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Reduction of the carbon footprint of college freshman diets after a food-based environmental science course

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Abstract

The goal of this study was to evaluate the impact of a two-quarter freshman course series entitled "Food: A Lens for Environment and Sustainability" (Food cluster) on the carbon footprint of food choices by college freshmen attending a large public university in California. Students enrolled in the course completed a baseline questionnaire about their diets in early fall quarter and then again at follow-up, about 6 months later at the end of the winter quarter. The control group consisted of freshmen enrolled in a different course series entitled "Evolution of the Cosmos and Life" (Cosmos cluster). The instruction in the Food cluster included lecture material on general environmental science and life cycle analyses of food, an analysis of a reading comparing the environmental footprint of various types of meats, and classroom exercises to calculate the environmental footprint of typical foods. The Cosmos cluster instruction included climate change, but no information about food. While the two groups were statistically indistinguishable at baseline, throughout the period of the study, Food cluster students decreased (a) their overall dietary carbon footprint for a 2000-kcal normalized diet by 7% ($p = 0.062$), (b) the beef component of their dietary carbon footprint by 19% ($p = 0.024$), and (c) their reported ruminant consumption by 28% ($p < 0.001$). At follow-up, the overall dietary footprints for Food cluster students were 4153 and 5726 g $CO_{2\text{-eq}}$/day for female and male students, respectively, compared to 4943 and 6958 g $CO_{2\text{-eq}}$/day for female and male Cosmos students. In the Food cluster, both genders decreased their reported ruminant meat consumption by about a serving per week, while reported ruminant meat consumption increased for males in the control group. Modest, voluntary dietary changes such as those observed in this study could play an important role in mitigating climate change. Extrapolated across the entire US population, the difference in dietary carbon footprint observed between the Food cluster and control group would amount to 33% of the reduction required for the 2013 President's Climate Action Plan (2013).

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s10584-019-02407-8) contains supplementary material, which is available to authorized users.

1 Introduction

Food production and distribution systems are a significant contributor to greenhouse gas (GHG) emissions. The United Nations reported that livestock alone account for 14.5% of all anthropogenic emissions (Gerber et al. 2013), while the food system contributes up to 29% (Vermeulen et al. 2012). Shifts in food demand are increasingly viewed as untapped opportunities for meeting climate targets (Eshel et al. 2016; Springmann et al. 2018; Westhoek et al. 2014). In fact, many researchers consider dietary shifts essential if we are to avoid a > 2 °C global temperature shift (Bryngelsson et al. 2016; Hedenus et al. 2014; Stehfest et al. 2009; Bajzelj et al. 2014; Godfray et al. 2018). A new report proposing a diet for planetary and human health for a population of 10 billion allows little or no red meat, and states that small increases in red meat and dairy can make sustainability goals not reachable (Willett et al. 2019).

Recent calculations (Harwatt et al. 2017) of dietary shifts have shown that if the entire US population replaced the beef in their diets with beans, the result would be a savings in CO_2-eq amounting to 46 to 74% of the reduction required to meet US Climate Action Plan goals for 2020 (depending on the conversion factor used for g CO_2-eq produced per g of beef). While theoretical, these calculations are striking in that they show the profound role that food choices could play in abating climate change.

Over the past several decades, knowledge of the environmental impact of food choices has steadily grown. In general, animal products result in greater GHG emissions than plant foods due to the resources required to grow feed crops for livestock (Heller and Keoleian 2015; Meier and Christen 2013; Tilman and Clark 2014, b). Ruminant animal products, including beef, cheese, and dairy, are the animal foods with the highest GHG emissions per kilogram, per kilocalorie, and per serving, due to methane from digestion and manure, and nitrous oxide from manure. Methane and nitrous oxide have much larger climate warming effects per unit mass than CO_2.

Most analyses of the impact of dietary changes on GHG emissions have been based on hypothetical diets rather than on actual observed consumption patterns. Thus, we currently know very little about the true potential for dietary shifts to mitigate climate change. Meier and Christen (2012) suggested that the diet of female subjects in their study could serve as an example of a realistic lower carbon footprint dietary pattern appropriate for males to move toward as it accounts for factors like food availability and cultural conditions. In general, the males in this study had higher meat consumption while women consumed higher levels of fruits and vegetables. Green et al. (2015) modeled GHG emissions reductions that could be achieved while minimizing changes to the existing diet in the UK and found that realistic dietary scenarios that reduce rather than eliminate more resource-intensive foods fared almost as well as stricter diets. Scarborough et al. analyzed the self-reported dietary patterns in the UK of 65,000 people and found that the greenhouse gas emission (GHGE) of meat eaters were about two times those of vegans (Scarborough et al. 2014).

The potential for education about the effects of dietary choices on the environment and climate change is an important topic which is only beginning to be explored. The primary objective of this study is to evaluate the impact of an environmental science course taught through the lens of food on the carbon footprint of the students' voluntary dietary choices. Specifically, we compared changes in the carbon footprint of self-reported dietary choices and protein consumption in Food cluster students and a control group, before (baseline) and after the course (follow-up), and also examined differences in these changes between male and female students.

2 Methods

2.1 Study participants

Students in the test group were University of California Los Angeles (UCLA) freshmen enrolled in a year-long freshman cluster course entitled, "Food: A Lens for Environment and Sustainability," referred to as the Food cluster. Students completed surveys at baseline, which was the start of fall quarter, and then again 6 months later at follow-up, at the end of the winter quarter. A science-based course entitled, "Evolution of the Cosmos and Life," referred to as the Cosmos cluster, was chosen as a control group because it fulfilled similar General Education requirements as the Food cluster and thus may have attracted a similar group of students. The study was approved by the UCLA Institutional Review Board.

2.2 Cluster courses

The UCLA cluster program offers a range of year-long (three academic quarters) courses that cover "Big Ideas," and all fulfill various General Education requirements. Each year, the cluster program offers ten of these multi-disciplinary courses, drawing faculty and teaching assistants from multiple departments. These courses are open only to incoming freshman students, and about one-third of the UCLA freshman class enrolls in a cluster course. The first two quarters of these courses, the ones covered by this study, are "traditional" lecture/ discussion section courses—students attend lecture with the entire class two or three times a week, for the Cosmos and Food clusters, respectively, and a smaller discussion section of 20 students led by a Teaching Assistant once a week.

