# Optimization of Greenhouse Gas Emissions through Meal Planning and Purchasing

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**Abstract**:

Preserving the world as we know it has become a more prominent issue in recent years. There has been an increased awareness of each individual's impact on the environment, more commonly known as the individual carbon footprint. Changing the food one eats can play a big role in reducing their carbon footprint, as the carbon footprint takes into account the greenhouse gas emissions produced by growing, harvesting, processing, transporting, storing, cooking and disposing of the food. Incremental changes need to be made on a smaller scale in order to change the trajectory of climate change.

With this idea in mind, we seek to formulate a model representative of the optimal school menu over a four week period. We aim to contrive this model for an organization which serves 350 individuals and satisfies all necessary nutritional requirements while minimizing the greenhouse gas emissions (GHGE). This model will also calculate the cost of executing the optimal menu.

**Table of Contents**

## 1. Introduction

Over the past few years, climate change has been one of the topics at the forefront of our society. The question as to how we can reduce our carbon footprint to mitigate the devastating effects of climate change has become increasingly more popular.

There are both natural and anthropogenic causes of climate change; however, many believe that humans and our everyday activities are the leading contributors. Greenhouse gas emissions (GHGE) have elevated the concentrations of methane, nitrous oxides, and carbon dioxide to levels that will become exponentially more harmful to our planet.

With this idea in mind, we decided to analyze a situation in which the majority of people have encountered throughout their lives. An application our group deemed interesting was taking the viewpoint of a public organization that provides food to groups of individuals on a daily basis. We came to this conclusion as research has shown that food production accounts for approximately 26% of global GHGE (Ritchie). This comes from the production and maintenance of livestock and fisheries, agricultural procedures, land usage, and supply chain logistics.

Our interest is to address this issue through the supply chain by optimizing public meal services to reduce GHGE with consideration of personal and cultural food preferences, allergies, and cost. Our perspective of approach will be from that of a public school that provides lunch on a daily basis to its students. Although there will not be direct control over preprocessing, transport, and packaging, there will be freedom to make purchasing choices and meal planning to satisfy our constraints, while optimizing our objective function.

While small in nature, the theoretical approach is applicable to many organizations across the globe.

## 2. Problem Description

We are defining our problem in a way to mimic a school cafeteria by scheduling a menu over four weeks (a 28 meal period) for 350 students and faculty. On the weekends (the last two days of each week long-period) we will take into account that many students (around 20% of the student population) have meals sent home with them over the weekends at public schools.

Every day, the number of meals and sides produced will be determined according to the number of students purchasing lunch. The cafeteria knows in advance the number of meals needed, as students indicate what they will buy in the morning. During the week, demand is distributed N(250, 20) and over the weekend N(50, 5). There will be two entrees and three sides available every day. It is assumed that 50% of buying students will purchase one entree and 50% of students will purchase the other entree. Three sides will be produced for every student who is buying lunch.

There will be a list of *n* entrees and *k* sides. Every meal will consist of an entree, as well as three sides with a requirement that at least one of the sides be a vegetable or fruit and at least one of the others not. Over a certain period of time *t*, entrees and sides will not be allowed to be repeated, as repeated meals will reduce student satisfaction with meals and lead to higher food waste. We will also have a select number of *k* sides (and certain entrees) that will be nut-free, as there are some students who experience food allergies. We will also have a set number of constraints for the sides, including requirements for fruits and vegetables.

We determined that our ability to reduce the carbon footprint of cafeteria options will be most effective by focusing on food waste and the carbon footprint associated with individual food items by weight.

- In an attempt to model food waste *w*, over a certain period of time *t*, entrees and sides will not be allowed to be repeated. We will also assume that having more meal choices will lead to lower food waste by students. More meal choices, however, could lead to more food waste in the kitchen and our model will attempt to optimize these opposing forces.

