Linear Optimization modelling for sustainable diets among Ghanaian migrants

(Practical Example)

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What is a sustainable healthy diet?

- Definition by FAO and WHO: Sustainable healthy diets are dietary patterns that:
- promote all dimensions of individuals' health and wellbeing (nutritional adequacy);
- have low environmental pressure and impact;
- are accessible, affordable, safe and equitable; and
- are culturally acceptable.

How does a sustainable healthy diet look like?

- Defining healthy and sustainable food patterns is complex.
- What should be taken into account?
- Should be based on a systematic investigation and sound data on each dimension.
- Dependent on the availability and accuracy of data on food characteristics.

Approaches towards more sustainable diets

1. Evaluate the sustainability characteristics of hypothetical diets.

- Starts with a theoretical diet (e.g., EAT-Lancet diet) and compares it with current diet or recommendations

- **Advantages:**
- No need for individual food consumption data

- **Limitations:**

- No consideration of cultural acceptability
- Diet designed based on predetermined assumptions –does not ensure improvement in sustainability dimensions, verified a posterior
- No consideration of other diets that could be more sustainable

Approaches towards more sustainable diets

2. Evaluate the sustainability characteristics of existing diets.

- Looks at the variability of impacts of self-selected diets and classifies individuals into groups based on different levels of nutritional quality or environmental impact.

- **Advantages:**
- Better consideration of cultural acceptability
- Better understanding of trade-offs between sustainability dimensions

- **Limitations:**

- Requires food consumption data at the individual level
- Improvement of one sustainability dimension does not ensure improvement of others

Approaches towards more sustainable diets

3. Identify existing positive deviants (multi-criteria approach)

- Selects individuals whose diet combines several positive characteristics (e.g., in terms of environmental impact and nutritional quality) and compare their diet to the general population's diet.

- **Advantages:**
- Greater consideration of cultural acceptability, as these diets are actually consumed

- **Limitations:**

- Magnitude of improvements might be small and might not be perfectly adequate
- Improvement in one characteristic (e.g., GHGE) does not ensure improvement in others (e.g., water consumption)

Approaches towards more sustainable diets

4. Design more sustainable diets with constrained optimization (multi-criteria approach)

- A mathematical technique that finds the optimal combination of decision variables (i.e., foods available) for a population, a subpopulation, or an individual that fulfils a set of constraints (e.g., nutritional requirements), while minimizing or maximizing an objective function (e.g., total deviation from observed diet, total GHG)