2.2.1 Food cluster instruction

For the fall and winter quarters, students attended three 1-h lectures per week (see SI for syllabus). In the fall, the course covered general environmental science topics such as biodiversity, ecology, climate regulation, nutrient cycling, and the water cycle. Case studies were used to show the impacts of food systems on these processes and ecosystem services. As a writing assignment, students analyzed a peer-reviewed paper comparing the greenhouse gas emissions associated with various animal-based foods (Eshel et al. 2014). Through classroom activities, students learned how to calculate the environmental footprint of meals using conversion factors from the Heller and Keoleian (2015) life cycle assessment (LCA) meta-analysis.

The first half of the winter quarter covered the carbon cycle, wind currents, atmospheric science, the mechanics of global warming, and histories of food production. The second half of winter quarter covered nineteenth to twenty-first century food production, urbanization, policy, and social impacts of food systems as well as art and film practices about food, eating, and sustainability to serve as models for students' creative work. Each student had to write a research paper on the carbon cost of producing a grocery store item of their choice, and then make a short film or performance to communicate something about their research findings for a general audience. Students also took midterm and final exams in both fall and winter quarters based largely on the Withgott and Laposata textbook *Environment: The Science Behind the Stories* (2014) and selected additional readings. The spring quarter seminars were not included in the study period.

2.2.2 Cosmos cluster instruction

Students attended two 75-min lectures per week (see SI for syllabus) covering a broad range of general science topics, including the Big Bang, stellar nucleosynthesis, planet formation, plate tectonics, biological evolution, genetics, and human evolution. Cosmos draws from the fields of astronomy, geology, ecology, physiology, and evolutionary biology to address questions about the origins of the universe and the evolution of life. Although this curriculum did include some information on climate change, for example the greenhouse effect and the carbon cycle, it did not cover in-depth strategies to alleviate climate change nor was there any material about food system or diet impacts on climate change.

2.3 Evaluation data

To evaluate the impact of the course on dietary behavior and knowledge of basic environmental science topics, a questionnaire was developed and administered online using Survey Monkey (www.surveymonkey.com), at the start of the course, and during the last week of the second quarter. Students were asked to estimate the number of servings consumed per week of 22 food categories, and respond to other questions about stress eating, their willingness to consume insects, and basic environmental science knowledge. Students were given a link to the online questionnaire when they were in class and by email. Participation was optional, and no identifying information was requested. To maintain student anonymity while matching up questionnaires provided by individual students at the start and end of the study, we asked students to provide (a) their favorite number, (b) the name of their first best friend, and (c) the name of their first pet. In every case, we were able to match follow-up questionnaires with baseline questionnaires using the responses to these questions. This method also allowed us to delete surveys for students who did not complete both pre- and post-surveys, and duplicates when students submitted the same survey more than once.

2.4 Calorie normalization for calculation of overall and beef dietary C footprints

We standardized each student's diet to 2000 kcal so that carbon footprint results would be comparable to those for the 2000-kcal/day diets that are typically discussed in the literature (Heller and Keoleian 2015; Meier and Christen 2013; Scarborough et al. 2014). To do this, we calculated total calories for each student by summing reported servings across all food categories. Caloric values for a serving of food were obtained from the USDA Food Composition Databases (https://ndb.nal.usda.gov/ndb/) by averaging calories of all food items within the food category. Standard serving sizes were clearly marked on the questionnaire, and it was assumed students were able to estimate weekly servings from the various food categories. Under- and overestimation of total caloric intake (relative to 2000 kcal per day) was adjusted for by using a multiplier calculated for each student which standardized total calories to 2000 kcal/day. This approach maintained the caloric distribution of food that the student reported between categories. Food waste was not considered here as a contributor to the dietary carbon footprint.

2.5 Conversion factors for GHG emissions

A summary of life cycle assessment (LCA) data of foods (Heller and Keoleian 2015) was used to calculate conversion factors (in g CO_2-eq/g food) for each of the categories listed in the questionnaire. For example, the conversion factor for the category "Temperate fruits" is the average of the Heller and Keoleian (2015) conversion factors for the five fruits listed in the questionnaire as examples of temperate fruits. Conversion factors for seeds and vegan milk alternatives, which were not included in the Heller and Keoleian paper, were obtained from another meta-analysis of LCA data (Meier and Christen 2013).

Because footprint calculations are especially sensitive to the beef conversion factor, we calculated the footprints using both US LCA data (40.2 g CO_2-eq/g beef) (Nijdam et al. 2012) and the average value given in Heller and Keoleian (2015) (26.45 g CO_2-eq/g beef). Harwatt et al. (2017) recently used this approach in their analysis of the carbon footprint reduction of replacing beef with beans, using a global average of 25.5 g CO_2-eq/g beef (Nijdam et al. 2012) and the US LCA value of 40.2 g CO_2-eq/g beef. Values used for other studies generally fall within this range. For example, Green et al. (2015) used a value of approximately 35 g CO_2-eq/g beef for a study of footprints in the UK. This range in values stems in part from the different beef production methods (Ogino et al. 2016).

2.6 Statistical analysis

Microsoft Excel was used to normalize calories and calculate carbon and beef footprints as well as the total reported protein and total protein corresponding to each student's calorie-normalized diet. Within each cluster, females and males were significantly different from each other in carbon footprint. Thus, questionnaire responses and footprint calculations were grouped into eight groups (by gender, cluster, and time point for statistical analysis). *R* was used to determine normality of overall carbon footprint, beef carbon footprint, reported ruminant consumption, and protein (both based on both reported data and the kcal-normalized diets) for each group using the Shapiro test and visual observation of histograms. Significance of differences between groups was tested using *t* tests when both groups were normally distributed and non-parametric analogs to *t* tests in cases of non-normal distribution. Paired *t* tests and the Wilcoxon signed-rank test were used when comparing fall and winter questionnaire responses of the same students, since the responses from individual students were matched, and unpaired *t* tests and the Mann Whitney Wilcoxon test were used to compare differences between the clusters and genders.

3 Results

3.1 Survey response

For the Food cluster, 66 females and 24 males completed both the fall and winter surveys. This total of 90 was 58% of the total winter enrollment of 154. For the Cosmos cluster, 56 females and 17 males completed both surveys. This total of 73 students was 42% of the Cosmos winter enrollment of 175.

