Title: **Not Wasting What's Not Wanted**

0 Executive Summary

Worldwide, environmental awareness is spreading, as countries, corporations, and communities take up recycling programs, make efforts to reduce carbon dioxide emissions, and act against animal extinction. Consequently, there is growing concern surrounding the habits of food consumption, namely food waste. Approximately one third of all food produced in the world for human consumption goes uneaten. At the same time an estimated 42 million people are food-insecure in America alone [1,21].It does not make sense to throw away perfectly edible and nutritious produce, grains, and dairy products simply due to aesthetic deformities, or lack of sales, while billions starve worldwide. We explore the possibilities of purposing food waste, either redistributing unwanted food to the needy, or by using food for compost, bio-fuel, or other non-food purposes.

As mentioned above much of this waste consists of misshapen or unattractive products that are otherwise nutritious and consumable and could be used to feed those without food security, instead of rotting in landfills. We began by developing a model to determine whether or not a state is capable of feeding it's food-insecure population with the food waste it generates by comparing the tons of food waste generated with the tons of food needed to feed those without food security in a state. We determine the tons of food needed to feed the food-insecure based on the recommended daily nutritional value for children, teens, and adults as well as the number of meals already through government programs. Although we created a model that could be used to determine the possibility of feeding food insecure families with re-purposed food waste, we looked specifically at Texas to determine the viability of such a plan. Our findings reveal that Texas is capable of generating enough food waste to feed it's food-insecure population.

Then, we shifted our focus from statewide food waste to smaller scale household food waste, analyzing the annual food waste generated by individual households of different sizes and incomes. We divided food into five major groups: Meat, Milk, Protein, Oils, and Fruits/ Vegetables. Then, using data for consumption and waste for each food categories, we created a model to predict the yearly waste in tons of an individual given their income and age. For the purposes of our model there were two age brackets - higher income which consists of those above 185% of the poverty line and lower income. Additionally there were three age groups - young children age 2-13, teenagers age 14-19, and adults older than 19. We found that higher income teenagers waste the most food (.0851 tons per year) while young low income children waste the least (.0565 tons per year). We also used our model to predict the yearly food waste for the following four distinct household situations, each with different annual incomes, ages, and family sizes.

Finally, with our new universal knowledge of food wastes, we suggested specifc strategies for repurposing the wasted food in Lake County. Specifically, we addressed the monetary values of composting, biofuel creation, general redistribution and recycling, to determine the most monetarily efficient use of the food waste. Eventually, we monetarily compared the different techniques, citing sources of error and possible causes of variations in accuracy. Based on our results, we discovered that the most monetarily efficient method in the first year was recycling ($215000000), followed by biofuel ($52,291,000), general redistribution ($8,210,947), and finally, composting ($ 100,225,830).

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1 Part 1: Just Eat It!

1.1 Restatement of Problem

We are tasked with the following:

- Create a mathematical model that a state could use to determine if it could feed its food-insecure population using the wasted food generated in that state.
- Apply the validity of the model to Texas.

1.2 Assumptions

- Assumption: Food insecurity covers both low-level and very low-level food security.

  Justification: The majority of the data concerned with food insecurity does not differentiate between low level and very low level food security, so our model does not either.

- Simplification: The annual percentage of children (age 0-18) and adults (age 18+) that constitute the food-insecure population per state remains constant for all states.

  Justification: Generally, the children to parent ratios are the same across the US and the differences are not statistically significant enough to introduce a necessary error.

- Assumption: The distribution of food groups for a "healthy meal" remains constant for all age groups.

  Justification: While the total amount of food consumed will increase with age, the proportions of the recommended amount of different food groups stays approximately the same as one grows up.

- Simplification: For the sake of simplicity, we will assume that all children of ages 5-18 are enrolled and attend schools.

  Justification: A vast majority of students attend schools to the point that it isn't statistically significant when a student doesn't attend school. It's not easy to measure number of students **not** in school from year to year.

- Assumption: People eat, on average 3 meals a day, 7 days a week, totaling to 1095 meals annually.

  Justification: Although different people have different dietary needs, the recommended amount and most common diet is 3 meals per day.

- Simplification: There are equal numbers of children of each age within the United States.

  Justification: Since the numbers of children within each age are approximately the same, depending mostly on insignificant generational anomalies, it is reasonable to assume that there are equal numbers of children of each age within the US.

- Simplification: The daily food consumption of teens age 14-18 and adults age 19+ is the same.

  Justification: Our model for this section only seeks to find total food needed rather than dietary needs within a particular subgroup. We can approximate average dietary consumption among teenagers and adults combined. Additionally, the dietary needs are similar between teenagers and above. However, for the purposes of calculating free lunch benefits, we consider teens and adults into two separate categories.

