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The Carbon Footprint of School Lunch: Moving Toward a Healthy and Sustainable Future for the Next Generation

Renate Boronowsky [1], Kevin Lin-Yang [1], Lucretia Natanson [2], Kira Presley [1], Yashvi Reddy [1], Alexis Shenkiryk [1], May Wang [3], Wendelin Slusser [3,4], Pamela A. Koch [5], David A. Cleveland [6], Shannon Roback [7], Deborah Olarte [8], Jennifer Molidor [9] and Jennifer A. Jay [1,*]

[1] Department of Civil and Environmental Engineering, University of California Los Angeles, Los Angeles, CA 90095, USA; renate.ware@gmail.com (R.B.); kevinlinyang00@g.ucla.edu (K.L.-Y.); kiragracepresley@gmail.com (K.P.); yashvireddy17@g.ucla.edu (Y.R.); alexisshenkiryk@g.ucla.edu (A.S.)
[2] Natanson Consulting, Bellevue, WA 98004, USA; lucynatanson@gmail.com
[3] Field School of Public Health, University of California Los Angeles, Los Angeles, CA 90095, USA; maywang@ucla.edu (M.W.); wslusser@conet.ucla.edu (W.S.)
[4] Los Angeles David Geffen School of Medicine, Healthy Campus Initiative, University of California, Berkeley, CA 94704, USA
[5] Department of Health Studies and Applied Educational Psychology, Teachers College, Columbia University, New York, NY 10027, USA; pac14@tc.columbia.edu
[6] Department of Geography, University of California Santa Barbara, Santa Barbara, CA 93106, USA; cleveland@ucsb.edu
[7] Department of Health Sciences, California State University, Dominguez Hills, Dominguez Hills, CA 90747, USA; sroback@csudh.edu
[8] Department of Nutrition and Food Studies, Steinhardt School of Culture, Education, and Human Development, New York University, New York, NY 10003, USA; ddo223@nyu.edu
[9] Center for Biological Diversity, Tucson, AZ 85702, USA; jmolidor@biologicaldiversity.org
* Correspondence: jennyjay@ucla.edu; Tel.: +1-310-866-2444

Abstract: This study aimed to quantify the carbon footprint of elementary school lunch menus across six major urban school districts in the United States and to simulate the effect of sustainable food policies on carbon emissions reductions while ensuring nutritional requirements remain adequate. We analyzed a total of twenty distinct meals per district selected from a four-week period and calculated their carbon emissions using life cycle assessment data. We then modeled three scenarios to reduce carbon emissions: (1) a reduction in beef meal offerings to one day per month, (2) an introduction of one entirely plant-based day per week, and (3) a combination of scenarios 1 and 2. Our findings revealed that beef-containing meals had the highest carbon emissions, while plant-based meals had the lowest. Implementing the one monthly beef meal scenario led to an average savings of 34% in emissions, while the plant-based day scenario led to a 32% reduction in emissions. Combining both policies resulted in an average reduction of 43% in emissions. Importantly, our nutritional analysis demonstrated that implementing these sustainable food policies resulted in meals with statistically similar macronutrient and micronutrient profiles and contributed to increased dietary fiber intake. These results highlight the potential environmental and health benefits of adopting sustainable nutrition policies in elementary schools.

Keywords: dietary carbon footprint; school lunches; sustainability; nutrition; planetary boundaries

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1. Introduction

Few food-related topics in the United States are as hotly debated as the National School Lunch Program (NSLP). The NSLP was established in 1946 and signed into law by President Harry Truman under the Richard B. Russell National School Lunch Act. The goal was to establish a federally supported meal program to provide nutritionally balanced, low-cost, or no-cost lunches to students during their school day. This program now provides daily lunches to over 30 million children nationwide, approximately 40% of US children, and in some states like California, free school lunches are offered to all children attending public schools [1]. At the federal level, the NSLP is administered by the Food and Nutrition Service (FNS) housed within the United States Department of Agriculture. At the state level, the program is governed by various state agencies (e.g., the Department of Education) that form interagency agreements with School Food Authorities (SFAs).

State agencies are required to review school lunches every three years through an administrative review (AR) using a risk-assessment approach. Nutritional adequacy is determined through a multidimensional AR which includes an off-site USDA-approved menu review to prove past meals offered contain the required components/qualities, an onsite observation of the serving line to ensure students receive at least three components for lunch and each meal contains at least ½ cup of fruits or vegetables, and assessed compliance with dietary specifications (calories, sodium, saturated fat, trans fat). Although NSLP lunches must meet federal nutrition requirements, decisions about the specific meals served and methods of preparation are left to the discretion of individual SFAs. Any errors in compliance result in corrective action and fiscal action when required, the latter denoted by disallowing nutrient-deficient meals. However, pointedly, the 3-year cycle AR currently has no requirement for follow-up by state agencies.

School meals can be critical for food-insecure students who may not be meeting their nutritional needs at home [2]. Though the NSLP was implemented to safeguard the health and well-being of the nation's children, the program has been heavily criticized for lacking focus on dietary guidelines and nutrition and for its impact on the environment. Despite the progress made through federal policies such as the Healthy, Hunger-Free Kids Act of 2010 (HHFKA), most school meals are still falling short of current health and sustainability goals [2–4]. Most common entrees include chicken nuggets, pizzas, cheeseburgers, hot dogs, and deli meat, with few plant-based options beyond nut butter sandwiches. With 4.7 billion school lunches served [5], these high-emissions meals come with a substantial climate impact. Higher emissions foods are also linked with higher impacts on natural resources, such as land and water, higher manure pollution, and species decline [6].

Numerous studies, including those by the EAT-Lancet Commission on Food, Planet and Health, have concluded that a shift in our diet to foods with low environmental footprints, namely, plant-based foods, is a powerful, even essential, strategy to respond to the climate crisis and improve human health [7–14]. Without major changes to the food system, emissions from our food system alone would exceed the allowable greenhouse gasses from all sectors to meet climate targets [8]. While for some populations the current or increased consumption of animal-source foods could improve dietary nutritional quality, for most people in the world, especially in the high-consuming populations of the Global North, mostly or completely plant-based diets can also be nutritionally adequate, and even healthier than standard omnivore diets, including for key nutrients like calcium and iron [11,14].

Numerous studies have been conducted in European countries on the matter of school lunch quality, particularly on the nutrition front. In a cross-national comparative study [15], researchers found that while it is difficult to prove improved health through school lunches, there is a need for improved research design; for instance, more studies that go beyond the integration of one additional commodity (i.e., more fruit), which is our aim to do by comparing various school lunches. One study [16] that focused on French primary school lunches concluded that lunches with meat possessed high nutritional qualities yet contrasted the vegetarian options that were at risk of worsening nutritional quality, conveying an overall need for environmentally conscious lunches to be revised and improved on an international scale.

In the United States, a recent study [17] demonstrated that policies reducing animal products and promoting foods like whole grains, nuts, and legumes could significantly lower the global warming potential of school meals and that these policies should be promoted. Compared to existing studies, we found there was a gap in directly comparing school meals distributed across various school districts in the United States. This allows us to analyze the overall picture of nutritional adequacy and consequent emissions of American school lunches.

Several challenges exist for individual school districts participating in the NSLP, but perhaps the biggest challenge is the rising cost of providing healthy and nutritious, prepared lunches with proper kitchen equipment and staffing. Many districts are left with insufficient funding and support and must supplement the NSLP with the school district general fund, which in turn impacts other district funding needs. And many school systems are left without adequate kitchen equipment or staff to prepare fresh meals. While we recognize this as a major barrier for school lunch programs, we chose to not focus on the programmatic and policy shifts that would be needed to make these improvements, and instead make the basic assumption that policy and funding criteria are met.