- We can further optimize our objective by purchasing foods which have a lower carbon footprint. An index which gives the $CO_2$ equivalents by weight will be used to measure the carbon footprint.

Ultimately, our objective is to set a four week meal plan that minimizes the output of *g,* greenhouse gas emissions, while meeting certain nutritional standards for students and keeping *c* costs within the school's budget.

## 3. Literature Review

The first step to our literature review is to understand both the landscape and background regarding GHGE and dietary standards for public school lunches.

There are many different sources of GHGE from food production. For example, sulfur hexafluoride is a strong gas that is released from equipment manufacturing, installation, servicing, and disposal. GHGE also originate from natural gas, petroleum, and coal usage in various industries such as agriculture, transportation, and manufacturing.

Additionally, food waste is a significant source of unnecessary emissions. For example, Wilkes et al. state, "Just and Price found that requiring students to take at least one serving of fruit or vegetable at three elementary schools (kindergarten through fifth grade) in Utah significantly increased the amount of fruits and vegetables wasted, from 0.17 to 0.92 servings discarded per student." To reduce emissions, dietary changes can be made, reductions can occur in food waste, and low carbon emission foods can be made more scalable and affordable.

As we look to minimize GHGE, it is important to note that healthy omnivorous diets optimized for nutrition are more expensive compared with healthy vegetarian diets according to wholesale food cost data drawn from the Bureau of Economic Analysis in the System of National Accounts.

The issue of optimizing a food schedule for an organization of individuals has been approached by many different people across the globe. Each study contains different foci involving GHGE, cost, waste, satisfaction, and many other considerations.

Eustachio Colombo et al. looked to develop a process in food supply for schools in Sweden to reduce GHGE while factoring in nutrition, cost, and cultural acceptability. Multiple models were constructed to solve this problem from different angles.

Ahmed et al. focused on the effects of agricultural and animal-based food products on the environment. They investigated the comparability of food production to waste to address long-term global warming effects.

Additional research papers were reviewed to deduce assumptions that are needed for our optimization model. Our study looks to combine as many of these factors to produce the most relevant solutions for helping reduce the effects of climate change from food production. The following assumptions were discussed in the literary works:

1. The GHGE of the foods are expressed as carbon dioxide equivalents ($CO_2eq$) of food products
2. About ⅓ of all food production is wasted
3. Population is separated equally between male and female
4. Food and labor account for 90% of the costs for preparing school meals
5. Food GHGE can be broken down into supply chain (18%), livestock and fisheries (31%), crop production (27%), and land usage (24%)
6. Average global consumption of protein is three times the recommended level

7. There is an average school budget of $3.00 per student and faculty (about $0.25 above the mean cost in 2019)
8. One in 13 children experience a food allergy
9. Total variable cost is calculated taking the total weight of each product multiplied by the standard cost of those products
10. Serving more fruits and vegetables tends to lead to increases in food waste, which is a major contributor to GHGE
11. Every meal contains an entree and two sides; these can include a fruit, vegetable, grain, protein, or dairy
12. The average daily calories intake is 2000 or less per day
13. Food categories considered are cereals, bread, solid dairy (e.g. cheese), other dairy (e.g. milk), red meat, poultry, beans, roots and tubers, vegetables, fruits and berries, fish, oils, solid fats (e.g., butter, margarine), eggs, and other (e.g., seeds, salt, sugar, jams)
14. School lunches will be based on the dietary guidelines established by the U.S. Department of Health & Human Services

| **Source** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ahmed et al. | X | X | X | | | X | | | | | | | | |
| Centers for Disease Control and Prevention | | | | | | | | X | | | | | | |
| Eustachio Colombo et al. | X | | X | | | | | | X | | | | X | |
| Office of Disease Prevention and Health Promotion | | | | | | | | | | | X | X | | X |
| Ritchie | X | | | | X | | | | | | | | | |
| School Nutrition Association | | | | X | | | X | | | | | | | |
| Wilkie et al. | | | | | | | | | | X | | | | |

## 4. Proposed Model

The proposed model for our above discussed problem can be seen below.
Initially, we define the sets for the model:

$F = \{1, 2, ..., n\}$ : index for available entrees
$F2 = \{1, 2, ..., k\}$ : index for available sides
$N = \{1, 2, ..., q\}$ : index for nutrients for entrees
$D = \{1, 2, ..., t\}$ : index for days of meal rotation

Since we have entrees and sides separated into different data sets, we have created different input variables for entrees and sides for each data dimension.