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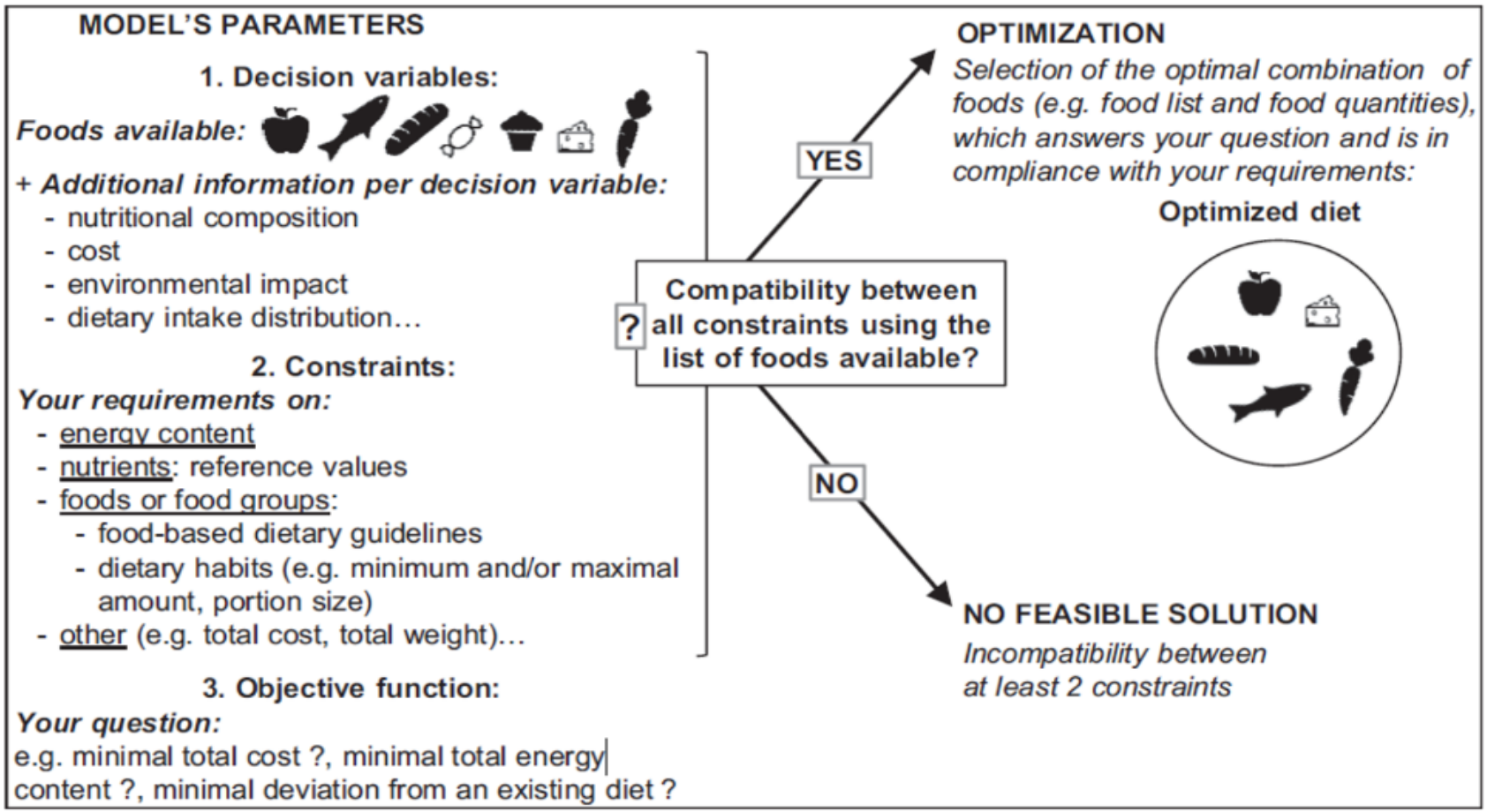