In several major U.S. cities, school districts have implemented policies and initiatives to address sustainability and the climate crisis. Portland Public Schools have enacted a "Climate Crisis and Sustainability" policy that encourages plant-based meals, local food sourcing, and waste reduction [18]. The Los Angeles Unified School District has implemented the "Good Food Procurement Policy" to prioritize sustainable and locally sourced food, reduce meat and dairy consumption, and increase plant-based options [19]. Several other major districts have also taken steps to promote sustainability more broadly, such as implementing energy-efficient practices, conservation efforts, waste reduction programs, and green building initiatives [20–23]. As awareness of climate change and sustainability continues to grow, more school districts will likely adopt food policies that directly address these issues. In addition, as climate impacts on agriculture intensify, school districts will need to adopt policies out of necessity to secure meal programs with climate-resilient foods.

The largest school district in the US is New York City Public Schools with 1,075,710 students enrolled in 1207 schools [24]. NYC Public Schools have implemented policies to improve both the environmental sustainability of their meals and the health of their students [25]. These policies include a vegetarian Monday and a fully plant-based (vegan) Friday, reducing the frequency of beef meals, eliminating processed meats, increasing plant-based snack availability, providing water stations, offering alternative milk options, and making milk consumption optional [25,26]. Although many schools across the United States have implemented policies to improve the health of their students, it is also imperative, given the global environmental crisis, that more schools reduce the environmental impact of their school meals [27].

Research is needed to quantify the impact of these policy changes on the environmental footprint, including those of the NYC school district. Our research objective for this study is to explore school district policies that could help promote healthy diets for students while lowering the carbon emissions of school food. For the purposes of this study, a "healthy" school lunch is denoted by the USDA to emphasize fruits, vegetables, whole grains, and a balance of nutrients with supplementary benefits of limited added sugar and sodium (notedly, no mention is made of meat). To achieve our research objective, we quantified carbon emissions from meals served in six school districts (New York City, Chicago, Long Beach, Miami, Portland, and Austin). Using available life cycle assessment (LCA) data, we modeled the impact of three NYC Public Schools policies: reducing beef consumption to once per month, implementing one plant-based (vegan) day per week, and combining both interventions. Our study focuses on estimating the reduction in carbon emissions that result from these school lunch program changes. We also explored the nutritional implications (protein, fiber, vitamin A, vitamin C, calcium, and iron) for one school district, discussing their impact on student health in the US.

The primary goal of this paper is to explore potential impacts, propose actionable recommendations, and provide a framework for policy implementation. While the sample selection may not be representative of all possible scenarios, it serves as a practical illustration to support the policy argument rather than a definitive, scalable statistical study. Further, this paper bridges the gap between broader environmental policy discussions and actionable, localized changes in school meal programs.

2. Materials and Methods

2.1. School Selection

To portray a wide range of student populations in the United States, we focused on school districts in several distinct geographic regions: the Pacific Northwest, Southwest, North Central States, South Central States, Northeast Atlantic States, and Southeast Atlantic States. From these regions, we chose six school districts situated in major urban areas: New York, Long Beach, Chicago, Austin, Portland, and Miami. While there may be uncertainty surrounding the representatives of each school district's lunch meal compared to the rest of the geographical region, we found these districts boast diverse demographics and host sizable student populations, allowing us to maximize the potential influence of our efforts.

Specifically, our attention was directed toward assessing the carbon footprint associated with primary school lunch menus located in New York, Long Beach, Chicago, Austin, Portland, and Miami school districts. It is important to note that the issue of food insecurity is most prevalent in large urban areas, particularly among single-parent households and people of color, as indicated by the Economic Research Service—Food Security and Nutrition Assistance. The inclusion of these marginalized groups was a priority for us. To achieve this, we intentionally selected school districts situated in urban areas characterized by diverse demographics and substantial student enrollments. This strategy is especially impactful because it targets those areas where free and reduced-cost school lunches can make the most significant difference. Further, we chose primary schools with the intention of selecting students who are at a more impressionable age, where educating them about the environmental consequences of their dietary choices can lead to greater awareness and behavioral changes in the future.

It is worth highlighting that this research solely relies on publicly available data. For a comprehensive overview of the demographic information pertaining to these districts, please refer to Figure 1 [24].

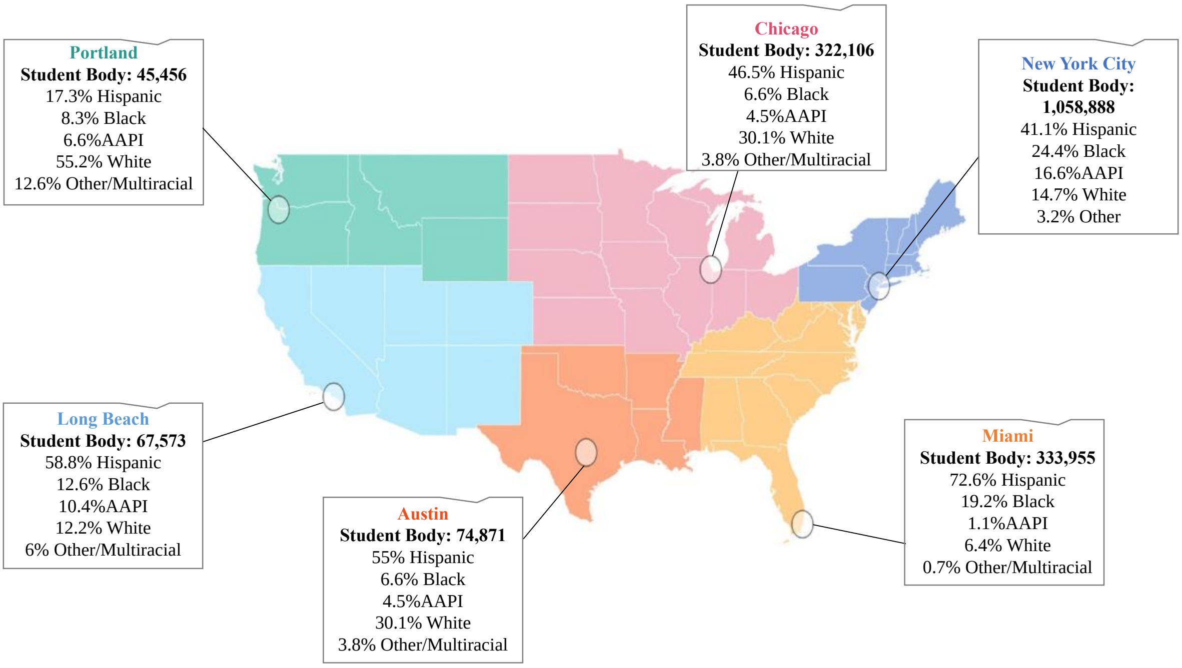


Figure 1. Map of cities and geographic regions studied with school district size and demographics.

2.2. Menu Selection and Meal Design

For each school district, we selected available daily lunch menus over a 4-week period between March and 2022. When multiple menu options were available in a day, we chose the item with the highest CO_2 emissions, while recognizing that low-carbon footprint foods are sometimes offered on the same day (with the exception of a 2004 menu from NYC Public Schools, which was chosen to ensure the meals we analyzed for the scenarios were selected well before any of the sustainability policies were implemented).

