DIETARY RECOMMENDATIONS FOR THE REPUBLIC OF OPTMIZATION

World Bank and Team C2

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1. Executive Summary

The Republic of Optimization has a population of 100 million people, including 20 million children. The country has experienced a recent surge in child mortality, mostly due to under-nutrition and malnutrition that stem from a shortage of micronutrient-dense foods and/or from an inappropriate selection of locally available foods in the children diets. The objective of this project is to provide diet recommendations for the children in terms of food items, that meet all the nutritional requirements while reducing the energy intake as well as the cost and, based on the local food availability and the children's current consumption patterns. Also, we aim to identify the most restrictive nutritional requirements and an optimal tradeoff between cost and calories, to provide insights to the World Bank to develop policy interventions in that country.

The WHO and UK nutritional guidelines were used as a benchmark to formulate the diet plan for the children. A multi-objective linear optimization model was designed to ensure that the nutritional guidelines were met within the currently available food sources in the country while minimizing the cost and the energy intake at the same time while incorporating the current consumption pattern of children in harvest and non-harvest seasons of the country and the availability of food items. The model optimized the food items in grams for a single child with flexibility to scale the diet to meet a larger section of the children population. With that model, we analyzed four scenarios: UK – harvest /non-harvest and WHO harvest/non-harvest. To solve the model, we used GAMS and to transform the inputs and outputs of GAMS, we used MATLAB.

The first insight was that for all the four guidelines/seasons scenarios we evaluated, the nutritional requirements could be met which meant that the recent surge of children mortality was primarily due to an inappropriate selection of available food items rather than a shortage of micronutrient-dense foods. The second insight, was that for the non-harvest season, the recommended intake will always be less energy efficient than the intake for the harvest season. The third insight was that the difference in performance between the guidelines is higher in cost compared to calories, in which at lower costs, the WHO guideline was marginally better. Based on the WHO-Harvest scenario, the fourth insight was that at minimized cost, the food items from the groups of grains, oils and dairy made up for 95% to 99% of the grams in the diet. This implies that a diet based on these groups could cover most of nutritional requirements for extremely poor countries that cannot afford to pay low calorie, hence, more costly food items. Finally, we also found that the most energy efficient food groups were the proteins and vegetables.

Based on these insights, the World Bank should keep in mind that it shouldn't plan for a unique solution that addresses the expected performance of the country but rather an optimal frontier from which it can evaluate extreme cases as well. Also, educational policies are recommended to shift the current consumption pattern to proteins and vegetables. As future work, we propose to characterize additional scenarios over the efficient frontier. add a diversity objective to the model, formulate a meal optimization approach and adjust the model to process multiple scenarios in parallel.

2. Introduction

The Republic of Optimization is facing a pressing problem of rapidly growing child mortality as the result of the inability to fulfill the nutrient requirements for its child population and needs to identify the root-cause for this problem. Among the potential reasons, there is the shortage of the micro-nutrient dense food, the inappropriate selection of food items in the regular meal options for the children, or the combination of both. Given that the nature of the problem is complex, it requires a comprehensive analysis of the dynamics between the key factors: cost, calories, nutritional requirements and food items availability.

3. Objective

The objective of this project is to provide diet recommendations for the children in terms of food items, that meet all the nutritional requirements while reducing the energy intake as well as the cost and, based on the local food availability and the children's current consumption patterns. Also, we aim to identify the most restrictive nutritional requirements and an optimal tradeoff between cost and calories, to provide insights to the World Bank to develop policy interventions in that country.

4. Methodology

To approach this problem, we decided to implement a multi-objective linear optimization model. Since you need to find a diet composition that reduces the energy intake as well as the cost, and ensures that the nutritional guidelines are met with the current food supply, this technique is perfect. On one side, this technique allowed us to find the best possible outcome at the same time it ensured the restrictions were met. On the other side, we could formulate the restrictions for this model as linear equations. When we talk about restrictions, we refer to formulas that describe the interactions of the situation that is being captured. Finally, a multi-objective problem granted us the ability to evaluate different combinations of the best possible outcome for each of the objectives at the same time. You can find the detailed formulation with the respective explanation in the Appendix 1.

