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RESEARCH ARTICLE

Integrating climate and food policies in higher education: a case study of the University of California

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ABSTRACT

Most climate change mitigation policies, including those of higher education institutions, do not include food system greenhouse gas emissions (GHGE). Yet the food system contributes ~30% of anthropogenic GHGE, mostly from animal source foods. Food system changes are necessary to meet GHGE mitigation targets and could do so relatively inexpensively and rapidly with major health, social and environmental co-benefits. To estimate the potential impact of integrating higher education institution climate and food policies, we used the case of the University of California (UC), comprising 10 campuses with 280,000 students. The UC is a leader in climate and food research, and has major policy initiatives for mitigating climate change and for promoting healthy, sustainable food systems. Like most higher education institutions, the UC climate change mitigation target for 2025 covers only Scope 1 and 2 GHGE (campus-generated and purchased energy), yet Scope 3 GHGE (indirect, including food system) are often institutions' largest. We created scenarios using results of studies of US dietary changes, and existing, planned or potential UC food system changes. These scenarios could reduce UC Scope 3 food emissions by 42–55%, equivalent to 8–9% of UC's targeted energy GHGE reduction, and 19–22% of offsets need to reach that target. These results have implications for broader climate policy in terms of food systems' high GHGE, the health, environmental, economic and social benefits of food system changes, and ways these changes could be implemented. To our knowledge this is one of the first empirical studies of the potential for integrating climate and food policy in HEIs.

Key policy insights

- Most higher education institution climate policies, including those of the University of California (UC), do not include food system GHGE
- Research at higher education institutions makes major contributions to understanding the need to reduce food system GHGE to achieve Paris Agreement goals
- Higher education institutions, including UC, have made many food system changes, but their climate co-benefits are not optimized, documented or integrated with climate policies
- Our food system change scenarios show that UC's food system could substantially reduce GHGE
- These changes can incentivize UC and other higher education institutions to integrate their climate and food policies.

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1. Introduction

Anthropogenic global climate change is an existential emergency threatening Earth's ecosystems and human society (IPCC, 2018; Lenton et al., 2019; USGCRP, 2018), yet greenhouse gas emissions (GHGE) continue to increase at relatively rapid rates (WMO, 2019) in spite of the recent Paris Agreement by world nations to mitigate emissions (UNFCCC, 2015). The food system (Vermeulen et al., 2012), especially ruminant animal source foods and animal source foods in general (Eshel et al., 2014; Godfray et al., 2018), and food waste (Hiç et al., 2016), contributes one third or more of GHGE. Therefore, there is an urgent need to reduce food system GHGE to meet the goals of the Paris Agreement and avoid catastrophic climate change, while feeding a growing population (Harwatt, 2018). Recent work suggests that this is best done through a combination of healthier, more plant based diets in addition to technological improvements and reduction in food waste (Bajželj et al., 2014; Godfray et al., 2018; Hedenus et al., 2014; Springman et al., 2018; Willett et al., 2019).

Diets supported by the current food system are also a major cause of a pandemic of overweight, obesity and noncommunicable diseases (NCDs), including diabetes, heart disease and cancer (Afshin et al., 2019; Aleksandrowicz et al., 2016; Chen et al., 2018). In addition, NCDs are both associated with mental illness, and share the same risk factors (Stein et al., 2019). It is now well established that diets with the least climate impact can also have the most health benefit (Hallström et al., 2015; Macdiarmid, 2013; Springmann et al., 2016; Tilman & Clark, 2014). However, there are tradeoffs, for example for populations obtaining most of their energy from starchy carbohydrates, the addition of meat 'or other major protein sources is likely to mitigate micronutrient deficiencies and have metabolic benefits by reducing high glycaemic load' and improve overall health (Willett et al., 2019, p. 10).

The pandemic of NCDs contributes to rapidly rising health care costs which could reach $47 trillion annually by 2030 globally (Bloom et al., 2011), and a total of $95 trillion for 2015–2050 in the US, or $265,000 per person (Chen et al., 2018). NCDs exacerbate economic inequities within societies globally (Nugent et al., 2018), and in the US (NASEM, 2017). Health care costs of diet-related NCDs also generate GHGE (Eckelman & Sherman, 2016; Hallström et al., 2017).

While our understanding of the linkages between the climate and food systems is growing rapidly, most climate and food policies do not reflect this understanding. For example, many climate policies include only Scope 1 and Scope 2 emissions (from energy sources), and sometimes a portion of Scope 3 (commuting, work and business travel), even though Scope 3, including food, comprises the majority of most institutions' emissions (GHGP, 2011). These include the policies of most higher education institutions (HEIs) that provide much of the research establishing these linkages (for example, AASHE, 2019), and are educating the scientists, activists and policy makers who will be critical in achieving policy integration.

HEIs see themselves as leaders in addressing climate change, e.g. since 2006 as part of Second Nature, which is a higher education non-profit organization promoting action on climate change. In this role they have created a number of commitments, including the Climate Leadership Network, to 'lead on climate and sustainability' now comprising 'hundreds' of HEIs in the US (SN CLN, 2020a). In 2018, HEIs from across North America formed the University Climate Change Coalition (UC3), affiliated with the Climate Leadership Network, to share knowledge and experience in mitigating climate change with each other and 'surrounding communities, and public and private sector partners' thus 'serving as models for climate solutions' (SN UC3, 2020).

Many HEIs are also making food system changes with goals of increasing healthfulness and decreasing negative environmental and social impacts (e.g. Middleton & Littler, 2019), but their climate co-benefits are seldom quantified and so not integrated with climate policy. As a result, food system changes are rarely part of climate policy-making, resulting in 'distorted decision-making' that overemphasizes costs, and in climate policies that fail to reach goals (Karlsson et al., 2020, p. 293). It is therefore critical to examine the potential for better integration between climate and food policies at HEIs.

We chose the University of California (UC) as a case study of the potential for integrating these policies because it is a key player in HEI climate policy; the above-mentioned UC3, for example, was envisioned by UC President Janet Napolitano (SN, 2020a). Like many other HEIs, UC is also a major contributor to climate and food systems research, and promotes major policy initiatives in both climate and food. These include the Carbon Neutrality Initiative (CNI) with the goal for UC of net zero Scope 1 and 2 GHGE by 2025, and the

Global Food Initiative, which targets improving health, food security and sustainability at UC, in California, the US and the world. UC is one of the world's leading public research universities, with 280,000 students and 240,000 faculty and staff on 10 campuses. It is also the third largest employer in California, whose 40 million residents makes it the most populous state, while its economy ranks 5th among nations.

Our goals here are, first, to estimate the GHGE reductions of food system change scenarios for UC in order to evaluate the potential for these food system changes to contribute to UC and HEI climate policy. Our scenarios are based on studies of changes in the US food system, and on examples of food system changes at some UC campuses. Our second goal is to use results of our scenarios to stimulate discussion of the imperative for integrating food system changes within broader climate policy. This includes the food systems' high GHGE, the economic, health, environmental, and social benefits of food system changes, and the ways in which these changes could be implemented. To our knowledge, this is one of the first empirical studies of the potential for integrating climate and food policy in HEIs.

2. Climate and food policy at the University of California

2.1. UC climate policy

UC's main climate change mitigation policy, the CNI, was established in 2013 and is promoted as a leading example for global climate policy (Victor et al., 2018). The CNI goal is eliminating or offsetting all Scope 1 (on-campus energy sources) and Scope 2 (off-campus energy sources – purchased electricity and steam) GHGE by 2025 (amounting to 1,129,233 MtCO_2e yr^{-1} as of October 2018), and by 2050 a portion (commuting to campus and business travel) of Scope 3 GHGE. These goals have since been adopted into UC's Sustainable Practices Policy, which sets operational goals in sustainability for the entire UC system.

The three prongs of CNI's mitigation effort (increased efficiency, alternative fuels, electrification) all have major technical, infrastructural and financial challenges that limit their scalability over the short and medium term (Victor et al., 2018), so that purchasing offsets of 477,117 MtCO_2e (UC CNI, 2018) (42% of targeted emissions as of October 2018) will be necessary to meet the 2025 goal (CNFMTF, 2017, p. 12), and major investment will be required, with ~$429 million spent on UC carbon neutrality-related research during 2009–2014 (St. Clair & Chiang, 2016).

The CNI position on Scope 3 emissions (indirect emissions from purchased goods and services, including food), is that they 'are subject to long-term goals but actionable plans will require more leadership' (Victor et al., 2018). While some CNI policy background documents do mention food, e.g. the need to reduce animal food consumption and food waste (Forman et al., 2016, pp. 10–11), the policy proposes no food system changes (CNFMTF, 2017).

A CNI survey found the UC community skeptical of the CNI's vision for meeting its goals, including the need for offsets and market-based solutions in general, and wanting a broader approach. In response it was suggested that the CNI 'appeal beyond climate solutions' by linking to other initiatives, for example 'water, transportation, or other sustainability goals, new initiatives like the Healthy Campus Network program, or even social-justice initiatives' (Bales et al., 2018, p. 66). These other initiatives involve changes in behaviour and underlying knowledge and values as key components, which are explicitly omitted from the CNI due to the 'variability of human behavior and most campuses' limited experience with inducing behavioral savings on a sustained basis', although the CNI does acknowledge the potential of behaviour change (Meier et al., 2018, p. 33).

In sum, UC CNI policy is currently reducing Scope 1 and 2 GHGE to reach the 2025 target of zero emissions, which will be technically and infrastructurally difficult and expensive, and does not include food system or other Scope 3 GHGE, which likely constitute the majority of UC related emissions. The 2050 target includes some Scope 3 transportation emissions, but not food system emissions.

2.2. UC food policy

UC's sustainable food policy was established in 2009. One of its major goals is that 'each campus and health location foodservice operation shall strive to procure 20% sustainable food products by the year 2020, while maintaining accessibility and affordability for all students and UC Health location's foodservice patrons' (UCOP, 2019, p. 15). 'Sustainable food' is defined as a food or beverage purchase that meets just one of 20 criteria (with the option for adding more) that include those focused on animal welfare, social justice, and environmental sustainability. It does not include climate change mitigation or nutritional quality in the policy, although campuses are 'encouraged' to promote 'healthy' and 'sustainable' food (UCOP, 2019, pp. 30–31). This policy is currently being revised to reflect changes in market standards and definitions of sustainability, and some measures to reduce GHGE of campus food systems by serving plant-based foods are being considered.

In addition, a systemwide Global Food Initiative was established in 2014 to: 'help individuals and communities access safe, affordable and nutritious food while sustaining our natural resources', to 'shape, impact and drive policy discussions', and to draw on 'UC's leadership in the fields of agriculture, medicine, nutrition, climate science, public policy, social science, biological science, humanities, arts and law, among others' (UCOP, n.d.). The Initiative's purview is 'both external, such as how UC translates research into policy and helps communities eat more sustainably, and internal, such as how UC leverages its collective buying power and dining practices to create desirable policies and outcomes' (UCOP, n.d.). While reducing GHGE to mitigate climate change could easily be included under these broad goals, to date it has not been.

Since 2016, the main focus of the Global Food Initiative is the Healthy Campus Network. It grew out of the Healthy Campus Initiative (HCI) at UC Los Angeles (UCLA), created in 2013 (Slusser et al., 2018). The main goal of the Network is to build on the experience of the HCI, UC San Francisco (UCSF)'s ban on the sale of sugar-sweetened beverages, and UC's smoke and tobacco free policy, to 'advance a culture of health and well-being' (UC GFI, 2017). The Network does not include reducing food GHGE, although this is currently being discussed.