Next, we obtain the input data for the model:

$E_{i\,q}$ : nutrient for entree (i, q)
$S_{j\,q}$ : nutrient for side (j, q)
$c_i^x$ : cost for entree i
$c_j^y$ : cost for side j
$w_i^x$ : waste for entree i
$w_j^y$ : waste for side j
$g_i^x$ : greenhouse gas emissions (GHGE) for entree i in terms of $CO_2$ equivalents by weight
$g_j^y$ : greenhouse gas emissions (GHGE) for side j in terms of $CO_2$ equivalents by weight
$a_i^x$ : binary variable denoting allergy for entree i
$a_j^y$ : binary variable denoting allergy for side j
$d_t^x$ : demand for entree on day t
$d_t^y$ : demand for side on day t
$U_q$ : maximum total nutrient value for nutrient q
$L_q$ : minimum total nutrient value for nutrient q
$B$ : budget allocation for total menu cost
W : waste allowed for total menu cost
$v_j^y$ : binary variable denoting fruit or vegetable for side j

Once again, the breakdown between entrees and sides is reflected in our input data. Greenhouse gas emissions are the critical values in which we are trying to minimize.

Our decision variables are shown below:

$$X_{i\,t} = \begin{cases} 1 \; if \;\; entree \; i \; is \; used \; on \; day \; t \\ 0 \; otherwise \end{cases}$$

$$Y_{j\,t} = \begin{cases} 1 \; if \;\; side \; j \; used \; on \; day \; t \\ 0 \; otherwise \end{cases}$$

For our objective function, our goal is to minimize the GHGE and find the optimal menu for reducing GHGE:

$$Minimize \sum_{t \in D} \left( \sum_{i \in F} X_{i\,t} \cdot c_i^x \cdot d_t^x + \sum_{j \in F2} Y_{j\,t} \cdot c_j^y \cdot d_t^y \right)$$

The constraints for our projected model are as follows:

Set the number of sides and entrees needed each day:

$$\sum_{i \in F} X_{i\,t} = 2 \; \forall \, t \in D$$

$$\sum_{i \in F2} Y_{j\,t} = 3 \; \forall \, t \in D$$

Minimum allergen-free entree and side:

$$\sum_{i \in F} X_{i\,t} \cdot a_i^x \leq 1 \; \forall \, t \in D$$

$$\sum_{j \in F2} Y_{j\,t} \cdot a_j^y \leq 2 \; \forall \, t \in D$$

Each entree and side cannot repeat within seven days:

$$\sum_{t}^{t+7} X_{i\,t} \leq 1 \; \forall \, i \in F, \; t \in D$$

$$\sum_{t}^{t+7} Y_{j\,t} \leq 1 \; \forall \, j \in F2, \; t \in D$$

Nutrient minimum and maximum per week:

$$\sum_{t \in D}^{t+7} \left( \sum_{i \in F} X_{i\,t} \cdot E_{i\,q} + \sum_{j \in F2} Y_{j\,t} \cdot S_{j\,q} \right) \geq L_q \; \forall \, t \in D(1, \, 8, \, 15, \, 22) \, , \; q \in N$$

$$\sum_{t \in D}^{t+7} \left( \sum_{i \in F} X_{i\,t} \cdot E_{i\,q} + \sum_{j \in F2} Y_{j\,t} \cdot S_{j\,q} \right) \leq U_q \; \forall \, t \in D(1, \, 8, \, 15, \, 22) \, , \; q \in N$$