We decided to formulate the model to target one child at a time, without considering the magnitude of the population, to make the results scalable to any population size without rerunning the model. Also, we decided to optimize for grams of food items instead of units, to facilitate the interpretability of the model and to adjust it to situations where the portion size of a food item might vary or be unknown.

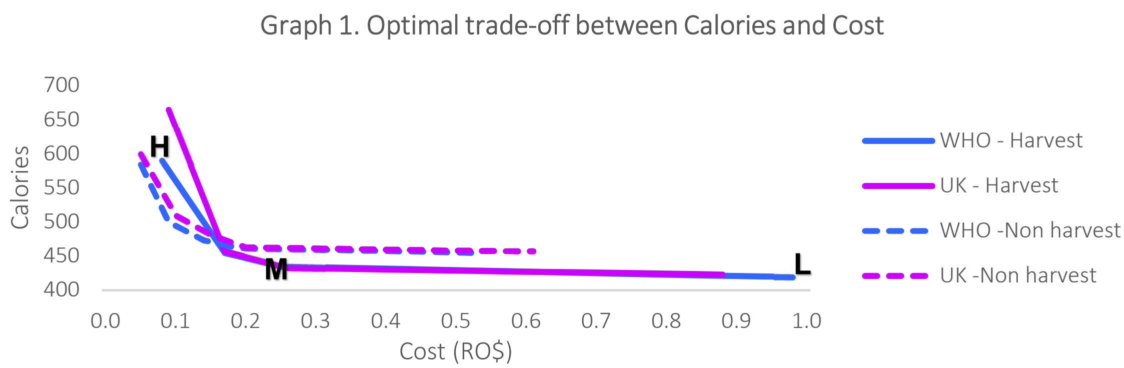
Considering that the magnitudes and units of the objectives were different (calories and RO$), we initialized the model finding the minimum cost without controlling the calories and then we used this value as the initial value of the maximum cost restriction (alpha). To understand the behavior of the calories when the cost changed (tradeoff), we run the model several times increasing the value of alpha each time until the value of the total calories remained unchanged. Regarding the illustration of the current consumption patterns, we decided to frame them among the 4th and 6th decile of the distribution you provided, to guarantee a representative behavior of the children consumption pattern and avoid giving recommendations based on outliers' behavior. Also, as we decided to focus in characterizing the diet based on food items and not meals, several information provided was not used: courses.csv and preferences.csv.

To implement this model, we used MATLAB to transform the inputs and outputs from GAMS and GAMS to solve the model. Given that the model was simple, it was solved in seconds by GAMS. To process the results, we used R and Excel. Finally, since the tradeoff added complexity for processing the results, we decided to run one scenario (combination of guideline and season) at a time.

5. Findings

5.1 Optimal trade-off between calories and cost

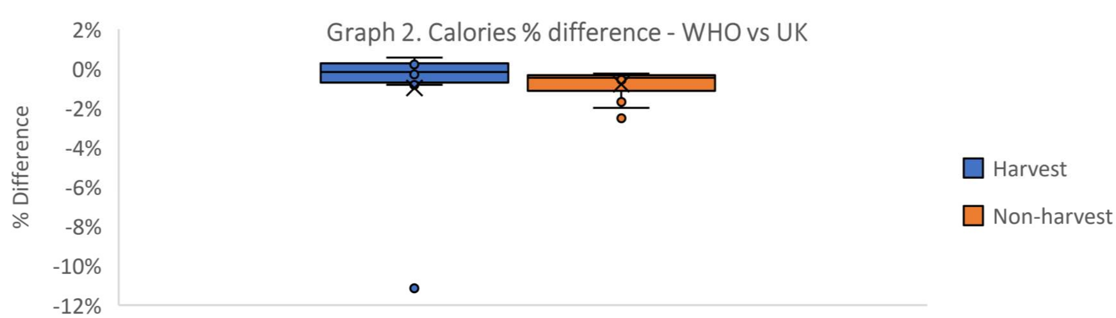
By varying the maximum cost to be spent for a child in a day (starting with the minimum possible cost), we built a frontier that characterized the trade-off between calories and cost. The main takeaways from this result are:



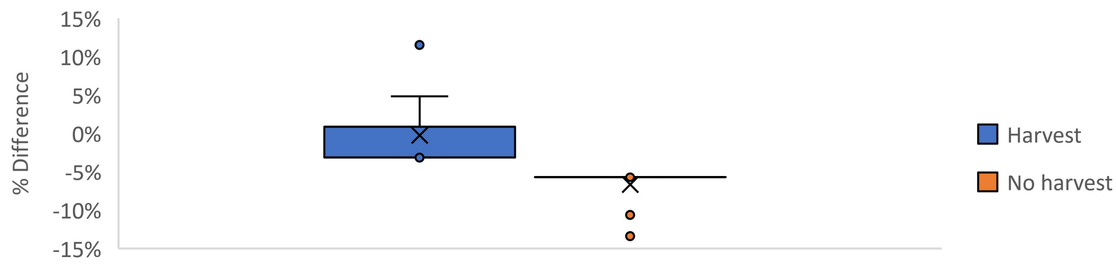
a) For the four combinations of guidelines and seasons we evaluated, we found that in every scenario we met the nutritional requirements. This means that the root of the recent surge of children mortality is an inappropriate selection of available food items rather than a shortage of micronutrient-dense foods.

b) Even without a budget restriction, for the non-harvest season, the energy intake for the optimal diet was 8% higher than the energy intake for the harvest season. This suggest that the availability of micronutrient-dense foods with low calories is reduced for the non-harvest season compared with the harvest season.

c) When we observed the diet composition for the lowest cost on each guideline, the WHO-based diet provided 11% less calories than the UK guideline. On the other hand, when the calories were minimized, the WHO-based diet was 12% more costly for the harvest season and 13% less costly for the non-harvest season compared to the diet obtained with the UK guideline. Finally, as observed in Graph 2 and Graph 3, the difference in performance between the guidelines was higher for cost than for calories, meaning that either guideline would ensure a proper nutrition for the population.

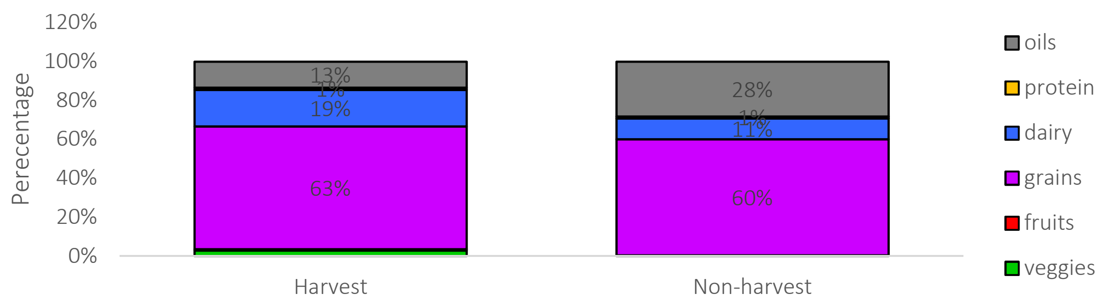


Graph 3. Cost % difference - WHO vs UK



d) As shown in Graph 4, when the cost was minimized, the food items from the groups of grains, oils and dairy made up for 95% to 99% of the grams in the optimal diet for the WHO guideline. This implies that a diet based on these groups could cover most of nutritional requirements for extremely poor countries that cannot afford to pay low calorie, hence, more costly food items.