3.2 Estimated total calories from reported data

For the baseline survey, total kilocalories (calculated from reported consumption of foods from 22 food categories) for females averaged 1350 and 1196 kcal/day for the Food and Cosmos clusters, respectively. For the follow-up, total kilocalories averaged 1243 and 1098 kcal/day for the two clusters, respectively. For males in the Food and Cosmos clusters, total calories averaged 1837 and 1610 kcal/day at baseline, respectively, with corresponding values of 1606 and 1638 kcal/day at follow-up. Differences were not statistically significant. It is notable that average total kilocalories estimated from reported foods consumed were fairly close to the 2000-kcal/day diet typically discussed in the literature.

3.3 Shifts in servings reported and carbon footprint of student diets

Figure 1a, b shows the change in reported servings from baseline to follow-up for each food category for both male and female students in each cluster. Bars to the left indicate a decrease from baseline to follow-up. See the SI for average reported servings for both groups and baseline and follow-up, and for descriptive statistics and hypothesis testing for vegetable, French fry, and cheese servings reported per week. Notably, women in the Food cluster increased their vegetable intake throughout the study by 27% ($p = 0.0068$) while the Cosmos females did not change significantly. Also, Food cluster men decreased their French fry consumption by 48% ($p = 0.054$).

The contribution of each food category to carbon footprint for female and males Cosmos students in the fall is shown in Fig. 2. For the pie chart, various food categories on the questionnaire were combined into groups such as "Grains." The contribution by ruminant meats was by far the largest contributor in all groups of students.

Table 1 shows the overall dietary carbon footprint for 2000-kcal normalized diet (overall diet CF (norm)), the beef portion of the carbon footprint for 2000-kcal normalized diet (beef CF (norm)), and the reported servings of beef per week for the Food and Cosmos clusters at baseline and follow-up as well as the results of statistical tests of the differences between the clusters. Additional descriptive information on data range and spread for each group can be found in SI. Comparing all survey responses from the two courses, there were no significant differences between the Food ($n = 90$) and Cosmos ($n = 73$) clusters at baseline for these parameters. At follow-up, the two clusters were significantly different from each other with respect to the overall diet CF (norm) ($p = 0.024$), beef CF (norm) ($p = 0.017$), and reported servings of beef ($p = 0.054$). In addition, when baseline and follow-up surveys for each student were matched and compared using paired hypothesis tests, students within the Food cluster showed significant changes over the time period of the study for the overall diet CF ($p = 0.062$), beef CF ($p = 0.024$), and reported servings of beef ($p < 0.001$), while the same variables for the Cosmos cluster students did not show significant changes between the baseline and follow-up.

Because male and female students had distinct dietary patterns, we also analyzed the data by gender for each cluster. Figures. 3, 4, and 5 depict the overall CF, beef CF, and reported ruminant meat servings per week, respectively, for all students (a), female only (b), and male only (3). For these figures and the statistical tests, we use the US-only life cycle analysis data for beef (Nijdam et al. 2012) (see "Methods"). See the SI for carbon footprints of food categories using the beef conversion factor by Heller and Keoleian (2015).

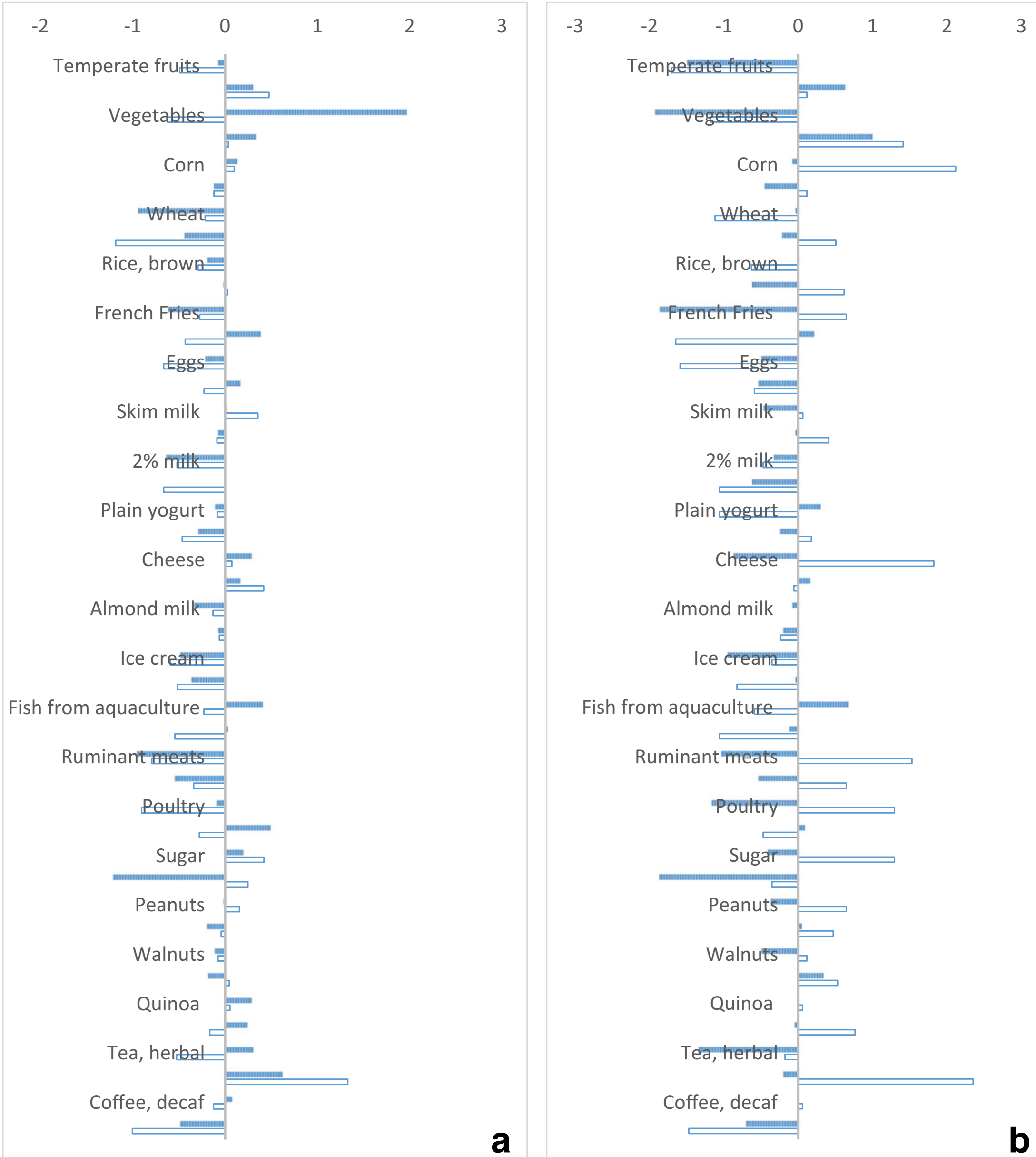

Fig. 1 Baseline to follow-up shifts in servings reported for all food categories for **a** female and **b** male students in the Food (filled bars) and Cosmos (empty bars) clusters. Bars going to the left show a decrease from baseline to follow-up. See Tables 2 and 3 and the SI for descriptive statistics and hypothesis testing for ruminant meats, vegetables, French fries, and cheese