Here is the breakdown of the minimum and maximum values assumed for nutrients:

| <u>Nutrient</u> | **Minimum (person per day)** | **Maximum (person per day)** |
|---|---|---|
| ***Calories*** | 500 cal | 1000 cal |
| ***Carbs*** | 70 g | 120 g |
| ***Protein*** | 24 g | 28 g |
| ***Sugar*** | 14 g | 25 g |

Cost and waste maximum per week:

$$\sum_{t \in D}^{t+7} \left( \sum_{i \in F} X_{i\,t} \cdot c_i^x + \sum_{j \in F2} Y_{j\,t} \cdot c_j^y \right) \le B \;\forall\, t \in D(1,\ 8,\ 15,\ 22)$$

$$\sum_{t \in D}^{t+7} \left( \sum_{i \in F} X_{i\,t} \cdot w_i^x + \sum_{j \in F2} Y_{j\,t} \cdot w_j^y \right) \le W \;\forall\, t \in D(1,\ 8,\ 15,\ 22)$$

Here is the breakdown of the maximum values assumed for cost and waste:

| <u>Constraints</u> | **Maximum (person per day)** |
|---|---|
| ***Cost*** | $2.00 |
| ***Waste*** | 2.1 $CO_2$eq (rounded to 11,500 in total) |

Minimum requirement of at least one fruit or vegetable side per day:

$$\sum_{j \in F2} Y_{j\,t} \cdot v_j^y \ge 1 \;\forall\, t \in D$$

Maximum requirement of no more than two fruit or vegetable sides per day:

$$\sum_{j \in F2} Y_{j\,t} \cdot v_j^y \le 2 \;\forall\, t \in D$$

## 5. Model Validation and Computational Results

In an effort to garner more knowledge about our model, we developed separate models as a sensitivity analysis. Through editing constraints and the objective function, we observed changes in the GHGE and cost variables. We chose six common scenarios to edit our proposed model. We kept all assumptions constant, and only changed the constraint or objective listed below.

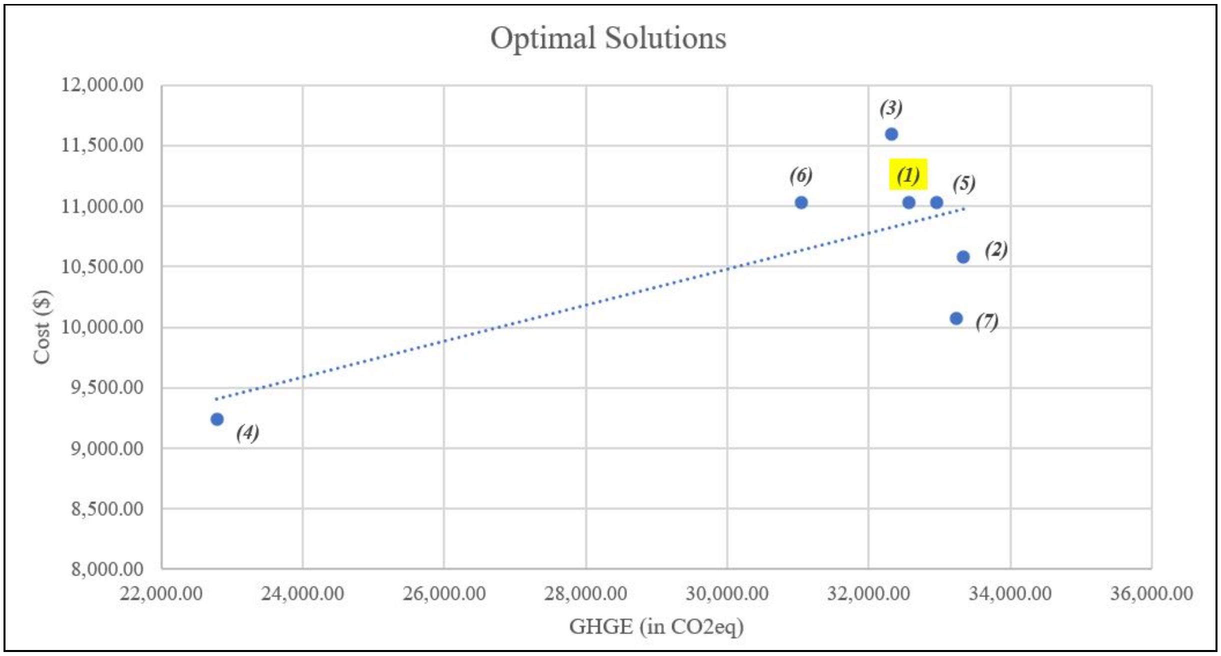
Please see the following table with the results from these alterations:

| Sensitivity Analyses | Index | GHGE (in $CO_2$eq) | Cost (in $) |
|---|---|---|---|
| ***Proposed Model (as stated above)*** | 1 | 32,561.17 | 11,033.87 |
| ***Change objective to minimize cost*** | 2 | 33,341.61 | 10,583.60 |
| ***Unlimited budget (no cost constraint)*** | 3 | 32,318.16 | 11,590.81 |
| ***No repetition constraint*** | 4 | 22,787.88 | 9,239.45 |
| ***Every entree at least once*** | 5 | 32,957.15 | 11,033.90 |
| ***No nutritional constraints (minimize GHGE)*** | 6 | 31,045.05 | 11,033.91 |
| ***No nutritional constraints (minimize cost)*** | 7 | 33,243.54 | 10,073.60 |

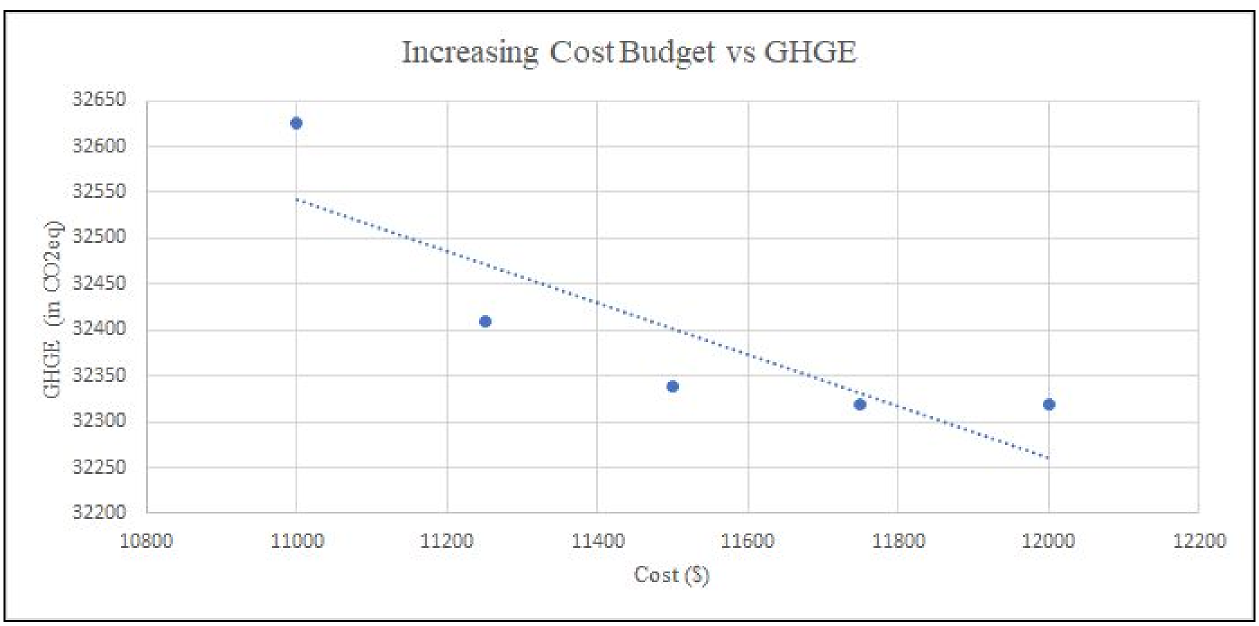
As seen in the above table, the scenario that best minimizes GHGE (22,787.88) is the model which eliminates the repetition constraint. This makes sense, as the same entrees and sides can be served each day. This model also most effectively minimizes cost ($9,239.45), which is nearly $2,000.00 cheaper than our proposed model. However, it is unreasonable to serve the same meals every day as students would be dissatisfied with the lack of variety.