1.3 Developing the Model

Our model consists of a conditional 2-value system, with G_N representing the total amount of food waste produced in a given area per year in tons and F_N representing the total amount of food needed to feed all age groups of a food-insecure population in a given area per year in tons.

If $G_N - F_N < 0$, then the region is not capable of adequately repurposing its food waste to feed the food insecure population.

Else-wise, if $G_N - F_N \geq 0$, then the region is capable of feeding its food insecure population with repurposed food waste.

1.3.1 G-N

G_N, representing the total amount of food wasted per year in an area in tons but able to be repurposed, uses 4 key parameters, namely the four essential food groups. g_p represents the total amount of grains produced per year, in a single area, in tons; FV_p represents the total amount of fruits and vegetables produced per year, in a single area, in tons; P_p represents the total amount of proteins produced per year, in a single area, in tons; and D_p represents the total amount of dairy produced per year, in a single area, in tons. Overall, we can express G_N as the equation:

$$G_N = 0.16(g_p) + 0.45(FV_p) + 0.205(P_p) + 0.057(D_p)$$

The coefficients of 0.16, 0.45, .205, and 0.057 represent the percentage of grains, fruits and vegetables, proteins, and dairy wasted per year, respectively, that can be repurposed for consumption. The percentages of each food group wasted per year that can be repurposed for consumption is a summation of waste from agricultural production, post-harvest handling and storage, processing and packaging, and supermarket retailing [1]. Household consumption is not included in the percentage because it is unlikely for consumers to consciously return uneaten food back into the market.

1.3.2 F-N

In our model for F_N, we identified the key factors being the number of people in a given area and how much food is needed annually which can be further broken down into the number of meals a person in a given age group consumes in a year and a constant which identifies how many tons are in a meal.

Defining M_a as the number of meals per year per person in a given age group; Ti as a constant representing how many tons 1 meal constitutes; and A_i as the number of people in one age group in a given area, the total tons of food needed per year for one age group will be the product $M_{a_i} * T_i * A_i$. Using dimensional analysis, the equation has units of tons per year which is consistent with what we are modeling. The value i determines the age group, with $i = 1$ corresponding to children (ages 2-13), $i = 2$ corresponding to teens (ages 14-18), and $i = 3$ corresponding to adults (ages 19 and above). Thus,

$$F_N = \sum_{i=1}^{3} (M_{a_i} * T_i * A),$$

.

We have 3 separate age groups because children and teens both qualify for the Free Lunch Program - adults do not - whilst teens and adults both have very similar consumption patterns - children have different patterns.

1.3.3 Calculating T_a

According to the following source, we develop the data table below [8]:

Daily Food Intake (oz) for 4 age groups				
Food group	2-3 years	4-8 years	9-13 years	14-18 years
fruits and vegetables	9.3	12.4	15.5	21.7
grains	3	5	6	8
proteins	2	4	5	6.5
diary	17.2	21.5	25.8	25.8

However, our age groups are organized into 2-13 years, 14-19 years, and 19+ years. To adjust the data, we calculate the weighted average of the values above for ages 2-3, 4-8, and 9-13 to determine the daily consumption in oz for the general age group of 2-13. Under the assumption that there are approximately equal amounts of children of each age, ages 2-3 has a weight of $\frac{2}{12}$ and ages 4-8 and 9-13 have weights of $\frac{5}{12}$ each because 2-13 is a total of 12 years wheras the subgroups of ages are 2, 5, and 5 years respectively. Thus, the daily intake based on our predetermined age groups of 2-13, 14-19, and 19+ are:

Daily Food Intake (oz) for 3 age groups			
Food group	2-13 years	14-18 years	19+
fruits and vegetables	13.18	21.7	21.7
grains	5.0	8	8
proteins	4	6.5	6.5
diary	22.58	25.8	25.8
Total oz	44.8	62	62

Thus,

$$T_1 = \frac{40.1oz}{day} * \frac{365days}{1year} * \frac{3.125 * 10^{-5}tons}{1oz} * \frac{1yr}{1095meals} = 4.177 * 10^{-4}tons\ per\ meal$$

and

$$T_2 = T_3 = \frac{62oz}{day} * \frac{365days}{1year} * \frac{3.125 * 10^{-5}tons}{1oz} * \frac{1yr}{1095meals} = 6.458 * 10^{-4}tons\ per\ meal$$

.

Although the T values are the same for teens and adults, their M values will differ due to certain percentages of teens qualifying for free school lunches, which is why we ultimately chose to separate them into 2 separate groups.

1.3.3 Calculating M_a

Almost all children and teens attend school and 66.3% of students without food security will be eligible for a free lunch. According to [6], the National School Lunch Act provides eligible students with one free or low cost lunch each school day. On average students spend 180 days in school [7]. Thus, eligible children will receive 180 free meals out of their yearly total of 1095 meals.