Graph 4. Weight composition by food group at Minimum cost (WHO)

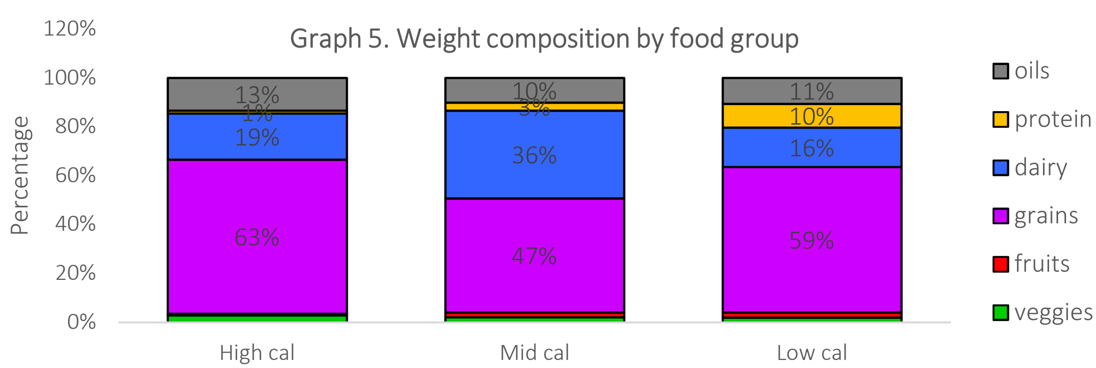


5.2 Diet characterization for the WHO - Harvest scenario along the efficient frontier

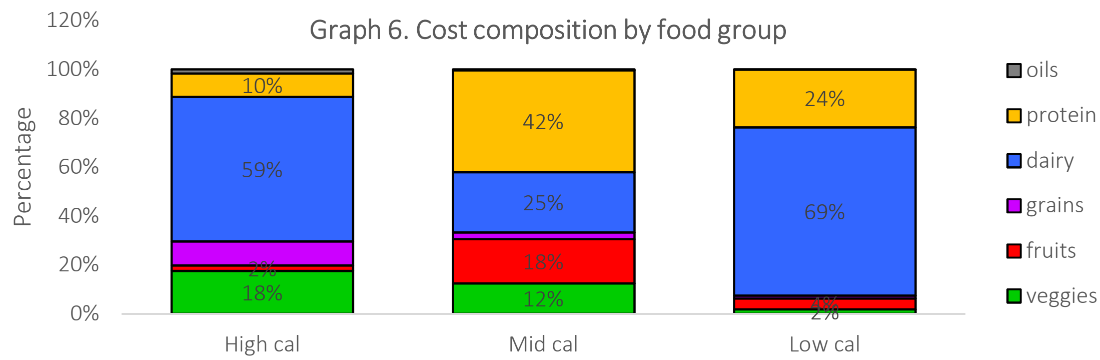
To provide insights into how the diet composition varies for different requirements of calories and cost, we chose three inflection points on the WHO - Harvest frontier: *High cal* (590 calories vs 0.083 RO$), *Mid cal* (434 calories vs 0.25 RO$) and *Low cal* (419 calories vs 0.97 RO$).

5.2.1 Diet composition by food group

The predominant food groups across the three selected scenarios were grains, dairy and oils. From the comparison between the weight and cost breakdown of the selected items (Graph 5 and Graph 6), we observed that grains and oils were the cheapest source of macronutrients compared to the other groups. Other conclusion from this breakdown was that dairy might be a substitute for protein in low-budget situations.