In sum, UC food policy has made much progress toward healthier, more sustainable campus food systems, much of which also reduces GHGE, though emission reduction has not been an explicit goal, the effect on emissions has not been well documented, and food policy is not linked to climate policy.

3. Methods

Our methods comprised four main steps summarized in this section; more details are in the Supplementary Information, including tables for each scenario.

3.1. Step 1, constructing scenarios

To estimate the potential for food system change to reduce UC GHGE, we created two sets of scenarios and estimated their GHGE reductions compared with a baseline (column 1, Tables S3-S7). First, we created nine scenarios using five peer reviewed life cycle assessment studies of the effect of change in the US diet on GHGE, assuming these changes were adopted by the UC population (Tables S3-S7). Some scenarios also included a reduction in food waste. Scenarios US1-US3 are US Department of Agriculture recommended diets compared with the current, or standard American diet (SAD) for food eaten and wasted (Heller & Keoleian, 2015) (Tables S3). US4-US6 are alternative diets based on changing about 50% of the calories in SAD in ways that reduce GHGE in the food system as well as the risk of NCDs, which reduces their health care costs (GHGE of health care costs are also reduced, but not included in our scenarios) (Hallström et al., 2017) (Tables S4). The main changes were increasing fruits, vegetables and whole grains, and decreasing refined grains and red and processed meat. US7 is a diet which replaces all beef in the SAD with plant foods (Eshel et al., 2016) (Tables S5). US8 is the diet of the US population quintile with mean GHGE compared with the diet of the quintile with the highest GHGE (Heller et al., 2018) (Tables S6). US9 is a diet shifting 48% of meat and dairy calories in the SAD to a non-dairy vegetarian diet (Weber & Matthews, 2008) (Tables S7).

We created a second set of eight scenarios based on existing, planned or potential food system changes on some UC campuses, assuming these changes were fully implemented across all campuses (Tables S9-S14). We included UC campus practices and policies in two of the three main categories affecting the food system at the retail and consumer levels (Garnett et al., 2015): informational and educational food environments (scenario UC1), and physical food environments (scenarios UC2-UC8, Table S8). We found no examples of the third area, food prices.

Scenario UC1 is the effect of a course on food and the environment at UCLA on students' self-reported food intakes from before to after the course, compared with analogous data for students in a control course (Table S9); UC2 is the substitution of 30% plant blended burgers for 100% beef burgers in UCLA dining halls (Table S10); UC3 is based on UC2, but assumes replacement with 100% plant burgers (Table S10); UC4 is the elimination of beef from 4 UCLA dining halls one day a week, and assumes it is replaced with beans with the equivalent amount of protein (Table S11); UC5 is based on UC4, but assumes beef is replaced with chicken (Table S11); UC6 is the removal of trays from dining halls at UC Santa Barbara (UCSB) to reduce food waste (Table S12); UC7 is the elimination of sugar sweetened beverage sales at UCSF to improve health, and assumes they are replaced by tap water (Table S13); UC8 is the anaerobic composting of food waste based on a pilot project at UC San Diego, and assumes food waste would otherwise be sent to landfills (Table S14).

3.2. Step 2, estimating GHGE reductions for scenarios

We estimated the maximum effect of each scenario on reduction in GHGE as CO_2e cap^{-1} yr^{-1} (column 2, Tables S2, S8). For the scenarios based on US food system changes (Tables S3-S7) we used the amount of CO_2e cap^{-1} yr^{-1} reduction from the pre-change baseline in the study cited, or calculated it using national data in the study divided by the US population size for the appropriate year.

For CO_2e cap^{-1} yr^{-1} in the scenarios based on UC examples we used GHGE intensities in the literature for the food system changes in each scenario to estimate the difference between baseline emissions before the change and emissions after the change, and divided this by the appropriate population (Tables S9-S14). For example, for the UCLA blended burger scenario (Table S10), we used GHGE intensities for beef in the US to calculate CO_2e yr^{-1} for the beef used for 100% meat burgers before introduction of blended burgers and subtracted from this the sum of 70% of beef emissions plus the emissions from the plant foods comprising 30% of the blended burgers. We then divided this by the estimated number of students eating in the dining halls per year.

3.3. Step 3, estimating the scenarios' GHGE impact for the UC population

We used each scenario estimate of reduced CO_2e cap^{-1} yr^{-1} to calculate the reduction in $MtCO_2e$ yr^{-1} for the on-campus meals eaten by the UC population (students, staff and faculty) (column 3 Tables S2, S8). We assumed that all first year students ate three meals per day during the academic year, all other students ate one meal per day (lunch) during the academic year, and faculty and staff ate one meal per day (lunch) five days per week throughout the year (not including holidays) (Table S1). For scenarios US1-US9, UC1, UC6, UC7 and UC8 we used all meals eaten on campus, but for the other UC scenarios we removed the breakfasts of first year students. We did this because we assumed that students would not eat burgers or beef for breakfast. We defined the academic year as the days during which residential dining halls were open (based on UCLA's schedule), not including summer sessions. Because we did not count meals of summer session students, conference attendees, special programme (e.g. summer sport) participants or campus visitors, our estimates are conservative.

3.4. Step 4, estimating the scenarios' contribution to food system GHGE and to CNI goals

We calculated the reduction in GHGE of each scenario as a percentage of UC baseline Scope 3 food system emissions (column 4, Tables S2, S8). The baseline for most of the US scenarios was based on data in the study used for each scenario. Where this was not possible, and also for all of the UC scenarios, we used the mean food system GHGE for the US population based on (Heller et al., 2018).

To calculate the contribution to the UC CNI defined target of net zero Scope 1 and 2 GHGE by 2025 we divided the scenarios' reduction in $MtCO_2e$ yr^{-1} by the amount to be eliminated or offset (129,233 $MtCO_2e$ yr^{-1}) as of 2018 (UC CNI, 2018) (column 5, Tables S2, S8). To calculate the contribution to the amount of offsets needed to achieve net zero Scope 1 and 2 GHGE in 2025, we divided the scenarios' reduction in $MtCO_2e$ yr^{-1} by the amount needing to be offset (477,117 $MtCO_2e$ yr^{-1}) as of 2018 (UC CNI, 2018) (column 6, Tables S2, S8).

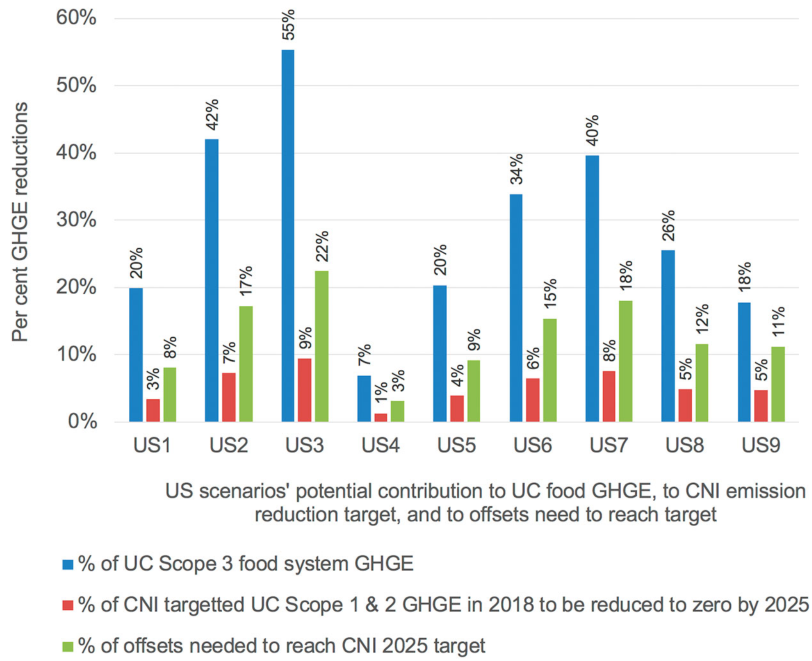

Figure 1. Potential of US diet change scenarios to reduce UC GHGE. See section 3.1 and SI for more details. US1. Change from SAD to US Department of Agriculture 2000 kcal day^{-1} recommended diet, plus 50% reduction in food waste. US2. Same as #1 for lacto ovo vegetarian diet. US3. Same as #1 for vegan diet. US4. Healthy alternative diet 1 (HAD1); including 45% reduction in red and processed meat. US5. HAD2; same as HAD1, with 73% reduction in red and processed meat. US6. HAD3; same as HAD1, with 100% reduction in red and processed meat. US7. Replace all beef in loss-adjusted SAD with equivalent nutrient content plant food. US8. Change diet of US population quintile with highest diet GHGE to diet of quintile with mean GHGE. US9. Shift 48% of meat and dairy calories to non-dairy vegetarian diet.

4. Results

4.1. The potential of scenarios based on US food system changes to reduce UC GHGE

We found an average potential reduction for the scenarios of 623 kg CO_2e capita^{-1} yr^{-1}, and of 61,606 MtCO_2e yr^{-1} for UC on-campus meals (Figure 1, cols. 2–3 Table S2). This is equal to an average 29% of total 2018 UC Scope 3 food system emissions, 6% of 2018 UC Scope 1 and 2 emissions, and 13% of the offsets needed in 2025 (cols. 4–6 Table S2).

4.2. The potential of scenarios based on UC campus food system changes to reduce UC GHGEs

The UC scenarios produced a wide range of reductions in kg CO_2e cap^{-1} yr^{-1}, from 7 for scenario UC2 (blended burgers) to 309 for scenarios UC1 (academic course) and UC4 (tray-less dining) (col. 2 Table S8). If adopted across the UC population, they would reduce UC GHGE from between 1,500 and 46,800 MtCO_2e yr^{-1} (col. 3 Table S8), equal to 1–21% of total 2018 UC Scope 3 food emissions, 0.1–0.4% of 2018 UC Scope 1 and 2 emissions, and 0.3–10% of offsets needed in 2025 (cols. 4–6 Table S8).

The combined potential of multiple food system changes was much greater. To estimate this, we created scenario UC9, by combining the effects of the physical food environment scenarios (UC3, UC4, UC6-8) whose modes of action do not overlap. UC9 shows a potential reduction of 468 kg CO_2e cap^{-1} yr^{-1}, or 73,376 MtCO_2e yr^{-1} for on-campus meals for the UC population, equal to 34% of total 2018 UC Scope 3 food emissions, 7% of 2018 UC Scope 1 and 2 emissions, and 15% of offsets needed by 2025 (Figure 2a, scenario UC9 Table S8).