Furthermore, according to the Center on Budget and Policy Priorities, the average SNAP (formerly known as the Food Stamps Program) recipient receives \$4.20 a day, equating to \$1533 a year. The number of meals bought with SNAP's benefits will be $\frac{1533}{\overline{C}}$, with $\overline{C}$ being the average cost of a meal in the given region.

Thus, M_a, the amount of meals that will be provided by food waste, will be the total number of meals in a year minus the meals provided through the SNAP and free school lunch program:

$$M_{a_1} = 1095 - 180 - \frac{1533}{\overline{C}}, M_{a_2} = 1095 - 180 - \frac{1533}{\overline{C}}, M_{a_3} = 1095 - \frac{1533}{\overline{C}}$$

We subtract 180 from M_{a_1} and M_{a_2} and not M_{a_3} because only students, not adults, will benefit from free lunches.

1.4 Application to Texas

With application to Texas, we determined g_p, the total amount of grains produced per year to be 5,013,000 tons by taking the sum of the state receipts for sorghum, wheat, and rice and divided by the price per ton found for grain products found in our research [25]. Similarly, we determined FV_p, the total amount of fruits and vegetables produced per year to be 2,961,000 tons by taking the sum of the state receipts for corn, watermelon, onions, grapefruit, cabbage, oranges, grapes, pumpkins, and cucumbers and divided by the price per ton found for fruit and vegetable products. P_p, the total amount of proteins produced per year was found to be 5,274,000 by taking the sum of the state receipts for cattle and calves, broiler chickens, chicken eggs, "all other animals", hogs, and turkeys and divided by the price per ton found for protein products. Finally, D_p, we found the total amount of dairy produced per year to be 2,216,000 tons by taking the sum of the grain receipts for dairy products. Essentially, these values were calculated based upon the state receipts of each food group in Texas, expressed in dollars, divided by the price of each commodity per ton. Overall,

$$G_{Texas} = 0.16(5,013,000) + 0.45(2,961,000) + .205(5,274,000) + 0.057(2,216,000) = 3,342,012 tons$$

According to the United States Department of Agriculture, the estimated number of food insecure individuals in Texas is $4,320,050$ [13]. Approximately, 68.45% of food insecure individuals are adults [13]. Hence, $A_3 = 2,956,927$. To calculate A_1 and A_2, we again assume that there are an equal amount of people of each age, so 12/17ths of the $A_1 = 962,204$ and $A_2 = 400,918$.

The average cost for a meal in Texas is, $\overline{C} = \$2.59$. Thus,

$$M_{a_1} = 1095 - 180 - \frac{1533}{\overline{C}} = 1095 - 180 - \frac{1533}{2.59} = 323 \text{ meals}$$

$$M_{a_2} = 1095 - 180 - \frac{1533}{\overline{C}} = 1095 - 180 - \frac{1533}{2.59} = 323 \text{ meals}$$

$$M_{a_3} = 1095 - \frac{1533}{\overline{C}} = 1095 - \frac{1533}{2.59} = 503 \text{ meals}$$

.

Finally, $F_N = (962,204*323*4.177*10^{-4}) + (400,918*323*6.458*10^{-4}) + (2,956,927*503*6.458*10^{-4}) = 1,173,967$

With $G_{\text{N}} = G_{\text{Texas}} = 3{,}342{,}012$ tons of total food wasted but able to be repurposed, we compare G_{Texas} to $F_{\text{Texas}} = 1,173,967$ tons of total food in a healthy diet needed for one year. As we can see, $3,342,012 > 1,173,967$ so it can concluded that $G_{\text{Texas}} > F_{\text{Texas}}$ and thus the food-insecure population of Texas can be fed by the wasted food generated by the state.

1.5 Summary and Assessment of Model

To evaluate the stability of our model, we first determine the sensitivity of our variables. Since the variable T_i is based on profession nutritionist's recommendation of what children and adults should eat daily, it should be a very stable parameter. A is based on current population count for those without food security, and *based on previous data* it should may / not change in the following x years. M_i is the most sensitive variable, in which we made the largest generalization, by taking \$1533 , the annual monetary benefit for SNAP recipients, as a result of the average SNAP participant. However, the monetary value does vary depending on household and income size. Based on available data, though, this remained our most reasonable value. M_i also incorporates the cost of the meal, though this will also remain relatively stable over the years given lack of droughts or other natural disasters inhibiting the growth of crops in a state - even then, imports from other states may offset this difference in availability of food (which in turn affects the price of a meal). Thus, our model is not overly sensitive to any small changes in any parameter.