Removing the nutritional constraints and with the objective function being either to minimize GHGE or minimize cost provided the next lowest values for these respectively.

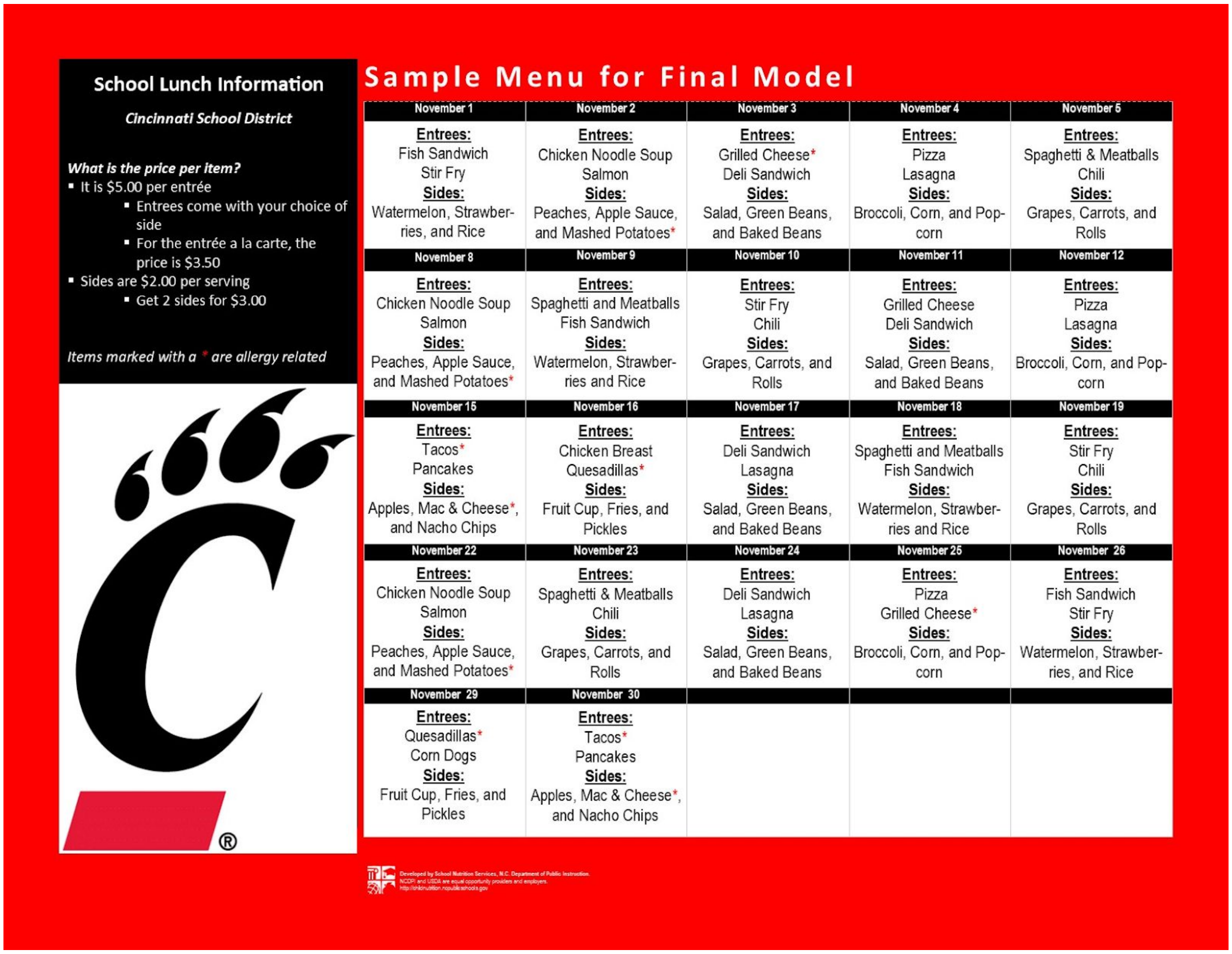
A graph of these optimal solutions can be seen below. Each data point is labeled by their associated index; for example, (1) portrays our proposed model outputs for both GHGE and cost.