For scenario UC10 we replaced the reduced beef scenarios (UC3 and UC4) in scenario UC9 with the UCLA course (scenario UC1), because the reduced GHGE of UC1 was almost entirely due to students' decrease in

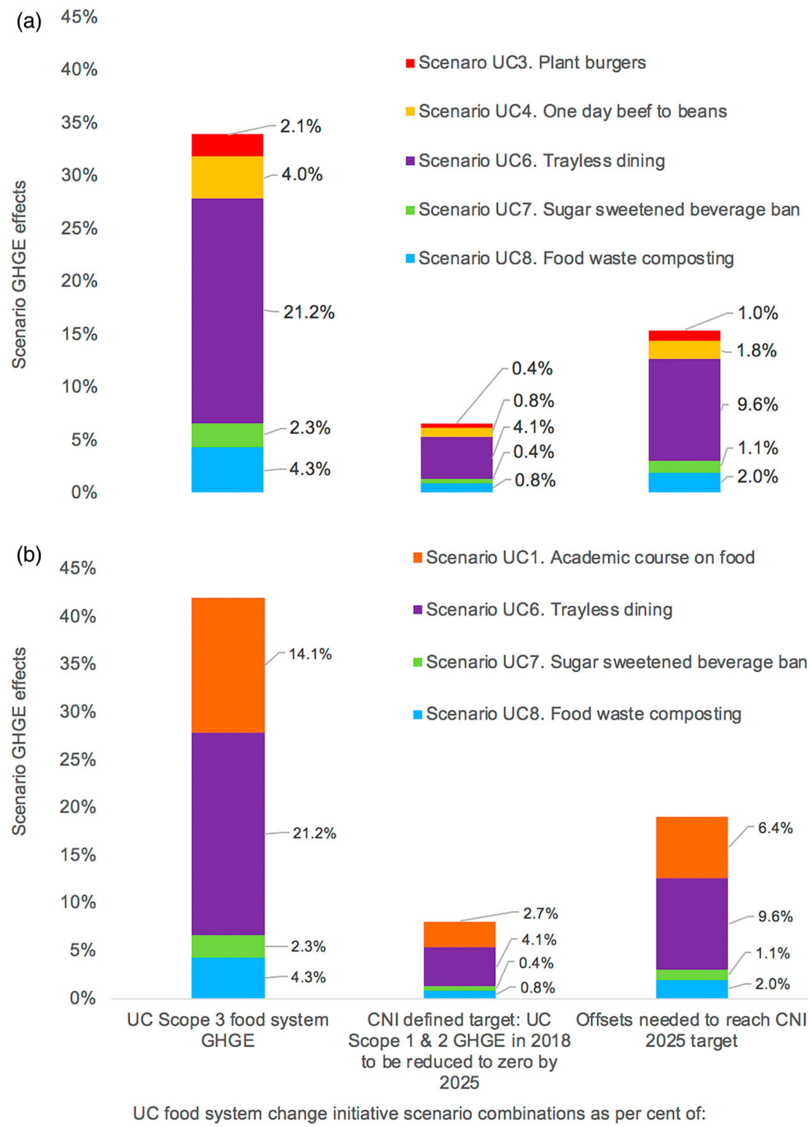

Figure 2. Combined effect on GHGE reductions of scenarios based on UC campus food system changes. a. Combining the effects of non-overlapping physical food environment scenarios. b. Combining the effects of the academic course (replacing the reduced beef food environment scenarios in Figure 2a), tray-less, sugar sweetened beverage sales ban, and food waste composting scenarios.

reported beef consumption. UC10 has a potential reduction of 714 kg CO_2e capita^{-1} yr^{-1}, or 90,697 MtCO_2e yr^{-1} for on-campus meals for the campus population, which translates into 42% of total 2018 UC Scope 3 food emissions, 8% of 2018 UC Scope 1 and 2 emissions, and 19% of offsets needed by 2025 (Figure 2b, scenario 10 Table S8).

5. Discussion

5.1. The necessity of including food and other Scope 3 emissions in HEI climate policy

Results of our US and UC scenarios show that if food systems were included in UC climate policy, changes like those in our scenarios could reduce UC food systems emissions by up to 42–55%, equivalent to 8–9% of CNI defined Scope 1 & 2 GHGE in 2018. If this policy change is not made before 2025, then UC food system changes could contribute up to 19–22% to the offsets needed to reach CNI goals for 2025. The effect of food system changes in terms of UC Scope 1 and 2 (energy) GHGE is smaller than would be expected based on average cap^{-1} fossil fuel combustion CO_2e emissions for the US. This is likely largely because UC Scope 1 and 2 emissions cap^{-1} of the UC population, weighted for the amount of time spent on campus, is several times higher than the US average cap^{-1} fossil fuel emissions (section SI 4, Table S15).

Including food system changes would of course reduce total UC GHGE, so that there would be fewer emissions to mitigate when Scope 3 is eventually included in climate policy, which is the long term plan. This is a major advantage over the current practice of purchasing offsets from off campus, because they will not contribute to reduced Scope 3 GHGE at the time when they are eventually included.

According to the Greenhouse Gas Protocol organization, whose guidelines for GHGE accounting are widely used by HEIs, including the CNI, Scope 3 GHGE, which include food system emissions, can be the 'largest source of emissions' and the most significant opportunity to reduce them (GHGP, 2011, p. 5). For example, Cambridge University (UK) estimated that of its total 2012–13 emissions, Scope 3 emissions were 70%, of which business and commuter travel comprised only 14% (AECOM Limited, 2014), and Barnard College (US) estimated of its total emissions Scope 3 emissions were 68%, of which 14% was from food production and distribution (but not including food waste disposal) (GIES, 2016).

Food systems GHGE in the US account for 13.6% of fossil fuel CO_2 emissions (Canning et al., 2017), but they also emit a large proportion of both methane and nitrous oxide, which have relatively short atmospheric lifetimes but global warming potentials (GWPs) much greater than that of CO_2 (Myhre et al., 2013, p. 714). Therefore, if their emissions can be stabilized, their additional warming effect will go to zero, while the warming effect of CO_2 will continue even if emission rates are stabilized. In the US in 2016, agriculture accounted for 80% of nitrous oxide emissions, mostly from soil, and 32% of methane emissions, 94% of that from enteric fermentation of ruminants, and manure management (calculated using data in EPA, 2018). Because of methane's short lifetime and high 20-year GWP (86 times that of CO_2), reducing its rate of emissions is especially important for achieving climate change mitigation over the shorter term, and reduced animal source food consumption will be key (Balcombe et al., 2018; Godfray et al., 2018). Beef is by far the most emissions intensive food, and just substituting beans for beef in the 2012 US diet on either an energy or protein mass basis would reduce annual emissions by 334 $MMtCO_2e\ yr^{-1}$ (Harwatt et al., 2017), about 6% of US 2012 net GHGE (EPA, 2015).

Our US scenarios, and several of our UC scenarios, illustrate the strong contribution to reducing GHGE of reducing animal food, especially beef. For example, per gram of protein, ruminant meat produces over 250 times as much CO_2e as legumes (Tilman & Clark, 2014). A US Department of Agriculture recommended vegan diet would reduce GHGE by more than 1,080 kg $CO_2e\ cap^{-1}\ yr^{-1}$ compared with the SAD (scenario US3). Just replacing the beef in the SAD with plant food with equivalent nutrients would reduce GHGE by more than 860 kg $CO_2e\ cap^{-1}\ yr^{-1}$ (scenario US7).

HEI's are adding more plant-based foods on campus, in part to reduce GHGE (Middleton & Littler, 2019). The World Resource Institute has developed a Cool Food Pledge that a number of HEIs have signed, including UC's five medical centres (not included in this study). The Pledge commits HEIs to reducing food GHGE by 25% by 2030 relative to 2015, focused on replacing animal source food protein with plant protein (CFP, 2019). In the most recent survey of the US Association for the Advancement of Sustainability in Higher Education members, 83% of the 397 reporting indicated having a 'vegan dining program that makes diverse, complete-protein vegan options available to every member of the campus' (based on data in AASHE, 2020). Universities are even beginning to remove ruminant meat from campus as part of climate policy, e.g. the University of Cambridge and Goldsmiths, University of London, in the UK, and the University of Coimbra, in Portugal.

Yet Scope 3 emissions are still omitted from most higher education policies in part due to the difficulty of documenting and measuring them. Most Association for the Advancement of Sustainability in Higher Education members do not estimate Scope 3 GHGE, or only the employee commuting and air travel portion (AASHE, 2019; Sinha et al., 2010). The Climate Leadership Network member HEIs are only required to report Scope 3 emissions from 'commuting and from air travel paid for by or through the institution' (SN CLN, 2020b). Among the many panels and sessions in the agenda for the 2020 Higher Education Climate Leadership Summit (co-sponsored by Second Nature) the only one including food was by a venture capital fund director (SN, 2020b).

5.2. Other benefits of including food system change in climate policy

Our food system change scenarios not only reduce GHGE, but could provide many health, environmental and social benefits that can contribute to reducing the net costs of comprehensive climate change mitigation, and to motivating institutional policy change and individual behaviour change.

Compared with the current CNI strategies for reducing Scopes 1 and 2 GHGE, reducing food system GHGE would not require new technology or infrastructure, and would be much less expensive per unit CO_2e reduced (next section). In turn, UC food policies' emphasis on increasing health, sustainability and social equity would be served by explicitly addressing climate change. In addition, slowing climate change would reduce air pollution, flooding, wild fires, and extreme temperatures, and their negative effects on food production in California (Bedsworth et al., 2018) and worldwide (IPCC, 2018).

Many lower GHGE intensive foods such as fruits, vegetables, and whole grains and legumes, are healthier than foods with higher GHGE, especially red and processed meat and dairy (Tilman & Clark, 2014), which account for the majority of US food system GHGE. Thus, increasing healthy foods and decreasing unhealthy foods could contribute to reducing NCDs (Springmann et al., 2016), with additional climate co-benefits via reducing GHGE in the health care system (Eckelman & Sherman, 2016; Hallström et al., 2017).

However, these climate and health goals need to be explicitly linked in policy, because actual diets may not achieve this (Rosi et al., 2017). Diets recommended as being equally nutritious can have very different climate impacts, e.g. the Mediterranean, vegetarian and vegan diets in the Dietary Guidelines for Americans (Blackstone et al., 2018). Sugar has low GHGE, but makes a large contribution to disease risk (Payne et al., 2016). In scenario UC7 (replacing sugar sweetened beverages with tap water) (Table S13), direct GHGE emission reductions are relatively small, but the health benefits (Epel et al., 2019) would reduce health care costs (Huang et al., 2019) and their GHGE (Eckelman & Sherman, 2016).

Another co-benefit of healthier diets is increasing social equity, because minority populations in the US are disproportionately affected by obesity (Hales et al., 2017) and NCDs, e.g. diabetes (Cheng et al., 2019). Low income and low food security are also strongly related to risk of diet-related and other NCDs (Gregory & Coleman-Jensen, 2017). These higher risk populations have made up an increasing proportion of US HEI students over the last 20 years (Espinosa et al., 2019), including the UC (SI 1).

5.3. Financial costs and benefits of food system change as part of climate policy

Many food system changes that would reduce GHGE could also reduce UC costs because many lower GHGE intensity and healthier foods are also less expensive. If all UC students replaced 1 serving wk^{-1} of beef with beans (scenario UC4, Table S8), net savings would be >$9 million yr^{-1}. Our US scenarios 2–7, 9, and UC scenarios 1–5 reduced beef consumption. Over time, healthier diets will reduce the prevalence of NCDs and therefore the cost of health care. Conservative estimates of US health care cost savings due to healthier alternative diets (Table S2, scenarios US4-6) resulted in savings of $77–93 billion (75% from diabetes), equal to 35–42% of the total costs for treating the diseases affected (Hallström et al., 2017). If the UC population adopted the HAD-3 diet (including no red or processed meat) (Hallström et al., 2017) savings could be $10 million yr^{-1} from on-campus meals once these diets had been established for some time.

Healthier diets would also decrease UC costs for health insurance and lost employee productivity, a potential recognized by the UC Office of the President's recent sponsorship of a system-wide Healthy Beverage Initiative to increase tap water consumption and decrease sugar sweetened beverage consumption, and a Diabetes Prevention Program. In addition, because food systems emissions comprise a disproportionately higher amount of methane and nitrous oxide, the social cost savings would be disproportionately greater than reduction in energy GHGE, which are mostly CO_2 (IAWG, 2016; Shindell et al., 2017).