In the context of school lunches, LCA allows for a comprehensive evaluation of the carbon emissions associated with the production, processing, packaging, transportation, preparation, and disposal of ingredients and meals. These system boundaries are referred to as "cradle-to-store" [28]. For this study, we focus entirely on production due to the limited availability of both LCA data and knowledge of the school's practices or procurement pathways. Many conversions are derived from Heller and Keoleian's estimations based on a meta-analysis approach that drew from sources "representing a variety of countries of origin, climatic conditions, transportation distances, and production methods" and thus provides estimates, not definitive figures [29]. All LCA conversions can be found in Section S2 of Supplementary Materials [29–32].

To facilitate accurate life-cycle analysis calculations, standardized recipes and serving portions were utilized to estimate ingredient quantities in each meal (see Section S3 of the Supplementary Materials). In instances where identical meal options were available across multiple school districts (e.g., a cheeseburger), a consistent recipe was adopted for that specific item. Furthermore, to align with the FDA's recommended caloric intake guidelines for lunch (i.e., 550–650 kcal), the quantity was adjusted to ensure that the total calories fell within the prescribed range. Standardizing ingredients and caloric output allowed for a more accurate comparison and assessment of carbon emissions.

2.3. Carbon Emissions Estimation

After finalizing the menu selection and meal design, the ingredients were entered into a carbon emissions calculator that relies on life cycle assessment data. We created the calculator using Google Sheets (the calculations and references are located in Section S1 of the Supplementary Materials). Condiments such as salt, pepper, and spices were omitted in the calculations.

To assess the impact of the school food policies, we categorized each meal into one of six meal groups based on the primary protein source of the dish; namely, beef, poultry, pork, fish, eggs/dairy (referred to as Ovo–Lacto or Vegetarian), and plants (referred to as Plant Based). The average for each meal group across all districts is also given (Table 1). Beef meal carbon footprints were statistically significantly ($p < 0.0001$) higher than all other meal types. Plant-based meals were statistically significantly lower than all other meal types ($p = 0.0011$ for vegetarian, $p < 0.0001$ for chicken, $p = 0.0003$ for fish, and $p < 0.0001$ for pork).

Table 1. g CO_2eq emissions across meal types within each district used for policy modeling.

Meal Type	Austin	Chicago	Long Beach	Miami	NYC	Portland	Average (Not Including Shaded Cells)	Standard Deviation (Not Including Shaded Cells)
Plant-Based	(n = 0)	(n = 0)	(n = 0)	(n = 0)	393 (n = 5)	(n = 0)	393 (n = 5)	43.5
Vegetarian	422 (n = 1)	684 (n = 4)	(n = 0)	597 (n = 2)	756 (n = 6)	634 (n = 2)	618 (n = 15)	±125
Poultry	1367 (n = 9)	1132 (n = 12)	1194 (n = 7)	1032 (n = 6)	1164 (n = 7)	1225 (n = 10)	1186 (n = 51)	±111
Fish	679 (n = 1)	687 (n = 1)	(n = 0)	825 (n = 2)	978 (n = 1)	(n = 0)	792 (n = 5)	±141
Pork	(n = 0)	(n = 0)	743 (n = 2)	662 (n = 2)	(n = 0)	763 (n = 4)	723 (n = 8)	±53
Beef	3550 (n = 9)	3234 (n = 3)	3161 (n = 11)	3282 (n = 8)	4646 (n = 1)	4161 (n = 4)	3672 (n = 36)	±601

We then calculated the average carbon emissions for each group within each district to arrive at a representative sample that we could apply to our three chosen carbon-reducing scenarios (Table 1). As mentioned previously, most districts offered meals in each of the six groups; however, because the meal with the highest emissions was chosen when multiple meals were offered on a single day, some groups did not factor into the average. For example, when Austin offered plant-based meals, they always offered an additional meal that was higher in carbon emissions, so the plant-based meal was never chosen.

To calculate the amount of carbon emissions from the required milk cartons in school district meals, we used the standard 1% milk 8 oz carton (equivalent to 245 g). The value was entered into the carbon emissions calculator and multiplied by 20 to represent one 8-ounce carton of milk as part of the meal each day.

Once we established average CO_{2eq} emissions across districts for each of the six meal types, we modeled three scenarios by changing meal types within the month to reduce carbon emissions.

- Scenario 1: Beef reduction—all but one beef meal in the monthly meal plan was replaced with a lower-carbon chicken meal, which was the next most commonly consumed protein source (henceforth ‘one beef monthly’)
- Scenario 2: One plant-based (vegan) day a week replaced the highest carbon-emitting meal of each week with a plant-based meal (henceforth ‘plant-based weekly’).
- Scenario 3: The combination of scenarios one and two.

In the case of New York, where the policies had already been implemented, we compared against the average meal type for a 2004 menu (before policy implementation).

After calculating the carbon emissions across meals for each scenario, we multiplied this value by the number of students in the district to obtain the total carbon emissions for the district's student body. The savings for each policy were calculated by comparing the total emissions per district before and after policy implementation.

Meals were grouped by category (plant-based, poultry, etc.) and differences in carbon footprint between the types of meals were tested for significance using Student's *t*-test.

2.4. Nutritional Values Estimation

Though the primary focus of our paper is carbon emissions, we also evaluated the impact of sustainable food policies on the nutritional value of school menus for one sample district to determine if nutritional requirements were still met when employing various emission-lowering policies. All national school lunch program meals must meet the Recommended Dietary Allowances of the Dietary Guidelines for Americans, assuming that children receive one-third of their daily nutritional needs met at lunch [33,34]. Using this criterion, we evaluated school lunches for protein, calcium, iron, vitamin A, vitamin C, and calories, nutrients for which the NSLP provides recommendations. In addition, we examined the impact of these menu changes on fiber because research shows that most children (and adults) consume alarmingly low amounts of fiber [35].

In light of the fact that our analyzed menus were taken from primarily elementary schools, we chose to address the age range of 4–8 years. This age group was selected to ensure alignment with the minimum nutritional requirements stipulated by school meal guidelines. As showcased in Table 2, we have incorporated the daily nutritional benchmarks established by the Institute of Medicine for a 1200-calorie daily intake tailored to individuals within the 4–8 age bracket. The Food and Drug Administration (FDA) prescribes a caloric intake range of 550–650 Kcal for school lunch consumption [34]. To ensure an appropriate caloric level, we halved the 1200-calorie nutrient profile to establish the daily nutritional objectives for a 600-calorie meal. This corresponds to the midpoint of the recommended caloric intake range for school lunches, thereby ensuring that our study's findings are grounded in the specific needs of the target demographic.

Table 2. Daily Nutritional Goals.

MACRONUTRIENTS, MINERALS, AND VITAMINS		Age 4–8	Age 4–8
		DRI (Daily)	**½ DRI**
Calories		1200	600
Macronutrients			
Protein (g)	RDA	19	10
Fiber (g)	RDA	18	9
Minerals			
Calcium (mg)	RDA	1000	500
Iron (mg)	RDA	10	5
Vitamins			
Vitamin A (mcg RAE)	RDA	400	200
Vitamin C (mg)	RDA	25	13

Source: [36].

We compared the nutritional value of current menus with their respective modeled menus with the sustainable scenarios 1–3. As mentioned previously, we adjusted ingredients to ensure that the meals fell within the isocaloric range required by dietary guidelines. It is also important to note that in this study, we model the environmental impacts of specific school lunch program modifications that have been previously implemented in the New York City school district. Therefore, these modifications have already been aligned with the established nutritional standards of the NSLP, ensuring that all changes adhere to the comprehensive dietary requirements set forth by the United States Department of Agriculture (USDA).