2 Part 2: Food Foolish

2.1 Restatement of Problem

Since a greater focus has been placed on the large portion of food waste generated at the household level, we have been tasked with the following:

- Build a mathematical model to determine the yearly food waste generated from variables of annual income, and the ages/number of people in the family.
- Demonstrate the validity of the model by evaluating it for the following households:
  1. Single parent with a toddler, annual income of $ 20,500.
  2. Family of four (two parents, two teenage children), annual income of $ 135,000.
  3. Elderly couple, living on retirement, annual income of $55,000.
  4. Single 23-year old. annual income of $45,000

2.2 Assumptions

- Assumption: The United States has approximately the same food waste patterns as Canada, New Zealand, and Australia.

  Justification: All four countries are highly developed and are top 20 globally in median income. Therefore the lifestyles, including food use, should be comparable.

- Assumption: An average individual of given age and income will consume the same amount regardless of the size of their family, e.g. a 22 year old man with a $55,000 yearly income will on average have the same consumption patterns regardless of whether they are single or married with kids.

  Justification: Although a person's eating habits may be affected by their family, overall they will still have the same calorie needs based on age, and spending money based on income regardless of family status.

- Assumption: The percentage of food wasted for any given food type is independent of the income or age of the consumer, e.g. if a 30 year old man with a 37k yearly income wastes 16% of purchased dairy products so would a 58 year old man with a 100k yearly income.

  Justification: Although total consumption varies based on age and waste, it is reasonable that the percentage of food that is wasted is independent of total consumption.

- Assumption: We will define higher income as a family at or above 185% of the poverty line and lower income as below 185%. We assume that the consumption patterns are uniform within each group.

  Justification: We choose 185% to be consistent with data used to model consumption based on income. The simplification that food consumption patterns are uniform within the two income groups intended to match the data we found rather than create a more complex and error prone model.

- Assumption: There are equal numbers of children of each age within the United States.

  Justification: This assumption is a continuation of assumptions made in Part 1.

- Assumption: All food waste has a density of 463 pounds per cubic yard.

  Justification: Although different types of food waste, vegetables, meat, etc., have different density, our model approximates the total food waste, so we can just use the average density of all food waste. The specific value of 463 pounds per cubic yard came from U.S. Environmental Protection Agency Office of Resource Conservation and Recovery [10].

2.3 Getting Started

The two main data sources for our model were the 2007-10 National Health and Nutrition Examination Survey (NHANES) and the Food and Agriculture Organization of the United Nations, Global Food Losses and Food Waste, 2011. First we used the NHANES data to model the consumption among different age and income groups, and then used United Nations data to model waste based off of consumption. The two sources divided food into subgroups, but each had slightly different methods of organizing. For the purpose of our model we regrouped categories from the data sources in the following ways. We grouped Fruits & Vegetables: Total into Fruits & Vegetables. Dairy was redefined as Milk. All types of Grains were grouped as Cereal. Oils and Solid Fats were grouped as equivalent to Oils & Pulses. Meat and Fish were grouped into protein. Our reclassification leaves us with the following five major food groups: Protein, Meat, Milk, Fruits/Vegetales, and Oils & Pulses which are used throughout our model.

2.4 Definitions

We devised a method for demarcating food, income, and population groups before proceeding further. For each of the five food subgroups we chose a capital letter to refer to that group as shown in the table below.

Food Group	Assigned Variable
Cereal (grains)	C
Fruits & Vegetables	F
Milk	M
Oils & Pulses	O
Protein (Meat & Fish & Seafood)	P

Also, we assigned letters for each of the 3 age groups and 2 income brackets to be used in our model.

Food Group	Assigned Variable
Children (2-19)	c
Young Children (2-13)	y
Teenager (14-19)	t
Adult (>19)	a
Lower Income	l
Higher Income	h

Additionally, we let P_y refer to the average daily consumption of protein by a young child. Similarly M_{ah} refers to the average daily consumption of milk by an adult in a higher income family. This classification is generalized for all age, income, and food groups.

2.5 Calculations

Using our 5 food group classifications, we compiled the date from the 2007-10 National Health and Nutrition Examination Survey (NHANES)[26] into the following table.

Food Group	Child	Adult	Low Income	High Income	Avg
Cereal(Ounces)	6.46	6.47	6.34	6.54	6.46
Fruits & Vegetables(Cups)	2	2.64	2.27	2.61	2.47
Milk(Cups)	2.16	1.64	1.67	1,83	1.77
Oils & Pulses(Grams)	54.05	60.09	54.84	60.96	59.59
Protein(Ounces)	4.33	6.13	5.29	5.93	5.68

Note, for example, that the number of cups of milk per child per day is the same as M_c and that Average refers to the average consumption of all consumers.