Recognition of the financial co-benefits of food system changes can help to counter a major institutional obstacle to campus food system changes that are healthier and more climate-friendly – the conflict of these changes with the revenue generating role of campus food (e.g. BFI, 2016, p. 5). The for-profit food industry controls US and global food environments including those of UC and most other US HEIs, resulting in food environments dominated by ultra-processed and relatively unhealthy foods. The current socioeconomic system incentivizes businesses to sell food that is profitable, but bad for the climate, health and society, and allows them to block changes to the status quo (Swinburn et al., 2019, p. 32).

Most campuses support fast food franchises and have multi-year soda pouring rights contracts which promote foods that fuel poor health and food insecurity (Horacek et al., 2013; Poulos & Pasch, 2015). Many of these foods, especially ruminant meat and dairy, are also GHGE intensive (Tilman & Clark, 2014). However, the conflict between these campus food environments and the mission of HEIs to promote the well-being of their students, staff and faculty are rarely discussed or even publicly acknowledged. Yet our experience is that many UC students, faculty, and food system staff are eager to implement changes to increase campus food health and sustainability, including to reduce GHGE.

Thus, in order to integrate HEI climate and food policies, we need to discuss the often conflicting roles of food for profit and food for climate change mitigation, human health, and equity. Students are leading the way, e.g. advocating not renewing UC Berkeley's pouring rights contract with PepsiCo (Solis & Melgoza, 2019). It is likely that public HEIs in the US will have to relinquish the private sector business model that has increasingly dominated them (Newfield, 2016) in order to prioritize the broader public good and move toward climate and environment friendly, healthy diets that support social equity. This has happened in limited ways, as shown by the move to local food sourcing at UCSB (Cleveland et al., 2014), and the sugar sweetened beverage sales ban at UCSF (scenario UC7, SI 3.5). The integration of climate and food policy offers HEIs an opportunity to engage with the national and global environmental sustainability, public health and social justice communities in addressing the need for profound changes in values and structure needed to truly prioritize public good over private profit. This would also help public HEIs, e.g. in the US, to restore flagging public approval and support (Newfield, 2016).

5.4. Options for implementing HEI food system changes with climate co-benefits

Individual food choices are influenced by a wide range of interacting variables including biological predisposition, social and physiological conditioning, personal and interpersonal factors, and food environments (Contento, 2016; Leng et al., 2017). HEIs have the potential to alter physical, social, economic and informational food environments to support food choices that contribute to both climate and food policies, while they also have the purchasing power to effect the upstream food system to respond to those choices (Thottathil, 2019).

HEIs are also in a unique position to influence the motivations for food choice among their staff, faculty and especially students, given their educational mission of increasing knowledge and critical thinking skills, for example via classroom and interpersonal education and point of purchase signage. This is recognized in the ultimate goal of UC's Healthy Campus Network 'to influence social norms so that culture, environment and living well become integral to academic success' (UC GFI, 2017).

The UCLA course scenario (UC1) was the only one based on informational and educational food environments (Table S8). The food course presented information about the environmental impacts of foods, including GHGE intensity, and had a large effect on reducing GHGE of students' self-reported food intakes from before to after the course, compared with analogous data for students in a control course (Jay et al., 2019). Students reported much lower beef intake after the food course, which accounted for almost all of their emissions reductions. This effect was greater than that of the scenarios that explicitly reduced beef consumption (UC2-UC5) because the UCLA course affected all campus meals, not just the limited number of meals in the beef reduction scenarios.

These results may be due to the effect of the course on students' perceptions that the benefits of food choice change outweigh the costs, and on their confidence that their actions will make a difference (Orji et al., 2012). In contrast, food labels with health or climate impact information that do not have a larger supporting educational environment may not be as effective as 'indulgent' labels appealing to taste, as found in a US HEI study (Turnwald et al., 2017).

Seven of the food system changes we used in our UC scenarios (section 4.2) were physical food environment change and do not directly require conscious behaviour change. However, adding supportive information can enhance the effect of physical food environment changes (Steg, 2018), while lack of lack of information can undermine physical food environment changes. For example, when dining halls at several UC campuses increased the proportion of plant-based foods without adequate information, this resulted in lower student traffic.

Many of the physical food environment changes in our UC scenarios have been accompanied by changes in information and education. For example, UCLA's beefless Thursdays (UC4, UC5) have been promoted online and by large informational displays in the dining halls. Education following the sugar sweetened beverage sales ban at UCSF amplified the effect of the ban. Among employees previously drinking the most sugar sweetened beverages, those randomly assigned to a treatment group received a brief motivational intervention including a graphic description of amount of sugar ingested daily, help with setting goals, and educational materials (Epel et al., 2019). The treatment group reduced their sugar sweetened beverage intake three times more than the randomly assigned control group.

While data on long-term effects of educational interventions at HEIs are scarce (Deliens et al., 2016), a ten-lesson online curriculum 'focusing on healthful eating and physical activity, stressing nondieting principles such as size acceptance and eating competence' was effective in increasing university students' fruit and vegetable intake and physical activity, after the intervention and at a 15-month follow up (Greene et al., 2012). A study in Finland found that the barriers to making climate friendly food choices that students perceived as most important, differed from those most associated with their self-reported food choices (Mäkiniemi & Vainio, 2014), suggesting that helping students see the connection between their values and their food choices can support behaviour change.

The promotion of behavioural spillovers and educational outreach to surrounding communities and beyond is consistent with the mission of the UC CNI and Global Food Initiative (and of most HEIs) of sharing knowledge and experience with each other and 'surrounding communities, and public and private sector partners' thus 'serving as models for climate solutions' (SN UC3, 2020). Changes in information, education and social food environments will be needed in addition to changes in physical environments to increase the probability of food system changes on campus moving off campus. For example, a Danish study found that when people reported successfully increasing intake of healthy and decreasing intake of unhealthy foods, this had a spillover effect on the intention to make these food choices in the future (Bech-Larsen & Kazbare, 2014). A study of university students in the UK found their food choices were influenced by their perception of the eating habits of their social media peers (Hawkins et al., 2020).

5.5. Limitations of our study

Our results are conservative because the life cycle assessment studies we used in scenarios based on US food system changes do not capture all food system GHGE, for example, for land use change, especially important for animal products (Eshel et al., 2014). When land clearing is included, the food system GHGE are much higher and the proportional effect of reducing animal source foods is much greater, especially for beef. For example, when soybean (mostly for animal feed) is produced in the warm tropics by clearing rainforest, average annual emissions of CO_2e kg^{-1} of soybean over the 20 years for soil carbon pools to reach equilibrium are more than 30 times greater than when there is no conversion of land (Castanheira & Freire, 2013). Including CO_2e released by conversion of forests and woody savannahs to cropland and especially to grazing land, amortized over 20 years into the future, would result in the average U.S. diet producing almost 17 $MtCO_2e$ $capita^{-1}$ yr^{-1}, half from beef, which is about the same as total energy CO_2e $capita^{-1}$ yr^{-1} (Searchinger et al., 2018, p. 15). More comprehensive life cycle assessment accounting would increase the impact attributable to the food system and to the mitigating effects of the food system changes we analyzed.

Our scenarios also underestimate potential GHGE reductions as a result of food system change because some of the life cycle assessments included in our estimates used GWPs for methane that are outdated and lower than the current GWP, and methane is an important food system GHG, especially for ruminant meat and dairy, and food waste in landfills.

Variables for which we did not have data and that we did not consider in the scenarios, that could potentially take back some of the GHGE saved include: (1) leakage between on – and off-campus food choices, i.e. lower GHGE food choices on campus offset by an increase in higher GHGE food choices off campus, (2) leakage between on-campus food locations/times, e.g. lower GHGE food choices in one dining hall one day a week offset by an increase in higher GHGE food choices in other dining halls on the same day, or in the same dining hall on other days, and (3) indirect rebound, i.e. using monetary savings from substitution of less expensive lower GHGE foods to purchase other goods or services that increase GHGE, e.g. spending savings from substituting less expensive plant foods for more expensive animal source foods on air travel (Moran et al., 2018).

6. Conclusion

Our case study of the UC is one of the first quantitative studies of the potential for integrating HEI climate and food policies. As our scenario results illustrate, food system GHGE are an important component of UC emissions, and the kinds of food system changes in our scenarios can effectively mitigate them. Scope 3 emissions likely comprise the majority of HEI emissions, and GHGE reductions via diet change and food waste reduction can make important contributions to meeting the critical need for GHGE reductions in the near term (IPCC, 2018). This should be done as soon as possible to address the climate emergency (Lenton et al., 2019).

Food system changes on UC campuses could achieve relatively rapid GHGE reductions because, compared to the three-pronged approach of the CNI to reduce Scope 1 and 2 emissions, food system changes have limited technology and infrastructure needs, and lower costs. Research suggests that combining changes in the physical food environment with supportive information and curriculum content can be very effective in promoting food system change. Many small-scale successful interventions already exist on UC campuses that could be thoroughly documented, improved, and scaled up across the system. UC students, staff and faculty are working on and have already implemented many food system changes with potential climate co-benefits which we did not include in our scenarios because data were not available (section SI 5).

There is an urgent need to support changes like these at HEIs, as well as new food-climate initiatives, with rigorous analysis of their effects on GHGE, the environment, health, and equity, in order to provide feedback for adjusting their implementation to optimize benefits, incentivize their expansion, and provide high quality data on their potential for contributing to climate change mitigation goals.

Including food system GHGE in HEI climate change mitigation policies and highlighting the many health, environmental and social co-benefits of reducing them could help to secure broad support for climate change mitigation policies, which is currently lacking in the UC community (CNFMTF, 2017, p. iii). The justifications for the CNI in terms of UC's core mission apply equally to diet change as part of an integrated climate-food-equity policy (Forman et al., 2016).

Based on our results and analysis, developing an integrated HEI climate-food policy should be a participatory process beginning with a substantive institutional commitment to prioritizing the campus and public good over financial profit. This commitment would comprise explicit recognition of the potential for food system change to mitigate GHGE, and improve human health, environmental sustainability and social equity. Operationalizing the policy would include: establishing (1) a baseline for each campus's food GHGE; (2) protocols for data collection; (3) a dynamic database of food climate impact factors for evaluating the climate effects of diet and food system change, including median or mean $CO_2e\ kg^{-1}$ of food with options for different scenarios, e.g. for transport mode and distance, production system, and processing; (4) appropriate GWP standards, e.g. the 100-year GWP of 28 for methane currently used by CNI underestimates methane's short term impact on climate change, and therefore would underestimate the food system mitigation potential, since the food system, especially ruminant animal source foods, emits a disproportionate amount of methane (Balcombe et al., 2018; Godfray et al., 2018).

In 2019 UC President Janet Napolitano and all 10 UC campus chancellors (McMillan, 2019) signed a Climate Emergency Letter (EAUC, 2019) that recognizes 'the need for a drastic societal shift to combat the growing threat of climate change', and commits signatories to deliver relevant 'education across curriculum, campus and community outreach programmes'. Hundreds of other HEIs from around the world are also 'represented' by the letter. Current research shows that food system change is an essential part of that dramatic societal shift, and can provide many important health and equity co-benefits. Our results show that UC and other HEIs could make rapid progression on (and off) campus by including bold food system changes in their climate policies.