What is diet optimization?



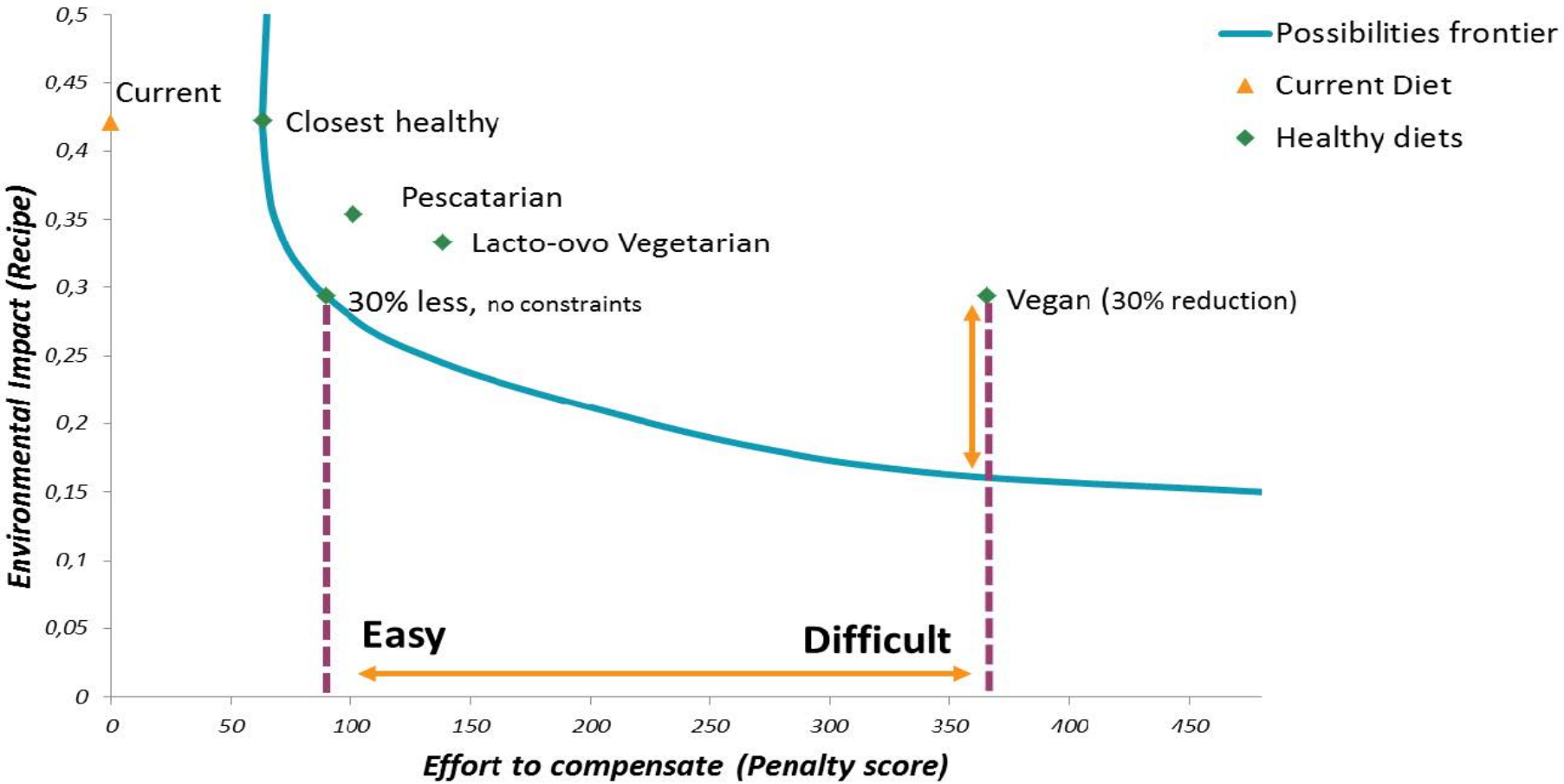
Source: Gazan et al. (2018)