3. Results

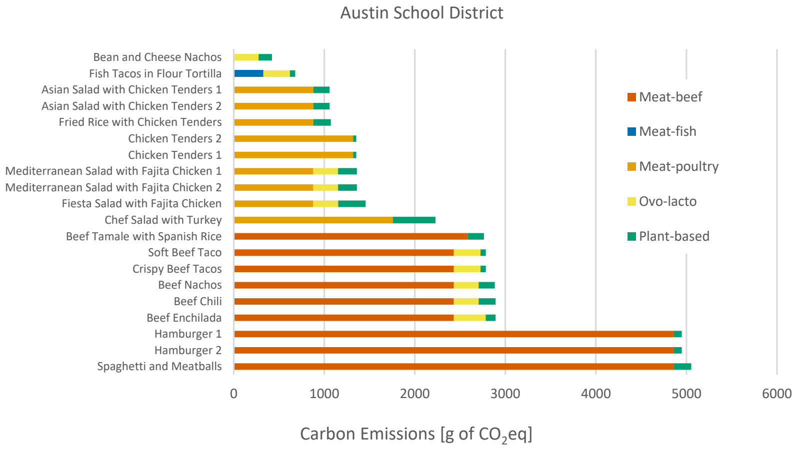
3.1. Carbon Emissions

The carbon emissions associated with the different meals served in the six K-12 districts are represented in Figure 2a–f. Meals that included beef as an ingredient had the highest carbon emissions and entirely plant-based meals had the lowest. Thus, districts with the most frequent servings of beef had the highest emissions, with Austin, Long Beach, and Miami leading in total dietary carbon equivalents. New York City and Chicago had the lowest overall emissions (presumably due to New York's infrequency of serving beef and frequency of serving plant-based meals, as well as Chicago's frequency of choosing chicken over alternative animal proteins). Across all school districts, the calculated average of carbon emissions per meal is 1737 g CO_2eq.

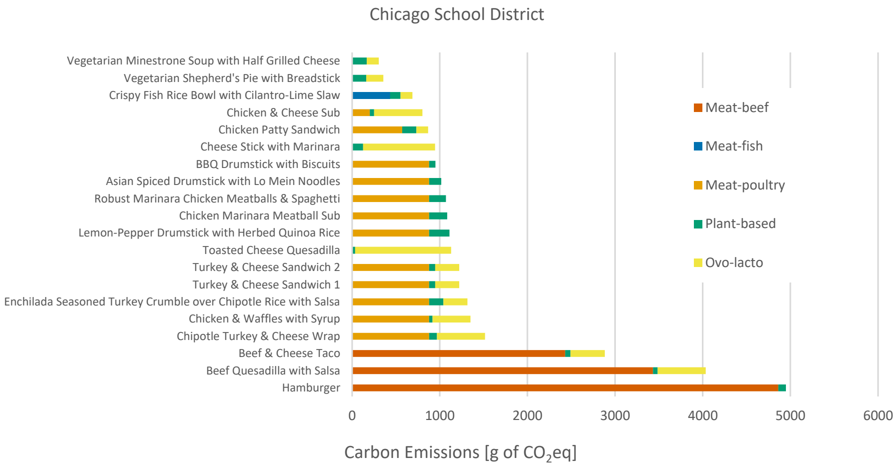
Figure 3a,b show the single-student carbon emissions profile for one month across schools with and without milk. As demonstrated in Figure 2b, the inclusion of a carton of milk can be a major contributor to the carbon emissions associated with school lunch meals. This information should be taken into consideration with respect to schools that have compulsory milk policies. Although there is no federal policy that makes school lunch milk mandatory, some schools have local policies that require students to take milk with their lunch. Our results from 2022 surveys suggest that promoting plant-based milk options or reducing the overall amount of milk served can significantly reduce the carbon footprint of school lunch meals. The USDA NSLP requirement for substituting non-dairy milk is extremely onerous, and could be much simplified to enable schools to promote non-dairy milk which could significantly lower the carbon footprint of school lunches [37].

New York's emissions were approximately 46% lower than the average of the other five districts, and less than half of the total emissions of the top emitting district (Austin). Yet the one beef monthly scenario in New York still represents 21% of their total emissions and, conversely, the total carbon footprint of four plant-based meals per month, plus all plant-based ingredients across other meals, emitted less than the single beef day.

The results of our policy scenarios (one beef monthly, plant-based weekly, and the combination of both policies) show that the reduction in emissions ranged from 22% to 51% depending on the strategy. Implementing the one beef monthly scenario led to a potential average emissions savings of 34%, while the plant-based weekly scenario decreased emissions by 32% (Figure 4). Combining both policies resulted in an average projected reduction of 43% in emissions. In all districts, using both strategies led to the greatest potential emissions savings, except for Portland, where utilizing the plant-based weekly scenario produced the greatest possible savings. Of all the districts, the greatest difference in emissions savings was for the projected results of Long Beach. If Long Beach were to implement policies that reduced their frequency of serving beef to once a month and replace their highest emitting meal each week with an entirely plant-based day, they could reduce GHG emissions by 51%.



(**a**)



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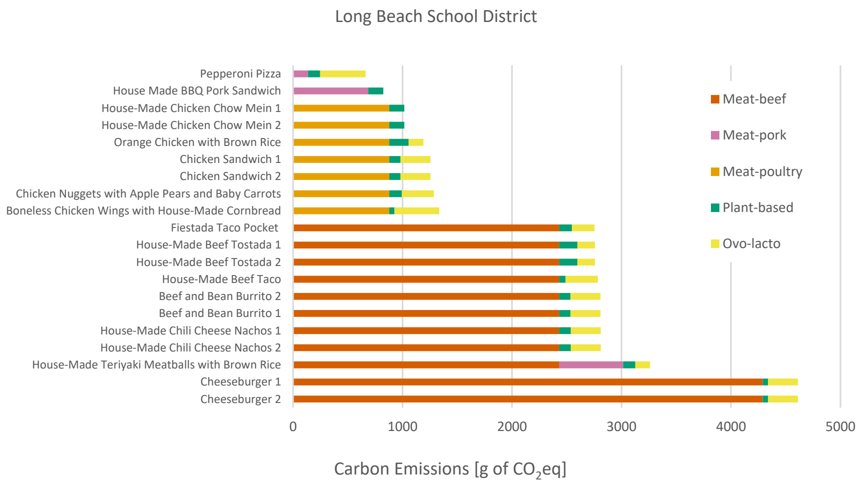

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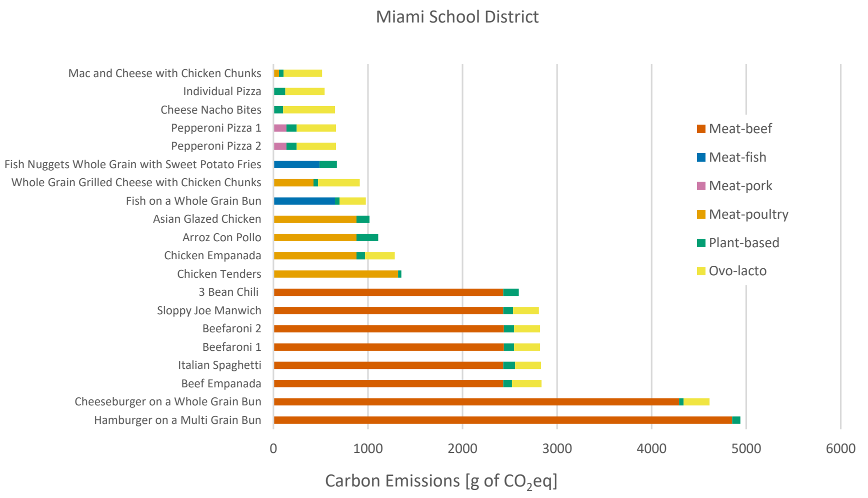
Figure 2. *Cont.*