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Supplemental Information for

Integrating sustainable climate and food policies: The case of the University of California

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SI 1. The UC population

To estimate the effect of diet/food system change scenarios extended to all UC campuses, we estimated the number of meals eaten yr^{-1} based on assumptions about the number of meals an average person in each of the population categories would eat (Table S1). We used faculty and staff FTE (full time equivalent) to more accurately capture the meals eaten, which is 13% smaller than the actual number of employees, the “head count” (140,223 v. 162,020 in 2018. We also deducted student teachers and staff from faculty and staff FTE to avoid double counting.

Table S1. University of California population and meals.

Population category	Population size, 2018[a]	Number of meals yr^{-1} eaten on campus by UC population[b]	Ratio: (meals on campus yr^{-1}) / (total meal yr^{-1})	Population size weighted by time (meals) on campus	Ratio: (equivalent population) / (total population)
First year student enrollment	46,677	34,027,533	0.67	31,075.37	0.67
Non-first year student enrollment	233,703	40,564,164	0.16	37,136.00	0.16
Total student enrollment	280,380	74,591,697			
Faculty and staff FTE[f]	140,223	33,653,592	0.22	30,733.84	0.22
Total UC population	420,603	108,245,289		98,945	0.24
Total UC on campus meals, with no breakfast for first year students (for beef replacement scenarios UC2-UC5, Table S8)		96,902,778			

[a]Only for the 10 UC academic campuses. Does not including the 5 medical centers, 3 national laboratories, agriculture and natural resources, office of the president, or other parts of the UC. See https://www.universityofcalifornia.edu/uc-system/parts-of-uc.

[b]Assumes: for first year enrollees, 3 meals d^{-1}, 243 days (academic yr)$^{-1}$ based on UCLA dining hall schedule, no snacks; for non-first year enrollees, 1 meal d^{-1} (lunch), 174 days (academic yr)$^{-1}$; for staff and faculty, 1 meal d^{-1} (lunch), 5 days wk^{-1}, 48 weeks yr^{-1}. These numbers don't include meals eaten by visitors, summer program participants, or attendees at sport, entertainment or other special events.

[c]Data from https://www.universityofcalifornia.edu/infocenter/freshman-admissions-summary (accessed 2020 June 14).

[d]Total enrollment minus first year enrollment.

[e]Data from https://www.universityofcalifornia.edu/infocenter/fall-enrollment-headcounts (accessed 2020 June 14).

[f]Academic + non-academic employees, data from https://www.universityofcalifornia.edu/infocenter/employee-fte (accessed 2020 June 14). Only for the 10 campuses, not other units. Number of student teaching and RA FTE deducted from total academic FTE; number of student staff FTE deducted from total non-academic FTE Assumed each FTE ate lunch 5 days wk^{-1}, 48 weeks yr^{-1}.

The UC student population is becoming more diverse. Between 2000 and 2018, the proportion of UC first year enrolees who were Chicano/Latino increased from 12 to 25%, and Black from 3 to 4%, while the proportion white decreased from 37 to 19% (UC 2020). During the same period the proportion of first year enrolees who were first generation increased from 34 to 39% (UC 2020), and in 2017-18 21% of California resident undergraduates were from households in the lowest annual income category (<$29k), a large increase since 2008–09 (UCOP 2019:39).

SI 2. Scenarios based on US food system changes

We created scenarios to estimate the effect on UC GHGE studies of the effect on GHGE of changes in the US food system (Table S2).

All of the US scenarios included energy data for the different diets. All except US8 made changes to alternatives to the SAD isocallorically or approximately isocallorically; for US8 the diet in the highest quintile for GHGE had 23984 kcal cap^{-1} d^{-1}, while the mean was 2153 kcal cap^{-1} d^{-1}. Details are in the tables for the scenarios.

Table S2. Estimates of the potential for US diet change scenarios to reduce UC GHGE: results of top-down scenarios.

1. Diet change scenario		2. Scenario effect (kg CO_2e $capita^{-1}$ yr^{-1})[a]	3. Scenario effect for UC on-campus meals (Mt CO2e yr^{-1}) for UC population[b]	Scenario effect for UC on-campus meals as per cent of UC: 4. Scope 3 food system GHGE[c]	5. CNI defined Scope 1 & 2 GHGE in 2018 to reduce to zero by 2025[d]	6. Offsets needed to reach CNI 2025 target[e]
US 1	Change from SAD for food eaten and wasted to USDA 2000 kcal day^{-1} recommended diet, plus 50% reduction in food waste[f]	-391	-38,662	-20.0%	-3.4%	-8.1%
US 2	Same as US1 for lacto ovo vegetarian diet[g]	-829	-81,960	-42.3%	-7.3%	-17.2%
US 3	Same as US1 for vegan diet[h]	-1,085	-107,217	-55.3%	-9.5%	-22.5%
US 4	Healthy alternative diet (HAD1); change about 50% of calories in SAD (including increasing fruits, vegetables and whole grains, and decreasing refined grains, and 45% reduction in red and processed meat[i]	-152	-15,059	-7.0%	-1.3%	-3.2%
US 5	HAD2; same as HAD1, with 73% reduction in red and processed meat[j]	-446	-44,074	-20.4%	-3.9%	-9.2%

US 6	HAD3; same as HAD1, with 100% reduction in red and processed meat[k]	-742	-73,305	-33.9%	-6.5%	-15.4%
US 7	Replace all beef in loss adjusted US diet with equivalent nutrient content plant food[l]	-868	-85,805	-39.7%	-7.6%	-18.0%
US 8	Change diet of US population quintile with highest diet GHGE to diet with mean GHGE[m]	-558	-55,173	-25.5%	-4.9%	-11.6%
US 9	Shift 48% of meat and dairy calories to non dairy veg diet[n]	-538	-53,203	-17.8%	-4.7%	-11.2%
	mean	-623	-61,606	-29.1%	-5.5%	-12.9%
	SD	268	26,520	-14.1%	2.3%	5.6%
	median	-558	-55,173	-25.5%	-4.9%	-11.6%

[a]Methods and assumptions vary for different scenarios.

[b]See Table S1. UC data are for 2018. Number of on-campus meals is different for different scenarios. Assumes each scenario applied to all members of the target population. Total effect on UC emissions underestimated because we did not include non-campus conference attendees or other visitors, or summer students, and because GHGE for meals on campus for non-first year students was average for all meals, which includes breakfast with below average emissions.

[c]The estimate of UC Scope 3 food system emissions are based on US cap^{-1} food system GHGE as appropriate for each scenario; see scenario tables' footnotes.

[d]= 1,129,233 Mt CO_2e in 2018 October (UC CNI 2018).

[e]= 477,117 Mt CO_2e yr^{-1} in 2018 October (UC CNI 2018).

[f]See Table S3. Based on data from (Heller and Keoleian 2015). USDA recommended diet in Dietary Guidelines for Americans (USDA and HHS 2010:79-80).

[g]See Table S3. Based on data from (Heller and Keoleian 2015). USDA lacto-ovo vegetarian diet in Dietary Guidelines for Americans (USDA and HHS 2010:81).

[h]See Table S3. Based on data from (Heller and Keoleian 2015). USDA vegan diet in Dietary Guidelines for Americans (USDA and HHS 2010:82).

[i]See Table S4. Change from SAD to HAD-1: red and processed meat: 45% reduction, refined grains: 65% reduction, fruits and vegetables: 100% increase, whole grains: 365% increase, beans and peas: 114% increase. Reduces relative risk of colorectal cancer, type 2 diabetes and coronary heart disease by 20, 35, and 40% respectively. Based on data from (Hallström et al. 2017). GHGE change due to diet change is only in food (not health care) system and includes food waste through retail level. To calculate scenario effect for total UC on-campus meals as % of UC Scope 3 food system GHGE, mean US value from (Heller et al. 2018) was used to calculate UC Scope 3 food system GHGE.

[j]See Table S4. Same as HAD-1, except: Change from SAD to HAD-2: red and processed meat: 73% reduction, refined grains: 65% reduction, fruits and vegetables: 100% increase, whole grains: 365% increase, beans and peas: 114% increase. Reduces relative risk of colorectal cancer, type 2 diabetes and coronary heart disease by 25, 42, and 45% respectively.

[k]See Table S4. Same as HAD-1, except: Change from SAD to HAD-3: red and processed meat: 100% reduction, refined grains: 65% reduction, fruits and vegetables: 100% increase, whole grains: 365% increase, beans and peas: 1100% increase. Reduces relative risk of colorectal cancer, type 2 diabetes and coronary heart disease by 29, 43, and 45% respectively.

[l]See Table S5. Plant foods in diet optimized for reduced GHGE were "affordable, commonly used, widely available and nutritionally equivalent or better." Based on (Eshel et al. 2016).

[m]See Table S6. Diet change from highest GHGE quintile to population mean includes change in foods and reduction in kcal. Meats and dairy contributed the most to GHGE reduction. GHGE cradle-to-farmgate; includes GHGE of edible food losses at retail and consumer level. Based on (Heller et al. 2018). Reduction in GHGE is only for the highest GHGE quintile, but distributed over all quintiles of the UC population to estimate scenario effect.

[n]See Table S7. Estimated using data from economic IO LCA of 1997 US food system. Based on (Weber and Matthews 2008b).

SI 2.1. Dietary Guidelines for Americans

The US government's Dietary Guidelines for Americans (DGA) has included a recommended healthy diet, as well as alternative diets (Mediterranean, vegetarian, vegan) that are equally nutritious. We created scenarios for the 2000 kcal day^{-1} vegetarian and vegan diets plus a 50% reduction in food waste with data from (Heller and Keoleian 2015), and included a 50% reduction in food waste. This study found a base line for SAD of 5.37 kg CO_2e capita^{-1} day^{-1}, including 2010 USDA LAFA data (USDA ERS 2015) and estimates of GHGE from food waste (Table S3). Animal foods accounted for 38% of food consumed in the US food system by weight, 29% by kcal, but 80% of GHGE, and in terms of food loss, 33% by weight, 23% by kcal, but 74% of GHGE. Using the 2000 kcal day^{-1} diet as the base for our scenario diets makes the estimated reductions in GHGE UC savings more conservative, since most people, especially young adults, typically consume more.

Table S3. Change in GHGE with USDA recommended diets.[a]

Scenario	GHGE (kg CO_2e capita^{-1} yr^{-1})			
	SAD[b] 2534 kcal yr^{-1}, average consumed	USDA recommended nutritionally adequate diets[c], 2000 kcal yr^{-1}		
		Healthy[d]	Lacto-ovo vegetarian	Vegan
Food eaten	1314	1314	876	621
Change from SAD for food eaten		0	-438	-694
Percent change for food eaten		0.0%	-33.3%	-52.8%
Food eaten + food wasted[e]	1960	1824	1386	1130
Change from SAD for food eaten + 50% reduction in food waste		-391	-829	-1085

Percent change for food eaten + 50% reduction in food waste	-20.0%	-42.3%	-55.3%

[a]Calculations based on data in (Heller and Keoleian 2015).

[b]SAD = standard American diet; food comprising SAD estimated from USDA LAFA data for 2010, including 0.72 kg CO_2e day^{-1} from excess kcal; GHGE for foods estimated from LCA data from various sources and various years.

[c]USDA diets as described in Dietary Guidelines for Americans (USDA and HHS 2010:79-80).

[d]The main reason the 2000 kcal day^{-1} healthy diet shows no reduction from the SAD diet for food eaten is that it includes large increases in dairy consumption that offset about two thirds of the reduction in emissions from reduced meat, poultry and eggs.