Advantages and Limitations for Diet Optimization

- **Advantages:**
  1. Simultaneous application of constraints to ensure nutritional adequacy and other aspects of sustainability
  2. Allows integration of bioavailability of nutrients and coproduction links with sophisticated models
  3. Help identify trade-offs by studying constraints that are difficult to fulfil or incompatible with other constraints

- **Limitations:**
  1. Can lead to no or unrealistic solution when constraints are too severe or incompatible
  2. Difficult to include cultural acceptability (proxy: deviation from current diet)
  3. Sensitive to starting a diet, or menu items
  4. Data intensive
  5. Difficult to interpret and explain changes

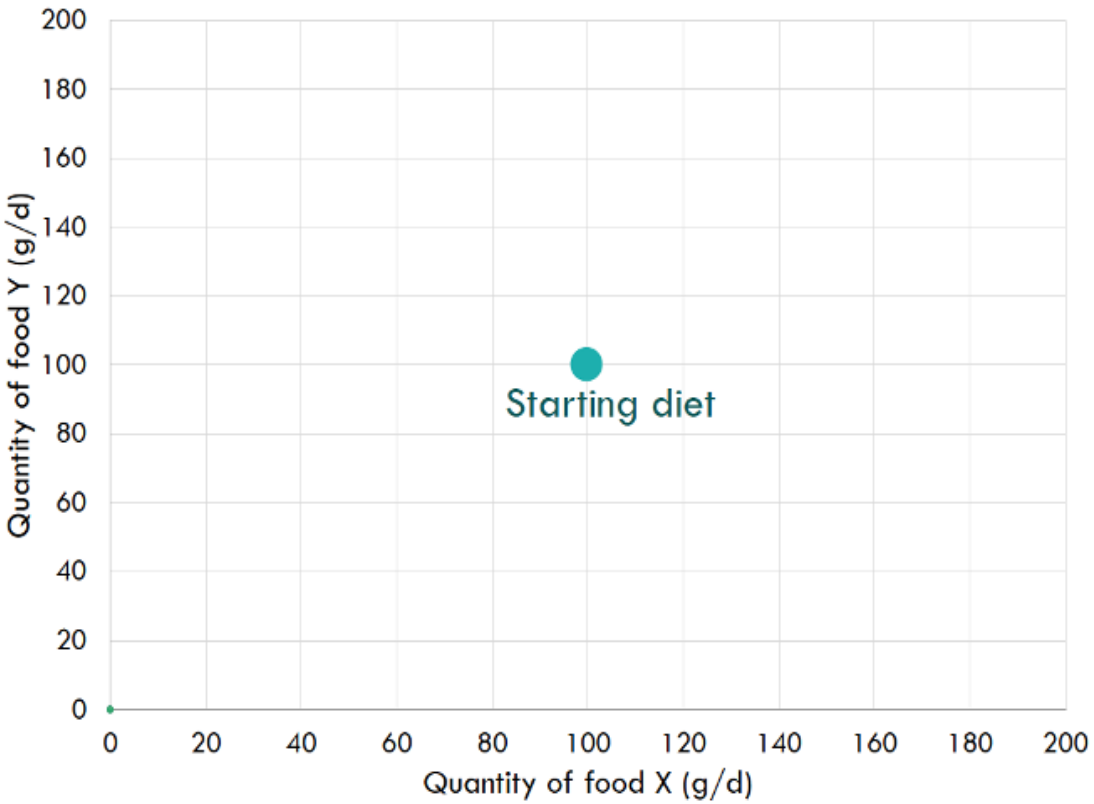
How Optimization works



Source: Blonk Sustainability Tools (2022)

How to find an optimized diet?

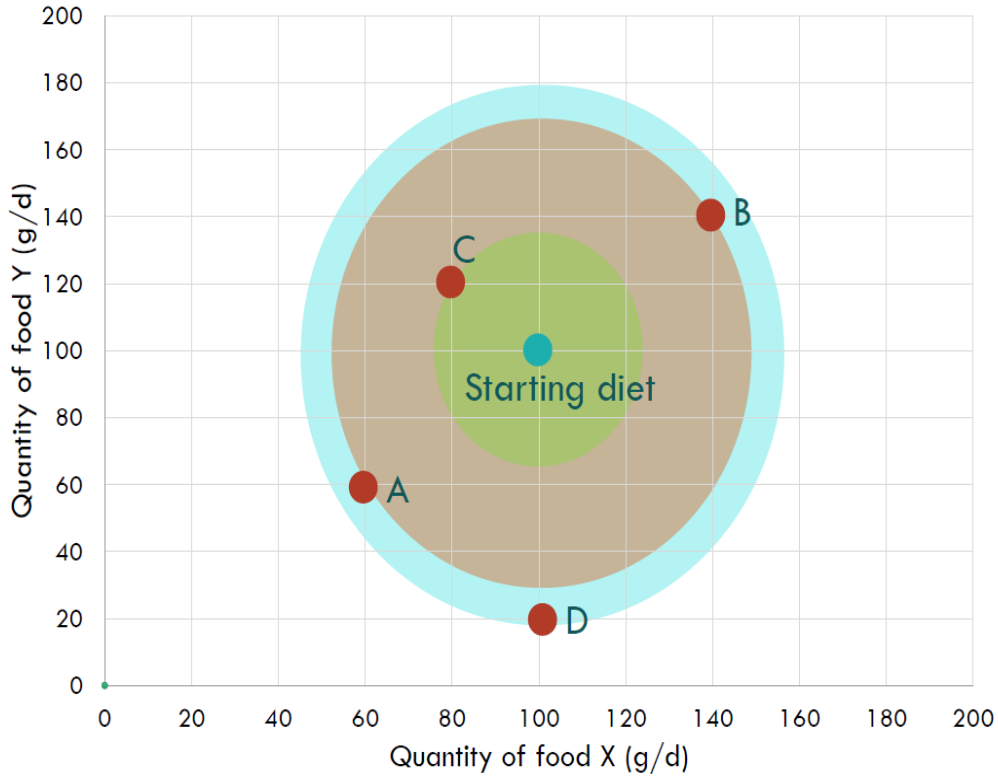
A (starting) diet is just a description of amounts per day of each food: for example100 grams of X, 100 grams of Y



Source: Blonk Sustainability Tools (2022)

How to find an optimized diet?