We recognize that the NHANES data only accounts for children age 2-19 in general. In our model, however, children are further divided into young children and teenagers in consideration of households with both toddlers and teenagers. The next step is to find an equation to convert K_c into K_y and K_t, where K refers to one of the 5 food groups. In order to do this, we found the population and per person daily consumption ratios between teenagers and children.

Now, we define S_y as the fraction of children who are young children and S_t as the fraction who are teenagers. Based on our assumptions, there are an equal number of American children at any given age. The young children range spans 12 years and the teenager range spans 6 years. Therefore the ratio of young children to teenagers:

$$\frac{S_y}{S_t} = \frac{12}{6} = 2$$
$$S_y = 2S_t$$

Also note that $S_y + S_t = 1$ because the sub populations of teenagers and young children combine to form the general population of children.

Using the food consumption calculations from part one of our model, we calculated that the ratio between the daily consumption of a young child and a teenager $\frac{K_y}{K_t} = \frac{44.84}{62} = .7232$ We also noted that the weighted average by population of the young child and teenage daily consumption must be the general child daily consumption resulting in the following equation:

$$K_y * S_y + K_t * S_t = K_c$$

Solving the system of the four above equations we found that:

$$K_y = .8869K_c, K_t = 1.2263K_c$$

Using these values we created an updated table as shown below:

Food Group	Young Child	Teenager	Adult	Low Income	High Income	Total
Cereal(Ounces)	5.73	7.92	6.47	6.34	6.54	6.46
Fruits & Vegetables(Cups)	1.77	2.45	2.64	2.27	2.61	2.47
Milk(Cups)	1.91	2.65	1.64	1.67	1,83	1.77
Oils & Pulses(Grams)	47.94	66.28	60.09	54.84	60.96	59.59
Protein(Ounces)	3.84	5.31	6.13	5.29	5.93	5.68

At this point we have values for P_y, P_h, etc., but we must also find P_{hy}, P_{la}, etc. Based on our assumption that the ratio of higher income to lower income consumption is independent of age we find:

$$I.e.\frac{P_h}{P_l} = \frac{P_{hx}}{P_{lx}} = 2$$

where $x \in c, t, a$. Also noting that the weighted average of consumption between income levels must equal the total average consumption and defining P_{tot} as average daily protein consumption among the total population combined with our above equation, we found that $\frac{P_h * P_l}{P_{tot}} = P_{hx}$ and $\frac{P_h * P_x}{P_{tot}} = P_{hx}$ where $x \in c, t, a$. It is important to note that this formula remains 100% consistent with all of the food consumption data from NHANES. Expanding this equation to all food groups, income ranges, and ages, we get:

$$Y_{ab} = \frac{Y_a * Y_b}{Y_{tot}}$$

where $a \in h, l$, $b \in c, t, a$, and $Y \in P, M, C, F, O$

Food Group	ly	lt	la	hy	ht	ha
Cereals(Ounces)	5.47	7.65	6.18	5.64	7.80	6.37
Fruits & Vegetables(Cups)	1.63	2.25	2.43	1.87	2.59	2.79
Milk(Cups)	1.80	2.46	1.55	1.97	2.70	1.70
Oils & Pulses(Grams)	43.85	60.63	54.97	48.75	67.40	61.10
Protein(Ounces)	3.58	4.95	5.71	4.01	5.54	6.40

The above table models the daily food consumption, but we also need to model waste. Based on data from the Food and Agriculture Organization of the United Nations [], we created the following table to show the percentage of food wasted due to being left uneaten within each food group. The study was done across the four countries of Canada, United States, Australia, and New Zealand. However, as described in our assumptions those values should be about the same throughout those four nations.

Type	Cereal	Fish & Seafood	Fruits & Vegetables	Oils & Pulses	Meat	Milk
Percentage wasted	27	33	28	4	11	15

For the purposes of our model we combine meat and seafood into a super category of protein. According to the Food and Agriculture Association of The United Nations, 6.7% of all protein consumption is fish. Using this value we take the weighted average of seafood and meat waste percentages to find the waste percentage of the protein super-category.

$$.067 * (33\%) + .933 * (11\%) = 12.474\%$$

If w units of a given food group are consumed, and for each unit of food purchased, y% is wasted, then the amount of food wasted z can be calculated as $\frac{w*y}{1-y} = z$ because the ratio of food consumed to food wasted is the same as the ratio of the percentage wasted (y) to the percentage eaten (1-y). For example $P_{ly} = 3.58$ so a low income young child consumes 3.58 oz of protein per day. Additionally 12.474% of protein is wasted. Therefore, a low income child has $\frac{3.58*.12474}{1-.12474} = .51$ ounces of protein waste per day. Repeating this process for each income level, age, and food group, we found the following projected waste values:

Food Group	ly	lt	la	hy	ht	ha
Cereals(Ounces)	2.02	2.83	2.29	2.09	2.88	2.36
Fruits & Vegetables(Cups)	0.63	0.88	0.95	0.73	1.01	1.09
Milk(Cups)	0.40	0.55	0.35	0.44	0.60	0.38
Oils & Pulses(Grams)	1.83	2.53	2.29	2.03	2.81	2.55
Protein(Ounces)	0.51	0.71	0.81	0.57	0.79	0.91

Finally, we need to convert the waste into a standard unit. For the purposes of our model, we choose to calculate the approximate tonnage of waste per yer. We convert all values to tons using standard unit conversions and our assumption of 463 pounds per cubic yard. Additionally, we multiply by 365 to find the yearly, rather than daily waste. Our results are shown in the table below.

Income and Age	ly	lt	la	hy	ht	ha
Tons wasted per year	0.0565	0.0788	0.0703	0.0617	0.0851	0.0768

2.6 Applying the Model

We apply our model for individual food waste to the four scenarios outlined in the prompt. In order to determine whether each family would fall under higher income or lower income, we look at the department of health and human services poverty line assignments. As described in our assumptions and as given in the NHANES data, 185% of the poverty line represents the cutoff between lower and higher income. That level varies with the number of people in the family. Using the scenarios and HHS data, we classify each family as higher and lower income. Finally, we take the sum of the waste of each individual in the family to produce the following table:

Scenario	Income Group	Food Waste in tons
Single parent with toddler, $ 20,500	lower	0.1268
Family of four (two parents, two teenage children), $ 135,000	higher	0.3237
Elderly couple, living on retirement, $55,000	higher	0.1535
Single 23-year old, $45,000	higher	0.0768

2.7 Summary and Assessment

Our model allows an early tonnage estimate for waste for an individual based on their age (2-13, 14-19, and > 19), and their income (above or below 185%). It does not apply for children under the age of two. The scenarios given in the prompt did not include 0 and 1 year olds because babies would be unlikely to have significant amounts of food waste. We then apply our model to the four family situations outlined in the prompt.

Based on our model, those with higher income had slightly higher waste than those with lower income. This is reasonable because people with higher income will have more money to spend on food, but everyone has relatively similar calorie needs. Additionally, teenagers had the highest level of food waste (.0788 and .0851 tons per year), which was slightly higher than the adult waste of (.0703 and 0.0768). This is consistent with the fact that teens may need slightly more calories than adults due to their ongoing growth and higher metabolism [15]. In the United States there are 35 million tons of food wasted per year [20]. Given that the United States has a population of 327,298,646 [24], there are $35,000,000/327,298,646 = .01069$ tons of food wasted per year per person. This value is slightly higher than the values we found, that number refers to the total waste while our model only applies to consumer waste. The biggest weakness of our model is the generalization of all incomes into higher or lower income. However, the differences in waste between higher and lower income brackets were less than 10%, so the error is bounded below 10% and is likely significantly lower.

3 Part 3: Hunger Game Plan?

3.1 Restatement of Problem

The problem at hand focuses on potential strategies for a school, community, or county to repurpose food at minimum cost, using modelling. We compare the methods of recycling, biofuel generation, composting, and general redistribution to determine the best way to maximize the generated food waste.

3.2 Assumptions

- Assumption: When food is recycled and made into products that make new food, the amount recycled equals the amount produced.

  Justification: Recycled food can make products such as a coarse grind, which can process food [4]. These food processors should be capable of matching food output from before. Furthermore, the relationship of food recreated equals food recycled will simplify later models.

- Assumption: Unless otherwise mentioned, all of the methods save the same amount of money allocated to go through waste management.

  Justification: The amount not fully utilized in each of the various methods would vary randomly according to year, and is almost insignificant. Therefore, we can assume that all of the food waste is utilized, leading to the same amount saved from waste management.

- Assumption: Each person eats about a ton (2000 pounds) of food per year.

  Justification: The average American consumes 1,996 pounds of food per year. For simplification purposes with regard to how many people can benefit from excess food, 1,996 pounds is rounded to 2,000 pounds [4].

3.3 Basis of the Models

We apply Illinois state receipt data to the model of G_N delineated in Part 1. We find that the annual average food waste for IL is 31,260,000 tons/yr, broken down into 14,134,000 tons/yr in vegetables and fruit, 16,007,000 tons/yr in protein, 376,000 tons/yr in dairy and 743,000 tons/yr in grains. We then multiply the ratio of $703{,}910/(12.8 * 10^6)$ which is the ratio of the population of Lake County [22] to the total population of Illinois [23] by each of the numbers above, resulting in an annual waste of 1,719,000 total tons/yr broken down into 777,270 in vegetables and fruit, 880,272 in protein, 20670 tons/yr in dairy and 40900 tons per year in grains.