For each gender as well as the class in aggregate, at the beginning of the study, the carbon footprints were very similar (and not statistically distinguishable) between students enrolled in the two courses. At the start of the school year (baseline), female students had mean carbon footprints of 4677 and 5083 g CO_2-eq/day for the Food and Cosmos clusters, respectively, for diets normalized to 2000 kcal/day. Mean carbon footprints of male students' kcal-normalized diets at the start of the school year (baseline) were 5486 and 5842 g CO_2-eq/day for the Food and Cosmos clusters, respectively. These average values are consistent with those calculated by Scarborough et al. (2014) of 5630 g CO_2-eq/day for medium meat consumers and 4670 CO_2-eq/day

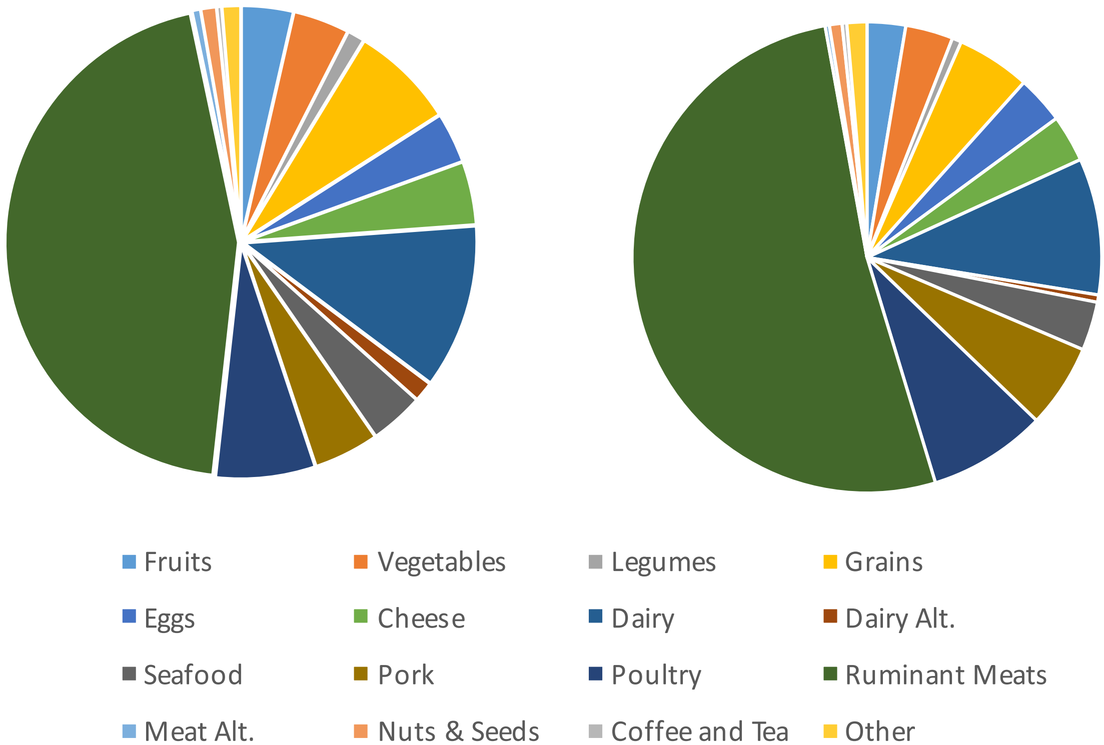

Fig. 2 Contribution to carbon footprint for food categories surveyed

for low meat consumers in the UK. The very similar starting diet indicates a level of appropriateness of the control group for the study, even though the students' interests played a role in their choice of courses.

At the end of winter quarter (follow-up), female food cluster students showed statistically significant decreases from baseline of 11% for overall diet CF ($p = 0.014$), 29% for beef CF (norm) ($p = 0.010$), and 34% for reported beef ($p = 0.0023$). Female students in the Cosmos cluster decreased their Reported Beef by 24% ($p = 0.068$), but did not significantly decrease their overall diet CF or beef CF. From baseline to follow-up, Food cluster males decreased their reported beef by 19% ($p = 0.071$), while the overall diet CF (norm) and beef CF (norm) remained the same. For Cosmos males, increases were observed for all three parameters, but they were statistically insignificant due to the small n (Table 2).

Comparing the two clusters at follow-up, female students in the two clusters differed from each other significantly for overall diet CF ($p = 0.032$), beef CF (norm) ($p = 0.013$), and reported beef ($p = 0.056$).

3.4 Protein consumption

The protein content in both the reported food servings and the 2000 kcal–normalized diet was well above commonly cited targets (approximately 46 g/day for females and 56 g/day for males, or 50 g/day for a 2000-kcal-per-day diet) in both clusters (see Table 3 for a summary and the SI for detailed description and statistics). In general, there was little difference between clusters or from baseline to follow-up.