[e]Food waste estimates for SAD diet from (Heller and Keoleian 2015) are 1.77 kg CO_2e day^{-1} total (1.4 kg CO_2e day^{-1} from the food system for edible food loss at retail and consumer levels, and 0.37 kg CO_2e day^{-1} for food waste sent to landfills). For 2000 kcal day^{-1} diets, we reduced CO_2e from waste proportionately.

SI 2.2. Healthy alternative diets to reduce NCD prevalence

Three healthy alternative diets were modeled by changing only foods in the SAD for which high quality data existed linking them to increased or decreased risk for NCDs, which was about half of the food on a calorie basis in a 2000 kcal day^{-1} SAD diet, and reductions in GHGE from the food system were calculated (Table S4) (Hallström et al. 2017). There were also reductions in GHGE from the health care system due to decreased risk of NCDs and health care which we did not include in this scenario. However, these could potentially contribute a relatively large reduction in all the scenarios since they all are based on diets healthier than SAD.

For example, type 2 diabetes is a major cause of renal failure, leading to the need for dialysis according to the US National Institutes of Health, making diabetes a very greenhouse gas intensive disease. Approximately 9.7% of US adults had diabetes in 2017, with annual per capita health care expenditures 2.3 times higher than people without diabetes, costing an estimated $327 billion that year (ADA 2018).

Table S4. Reduction in GHGE in the food system with a change from the Standard American Diet to Healthy Alternative Diets.[a]

Diet	GHGE (kg CO_2e capita^{-1} yr^{-1})		
	Best estimate	95% CI	Change from SAD to HAD
SAD[b]	1,397	985-1776	
HAD1[c]	1,245	990-1475	-152

HAD2	951	807-1091	-446
HAD3	655	576-742	-742

[a]Based on (Hallström et al. 2017). The food system boundaries for emissions from the food system were from production to retail (i.e. not including land use change, consumer transport, storage and preparation at the consumer stages, and household food waste). GHGE for foods changed were derived from recent life cycle assessment studies. We adjusted LCA data for beef to a GWP for methane of 34, per the most recent IPCC estimate (Myhre et al. 2013).

[b]SAD = standard American diet. Quantities of the foods changed in HADs based on the USDA Loss Adjusted Food Availabillity data (USDA ERS 2015).

[c]HAD = healthy alternative diets, modeled by decreasing red and processed meats progressively from HAD1 to HAD3, and decreasing refined grains and increasing whole grains, fruits and vegetables from SAD to HAD1, with no further change in HAD2 and HAD3.

SI 2.3. Replace all beef in SAD with plant food

Eshel et al, modeled the replacement of all beef in the US diet based on loss-adjusted USDA data with equivalent nutrient content plant food, and estimated the reduction in GHGE from only the production component of food life cycles (Eshel et al. 2016) (Table S5).

Table S5. Replace all beef with plant food.[a]

Scenario	kg CO_2 cap^{-1} yr^{-1} [b]		
	beef	plant replace-ment	net for replace-ment diet
Beef replaced in mean American diet (MAD) with plant nutritional equivalent	901	33	-868

[a]Based on (Eshel et al. 2016). "To evaluate plant-based replacement to beef we construct diets comprising combinations of plant items that adequately replace (as described below) the beef portion of the MAD. MAD = Mean American Diet = the 2000−2010 means (p 8164).

[b]Direct agricultural GHGE only (excluding uncertain emissions related to land use changes) (p. 8166), i.e. not food system GHGE.

SI 2.4. Convert US food GHGE population highest quintile to population mean

Heller et al. estimated the GHGE of self-reported US diets based on NHANES (National Health and Nutrition Examination Survey) data, and defined quintiles based on diet GHGE (Heller et al. 2018). Our scenario estimated the reduction in GHGE if the highest quintile changed to a diet with the mean GHGE, and distributed the reduction to the entire relevant UC population (Table S6).

Table S6. Convert highest food GHGE population quintile to population mean food GHGE.[a]

Scenario	US GHGE, Mt CO_2e d^{-1}	kg CO_2e cap^{-1} d^{-1} [b]	kg CO_2e cap^{-1} yr^{-1}
US population, all foods (includes food losses estimated at 24-25%, per Table 3, and p. S8) (Heller et al. 2018)	1,052,146	4.7	1,723
Add to mean an estimate of processing and packaging not captured in bottom up estimates = 27%[c]	1,336,225	6.0	2,188
5th quintile	478,819	10.7	3,920
Add to 5th quintile estimate of processing and packaging not captured in bottom up estimates = 27%[c]	608,100	13.6	4,979
Change 5th quintile to mean, NOT including processing and packaging		-6.0	-2,197
Change diet from 5th quintile to mean, including processing and packaging		-7.6	-2,791

[a]Calculations based on Table 3 in (Heller et al. 2018). System boundaries used were cradle-to-farm gate for the "vast majority of foods", with the exception of "foods within the FCID listing that require processing: flours, refined sugars, vegetable oils" (Heller et al. 2018:3).

[b]US pop (represented population for the 2005–2010 NHANES data used) = 222,909,266 (Heller et al. 2018:7, n. 6).

[c](Heller et al. 2018) estimated food processing not captured in bottom-up estimates = "15% of the total cradle to 6% for total ~ 27%. Estimates are for "food and agricultural sectors in aggregate…and apply only at the mean".

SI 2.5. Shift 48% of meat and dairy calories actual US diets to non-dairy, vegetarian diet

This scenario is based on a top-down economic input-output LCA of the US food system for 1997 (Weber and Matthews 2008b) (Table S7).

Table S7. Shift 48% of meat and dairy calories actual US diets to non-dairy, vegetarian diet[a]

	kg CO2e cap^{-1}, yr^{-1} 1997
Food system GHGE[b]	3,027
Shift 48% of red meat and dairy to non-dairy vegetarian diet[c]	-538

[a]Based on (Weber and Matthews 2008a) economic input-output LCA for the US in 1997, the only EIO LCA for the US.

[b]Calculated by dividing household GHGE yr^{-1} (8.1 Mt) by average size US household in 1997 (2.68 persons) (https://www.census.gov/prod/3/98pubs/p23-194.pdf)

[c]Based on data in Table 2 in (Weber and Matthews 2008a).

SI 3. Scenarios based on UC campus food system changes

Table S8 (and Fig 2) show our estimates of the effect of changes in GHGE from existing, planned or potential practices and policies for food system change on some UC campuses, based on bottom-up scenarios assuming these changes were implemented across all campuses.

In the study on which scenario UC1 was based (food and environment course), the student-reported data on servings per week of various foods were normalized to 2,000 kcal per week. In the study on which scenario UC7 (SSB sales ban) was based researchers did not estimate reduction in caloric intake, but UC7 assumed none of the calories in SSBs would be replaced, since SSBs were replaced with tap water.

We did not estimate changes in caloric intake for the other UC scenarios—for many it would not be possible or appropriate. The change in calories would be minimal, and people in the US consume about 20% excess calories currently (Heller and Keoleian 2015), contributing to obesity prevalence of 42% among US adults (ages 20 and over) and 21% among youth (ages 12-19) according to the CDC, which is an important risk factor for a number of NCDs including type 2 diabetes, heart disease and caner (Danaei et al. 2009).

Scenario UC1 (Table S8) is based on a peer-reviewed study of the reduction of student dietary GHGE emissions that resulted from a course offered at UCLA (Jay et al. 2019a). It is the only one of the campus scenarios that was analyzed in terms of effect on GHGE. Scenarios UC2-5 all reduce consumption of red meat, the most GHGE intensive food. Scenario 2 is based on the replacement of 30% of beef in burgers with plant food implemented at UCLA in 2018, and in scenario UC3 we estimated the effect if there were 100% replacement of beef (Table S10). Scenarios UC4 and UC5 use data on the implemented reduction of beef one day per week in UCLA dining halls begun in 2009, and our estimates if this was replaced by either beans or chicken (Table S11).

Data from UCSB dining of the effect of removing trays in the dining halls in 2009 provided the basis for scenario UC6. Since the total amount of consumer level food waste before trayless (19%) was less than the USDA estimate for total consumer level food waste (21%) (Buzby et al. 2014:12), we extrapolated the food waste reduction from the switch to trayless dining halls to all meals, equivalent to a 54% reduction in consumer level food waste (Table S10). Scenario UC7 estimates the reduction in GHGE from the elimination of sugar sweetened beverage (SSB) containers that would occur if the ban on SSB sales implemented at UCSF in 2015 was extended across the UC and SSB intake was replaced by tap water (Table S11). Scenario UC8 is the average effect of aerobically and anaerobically composting food waste, inspired by a successful pilot project at UCSD. We assumed that 50% of pre- and post-consumer food waste could be composted and estimated the reduction in GHGE using the US EPA WARM model (EPA 2019b) (Table S12).

Table S8. Estimates of the potential for UC food system change initiatives to reduce UC GHGE: results of bottom-up scenarios.

1. Diet change scenario number; campus case study, main data source		2. Scenario effect (kg CO_2e capita^{-1} yr^{-1})[a]	3. Scenario effect for UC on-campus meals (Mt CO_2e yr^{-1}) for UC population[b]	Scenario effect for UC on-campus meals as per cent of UC:		
				4. Scope 3 food system GHGE[c]	5. CNI defined Scope 1 & 2 GHGE in 2018 to reduce to zero by 2025[d]	6. Offsets needed to reach CNI 2025 target[e]
UC1	Academic course content on food and the environment; UCLA first year students, dietary recall[f]	-309	-30,525	14.1%	2.7%	6.4%
UC2	Blended burgers (70% beef); UCLA, dining data[g]	-7	-1,487	0.7%	0.1%	0.3%
UC3	Plant burgers (100% plant); UCLA, dining data[h]	-23	-4,608	2.1%	0.4%	1.0%
UC4	Replace beef 1 day wk^{-1} with beans, protein basis; UCLA, dining data[i]	-43	-8,597	4.0%	0.8%	1.8%
UC5	Replace beef 1 day wk^{-1} with chicken, protein basis; UCLA, dining data[j]	-40	-7,995	3.7%	0.7%	1.7%
UC6	Switch to trayless dining; UCSB, dining data[k]	-309	-45,825	21.2%	4.1%	9.6%
UC7	SSB ban on sales on campus; UCSF, US data[l]	-34	-5,039	2.3%	0.4%	1.1%

UC8	Composting campus food waste, UCSD, US data[m]	-63	-9,308	4.3%	0.8%	2.0%
UC9	Combined: food environment non-overlapping effects (scenarios UC3,UC4, UC6, UC7, UC8)[n]	-468	-73,376	33.9%	6.5%	15.4%
UC10	Combined: academic course, trayless, SSB ban, composting (scenarios UC1, UC6, UC7, UC8)	-714	-90,697	41.9%	8.0%	19.0%

[a]Methods and assumptions are different for different scenarios.

[b]This column first converts kg CO_2e capita^{-1} yr^{-1} to CO_2e meal^{-1}, using number of meals in each scenario, which is different for different scenarios; for example, for rows 2-5 we assumed burgers and beef only eaten at lunch and dinner. See tables for each scenario in Supporting Information. The next step in the calculation is multiplying the per meal CO_2e by the total number of meals for the UC population for 2018 (Table S1). Assumed UC first year enrollees ate 3 meals d^{-1}, 7 days wk^{-1}, 39 weeks yr^{-1}; non-first year students ate 1 meal d^{-1}, 5 days wk^{-1}, 39 weeks yr^{-1}; faculty and staff ate 1 meal d^{-1}, 5 days wk^{-1}, 39 weeks yr^{-1}. Total effect on UC emissions underestimated because no summer students, non-campus conference attendees or other visitors included, and because GHGE for meals on campus for non-first year students was average for all meals, which includes breakfast with below average emissions.

