based on 40 011 subjects, GHG and land use for the usual diet were not associated with mortality.

Contrary to the results obtained in The Netherlands, we found a significant association between dietary GHG emissions and the risk of overall mortality. Moreover, we observed a significant association with the incidence risk of CHD and type 2 diabetes (26% and 24% risk increase, respectively), when we compare the highest levels of dietary GHG emissions against the lowest.[21] The observed increased risk with total cancer was just borderline significant. We also explored the potential association with digestive cancer (esophageal, gastric and colorectal) for which the evidence of their relationship with red and preserved meat is stronger, but, we did not find any association.[25] This could be due to the low number of digestive cancer cases (n=743) in our sample, so we do not have enough statistical potential to observe this association.

This study has several strengths, since it is based on data from the EPIC-Spain cohort, which is part of one of the largest prospective studies in the world, with a participating population of thousands of individuals, of both sexes and different ages, from different European regions.[23] We estimated GHG emissions in the food production chain, using values from the study by Clune et al. (2017), which is the largest systematic revision providing the mean of 1718 values of GHG emissions from 369 on LCA studies on 133 food items, performed in different continents of the world. This is one of the most completed databases available at the moment. Moreover, our study provides evidence on the importance to reduce red meat intake in Spain as a measure to reduce dietary emissions of GHGs. This is of particular interest in Spain as it is one of the countries in which the MD diet is currently changing patterns.[35]

One potential limitation of this study is that it relies on diet questionnaires, which are exposed to have some errors. However, the 'diet history' method used in EPIC-Spain has fewer errors than other type of questionnaires.[23] On the other hand, participants came from different social background and different geographical areas. In addition, the pattern of dietary intake was very similar to that observed in population-based surveys carried out in Spanish regions (Guipuzkoa and Granada) included in the EPIC cohort. Furthermore, despite the food consumption database of EPIC is relatively old (1992–98) it is perfectly valid to perform the analysis we did here, since our aim was to compare high vs. low meat eater and the association of dietary GHG emissions with chronic diseases, but not to describe the GHG emissions of the current Spanish dietary patterns. Finally, the study does not consider the calculation of GHG emissions from other sources in the food production chain (post-distribution centers: such as processing, distribution, preparation and waste), because these GHG emissions calculations were not available in the review.[8]

Conclusions

This study shows a positive relationship between dietary GHG emissions and the amount of red meat consumption, in diets standardized by 2000 kcal and adjusted for sex and age, in the EPIC-Spain cohort. A significant association between dietary GHG emissions with total mortality and the risk of CHD and type 2 diabetes was observed. This study shows that a transition toward a more sustainable and healthy diet through the reduction in red meat consumption in high meat eaters can improve population's health and contribute to the mitigation of climate change (mainly a low consumption of meats). In other words, low meat consumption diets contribute to human and planetary health. Therefore, it would be advisable that national and international public policies aimed at mitigating climate change reinforce recommendations to reduce the consumption of red meat and promote adherence to 'more sustainable diets', such as the MD, which are also healthier.

Supplementary data

Supplementary data are available at *EURPUB* online.

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Ethics

The EPIC Spain cohort study was approved by the Ethical Committee of the University Hospital of Bellvitge. Hospitalet, Barcelona.

Conflicts of interest: None declared.

Key points

- A decrease in red meat consumption would lead to reduce GHG emissions.
- Dietary GHG emissions and risk of total mortality are positively associated.
- Risk of coronary heart disease and type 2 diabetes is associated with dietary GHG emissions.

- Decreasing red meat consumption can contribute to the mitigation of climatic change and improve health of general population.

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