Table 1 Overall dietary carbon footprint for 2000-kcal normalized diet (overall diet CF (norm)), beef carbon footprint for 2000-kcal normalized diet (beef CF (norm)), and the reported servings of beef per week for the Food and Cosmos clusters at baseline and follow-up. Testing for the difference between the means for the two clusters was conducted with an unpaired *t* test when both distributions were approximately normal and with the Wilcoxon signed-rank test when the distributions for one or both clusters were non-normal. Standard deviation, medians, and quartiles are given in SI. When the Food and Cosmos clusters differed with 90% or greater confidence, the numbers are italicized

Time of survey	Parameter	Units	Food mean	Cosmos mean	Comparing Food and Cosmos	
All students						
			Food (n = 90)	Cosmos (n = 73)	Test	p
Baseline	Overall diet CF (norm)	g $CO_{2\text{-eq}}$ day^{-1}	4900	5261	*t* test	0.20
	Beef CF (norm)	g $CO2_{\text{-eq}}$ day^{-1}	2260	2520	Wilcoxon	0.43
	Beef servings reported	Servings $week^{-1}$	3.5	3.6	Wilcoxon	0.60
Follow-up	Overall diet CF (norm)	g $CO_{2\text{-eq}}$ day^{-1}	*4572*	*5418*	*t* test	*0.024***
	Beef CF (norm)	g $CO_{2\text{-eq}}$ day^{-1}	*1832*	*2718*	Wilcoxon	*0.017****
	Beef servings reported	Servings $week^{-1}$	*2.5*	*3.4*	Wilcoxon	*0.054**
Female students only						
			Food (n = 66)	Cosmos (n = 56)	Test	p
Baseline	Overall diet CF (norm)	g $CO_{2\text{-eq}}$ day^{-1}	4684	5083	*t* test	0.22
	Beef CF (norm)	g $CO_{2\text{-eq}}$ day^{-1}	2063	2400	Wilcoxon	0.32
	Beef servings reported	Servings $week^{-1}$	2.8	3.2	Wilcoxon	0.35
Follow-up	Overall diet CF (norm)	g $CO_{2\text{-eq}}$ day^{-1}	*4153*	*4951*	*t* test	*0.032***
	Beef CF (norm)	g $CO_{2\text{-eq}}$ day^{-1}	*1473*	*2293*	Wilcoxon	*0.013****
	Beef servings reported	Servings $week^{-1}$	*1.8*	*2.4*	Wilcoxon	*0.056**
Male students only						
			Food (n = 24)	Cosmos (n = 17)	Test	p
Baseline	Overall diet CF (norm)	g $CO_{2\text{-eq}}$ day^{-1}	5494	5847	*t* test	0.47
	Beef CF (norm)	g $CO_{2\text{-eq}}$ day^{-1}	2801	2916	*t* test	0.80
	Beef servings reported	Servings $week^{-1}$	5.4	4.9	*t* test	0.63
Follow-up	Overall diet CF (norm)	g $CO_{2\text{-eq}}$ day^{-1}	5726	6958	*t* test	0.19
	Beef CF (norm)	g CO2-eq day^{-1}	2819	4118	*t* test	0.15
	Beef servings reported	Servings $week^{-1}$	*4.4*	*6.5*	*t* test	*0.10**

*, **, and *** denote greater than 90%, 95%, and 98% confidence in the difference between the means for the Food and Cosmos clusters, respectively

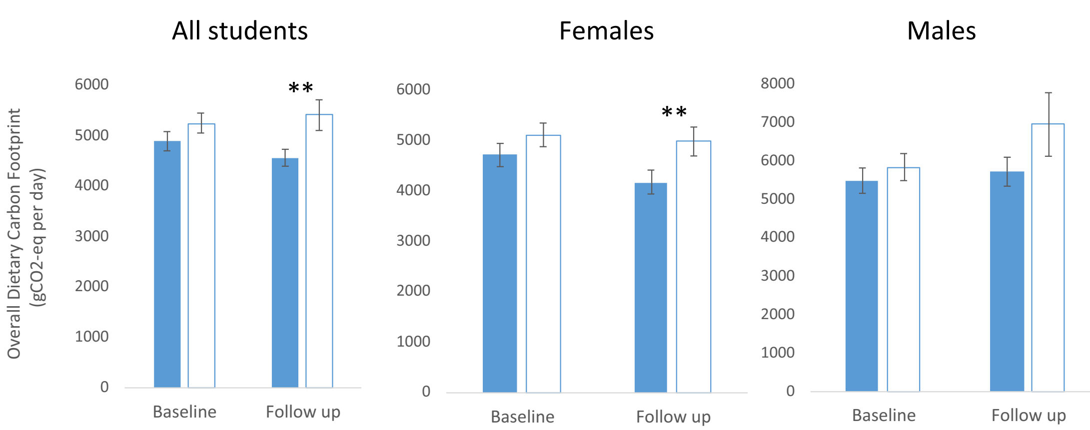

Fig. 3 Overall carbon footprint of 2000 kcal–normalized diet for all students (**a**), females (**b**), and males (**c**) in the Food (filled bars) and Cosmos (empty bars) clusters at baseline and follow-up. Error bars show standard error. Note change in scale. ** denotes a difference between the two clusters with 95% confidence

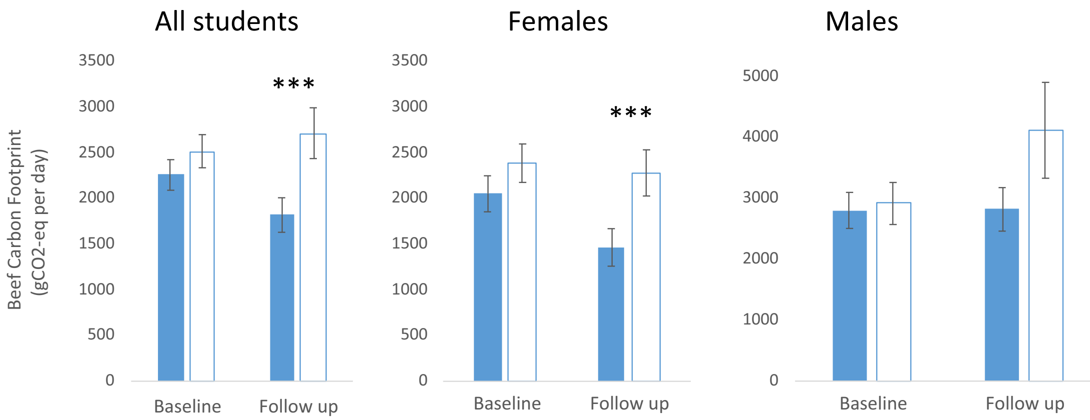

Fig. 4 Beef carbon footprint of 2000 kcal–normalized diet for all students (**a**), females (**b**), and males (**c**) in the Food (filled bars) and Cosmos (empty bars) clusters at baseline and follow-up. Error bars show standard error. Note change in scale. *** denotes a difference between the two clusters with 98% confidence

4 Discussion

4.1 Implications for climate change mitigation

This work illustrates both the important role that food can play in our carbon footprint and the influence that environmental education can have on our food choices, which are deeply ingrained and subject to many factors. The voluntarily dietary changes reported by UCLA students in response to increased education on food and sustainability could on a larger scale support climate goals in a substantial way.