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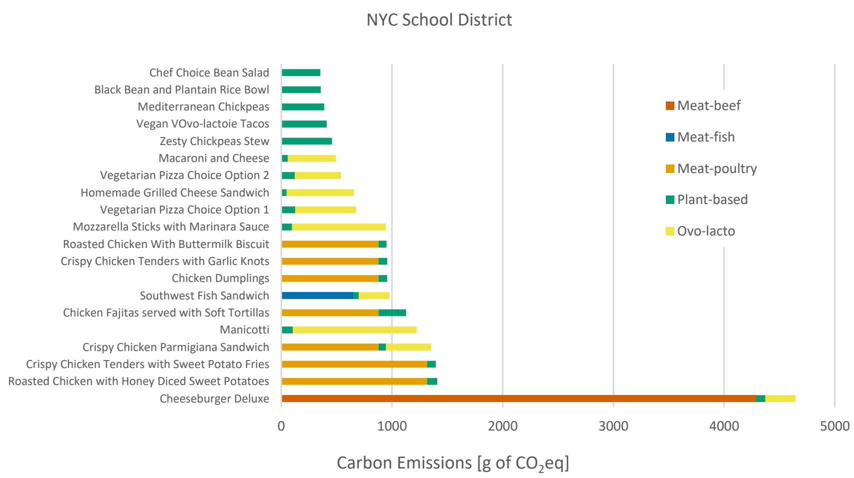

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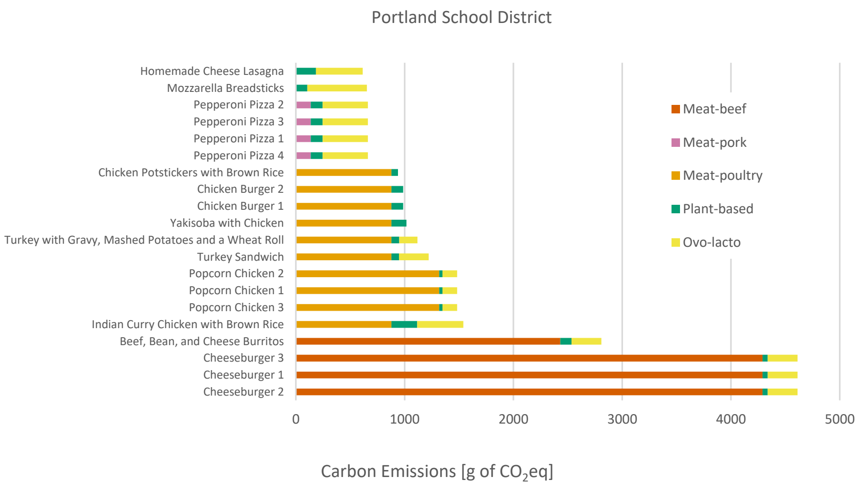
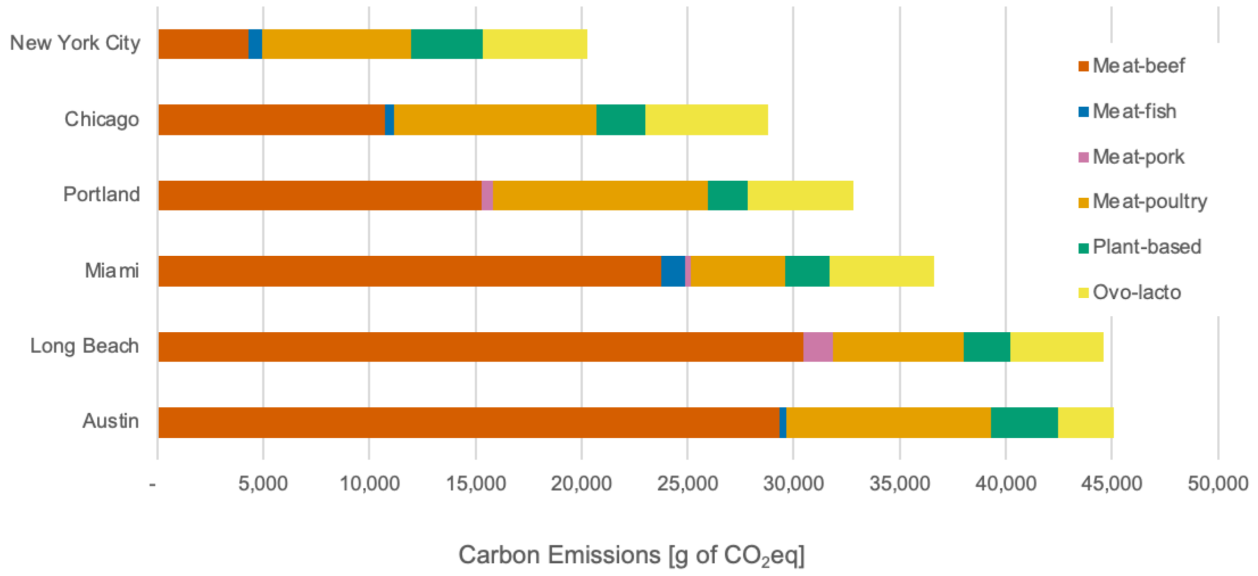


(**f**)

Figure 2. (**a**) Carbon emissions breakdown by lunch meal in the Austin School District over a month. (**b**) Carbon emissions breakdown by lunch meal in the Chicago School District in a month. (**c**) Carbon emissions breakdown by lunch meal in the Long Beach School District in a month. (**d**) Carbon emissions breakdown by lunch meal in the Miami School District in a month. (**e**) Carbon emissions breakdown by lunch meal in the NYC School District in a month. (**f**) Carbon emissions breakdown by lunch meal in the Portland School District in a month.



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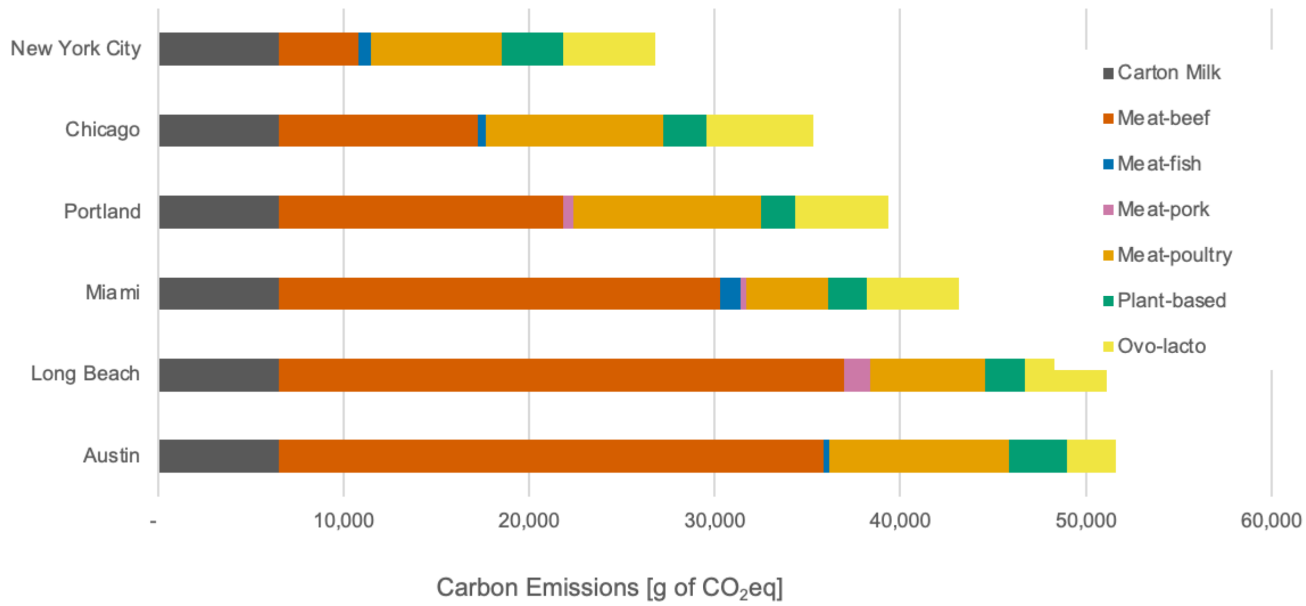