We can measure the similarity (distance) between diets by drawing circles where a diet is the center



Diet	X	Y	Distance
Starting diet	100	100	
A	60	60	Orange
B	140	140	Orange
C	80	120	Green
D	100	20	Blue

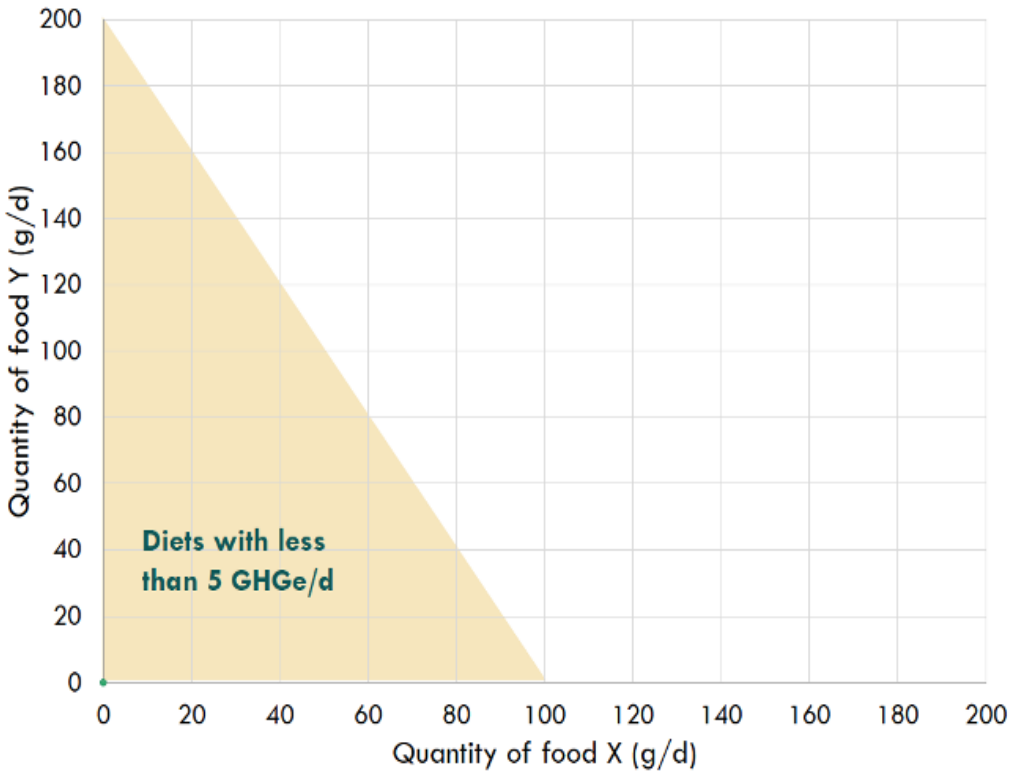
Green < Orange < Blue:

Diet C is the most similar to the starting diet
Diets A and B are equally similar
Diet D is the most different

Source: Blonk Sustainability Tools (2022)

How to find an optimized diet?

To choose we need to know which diets satisfy the nutritional and **environmental** requirements



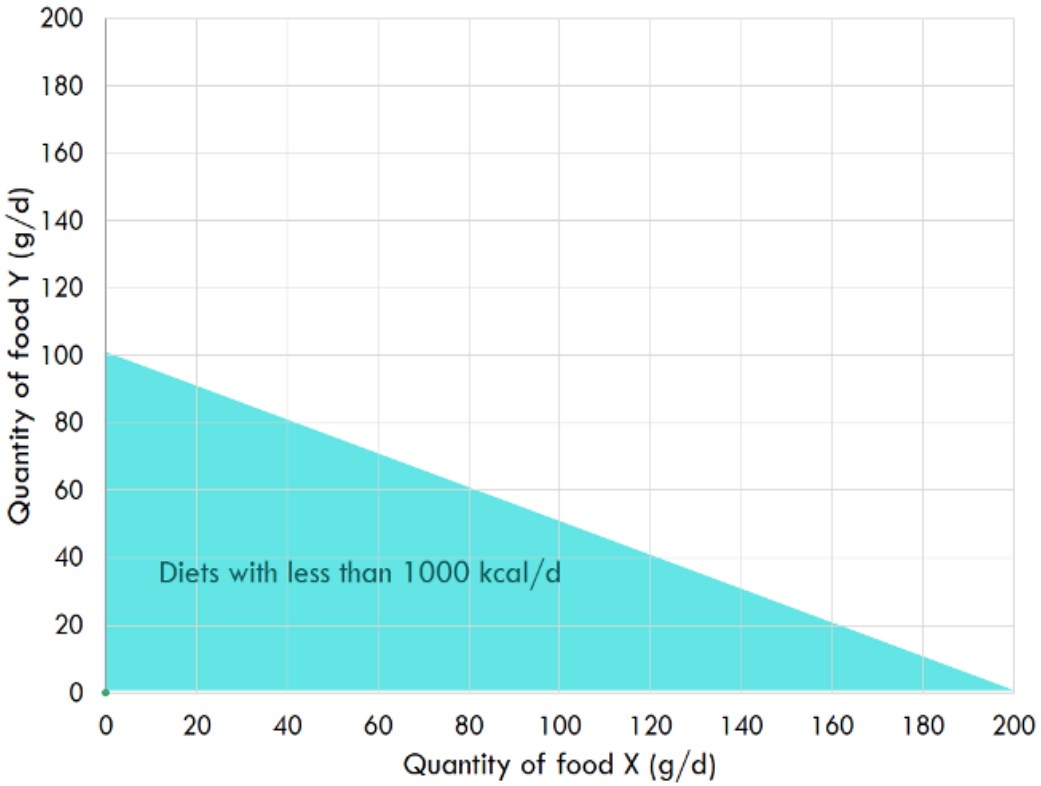
Property/g	X	Y
Calories	5	10
GHGe	**0.050**	**0.025**