A hypothetical calculation can be used to put this impact in context, similar to the recent analyses of the contribution to the President's Climate Action Plan (CAP) (Executive Office of the President 2013) (equivalent to the Copenhagen Accord) of a hypothetical beef to beans shift (Harwatt et al. 2017) and of healthier alternative diets (Hallström et al. 2017). The CAP target is "17% reduction below 2005 Emissions by 2020." If the overall Food Cluster versus Cosmos Cluster decrease (328 kg CO_2-eq /yr./capita) were applied to the US population in 2016 (323,127,513), the savings would be 106 million metric tons (MMT) of CO_2-eq. This is 33% of the 326 MMT CO_2-eq reduction that is needed to maintain CO_2-eq emissions below 5469 MMT (17% below the 2005 emissions) from the most recently reported (2016) net US

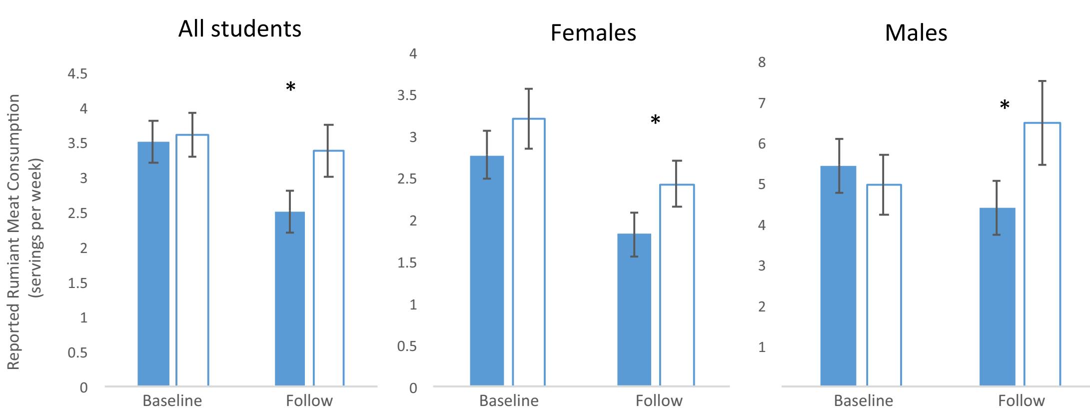

Fig. 5 Reported ruminant meat consumption for all students (**a**), females (**b**), and males (**c**) in the Food (filled bars) and Cosmos (empty bars) clusters at baseline and follow-up. Error bars show standard error. * denotes a difference between the two clusters with 90% confidence

Table 2 Average percent change from baseline to follow-up (B–F) for overall dietary carbon footprint, beef carbon footprint, and servings of beef per week. The baseline and follow-up values for the parameters are given in Table 1 and distribution information is presented in SI. After matching baseline and follow-up surveys for each student, paired hypothesis testing was used to determine the significance of the difference between baseline and follow-up for each cluster. Paired *t* tests were used when both data sets were approximately normal, and the Wilcoxon signed-rank (WSR) test was used when a normal distribution was not evident in both. Significant baseline to follow-up differences are italicized in the B–F and *p* value columns

	B–F	Test	*p*	B–F	Test	*p*
	All students					
	Food (n = 90)			Cosmos (n = 73)		
Overall diet CF (norm)	*− 7%*	*t* test	*0.062**	+ 3%	*t* test	0.61
Beef CF (norm)	*− 19%*	Wilcoxon	*0.024***	+ 8%	WSR	0.72
Beef Servings Report.	*− 28%*	Wilcoxon	*0.0004****	− 6%	WSR	0.48
	Female students only					
	Food (n = 66)			Cosmos (n = 56)		
Overall diet CF (norm)	*− 11%*	*t* test	*0.014****	− 3%	*t* test	0.66
Beef CF (norm)	*− 29%*	Wilcoxon	*0.010****	− 4%	WSR	0.75
Beef servings report.	*− 34%*	Wilcoxon	*0.0023****	*− 24%*	WSR	*0.068**
	Male students only					
	Food (n = 24)			Cosmos (n = 17)		
Overall diet CF (norm)	+ 4%	*t* test	0.40	*t* test	+ 19%	0.22
Beef CF (norm)	+ 1%	*t* test	0.94	*t* test	+ 41%	0.17
Beef servings report.	*− 19%*	*t* test	*0.071**	*t* test	+ 31%	0.23

*, **, and *** denote greater than 90%, 95%, and 98% confidence in the difference between the means for the Food and Cosmos clusters

GHGE of 5795 MMT (including net offsets from land use, land use change, and forestry) (EPA 2018). It should be noted, however, that our study population does not represent the population of the USA and may indeed be more malleable when it comes to diet.

It is useful to compare the GHG emission reductions possible through realistic changes in diet to those achievable through other lifestyle changes. The average of the female and male emissions reductions amounts to a drive of 4.5 miles per day in a typical car, for a total of 1659 miles over the year, which is 12% of the annual mileage for the average driver in the USA. The global average conversion factor for beef results in an average of 644 g CO_2-eq/day

Table 3 Total protein reported and total protein for a 2000 kcal–normalized diet at baseline and follow-up for female and male students in both clusters. All hypothesis testing for differences in the means between the Food and Cosmos clusters was done with the unpaired *t* test, as distributions were approximately normal in all cases. Information on median, quartiles, and standard deviation is given in SI. Where the difference between clusters was significant, values are italicized

Time of survey	Parameter	Units	Food mean	Cosmos mean	Food vs. Cosmos
Female students only					
Baseline	Total protein reported	g protein day^{-1}	74	74	1
	Total protein normal	g protein day^{-1}	*112*	*119*	*0.099**
Follow-up	Total protein reported	g protein day^{-1}	74	74	0.14
	Total protein normal	g protein day^{-1}	*112*	*119*	0.88
Male students only					
Baseline	Total protein reported	g protein day^{-1}	108	104	0.79
	Total protein normal	g protein day^{-1}	*113*	*133*	*0.025***
Follow-up	Total protein reported	g protein day^{-1}	99	109	0.44
	Total protein normal	g protein day^{-1}	128	134	0.49

* and ** denote greater than 90% and 95% confidence, respectively

for female and male emission reductions, which amounts to yearly mileage of 1058 miles in a 40-MPG car. A similar calculation by Berners-Lee et al. (2012) showed that changing the carbon footprint of the average UK diet to that of a typical vegetarian diet would lead to a GHG reduction equivalent to 50% of the country's car emissions.