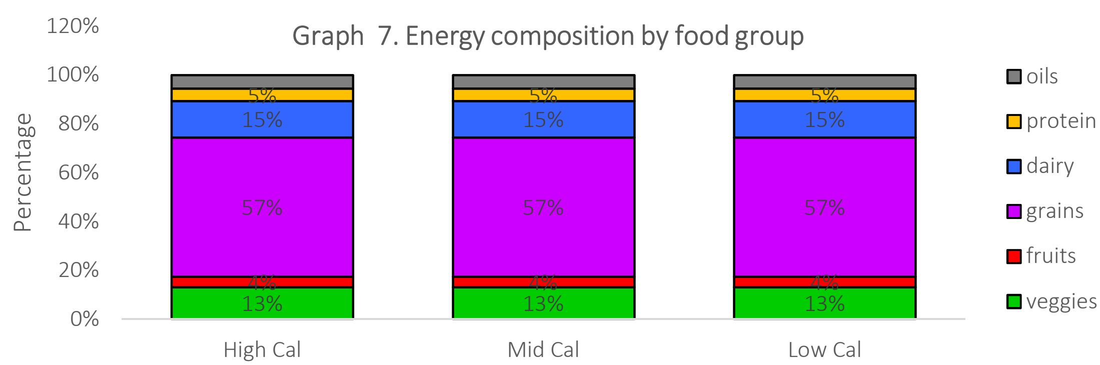


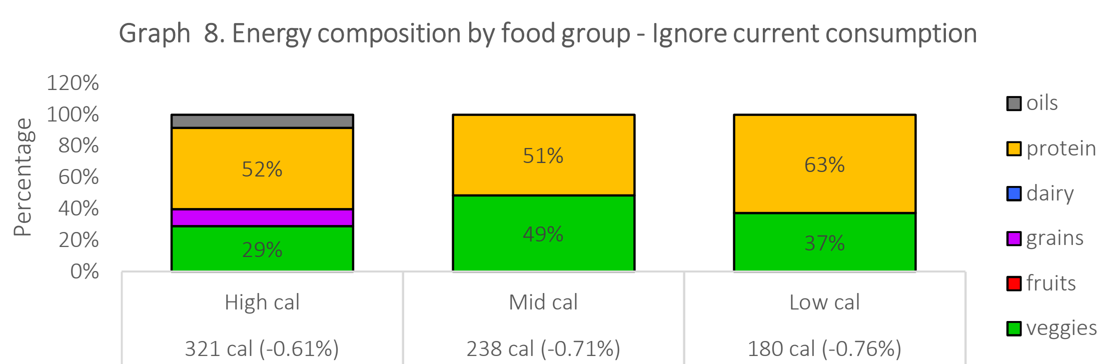
Graph 5. Weight composition by food group



Additionally, we observed that the current consumption pattern determined the distribution across the food groups given that the energy breakdown remained constant across the three scenarios, as evidenced in Graph 7. Moreover, for all the food groups except dairy, this percentage was equal to the upper limit of this pattern (6th decile of the daily energy intake distribution).

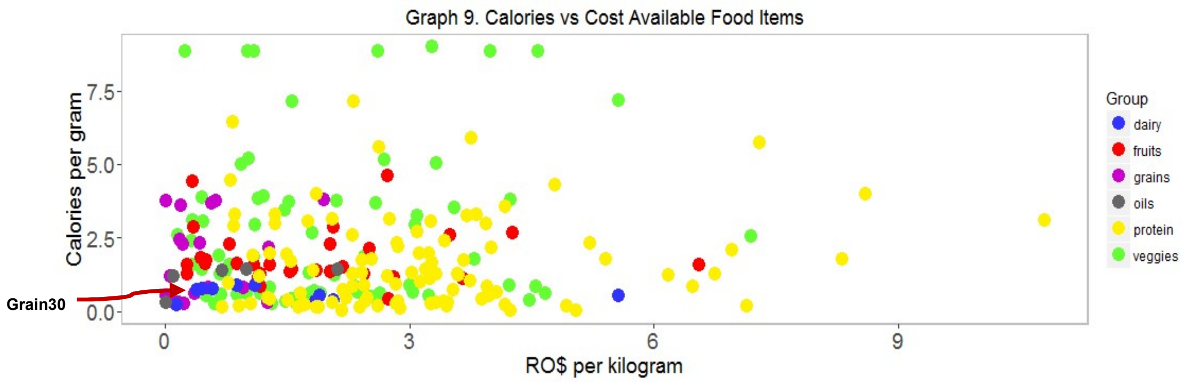
Furthermore, we evaluated the three scenarios without considering the current consumption pattern and we observed that the breakdown now varied across the scenarios (Graph 8), which support the previous thesis. Besides that, we also saw a dramatic shift of the food group composition towards protein and veggies which evidenced these two groups were the most efficient food groups in terms of the tradeoff between nutrition with a low-calorie intake.