Knowing the results of these scenarios, we also wanted to understand how changing the cost impacted the overall GHGE. The cost constraint was edited to show the various GHGE outputs with the following maximum costs: \$11,000, \$11,250, \$11,500, \$11,750, and \$12,000. As seen in the graphic below, we observed that the higher the budget, the lower the GHGE. This inverse relationship tends to flatten out, though, around \$11,800.




After finishing the model, we came up with a lunch menu that would best serve the school:



**School Lunch Information**

*Cincinnati School District*

*What is the price per item?*
- It is $5.00 per entrée
  - Entrees come with your choice of side
  - For the entrée a la carte, the price is $3.50
- Sides are $2.00 per serving
  - Get 2 sides for $3.00

*Items marked with a * are allergy related*

**Sample Menu for Final Model**

| November 1 | November 2 | November 3 | November 4 | November 5 |
|---|---|---|---|---|
| **Entrees:**<br>Fish Sandwich<br>Stir Fry<br>**Sides:**<br>Watermelon, Strawberries, and Rice | **Entrees:**<br>Chicken Noodle Soup<br>Salmon<br>**Sides:**<br>Peaches, Apple Sauce, and Mashed Potatoes* | **Entrees:**<br>Grilled Cheese*<br>Deli Sandwich<br>**Sides:**<br>Salad, Green Beans, and Baked Beans | **Entrees:**<br>Pizza<br>Lasagna<br>**Sides:**<br>Broccoli, Corn, and Popcorn | **Entrees:**<br>Spaghetti & Meatballs<br>Chili<br>**Sides:**<br>Grapes, Carrots, and Rolls |
| **November 8** | **November 9** | **November 10** | **November 11** | **November 12** |
| **Entrees:**<br>Chicken Noodle Soup<br>Salmon<br>**Sides:**<br>Peaches, Apple Sauce, and Mashed Potatoes* | **Entrees:**<br>Spaghetti and Meatballs<br>Fish Sandwich<br>**Sides:**<br>Watermelon, Strawberries and Rice | **Entrees:**<br>Stir Fry<br>Chili<br>**Sides:**<br>Grapes, Carrots, and Rolls | **Entrees:**<br>Grilled Cheese<br>Deli Sandwich<br>**Sides:**<br>Salad, Green Beans, and Baked Beans | **Entrees:**<br>Pizza<br>Lasagna<br>**Sides:**<br>Broccoli, Corn, and Popcorn |
| **November 15** | **November 16** | **November 17** | **November 18** | **November 19** |
| **Entrees:**<br>Tacos*<br>Pancakes<br>**Sides:**<br>Apples, Mac & Cheese*, and Nacho Chips | **Entrees:**<br>Chicken Breast<br>Quesadillas*<br>**Sides:**<br>Fruit Cup, Fries, and Pickles | **Entrees:**<br>Deli Sandwich<br>Lasagna<br>**Sides:**<br>Salad, Green Beans, and Baked Beans | **Entrees:**<br>Spaghetti and Meatballs<br>Fish Sandwich<br>**Sides:**<br>Watermelon, Strawberries and Rice | **Entrees:**<br>Stir Fry<br>Chili<br>**Sides:**<br>Grapes, Carrots, and Rolls |
| **November 22** | **November 23** | **November 24** | **November 25** | **November 26** |
| **Entrees:**<br>Chicken Noodle Soup<br>Salmon<br>**Sides:**<br>Peaches, Apple Sauce, and Mashed Potatoes* | **Entrees:**<br>Spaghetti & Meatballs<br>Chili<br>**Sides:**<br>Grapes, Carrots, and Rolls | **Entrees:**<br>Deli Sandwich<br>Lasagna<br>**Sides:**<br>Salad, Green Beans, and Baked Beans | **Entrees:**<br>Pizza<br>Grilled Cheese*<br>**Sides:**<br>Broccoli, Corn, and Popcorn | **Entrees:**<br>Fish Sandwich<br>Stir Fry<br>**Sides:**<br>Watermelon, Strawberries, and Rice |
| **November 29** | **November 30** | | | |
| **Entrees:**<br>Quesadillas*<br>Corn Dogs<br>**Sides:**<br>Fruit Cup, Fries, and Pickles | **Entrees:**<br>Tacos*<br>Pancakes<br>**Sides:**<br>Apples, Mac & Cheese*, and Nacho Chips | | | |