Hedenus et al. (2014) projected future GHG emissions under a set of scenarios with variations in food consumption, livestock productivity, and specific technical mitigation to investigate the role of these factors in meeting targets. From all sectors, a total of 10–13 GT CO_2 eq/year is thought to be the amount of GHGE that is allowable if we are to maintain a 2 °C warming or less. A scenario assuming current trends in food consumption and the increased livestock efficiency that is predicted by the FAO could result in global GHG emissions of approximately 12.7 GT CO_2 eq/year by 2070 from the food sector alone, which is approximately equal to the total target GHG emissions from all sectors. Scenarios predicting even greater increases in productivity and technical measures are able to reduce the projected GHG emissions from the food sector alone for 2070 to approximately 7 GT CO_2 eq/year. By shifting diets away from ruminant meat toward either other meats or legumes and cereals, the authors show that much lower GHG emissions can be achieved by the agricultural sector (as low as 3–5 GT CO_2 eq/year by 2070), which would greatly increase the chances of meeting overall GHG emission reduction goals.

Bryngelsson et al. (2016) studied the potential for GHG emission mitigation through combined advancements in technology and dietary changes in Sweden. Under optimistic projections of increased livestock efficiency and technical measures, but not accounting for diet shifts, food-related Swedish emissions of methane and nitrous oxide may be reduced by almost 50%. However, the authors assert that meeting climate goals is likely to require even more substantial cuts, pointing out that decreases in ruminant meat consumption of 50% or more to either other meats or vegetable sources are probably unavoidable if climate targets are to be met. The authors made predictions of the carbon footprint savings for various food consumption scenarios. In order of increasing emission mitigation potential, the scenarios modeled were 50% less meat, 80% reduction in ruminant meat (only beef from the dairy industry allowable), vegetarian (meat replaced by legumes, eggs, and cheese), climate carnivore (no ruminant products), and vegan. A vegan diet along with optimistic technological advances could reduce food-related emissions by up to 90% compared to the current (reference) diet.

Similarly, a study of dietary GHG emissions in Finland showed that switching to an all-vegan diet would cut the food-related GHG emissions by 50%, and the total GHG emissions for the country by 8% (Risku-Norja et al. 2009). The authors state that such sweeping changes in personal dietary choice are not realistic because food choices are subject to many factors, including culture and purchasing power, and instead suggest that institutions responsible for public catering are poised to achieve greater environmental impact by purchasing in high volume and providing examples of sustainable food consumption.

4.2 Implications for behavior change

This work adds to the literature on the role of behavior changes, such as decreasing ruminant meat consumption and eating locally, to reduce carbon footprint. See Joyce et al. (2014) for a review. More specifically, we demonstrate that providing an academic course about the impacts of food systems on the environment can be a promising strategy for shifting dietary choices among college students. The Health Belief Model (HBM) is a widely used theory to explain health-related behaviors such as dietary choices. In general, the HBM suggests individuals will engage in behaviors when they perceive the benefits to outweigh the costs, and they are confident of their ability to successfully perform that behavior (Orji et al. 2012). Education can influence behavior by altering perceived costs and benefits and providing guidance on performing desired actions (Orji et al. 2012). While the HBM typically refers to costs and benefits related to personal health, it can be logically extended to other personal values, such as environmental sustainability. In this case, the Food cluster instruction likely increased students' perceived cost of eating high-impact foods (e.g., ruminant meat) and may have also increased their confidence in how to replace these foods with less impactful options (e.g., increasing plant-based proteins). A systematic review of dietary interventions with college students found that interventions were most effective when they combined education with self-regulation strategies (e.g., reflecting on and monitoring own diet), and that education about food-related topics beyond nutrition could also be effective in changing students' dietary behavior (Kelly et al. 2013). For example, in a similarly designed quasi-experimental study, Hekler et al. (2010) found that students enrolled in a Food and Society course significantly improved their healthful eating, while students in the health-oriented control course did not. The authors explained the results as potentially attributable to process motivation, where students were motivated to change their diets more by social issues than by personal health (Hekler et al. 2010). Our Food cluster course similarly focused on dietary impacts beyond the individual, which may have contributed to our impact on behavior change. However, in general, evidence for the sustainability of dietary changes observed as a result of university-based educational interventions is lacking (Deliens et al. 2016).

The observed gender differences are also important for understanding behavior change. Prior studies have documented higher meat intake among males, compared to females (Daniel et al. 2011; Meier and Christen 2012). Beyond physiologic differences, males' higher demand for meat may be attributable to psychological and social factors related to masculinity. A review of food consumption stereotypes suggests meat is associated with masculinity, and meat eaters are seen as more masculine than vegetarians (Vartanian 2015). Rothgerber (2013) suggests males may be less responsive to educational/informational appeals to reduce meat consumption, as the perceived costs of giving up meat are greater for men. Given the increased opportunities for students to consume beef in all-you-care-to-eat dining facilities, it is not surprising that reported beef consumption increased among male students in the Cosmos cluster (control group).

While promoting dietary behavior change is difficult, diets are in fact constantly shifting. Beyond the college setting, several studies shed light on Americans' readiness to shift away from diets high in red meat. According to a United States Department of Agriculture (USDA) report on dietary trends, red meat consumption declined by 29% from 1970 to 2014, while chicken consumption more than doubled (Bentley 2017). Recent analyses of trends in American diet quality also found significant increases in consumption of other protein foods such as seafood, whole grains, nuts, and seeds (Wilson et al. 2016; Zhang et al. 2018). In a 2018 nationally representative survey of American adults, 41% of respondents reported reducing red meat and 55% reported reducing processed meat, compared with 3 years ago (Neff et al. 2018). Among meat reducers, 51% cited cost and 50% cited health as reasons, with cost more frequently cited among those with lower incomes and health more frequently cited among those with higher incomes (Neff et al. 2018). Several studies from other countries have noted low public awareness of the role of animal food consumption in climate change and that those concerned about animal welfare may choose higher welfare foods (e.g., pasture raised) rather than reducing consumption (see discussion in Clonan et al. 2015). Research in the USA found that consumers have inaccurate ideas of the relative carbon footprint of different food choices, but that informational strategies such as GHGE labeling can improve choices (Camilleri et al. 2019). Still, USDA recently reported increased meat demand due to lower costs, although these trends are not yet well understood

(USDA 2018). Given these observed trends, it is likely that both educational and economic interventions are needed to achieve desired dietary shifts. Economic levers did not play a substantial role in this study due to the format of the dining halls.