3.4 Developing a Model for Food Recycling

The United States has a problem of having too many individuals without food security, further exacerbated by the food wasted by those who have access. One strategy to reduce food waste is to recycle more food. Recycling food is the act of using wasted food to enhance agriculture, or mix food and other ingredients together to create other products, enabling food insecure individuals to take advantage of what is recycled. The food that is wasted can then be recycled and made into other products that farmers and factories can use to produce more food.

Let n = the number of years past 2017 and b = the number of tons of food wasted in any given region in 2017.

Using $\frac{109}{500}$ which is the ratio of food that is made but not consumed from part 1, we create the exponential equation:

$$a = b(\frac{109}{500})^n$$

where a is the amount of food created from food waste, in tons. The model was created using the idea that 109/500 of all food available will be wasted. The food that is left over will then be consumed again (albeit in a different form), but 109/500 of those leftovers will also be wasted again. This process repeats infinitely, but since the model can predict the amount of food created from food waste at any time (not just infinity), the variable n is created to account for time.

$c = (\frac{391b}{500}) * (\frac{109}{500})^n$

where c is the amount of food consumed after it has been recycled at least once, in tons

To show these models, a sample table for a hypothetical region that wasted 50,000 tons of food in 2017 is shown.

Amount of Food Eaten and Recycled, in tons		
Year	Amount Eaten	Amount Recycled
2018	39,100	10,900
2019	8,524	2,376
2020	1,858	518
2021	405	113

With respect to amount of food created by food waste, the series "starts" with an initial value of b. b is then multiplied by $\frac{109}{500}$ to get the amount of food consumed by those who aren't food insecure in the first year. After the first year, those who are food insecure begin to benefit from recycling. Hence, the first term of the series is 109b/500 Each successive amount of food is multiplied by 109/500 each year, hence producing the model labeled a, a geometric series.

For amount of food consumed by food insecure individuals, the amount is continuously multiplied by 109/500, except in the first year, when the initial amount of food produced is multiplied by 391/500 for food secure individuals. Hence, the first value is 391b/500, and the common ratio is 109/500. The sum of amount eaten and amount recycled each year is equal to the amount recycled from the year prior.

3.5 Verifying the Model

According to section 3.3, it is estimated than 1,719,000 tons of food are wasted each year in Lake County. Using the model from 3.4, we find that b = 1,719,000 tons.

The table below shows the amount of food eaten by those with food insecurity, as well as amount of food recycled, in Lake County.

Amount of Food Eaten and Recycled, in tons		
Year	Amount Eaten	Amount Recycled
2018	1633050	85,950
2019	81653	4298
2020	4083	215
2021	204	11

For every ton of food consumed, a consumer spends about $2,641 [4] [12]. Hence, in the first year of recycling, the monetary value would be $2,641 * 81,653 =$ $215,645,573. In general, the monetary benefits added year by year would be would be

$$\sum_{i=1}^{n}(2,641 * 1,344,258 * (\frac{109}{500})^n)$$

3.6 Developing a Model for Biofuel

Often, with the growing dependence of the world on fossil fuels, many turn towards biofuels as a solution to the problem of food waste. Food waste can be converted to energy through the use of an anaerobic digester, which generates about 260kwH of electricity per wet ton of food waste applied [5].

According to section 3.3, the estimated food waste in tons per year is 1,719,000 in Lake County. Assuming a monetary 11.7 cents per kilowatt hour [4]. We created a one parameter linear regression:

$$\text{Monetary Gain} = (.117) * (260) * T$$

Monetary Gain is defined as the annual profit in Lake County from the repurposement of food waste as fuel. The constant .117 represents the monetary value of 1 kWh in dollars, 260 represents the amount of kWh generated per ton with an anaerobic digestor, and T represents the number of tons of food waste produced each year in the given area. In this instance, T is 1,719,000, which comes from the annual waste in tons/year as outlined in 3.3, resulting in a yearly monetary gain of $52,291,000.

3.7 Developing a Model for General Redistribution

The simplest method for reusing the food waste is through general redistribution, or the act of giving the food to those in need. To monetarily measure this method, we will analyze the reduction in governmental costs due to the reduced necessity of governmental monthly food stamps. In Lake County, the cost of food stamp programs was $8,210,947 as of January 2017 [14]. This number should decrease if less people need food stamps. Ideally, grocery stores with a surplus of food (average of 21.8% of all food produced) should donate their food to food pantries, who can then distribute food to those in need. 21.8% of all food can feed well over 7.2% of the food insecure population (it should be able to feed 21.8%of all of the population), so by food redistribution via charities, $8,210,947 would be saved.