For more details on the relevant lunch menus for various scenarios, please refer to our excel model.

## 6. Conclusion

In solving the model, we developed a menu that would meet certain nutritional requirements, not exceed a budget, provide options for people with allergies, and minimize GHGE emissions based on a list of 20 entrees and 30 sides. Interestingly, while there are similar components to the menu on a weekly basis, the general solution does not simply repeat the same menu every week. This is heartening, because it shows that there is opportunity for a model like ours to optimize a school's cafeteria menu beyond simply selecting the lowest cost, lowest emissions foods and simply repeating them on the menu. This is likely due to the varied demand and the requirement to have two entrees on each day --- meaning there is the opportunity to mix and match the combinations of entrees and sides during the week.

The sensitivity analysis demonstrated a variety of different perspectives from which a problem like this can be approached. On every separate cut, small yet significant differences in both cost (range from \$9,239.45 - \$11,033.91) and GHGE emissions (range from 22,787.88 - 33,243.54) were observed. This is beneficial to note, because it demonstrates that the model can be applied to help optimize a variety of different situations. For example, a school in a low-income area that wants to meet nutritional requirements, but is more focused on cost than reducing GHGE, could reference our second iteration of the model, in which we minimize the cost. This would save a school of approximately 350 students \$500 a month or around 5%, compared to the model that minimizes GHGE.

One of the most interesting results of the sensitivity analysis, due to its drastic difference in both GHGE and cost, is the scenario in which the repetition constraint is removed. Two entrees, pizza and grilled cheese, are served at every meal with a combination of three of the following four sides: watermelon, apples, grapes, and french fries. This is exactly the type of meal that you would imagine in this scenario as it is both cheap and has limited animal products (leading producer of GHGE). Obviously, there are few students who would want to eat the same meal every single day. That being said, the drastic difference in cost (around \$2,000 a month less) and GHGE (around 10,000g a month less) compared to all of the other models raises the question: "Is there a situation where these savings could be mirrored?" A potential solution or next step that could be taken to answer this question is to expand the menu to include more foods that more closely mirror the cost and GHGE than the options that we included in our analysis.

In conclusion, models like ours could be applied to a variety of different types of menu scheduling objectives. We believe that minimizing GHGE will become an increasingly popular issue that must be faced though. As demonstrated above, computationally inexpensive models like ours have the opportunity to make a large impact in that battle.

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