[c]Estimate for total US food system GHGE from (Heller et al. 2018), = 1722.8 kg CO_2e cap^{-1} yr^{-1}.

[d]= 1,129,233 Mt CO_2e yr^{-1} in 2018 October (UC CNI 2018).

[e]= 477,117 Mt CO_2e yr^{-1} as of 2018 October (UC CNI 2018).

[f]See Table S9. kg CO_2e cap^{-1} yr^{-1} based on 365 days yr^{-1} for students in the study. Applied to all students on campus, assuming persistence of diet change through graduation.

[g]See Table S10. @ 40.2 kg CO_2e kg^{-1} beef. Assumes reported and normalized intake distributed equally across 2 meals d^{-1}. Applied to total UC population.

[h]See Table S10. @ 40.2 kg CO_2e kg^{-1} beef. Assumes intake distributed equally across 2 meals d^{-1}. Applied to total UC population.

[i]See Table S11. Assumes intake distributed equally across 2 meals d^{-1}. Applied to total UC population.

[j]See Table S11. Assumes intake distributed equally across 2 meals d^{-1}. Applied to total UC population.

[k]See Table S12. Only for first year students, an underestimate because many non-first year students eat in dining halls. Because we estimated the total amount of consumer level food waste before trayless (19%) was less than the USDA estimate for total consumer level food waste in the US (21%) (Buzby et al. 2014:12), we extrapolated the food waste reduction from trayless to all meals, equivalent to a 54% reduction in consumer level food waste.

[l]See Table S13. Assumes average intake d^{-1} distributed over lunch and dinner only; no leakage; did not subtract for alternative beverage, assumed to be tap water.

[m]See Table S14. Based on 50% of USDA estimate of food waste at retail and consumer level in 2010 (Buzby et al. 2014) and EPA WARM model (EPA 2019b) estimate for change in CO_2e.

[n]UC3 reduced to 6 days wk^{-1} to avoid double counting with UC4.

SI 3.1. UCLA course on food and the environment

An experiment at UCLA studied the effect of a two-quarter freshman year course on student food choice. The treatment group (Food cluster) consisted of freshmen enrolled in the course "Food: A Lens for Environment and Sustainability," which covered the environmental impact of food choices (Table S9) (Jay et al. 2019b). The control group (Cosmos cluster) was composed of freshmen enrolled in the course "Evolution of the Cosmos and Life", which did not include information on food and the environment. Students completed questionnaires about their diets at baseline in early fall quarter and at follow up at the end of winter quarter, about 20 weeks later, and these data were normalized to a standard 2000 kcal cap^{-1} day^{-1}. At baseline, the differences between treatment and control groups means for GHGE of the overall diet and of beef were not significantly different, and at follow up they were—the treatment group had emissions 309 kg CO_2e cap^{-1} yr^{-1} lower than the control group; the majority of this difference was due to beef (323 kg CO_2e cap^{-1} yr^{-1}), as a result of the treatment group reporting an average 0.9 fewer servings per week than the control group at follow up.

Table S9. UCLA Cluster Study, GHGE of reported diets and reported servings of beef.

Time of survey	Parameter	Unit	Food, mean (n=90)	Cosmos, mean (n=73)	Difference (Food - Cosmos)	test	p-value
Baseline	All food (normalized) b	kg CO2e cap^{-1} yr^{-1}	1,789	1,920	-132	t-test	0.20
	Beef (normalized)	kg CO2e cap^{-1} yr^{-1}	825	920	-95	Wilcox	0.43
	Beef servings (as reported)	servings wk^{-1}	3.5	3.6	-0.1	Wilcox	0.60
Follow Up	All food (normalized)	kg CO2e cap^{-1} yr^{-1}	1,669	1,978	-309	t-test	0.024
	Beef (normalized)	kg CO2e cap^{-1} yr^{-1}	669	992	-323	Wilcox	0.017
	Beef servings (as reported)	servings wk^{-1}	2.5	3.4	-0.9	Wilcox	0.054

[a]Based on (Jay et al. 2019a).

[b]Normalized to 2000 kcal cap^{-1} day^{-1} to adjust for wide range of reported values. GHGE intensities from (Heller and Keoleian 2015), except for beef from (Nijdam et al. 2012) (40.2 g CO_2e g^{-1} beef).

SI 3.2. Blended burgers

Several UC campuses are beginning to reduce the amount of beef in burgers by blending in plant foods and using 100% plant-based burgers. We used data from UCLA for our scenario (Table S10). In January of 2018, the food provider serving the residence halls at UCLA began making and serving a blended burger, which is 70% pasture-raised beef, 10% mushrooms, 10% onions, 5% quinoa, and 5% beets. The goal of dining services is to eventually reduce the beef content to 60%.

Table S10. Switch to blended burgers or plant burgers in UCLA dining halls.

Academic year estimates	100% beef burgers	Blended burgers (70% beef)[a]	100% plant burgers[b]
kg beef (academic yr)$^{-1}$ [c]	5,924	4,147	0
kg plant (academic yr)$^{-1}$	0	1,777	5,924
kg CO_2e beef (academic yr)$^{-1}$ [d]	238,165	166,715	0
kg CO_2e plant (academic yr)$^{-1}$ [e]	0	1,102	20,143
kg CO_2e total (academic yr)$^{-1}$	238,165	167,817	20,143
number students eating yr^{-1} [f]	9,435	9,435	9,435
kg CO_2e cap^{-1} (academic yr)$^{-1}$	25.2	17.8	2.1
kg burgers cap^{-1} (academic yr)$^{-1}$ [g]	0.6	0.6	0.6
Δ kg CO_2e cap^{-1} yr^{-1}		-7.5	-23.1

[a]The 30% plant content comprises: onion, roasted mushroom, quinoa, garlic salt, pepper (http://menu.dining.ucla.edu/Recipes/077109/1), with a combined CO_2e kg of 0.62 kg^{-1}.

[b]Beyond Burger vegan burgers GHGE 3.4 kg CO_2e kg^{-1} through retail; ingredients account for 57% of this (Heller et al. 2018:26).

[c]Based on an average of 452 pounds of ground beef purchased wk^{-1} over 2 weeks in 2019 by the 4 UCLA dining halls, assuming 50% of the ground beef used for burgers. Based on 6 days wk-1 only, to not double count for UCLA's beefless Thursdays. Academic year estimate of days dining halls open: UCLA Dining website calendar (http://menu.dining.ucla.edu/Hours/2018-12-11) shows closed completely for 20 days in Dec-Jan; no lunch or dinner for 3 days in Nov (22-24); reduced dinners 21 & 25. 2018-19 academic calendar (https://www.registrar.ucla.edu/Calendars/Annual-Academic-Calendar) shows Sep 24-Jun 14, so assume dining halls open Sep 18. Total days open academic year = 243.

[d]At 40.2 kg CO_2e kg^{-1} beef, for typical US beef production, the geometric mean of 52 LCAs (Harwatt et al. 2017).

[e]Plant portion of blended burgers was calculated using these proportions and GHG intensities.

[f]Number of student meal-days yr^{-1} = average of [lunch swipes (2,412,316) + dinner swipes (2,286,090)] for the academic year 2017-18, divided by 2 assuming that all students ate both lunch and dinner. Number students eating yr^{-1} = (no. student meal-days yr^{-1}) / (days yr^{-1} dining halls open = 249).

[g]Compare this with USDA LAFA data for 2016: availability of beef cap^{-1} yr^{-1} at retail/institutional level = 24.0 kg cap^{-1} yr^{-1} (USDA ERS 2018).

SI 3.3. Beefless Thursdays

Many campus dining halls have introduced programs to reduce animal food or meat in their food choices, such as Meatless Mondays, which is a global campaign. For our scenario we used data from UCLA's Beefless Thursdays, a program that began in 2009 and eliminates beef from all four dining halls every Thursday (Table S11). Since no data were available on what foods were consumed in place of beef, and what the rate of substitution was, we assumed 100% substitution on a protein basis, with beans and with chicken.

Table S11. Beefless Thursdays, UCLA.

Scenario (for academic year)	Before Beef-less Thursdays	After Beef-less Thursdays
Change in non-burger beef consumption[a]		
kg beef $(academic\ yr)^{-1}$	51,112	40,256
kg CO_2e beef $(academic\ yr)^{-1}$ [b]	2,054,714	1,618,284
Replace beef with chicken, protein basis		
additional kg chicken $(academic\ yr)^{-1}$ [c]	0	9,640
kg CO_2e chicken $(academic\ yr)^{-1}$ [d]	0	48,777
kg CO_2e $(academic\ yr)^{-1}$ TOTAL	2,054,714	1,667,062
kg CO_2e day^{-1} cap^{-1} $(academic\ yr)^{-1}$ [e]	0.875	0.710
kg CO2e cap^{-1} yr^{-1} [f]	212.538	172.440
Δ kg CO2e cap^{-1} yr^{-1}		-40.098
Replace beef with beans, protein basis		
additional kg beans $(academic\ yr)^{-1}$ [g]	0	25,128
kg CO_2e beans $(academic\ yr)^{-1}$ [h]	0	19,600
kg CO_2e $(academic\ yr)^{-1}$ TOTAL	2,054,714	1,637,885
kg CO_2e cap^{-1} day^{-1} $(academic\ yr)^{-1}$ [e]	0.875	0.697
kg CO_2e cap^{-1} yr^{-1} [f]	212.538	169.422
Δ kg CO_2e cap^{-1} yr^{-1}		-43.117

[a]Based on an average of 2,557 pounds of beef purchased wk^{-1} over 2 weeks in 2019 by the 4 UCLA dining halls, and served 6 days wk^{-1}, after subtracting 50% of the ground beef which we assumed to be used for burgers. Academic year estimate of days dining halls open: UCLA Dining website calendar (http://menu.dining.ucla.edu/Hours/2018-12-11) shows closed completely for 20 days in Dec-Jan; no lunch or dinner for 3 days in Nov (22-24); reduced dinners 21 & 25. 2018-19 academic calendar (https://www.registrar.ucla.edu/Calendars/Annual-Academic-Calendar) shows Sep 24-Jun 14, so assume dining halls open Sep 18. Total days open academic year = 243.

[b]At 40.2 kg CO_2e kg^{-1} beef, for typical US beef production, the geometric mean of 52 LCAs (Harwatt et al. 2017).

[c]Based on 23.2 g protein 100^{-1} g chicken, and 20.6 g protein 100^{-1} g beef.

[d]Based on 5.06 kg CO2e kg^{-1} chicken.

[e]= kg CO_2e (academic yr)$^{-1}$ / average people eating day^{-1}, where ave people eating day^{-1} = average meal swipes (academic yr^{-1}) / days dining halls open (academic yr^{-1}). Based on the average of lunch swipes (2,412,316) plus dinner swipes (2,286,090) for the academic year 2017-18, assuming that students ate both lunch and dinner = 9,435 students eating in dining halls. Data for number of swipes from Chris Wible, Dining Services, UCLA Housing.

[f]Assuming dining halls served lunch and dinners for 243 days (academic year)$^{-1}$, accounting for days closed.