5.2.2 Food item selection

Regarding the selection at the level of food items, we observed that *grain30* and *oil5* were selected in the three scenarios and combined, they made up for 60% to 74% of the total grams for the recommended diet (*Appendix 2*) which implied that ensuring their availability it's important to guarantee an efficient nutritional diet for the children. Moreover, as shown in Graph 9, *grain30* doesn't have neither the lower cost or the lower energy value, which evidences that looking only at the cost and calorie contribution of a food item would be wrong for their selection..



5.2.3 Nutritional composition of the optimal diets

As shown in Table 1, the nutrients that barely met the guideline requirements were calcium, zinc, thiamin and riboflavin. This means that under the current constraints, the acquisition of this nutrients is the most challenging one. We also observed that some nutrients might be restrictive under one scenario but not under another, as the case for vitamin c and food folate, which implies that there is not a physical shortage in their supply.

Nutrient	*guideline*	*high*	*mid*	*low*
protein	20.0	26.4	25.8	24.7
calcium	400.0	400.0	400.0	400.0
iron	7.0	13.1	15.0	14.9
zinc	6.5	6.5	6.5	6.5
copper	0.6	0.7	0.8	0.9
vitamin c	20.0	20.0	121.9	57.0
thiamin	0.7	0.7	0.7	0.7
riboflavin	1.1	1.1	1.1	1.1
food folate	50.0	50.0	103.2	62.6
vitamin B12	0.5	2.4	4.6	3.8

Table 1.

6 Insights and Recommendations

6.1 Evaluate different diet compositions to be prepared to handle uncertainty

Given that the macroeconomic variables that determine the budget of a country are difficult to anticipate, a unique dietary plan would not be enough to guarantee that the children's nutritional needs will be covered under every circumstance. Therefore, you need to evaluate different diet options, not only to react to the expected scenario, but to respond to extreme cases as well. On the other hand, we are aware that quite often the decision makers do not have sufficient economic or political power to implement an specific scenario, and for this reason is good to provide them with multiple choices. Having a frontier, as the ones we provided, will allow the decision maker to understand the tradeoff between cost and calories when deciding at which level the nutrition policy needs to be implemented.

6.2 Encourage the appropriate selection of food items

To stop the surge of children mortality and, in addition, to increase the nutritional efficiency per calorie ingested, you should recommend educational activities that promote the consumption of proteins and veggies. Although there is no certainty that the current consumption pattern relies only on the population preferences, the fact that these items are currently available in the Republic of Optimization, but are not being consumed might suggest this is the case. Therefore, improving the children's diet would be possible with the current food supply of the country.

6.3 Challenge the assumptions of the situation to be evaluated

Some restrictions that are imposed in analyzing these recommendations could be reconsidered. For example, we saw that by modifying the assumption about the consumption patterns of the population, the recommendations improved dramatically. Although this pattern might be representative from the population right now, the fact that the nutritional intake for the children improves without it in such a positive way, means that it's worthwhile to explore alternatives to modify the pattern, instead of only plan policies to adapt to it.

Other assumption that can be challenged in this context, is the availability of food items. In the context of this globalized world, importing food might be cheaper than producing it inside the country, and it would increase the exposure of the population to new alternatives.

6.4 Encourage the production of grains and oils

The food items that belong to the grains and oils group are very important under constrained budgets, given that they supply most of the macronutrients required at a very low cost.

7 Next steps

7.1 Characterization of different points from the provided guideline - season scenarios

We can provide you with the characterization at a food item level of all the points you desire on the different efficient frontiers for the guidelines and seasons that were provided.

7.2 Tradeoff between calories and food items diversity on the diet

Considering the three sample scenarios from the WHO-Harvest frontier, the fact that for each of the three scenarios, only between eight and ten items were selected from 237 available items, made us wonder about the value of diversity in a child's diet. Is it better to rely on a limited number of items compared to a large number? Although on each scenario, every food group was included in the diet, this might not be enough if we consider that children might get bored of eating the same items each day.