Indeed, individual food choices occur in broader contexts determined by more distal, upstream factors such as government and industry policies. While most research focuses on proximal, individual-level factors that are most difficult to change, more distal determinants hold the greatest potential for widespread behavior change (Stok et al. 2018). As such, although the Food cluster course addressed food choice through education at the individual level, campus policies to improve the food environment (i.e., availability, accessibility, and affordability of healthy, sustainable food) are crucial for both encouraging and supporting long-term behavior change. These policy changes are already occurring at UCLA and other campuses.

Willett et al. (2019) outline three lessons for global change in their report on sustainable and healthy diets: (1) no single actor is sufficient in promoting wide-spread societal change, (2) science and evidence will be essential in the process, and (3) many types of policy levers are needed. Education can play a role in all three of these issues, as a full understanding of the role of ruminant products on the environment will be required for societal license for the interventions promoting diet shifts (Godfray et al. 2018).

There is a rich history of environmental progress involving changes in deeply entrenched perception and behaviors occurring as a direct result of education. Indeed, the modern environmental movement is rooted in a growing public awareness of the consequences of human activity on our environmental resources and our quality of life. The Clean Water and Clean Air Acts arose out of our increasing awareness through the 1960s of the impacts of pollution on health. The 1969 blowout of an oil well off Santa Barbara shined a graphic light on the need to protect our coast waters from destruction by oil exploration and development, and the consequence was a public initiative creating the CA Coastal Act. Public education for decades about recycling and the need to process our waste in a more rational, less profligate way has resulted in recycling becoming a common, accepted behavior in our society. While it may be an overreach to suggest that significant environmental progress has resulted from public education alone, it is no exaggeration to argue that public education is virtually always an essential element of such progress.

Moreover, the dietary behavior changes observed in this study are relevant not only for climate change mitigation but also for public health nutrition. The health and environmental co-benefits of replacing animal with plant foods are well-established (Springmann et al. 2016; Tilman and Clark 2014, b; van Dooren et al. 2014). Model diets with reduced red and processed meat and refined grains, and increased fruits, vegetables, whole grains, beans, and peas not only reduced per capita annual emissions by 84 kg $CO_{2\text{-eq}}$ but also reduced the relative risk of three diet-related diseases (type 2 diabetes, coronary heart diseases, and colorectal cancer) by 20–45% (Hallström et al. 2017). In addition, these healthier diets reduced per capita annual emissions by 84 kg $CO_{2\text{-eq}}$ due to reduced health care costs, which was a conservative estimate.

4.3 Protein consumption

Our results are in accord with recent research indicating high protein consumption rates in young men. An analysis of the 2007–2010 National Health and Nutrition Examination Survey revealed that young men were averaging roughly 100 g protein/day (Pasiakos et al. 2015). The recently revised Dietary Guidelines for Americans (USDA) specified that teenage boys and adult men may need to reduce consumption of protein foods and increase their intake of vegetables.

4.4 Limitations and strengths of the study

This study has limitations that are important to understanding its value. First, the number of respondents was relatively small, particularly for males, which limited statistical power to detect differences.

Second, there were likely differences between the control and treatment populations with respect to interest in the environment, resulting in confirmation bias. However, choosing an environmental science course with a food focus that did not include climate was not possible. The control group for this study was similar to the study group in that the students were unlikely to become science majors (UCLA students often take cluster courses to satisfy science General Education requirements toward a humanities-related degree), but Food cluster students may have a greater interest in environmental issues and would therefore be more likely to encounter other sources of information outside the class that could influence their behavior.

Third, assessing diet with questions about consumption of a list of foods is subject to recall bias. In addition, while measurement error can be expected with any dietary assessment instrument, it is helpful to know the magnitude and direction of this error. Further, despite anonymity, students aware of the high footprint of certain foods may have under-reported consumption of those foods.

Another important limitation to the impact of interventions like ours is the lack of evidence for sustainability of diet change over time. In a global systematic review of interventions to improve university students' diets on campus, most studies that showed an immediate post-treatment effect either did not collect later follow-up or found that the effect disappeared (Deliens et al. 2016). However, Robinson (2010) suggests that dietary interventions connected to social movements are most likely to disseminate and endure. Dietary behavior has also been shown to track from emerging to later adulthood, suggesting that college may be a particularly impactful time to target behavior (Nelson et al. 2008). In this sense, students who solidify new eating habits in college are likely to continue and even share these habits as they become professionals, parents, etc. College students can be thought of, then, not only as emerging adults but also as emerging consumers and drivers of social norms. Approximately 20 million Americans enrolled in colleges and universities in fall 2018, thus there is clear opportunity to reach a large portion of the population (National Center for Education Statistics 2018).

Further, our two-quarter intervention is less scalable than an intervention of shorter duration. Unfortunately, the study presented here was not designed to determine which components of the intervention were most responsible for the observed change. Further research into this will be critical for the development of intervention of shorter duration. For example, four online modules on green eating impacted behaviors and perceptions in a positive way on a college campus (Monroe et al. 2015).

Finally, while we extend our results to the entire population in order to illustrate the important role food could have in mitigating climate change, it is not known if this intervention would be effective in a different population.

5 Conclusions

This study shows that, among college students, providing an academic course about the relationships between food choices and environmental sustainability can lead to voluntary shifts in reported food choices, resulting in a lower dietary carbon footprint. The fairly modest reductions in GHG emissions observed here, extrapolated across the population, could have far-reaching benefits toward achieving climate change targets. Most previous research on the carbon footprint of diets has addressed hypothetical diets, while this work shows the impact of observed reported food choices. Substantial dietary change is critical for providing healthful diets in a sustainable way to a population that will reach ten billion (Willett et al. 2019). Education to increase awareness of the impacts of food systems on the environment is required for the interventions that will be needed to attain this dietary shift.

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Author contributions JJ conceptualized the project, is an instructor in the cluster, conducted the analysis, and principally drafted the article. RD, DAR, CN, and AF are instructors in the clusters and contributed to the study design, analysis, and manuscript. SK and EW assisted with data analysis. ML and JR contributed to data interpretation and implications of results. DR gave guidance on life cycle assessment calculations. WS and MW assisted with questionnaire design and interpretation. DC and HM contributed to the discussion of dietary behavior change analysis and implications for climate change. All authors participated in helpful discussions and edited the manuscript.

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