SI 3.4. Trayless dining

With the goal of reducing food waste, campus dining halls have been going trayless, as students tend to take and waste less food if more trips are required. We used data from UCSB's Residential Dining trayless program which was introduced in fall 2009 (Table S12). We found reduction of 356 kg CO_2e cap^{-1} yr^{-1} due to reduction of 54% (99 g) of food waste, with only a very small additional amount due to reduction in electricity and water use. The only published study, at Indiana U, found an 18% (23 g) reduction in solid food waste, but no reduction in liquid food waste (Thiagarajah and Getty 2013). Due to lack of data, we did not include any reduction in GHGE due to reduced labor needed to wash and replace trays, or increase in GHGE due to increased dish breakage and time needed to clean tables (Thiagarajah and Getty 2013).

Table S12. Switch to trayless in dining halls.

	Before	After
Solid food waste person/tray^{-1} (g)[a]	181.4	84
Solid food waste cap^{-1} (academic yr)$^{-1}$ (kg)[b]	132.3	61
kg CO2e cap^{-1} (academic yr)$^{-1}$ from food system before consumer[c]	440.0	203
kg CO2e cap^{-1} (academic yr)$^{-1}$ from post consumer food waste to landfill[d]	71.4	0

Total Δ kg CO2e cap^{-1} (academic $yr)^{-1}$	-309

[a]Data are from Danielle Kemp, UCSB Residential Dining. This was a 54% decrease in food waste. The reduction in cost mo^{-1} was 10.3%. If we assume a direct relationship between food cost and waste, then the total amount of consumer level food waste before trayless = 19%, compared with the USDA estimate of 21% total consumer level food waste (Buzby et al. 2014:12).

[b]Assumes dining halls open 243 days (academic $yr)^{-1}$ (based on UCLA calendar), and students eating 3 meals day^{-1}.

[c]3.33 kg CO_2e kg^{-1} food, based on (Jay et al. 2019a); cf. 3.86 in (EPA 2019b).

[d]0.54 kg CO_2e kg^{-1} food waste in landfill without energy generation (EPA 2019b).

SI 3.5. Replacing SSBs with tap water

A focus of the UC HCN is the reduction of sugar sweetened beverages (SSBs) on campus, initiated by UCLA's elimination of soda from a new campus restaurant in 2013, which has been very successful, with no complaints from students about the lack of soda (Slusser and Malan 2016:44-45). In 2015 UCSF instituted a ban on the sale of all SSBs in its campus vendors, cafeterias and vending machines, in the context of a community public health coalition (Grumbach et al. 2017). UCSF administrators were convinced by researchers that they could not ethically profit from selling beverages its own researchers have shown is fueling increasing prevalence of NCDs (O'Connor 2016).

Because sugar, the main SSB ingredient, has relatively low GHGE in most LCAs, much of the potential direct impact on GHGE of reducing SSBs is on reduction of beverage containers. HCN beverage policy now includes encouraging tap water consumption, with most campuses also implementing programs to reduce plastic use in general and/or bottled water. The indirect emissions reductions in the health care system are potentially large because added sugar consumption is strongly linked to several NCDs, including type 2 diabetes, non-alcoholic fatty liver disease, cardiovascular disease, and stroke.

Because no data were available on reduction in SSB volume or container types on UC campuses with reduced SSB policies, we use data from California, the US, and the UK (Table S13). We estimated the reduction in GHGE from the elimination of SSBs, as per the ban at UCSF, assuming a consumption rate of 0.6 SSBs day^{-1}, based on California survey data (CHIS 2019), and using data on proportion of different containers based on recycling data for California (CalRecycle 2014). For GHGE factors we used a comprehensive LCA from the UK, which included all life cycle stages (ingredients, containers, secondary packaging, manufacturing, transport, refrigeration, container recycling, and waste management), for 0.75 liter glass, 0.33 liter aluminum, and 0.5 liter PET plastic containers (we did not use data for the fourth type, 2.0 liter PET containers) (Amienyo et al. 2013). For the three types of containers, the containers accounted for 71%, and ingredients for 11% of total GHGE, and sugar for 71% of ingredient GHGE.

We assumed the container sizes in California were the same as those in (Amienyo et al. 2013). We did not include GHGE changes from increased consumption of tap water, including the provision of any additional water filling stations.

Table S13. Eliminate SSBs.

SSB containers	Proportion CA sales, 2017[a]	Number cap^{-1} day^{-1} [b]	SSB GHGE, based on LCA study in UK[c]			Change in life cycle GHGE with elimination of SSBs	
			size container, liters	TOTAL kg CO_2e $liter^{-1}$	kg CO_2e $container^{-1}$	kg CO_2e cap^{-1} d^{-1}	kg CO^2e cap^{-1} y^{-1}
glass	0.134	0.076	0.75	0.555	0.416	-0.031	-11
aluminum	0.344	0.194	0.33	0.312	0.103	-0.020	-7
PET plastic	0.504	0.284	0.5	0.293	0.147	-0.042	-15
Total	0.982	0.554				-0.093	-34

[a]Beverage container sales in California, 2017. Less than 2% other container types not included. CalRecycle 2018, https://www.calrecycle.ca.gov/docs/cr/bevcontainer/rates/biannualrpt/julydecrpt.pdf.

[b]Estimate of intake of 0.564 SSBs cap^{-1} day^{-1} based on CHIS 2017 data for California: children and teen age group, consumed 0.63 or more glasses of soda + non-soda SSBs cap^{-1} day^{-1}, adults consumed soda 0.21 or more times cap^{-1} day^{-1}, and based on the ratio of soda to non-soda SSBs consumed by children and teens, consumed SSBs 0.56 or more times cap^{-1} day^{-1} (CHIS 2019).

[c]LCA for UK, includes ingredients, containers, secondary packaging, manufacturing, transport, refrigeration, container recycling, and waste management (Amienyo et al. 2013). If container sizes in California are smaller, the CO_2e per container would be greater.

SI 3.6. Composting pre-consumer food waste

Undergraduate students Enid Partika and William Tanaka at UCSD created a pilot anaerobic digestion and biogas production system they named the BioEnergy Project. Their goal was to design a system that would turn food waste destined for landfills into usable products—including fertilizer for organic produce and biogas for electricity. In just one year, the team repurposed more than 42,000 pounds of pre-consumer food waste from UCSD dining halls through their pilot. They estimated the potential reduction in GHGE using the EPA WARM model. They are currently developing methods to scale this to UCSD dining halls, including using the methane for cooking.

Since no data were available on the number of students generating the food waste for UCSD project, we estimated the potential for GHGE reductions using data on average pre-consumer food waste in the US and the EPA WARM model, applied to the UC population (Table S14). We assumed that food waste cap^{-1} was the US average reduced 50% by trayless and other interventions.

Table S14. Composting dining hall food waste (FW) aerobically and anaerobically[a]

	kg CO_2e cap^{-1} y^{-1}
Model estimate[b]	

	Aerobic composting for all FW	Anaerobic composting for all FW	Average
WARM 15 output for retail/institutional (pre consumer) FW: kg CO_2e for 63 kg FW cap^{-1} y^{-1}	-45	-37	-41
WARM 15 output for consumer level FW: kg CO_2e for 132 kg FW cap^{-1} y^{-1}	-95	-77	-85
WARM 15 output for total retail/institutional + consumer FW: kg CO_2e for 195 kg FW cap^{-1} y^{-1}	-140	-114	-126
Assume reduce FW by 50% via trayless and other interventions	-70	-57	-63

[a]Food waste cap^{-1} for US at institutional (i.e. pre-consumer) level and consumer level from USDA estimates for 2010 (Buzby et al. 2014:14).

[b]GHGE estimated using EPA WARM 15 (EPA 2019b). Baseline emissions before composting assumed to be from sending food waste to a landfill with CH_4 captured and burned for energy.

Key assumptions of the EPA WARM 15 model (EPA 2019a:1-4):

"Composting with application of compost to soils results in carbon storage and small amounts of CH_4 and N_2O emissions from decomposition.

The anaerobic digestion captures biogas from the digestion of organic materials. The biogas is assumed to be combusted to produce energy, offsetting emissions from fossil fuel consumption. Additionally, the digestate resulting from the digestion process is applied to agricultural lands, resulting in soil carbon storage, avoided use of synthetic fertilizers, and trace CH_4 and N_2O emissions during digestate curing and after land application.

Landfilling results in both CH_4 emissions from biodegradation and biogenic carbon storage. If captured, the CH_4 may be flared, which simply reduces CH_4 emissions (since the CO_2 produced by flaring is biogenic in origin, it is not accounted for in this assessment of anthropogenic emissions). If captured CH_4 is burned to produce energy, it offsets emissions from fossil fuel consumption."

SI 4. UC and US energy GHGE

One reason why the GHGE reductions of our scenarios are a relatively small portion of UC CNI-defined Scopes 1 and 2 energy emissions compared to their portion of UC food emissions is likely because the UC campuses have a disproportionately high level of energy cap^{-1} CO_2e based on time spent on campus (Table S15). In 2018 fossil fuel combustion emissions in the US were 15.38 Mt CO_2e cap^{-1} yr^{-1}. The average proportion of total time yr^{-1} spent on campus by the UC population in 2018 (based on number of meals, Table S1) was 0.24. If the energy cap^{-1} CO_2e on campus was proportional to the average for fossil fuel combustion for the US, we would expect the campus energy emissions cap^{-1} to be 3.62 Mt CO_2e cap^{-1} yr^{-1}, instead it is 11.41 Mt CO_2e cap^{-1} yr^{-1}, 3.15 times larger.

Table S15. US and UC cap^{-1} energy consumption.

Row	Variable	Value	Notes
1	Mt CO_2e cap^{-1} y^{-1} from fossil fuel combustion, US 2018	15.38	US GHGE 2018 = 5,547.2 MMt yr^{-1}, only for fossil fuel combustion in the energy category (EPA 2020); US population 2018 = 327167434 (USCB 2020).
2	Proportion of time spent on campus by UC population	0.24	Source: Table S1.
3	UC population size weighted by time on campus (based on no. of meals on campus)	98,945	Source: Table S1.
4	Mt UC Scopes 1&2 CO_2e yr^{-1}, estimate for 2018 October	1,129,233	Source: (UC CNI 2018).
5	UC Scopes 1&2 Mt CO_2e (UC weighted population $cap)^{-1}$ y^{-1}	11.41	row 4 / row 3
6	Expected Mt CO_2e cap^{-1} for weighted UC population on campus if proportional to US.	3.62	row 2 x row 1
7	Ratio: (estimated) / (expected), Mt CO_2e cap^{-1} yr^{-1} for weighted UC pop on campus	3.15	row 5 / row 6

SI 5. Other UC food system changes with likely climate co-benefits

UC students, staff and faculty are working on and have already implemented many food system changes with potential climate co-benefits that we have not included in our scenarios because the necessary data are lacking. These could all be documented, improved, expanded, and extended across all campuses to increases their contribution to climate change mitigation. For example, the reusable mug program at UCLA provides all incoming students with a stainless steel water bottle and encourages them to use water filling stations; the self-service Flex Bar at UCLA features flavorful dishes that emphasize plant ingredients with meat as a condiment; every Monday at UCLA one station in each dining hall serves only non-meat options; UCLA increased the sale of healthy food in vending machines by 20% compared with controls (Viana et al. 2018), Green Mondays once a month in one of UCSB's four dining halls eliminates meat; an undergraduate and UCen Dining staff at UCSB were successful in replacing all egg-based mayonnaise with a plant-based alternative; UC Berkeley's Café 3 has removed meat options from 9 of its 10 serving stations; many UC campuses have programs that rescue edible food from the waste stream, that compost food waste, and that grow food in campus gardens and farms.

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