7.3 Meal optimization model

Considering that our model was limited to individual food items selection instead of meal plan recommendation we may face the fact that these food items cannot constitute a recipe or, the fact that if they are not diverse enough, the children might get tired of consuming the same food items every day. Besides ensuring food item diversity by itself, one potential solution to these problems is to consider a meal plan approximation. One associated benefit of this approach is the inclusion of the consideration of people's preferences which potentialize their willingness to comply with the nutritional guidelines.

7.4 Multi-scenario optimization model

Adjust the model to handle in parallel several guidelines and seasons in order to make it scalable to a higher number of scenarios.

Appendix

Appendix 1. Formulation

Sets

$$i: food\ items\ \ i = 1 \dots 1007$$

$$j: nutrients\ j = 1 \dots 10$$

$$g: group\ of\ food\ items\ g = 1 \dots 6$$

Parameters

$$calories_i: calories\ per\ gram\ of\ food\ item\ i$$

$$comp_{ij}: amount\ of\ nutrient\ j\ per\ gram\ of\ food\ item\ i$$

$$guideline_j: amount\ required\ for\ nutrient\ j\ per\ day\ according\ to\ the\ evaluated\ guideline$$

$$consume_i = 1\ if\ children\ consume\ food\ item\ i, 0\ otherwise$$

$$price_i: RO\$\ per\ kilogram\ of\ item\ i$$

$$group_{ig}: 1\ if\ food\ item\ i\ belongs\ to\ group\ g, 0\ otherwise$$

$$low_g: low\ bound\ for\ calories\ consumption\ for\ group\ g$$

$$high_g: high\ bound\ for\ calories\ consumption\ for\ group\ g$$

$$\alpha: \max cost\ per\ day$$

$$M: big\ number$$

Variables

$$x_i: grams\ of\ food\ item\ i\ a\ child\ should\ eat\ in\ one\ day$$

*Objective (**Minimize**)*

$$cal = \sum_i x_i * calories_i$$

Restrictions

i. Not exceed the maximum cost per day. This restriction allowed us to understand the tradeoff between calories and cost.

$$\sum_i x_i * price_i / 1000 \leq \alpha$$

ii. Meet the minimum requirement for each nutrient based on the guideline requirement (UK or WHO).

$$\sum_i x_i * comp_{ij} \geq guideline_j\ \ \forall j$$

iii. Limit the food choices to what is currently consumed by the broader population (availability).

$$x_i \leq consume_i * M \ \ \forall i$$

iv. Meet the minimum distribution requirement of energy among the food groups based on the current consumption patterns of the population.

$$\sum_i x_i * calories_i * group_{ig} \geq lo\ \ _g \sum_i x_i * calories_i \,\forall g$$

v. Not exceed the maximum distribution requirement of energy among the food groups based on the current consumption patterns of the population.

$$\sum_i x_i * calories_i * group_{ig} \leq high_g \sum_i x_i * calories_i \,\forall g$$

vi. Non-negativity.

$$x_i \geq 0$$

Appendix 2. Grams per item selected in each WHO-Harvest scenario

Item	*Group*	*High*	*Mid*	*Low*	*Times chosen*
veg11	veggies	0.0	6.2	0.0	1
veg13	**veggies**	**8.4**	**9.9**	**14.0**	**3**
veg52	veggies	11.7	0.0	0.0	1
veg116	veggies	3.1	0.0	0.0	1
fruit17	fruits	0.0	16.3	15.7	2
fruit39	fruits	5.8	0.0	0.0	1
grain30	**grains**	**505.4**	**360.5**	**373.0**	**3**
grain47	**grains**	**20.9**	**11.8**	**6.8**	**3**
grain84	grains	0.0	5.4	0.0	1
grain142	grains	0.0	0.0	66.4	1
dairy9	dairy	107.8	0.0	0.0	1
dairy23	dairy	0.0	3.7	121.0	2
dairy35	dairy	49.5	287.7	0.0	2
protein83	protein	0.0	0.0	55.3	1
protein203	protein	8.3	0.0	0.0	1
protein229	protein	1.4	0.0	0.0	1
protein268	protein	0.0	26.4	18.2	2
oil5	**oils**	**111.9**	**82.4**	**79.5**	**3**