(**b**)

Figure 3. (**a**) Single-student monthly carbon emissions breakdown by lunch type for the six school districts studied (not including a carton of milk per meal). (**b**) Single-student carbon monthly emissions breakdown by lunch type for the six school districts studied (including a carton of milk per meal).

When we modeled the scenarios for New York, we switched to the 2004 NYC menu in order to not skew the data since they had already adopted both the one beef monthly scenario and the one plant-based weekly scenario. The resulting emissions from applying the combination of the modeled policies to the 2004 New York City menu were close to the calculated 2022 menu emissions, showing that the policies implemented by New York City have been a significant contributor to their lower dietary carbon footprint.

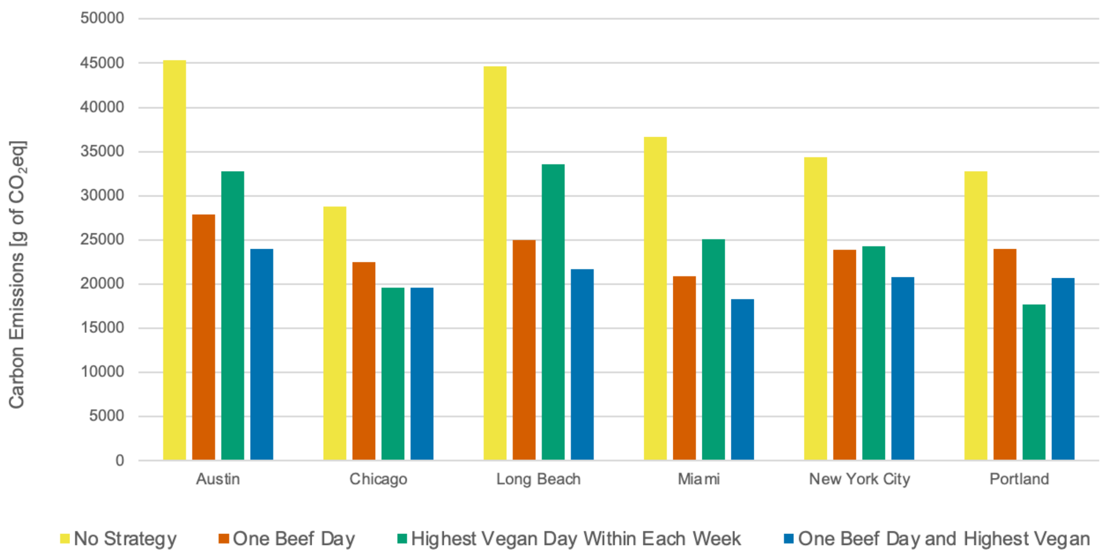

Figure 4. Modeled impact of school food policies on carbon emissions (g CO_2eq). Note that for New York the 2004 menu was used for the "no strategy" scenario.

3.2. Nutrition Results

School districts that administer the National School Lunch Program are required to meet nutrition standards that align with the Dietary Guidelines for Americans. School food service management must ensure that menus meet minimum calorie levels and also nutrient recommendations for specific minerals and vitamins, and protein and fat. Specifically, the nutrient composition of school lunch meals must meet the Recommended Dietary Allowances (RDAs) for protein, calcium, iron, vitamin A and vitamin C, and the dietary recommendations with regard to total fat and saturated fat (no greater than 30% and 10% of calories, respectively). While fiber is not specifically addressed in school lunch policy, it is known that fiber content varies and is important for health [38,39].

Table 2 below provides the daily nutritional goals from the Institute of Medicine for a 1,200 caloric daily intake for the age group 4–8. The FDA's recommended caloric intake guideline for school lunch is between 550 and 650 Kcal [40]. We divided the 1200-calorie nutrient profile by two to evaluate daily nutrition goals for a 600-calorie meal, the midpoint of the recommended caloric intake for school lunches. We employed the dietary recommendation values for elementary school students for our recipe generation calculations and we note that middle school and high school recommendations may be different.

We chose a representative school menu from Austin to analyze the nutrition profile from Table 2 using the scenarios we modeled for carbon emissions reduction. The results of the nutritional modeling are shown in Figure 5.

Introducing any of the three policy changes in the implementation of the NSLP did not compromise the nutrient composition of the menu. Compared to 'no strategy' having one plant-based day provided protein, fiber, and vitamin C that met or exceeded dietary recommendations (1/2 of the recommended levels). It did not provide enough calcium, iron, or vitamin A (using 1/2 dietary recommendations as the reference) but amounts of these nutrients were comparable to or exceeded the levels provided by 'no strategy'.

Having one beef meal monthly provided enough protein and vitamin C but not the other nutrients or fiber. However, it provided more fiber and vitamin A compared to 'no strategy'. Calcium target ranges were not reached with any of the scenarios, including no strategy, though this set of results did not include serving milk with the meal. Although milk is high in calcium, alternative plant milks with lower carbon emissions, such as almond and soy (fortified with calcium), could be substituted [41]. Similarly, iron intake increased beyond the no strategy scenario when a plant-based meal each day was introduced, but all scenarios still fell short of the target RDA. Consideration should be given to offering foods high in calcium other than milk to help meet the RDA for calcium such as spinach, collard greens, kale, and Ca-fortified plant-based yogurt.