3.8 Developing a Model for Composting

Composting, a gardener's favorite way to save money, is another method to reuse the immense food waste generated in the community. Only fruits, vegetables, and grains should be composted to create the most effective compost - the addition of other foods may attract maggots or denature the resulting soil[16]. The cost of compost is around $2.45 per 40 pounds [17], which converts to around $122.5 per ton. We take F, the amount of fruits/vegetables waste in tons in Lake County, and G, the amount of grains waste in tons in Lake County, and come up with the following equation:

$$\text{profit} = (122.5) * (F + G),$$

Where 122.5 is the monetary value of one ton of compost. In Lake County, F and G correspond to 777,270 and 40,900 tons, respectively, which equates to a profit of $100,225,830. Compost does not include other food groups for reasons delineated in the above paragraph.

3.9 Comparison of Strategies

Method	Monetary Value in first year
Recycling	$3,550,185,378
Biofuel	$52,291,000
General Redistribution	$8,210,947
Composting	$100,225,830

From these models, it is clear that recycling is the best option from a monetary standpoint. In the long-term, however, recycling may not be the best option. Since the amount of money saved from recycling decreases each year (modeled in 3.5), while the biofuel model saves the same amount of money each year, the biofuel model would save more money in the third year than recycling. Recycling saves $36,780,744 by year 3, whereas biofuels save $52,291,000 in year 3. However, it would take 86 years for the overall sum of biofuel profit to be higher than recycling profit. Let i equal the number of years past 2017.

For a geometric series, as is shown by recycling...

$$\sum_{i=1}^{n}(2,641 * 81,653 * (\frac{109}{500})^n)$$

$= (2641 * 81,653) * \frac{1-((109/500)^i}{1-(109/500)}$

The amount accumulated for biofuels is $52,291,000i$ Additionally, our model for General Redistribution has some positive externalities which we have not considered that cause it to be most likely be morally the best for the economy as the added supply of food for the insecure may mean that more are able to work, or willing to try to find jobs.

3.10 Summary and Assessment

All in all, our models show that the strategy of recycling food to recreate other food is the most beneficial (from an economic standpoint) in the short term, but using food waste to create biofuels is most beneficial in the long term. Using food waste for compost leads to a loss of money, and redistributing food via charities leads to saving money, but not nearly as much as biofuels and recycling.

Sensitivity Analysis for 3.4: The most sensitive variable for the recycling model is b, the amount of food wasted at the start, in 2017. As b increases, the amount of recycled food that can be repurposed greatly increases, but as b decreases, the amount of recycled food that can be repurposed greatly decreased. Changing b by 1 can make the monetary benefits increase or decrease by as much as 3 billion, making b a relatively sensitive variable.

Sensitivity Analysis for 3.6: The most sensitive variable for the biofuel model is T, the number of tons of food waste produced each year. However, similarly to the model for the recycling model, the sensitive variable is multiplied by some other quantity. However, in the biofuel model, T is multiplied by 30.42, whereas in the recycling model, b is multiplied by 3,550,185,378 (along with a fraction). Nonetheless, b is much more sensitive that T because the monetary benefits increase by 30.42 when T increases by 1, while when b increases by 1, monetary benefit can increase by as much as 200 million.

Sensitivity Analysis for 3.8: The sensitivity of the compost model can be measured by changing (F+G), which in turn changes C, since C+F+G = total food waste produced in an area. Changing (F+G) by 1 causes an overall shift of $-268.75 which is overall insignificant because -268.8 ¡¡ .1%, a very miniscule change in the overall monetary value for composting.

4 Conclusion

4.1 Strengths

- Our model incorporates key factors that have significant influence on food insecurity and monetary gains from better utilizing food waste.
- Our model addresses specific subcategories of food waste, such as proteins, grains, and dairy, which makes it more accurate in determining total food waste.
- Our model relies heavily on prior statistics that are reliable, lending credibility to the results.
- With sufficient information, our models in parts one and three are easily applicable to different states and counties respectively, while also addressing the states or counties that were not posed by the question.

4.2 Weaknesses

- Our model generalizes demographics regarding income, meaning that the numbers may be somewhat inaccurate; The income isn't as specific as it could be.
- Our models made significant amounts of assumptions, which while weren't logically faulty, may introduce unaccounted variations. Some constants may be too difficult to keep track of and truly preserve for all considerations.
- Our model may not adequately reflect sudden changes in the economy, such as extreme supply push inflation. A drop in the economy may lead to higher food insecurity rates.
- Although the use of tables provides examples of data and further illustrates the models, the quantity of tables in the paper detracts from the description regarding why the model is effective.

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