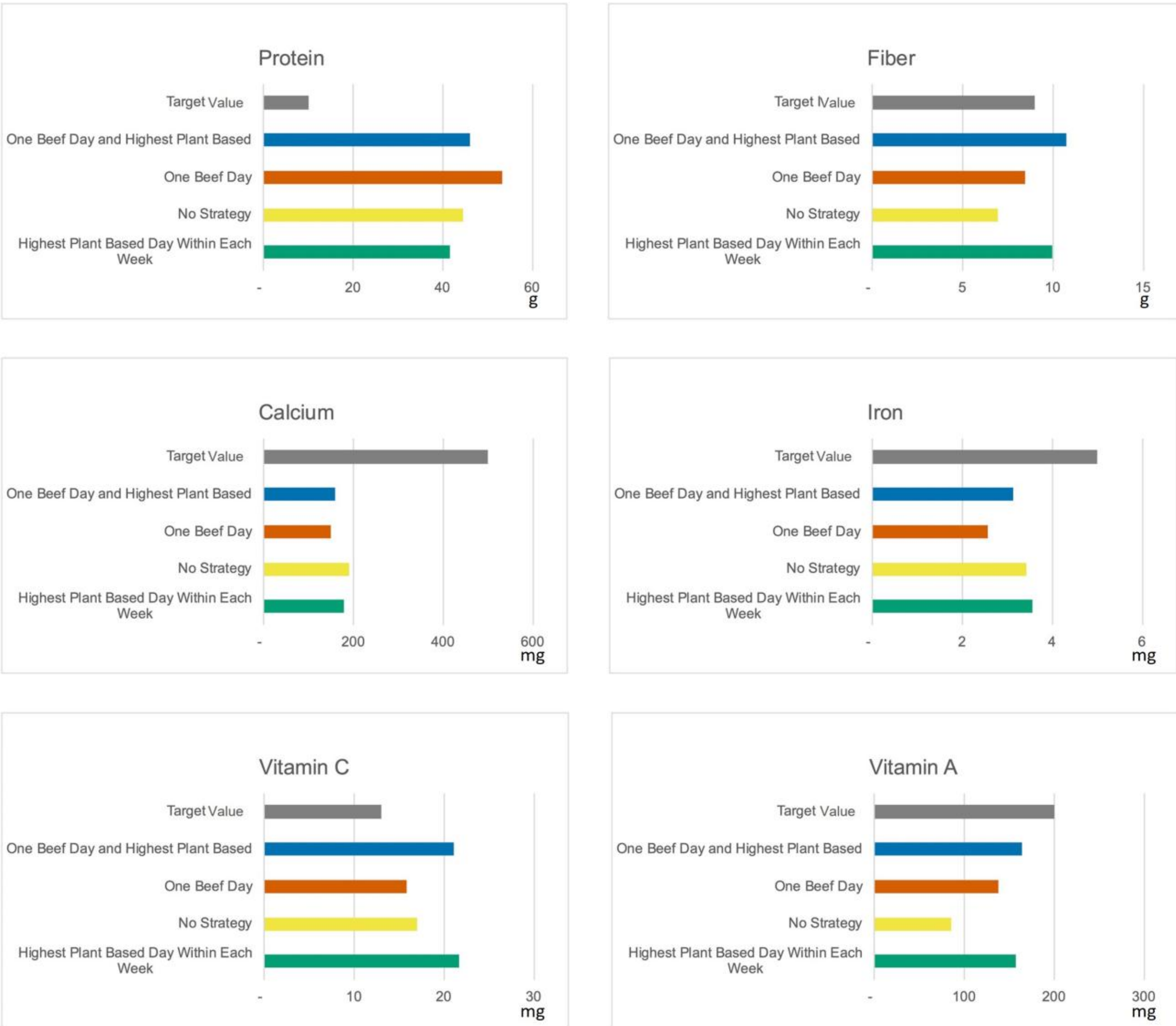

Figure 5. Nutrition profiles for protein, fiber, calcium iron, vitamin C, and vitamin A for school lunch scenarios.

4. Discussion

Our results highlight the potential effectiveness of implementing sustainable nutrition policies in reducing the carbon footprint of school lunch meals and the need for continued efforts to promote more sustainable meal options in schools. Based on our findings (and considering the 30 million children who consume school meals every day), if every school implemented the two strategies outlined in this paper (scenario 3), the United States could save around 471,143 metric tons of carbon emissions per month for a total of 4.03 million metric tons per year [42,43]. These savings are equivalent to 1.88 million gasoline-powered passenger vehicles driven for one year (assuming 10,000 miles per year).

This is a significant impact that clearly demonstrates the power school food policies have in reducing emissions; yet, these two policies alone do not keep us within the EAT–Lancet per capita planetary boundaries of less than 500 g of CO_2eq per meal [14]. These planetary bounds were found by taking the total allocation of carbon to the food sector and then dividing it by a population of 10 billion to arrive at 500 g of CO_2eq per meal or less, the same conclusion as in the EAT–Lancet study. When we average meal emissions across all schools studied (1,737 g CO_2eq) and assume every district in the U.S. provides only plant-based meals, the U.S. would save roughly 6.7 million metric tons of carbon per year and be below the planetary boundary.

Solutions to meet climate targets are necessarily complex and intersectional, and this study demonstrates how school meals could play a significant role in helping the US reduce dietary emissions. Carbon emissions could be reduced further if students change their diets outside of the lunchroom after becoming accustomed to plant-based choices [44,45]. Schools reducing the climate footprint of their meal programs may advance their success with implementation strategies that build a welcoming environment for these changes. This includes a supportive campus, classroom, and cafeteria as well as connecting with parents and the larger community to build support for climate-resilient meals.

To support these shifts, federal policy could clarify guidance on decreasing beef and increasing plant-based options in school meal programs, while federal funding for pilot projects that provide more money for staff training, staff acceptance of menu shifts, decent wages, and kitchen equipment could also benefit the efficacy of school efforts to make menu shifts to reduce emissions. In 2024 (beyond the scope of the data presented here in our assessment), the USDA released an update to child nutrition meal patterns [37] that opened the doors to more climate-friendly school meals [46]. The rule makes it easier for schools to serve beans, peas, and lentils in entrees, and diversify primary protein sources; allows bean dips (such as hummus) to count as a Smart Snack; makes it clear when and how schools can provide non-dairy milks as a fluid milk substitution; allows nuts and seeds to count as the full meats/meat alternates meal component; makes it easier to feature plant-based proteins at breakfast; allows tofu to be offered in the Summer Food Service Program, as well as CACFP and NSLP preschools; and clarifies ways to serve tofu across all child nutrition programs [37].

The current body of work on the carbon footprint of school food supports our findings that school districts are in a unique position to implement policies and dietary guidelines that could positively influence the environmental sustainability of school meals, while simultaneously fighting food insecurity and promoting healthy diets [4,17,47–51]. The study most similar to our work [17] collated life cycle inventory data and found that policies that reduce ruminant meat and promote foods like nuts, whole grains, and legumes would have a positive impact on several environmental indicators; however, it did not include a nutritional impact.

When implementing a climate-resilient food policy, school districts should be selective, where possible, with the types of plant-based foods they incorporate to reduce emissions. A systematic review [52] found in 34 dietary modeling publications, that red meat replacement resulted in benefits to health outcomes, dietary adequacy, meal costs, reduced greenhouse gas emissions, and reduced health system costs. Yet, the review also emphasized that minimally processed plant-based alternatives are ideal to replace red meats. Plant-based meat alternatives processed in an industrial food system may not provide the same degree of health benefits as widely available low-emissions foods such as legumes, pulses, and beans. On the other hand, plant-based meat alternatives, as well as legumes, pulses, and beans, come with more than an 86% reduction in emissions, land, water, and manure footprints, as well as eliminating slaughter pollution from the food chain [53] compared to beef. In a recent study of meat and milk alternatives, in terms of nutrition, health, environment, and cost, unprocessed plant foods such as beans performed best across all domains studied [54].

Having one plant-based day increased fiber intake for children consuming school meals. Currently, 97% of children in the U.S. have inadequate dietary fiber intake, which may contribute to high rates of the preventable chronic illnesses, like heart disease, type-2 diabetes, and high cholesterol, increasingly affecting children. Federal school meal programs often fail to meet the Institute of Medicine (IOM) minimum adequate intake of 14 g per 1000 kcal [39]. The 2020–2025 Dietary Guidelines for Americans lists fiber as a major "dietary component of public health concern" for all Americans, including children. High-fiber foods, including legumes, vegetables, and fruits, are also associated with a substantially lower carbon footprint [6].

While replacing beef meals with minimally processed plant-based foods is one strategy, another aggressive policy intervention to address climate and health could be to implement a plant-based default policy. A New York City hospital system of three hospitals recently implemented a plant-based default for their patient meals citing both health and environmental benefits [55]. Patients can still request meat-based or ovo–lacto meals, but the default meal service is plant-based. While the carbon emissions of this policy have yet to be studied, it closely aligns with a 2022 study that found university event attendees were 3.5 times more likely to choose the plant-based option if it was presented as the default. In this study of campus events, the plant-based default program led to an average reduction of 42.3% in greenhouse gas emissions, with similar reductions in land, nitrogen, and phosphorus use [56]. Policies like marketing items with a low carbon footprint label can also significantly increase the percentage of plant-based meals selected [57]. This growing body of evidence demonstrates specific policy and marketing shifts have the power to make a positive impact in more spheres than just carbon emissions.

These findings also suggest that implementing sustainable nutrition policies can not only reduce the environmental impact of school lunch meals but also provide health benefits to students. Children who are food-insecure often have relatively lower fruit and vegetable intake (less than five servings daily) and consume higher proportions of their daily fruit and vegetable intake at school [58,59]. This emphasizes the important role school lunch programs play in providing high-quality nutrition to the children who need it most and evidence suggests that nutrition service policies explicitly promoting plant-based foods can make a simultaneous positive impact on food security and diet quality [60]. In addition, there is some evidence that the universal application of school meal programs improves academic performance, particularly for food-insecure children [61]. Implementing universal meals along with increased plant-based foods would advance both the nutritional and academic goals of meal programs while serving lower emissions foods.

We were able to use a direct comparison of existing NYC school district policies and data to estimate the potential environmental impact of school lunches across several other districts. Of note, the two policy changes we studied were implemented in NYC beginning in 2019 and have withstood intense production and price fluctuations throughout the COVID-19 pandemic. One limitation with the NYC data is that the menu we chose prior to the policy change was approximately twenty years old; however, on average, the meals are considered representative of those currently served in other districts. To simplify the study, we used a limited data set with six representative schools from each US geographic region. Further, we made assumptions about the schools' ability to afford and access more sustainable menu choices. Creating more sustainable school menus is a difficult process and those considerations could be accounted for in future studies.

There are some uncertainties related to LCA conversion factors in general. The assessment of CO_2 emissions with respect to food is a complex undertaking and conversion factors can vary based on materials used, energy consumed, and waste produced during production. We attempted to choose factors closer to the average that coincide with the assumption that schools choose food with neither the best nor worst production profile (as mentioned in the Methods section, conversion factors can be seen in Table S1 in the Supplemental Materials). The variability of conversion factors could be examined more thoroughly by attempting to quantify emissions reduction from sourcing products produced in a particular way [62].

Another limitation of our analysis is that we did not include LCA data for processing and packaging; we focused on the production stage, which for most foods has the largest impact. It is also crucial to underscore that our assessment encompasses all five fundamental constituents of a meal, with a single exception involving the exclusion of milk, in accordance with a specific analysis. It is pertinent to acknowledge that within the context of school meal programs, students are obligated to select a minimum of three components to qualify for a reimbursable meal. Notably, one of these selections necessitates the inclusion of a fruit or vegetable, foods inherently characterized by lower emissions profiles. This consideration underscores the alignment of our analysis with the nutritional guidelines set forth within school meal frameworks, emphasizing the sustainability dimensions embedded in such dietary choices.

Emissions are not the only metric that defines food sustainability. Future studies could explore school food policies as they relate to the planetary boundaries for land use, nitrogen and phosphorus cycles, and water use, as well as social factors like equity and cultural relevance. In addition, future research might address the gap in understanding the impact of school food policies on habitat loss and degradation and species impacts. Food systems, particularly those highest in meat and dairy, are key drivers of deforestation and biodiversity loss. Studies show that dietary shifts incorporating more plant-based foods are a primary lever for change [63].

Further, we did not consider the receptivity of the student body when shifting towards a more plant-based menu selection. This could be particularly impactful in school districts with a large low-income population where food-insecure populations consume higher amounts of processed food. Food waste is not typically tracked in most school districts and an information gap could be addressed with future research on effective implementation strategies for serving more plant-based options to students to prevent food waste and minimize carbon emissions. Meat and dairy products carry a higher environmental cost to produce and a higher food waste footprint. Therefore, it may be worth exploring whether offering plant-based meals, as an option or as the default, could be more beneficial in food waste reduction efforts as well. Future studies might also assess the effective implementation of plant-based meal pattern shifts as a food waste reduction strategy. Liquid dairy is the most commonly wasted food item in school meal programs, and it carries a significant climate and water footprint as well as a high production of manure, which also drives methane emissions (a leading source of U.S. methane emissions comes primarily from cattle [64]). Finally, the additional assessment of the impact of serving culturally relevant meals including plant-based alternatives to beef that meet the regional needs of students in diverse (and often low-income) areas may prove useful. These are often also the communities most impacted by emissions pollution from food production.

Student interest in plant-based and climate-friendly meals is on the rise [65]. Millions of K-12 students already successfully participate in Meatless Monday and plant-based meal programs at schools across the U.S. every week. One common strategy to engage students and ensure that menu modifications are popular and successful are taste tests. Another is to model the side-by-side version of meals that are familiar and popular and introduce changes this way, particularly in line with the school's regional demographics and flavor cultures. A recent study has integrated education about food systems, experiential learning, and school lunch menu changes into a shift toward the planetary health diet [66].

The Center for Biological Diversity's forthcoming best practices guide for plant-forward and plant-based school food, *A Wildlife-Friendly Guide to Sustainable School Food*, argues that strategies that combine cafeteria materials, classroom curricula, school gardens, parent engagement, staff training, and student participation, can reinforce menu changes to meal programs and build a supporting and lasting school culture to ensure that the implementation of changes is rooted in success [67].

In addition, nonprofits and plant-based vendors have completed assessments of the most popular school meals across wide demographics and have designed plant-based versions of those meals—from veggie burgers to vegetarian sloppy joes and veggie lasagna—in addition to fresh, from-scratch, and new options.

5. Conclusions

This study provides insight into potential savings in carbon emissions through a reduction in high-carbon-emitting school meals within school districts. Through myriad meal plan scenarios we convey through our model, we can illustrate how school districts are in a unique position to implement policies and dietary guidelines that can positively influence environmental sustainability while simultaneously promoting healthy diets. New York City's two sustainable food policies have been successful in reducing the emissions generated by the diets of their students while also promoting healthy eating.

Our work demonstrates how sustainable food policies in school districts across the United States can significantly lower districts' carbon footprints while helping to promote healthy and sustainable food choices among students. This paper can thus serve as a guide for school districts seeking the application of these practices. Encouraging plant-based diets is healthy for both humans and the planet, proven to be safe and suitable for children, and children and adolescents are increasingly choosing these diets.

Adopting plant-based menus enables schools to spearhead the inevitable shift towards climate-centered food policies, serving as a model for other major sectors within the food system.

While this study focused on carbon emissions and adherence to existing nutritional standards, economic and health factors are equally important for understanding the broader implications of the proposed policy changes. Future research should examine the financial feasibility of such changes, including potential cost savings from sourcing plant-based foods, operational changes, and potential impacts on local food waste systems. Additionally, health outcomes, such as childhood nutrition and long-term dietary habits, warrant further investigation. Collaborative efforts with economists and public health experts could offer a more comprehensive understanding and enhance the findings presented here.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su17072955/s1. References [68–75] are citied in the Supplementary Materials.

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