Requirements	Min	Max
Calories	500	1000
GHGe	**0**	**5**

Source: Blonk Sustainability Tools (2022)

How to find an optimized diet?

To choose we need to know which diets satisfy the **nutritional** and environmental requirements



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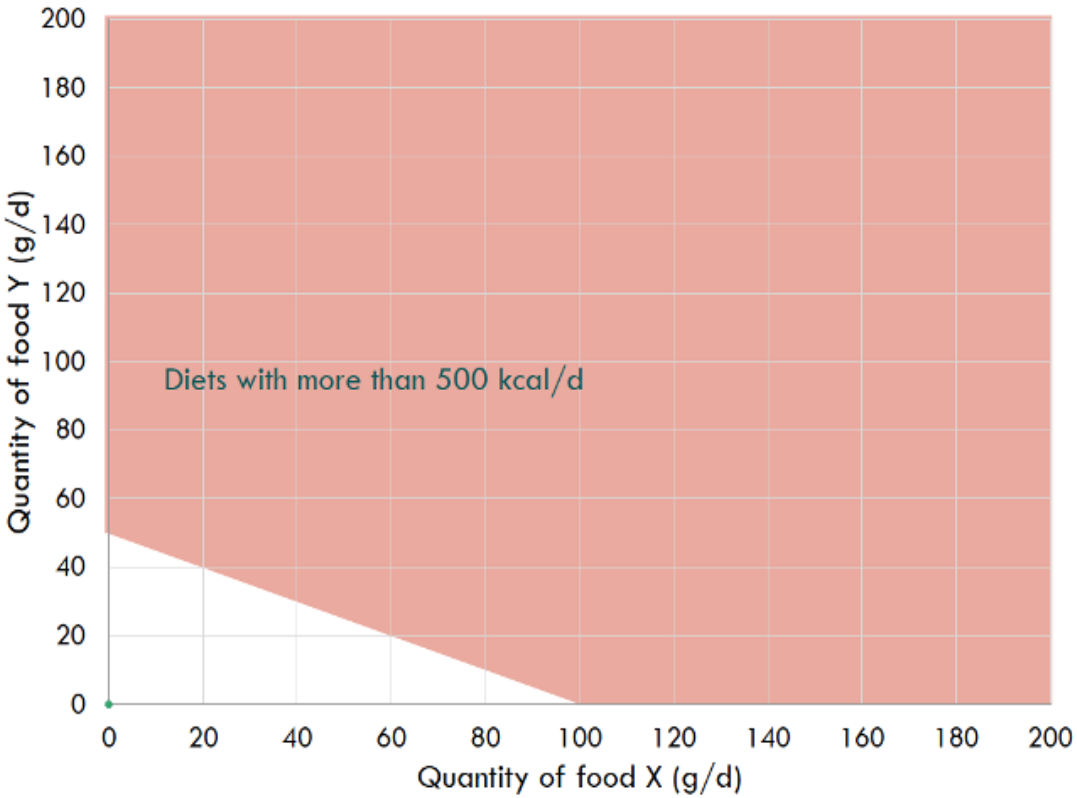

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How to find an optimized diet?

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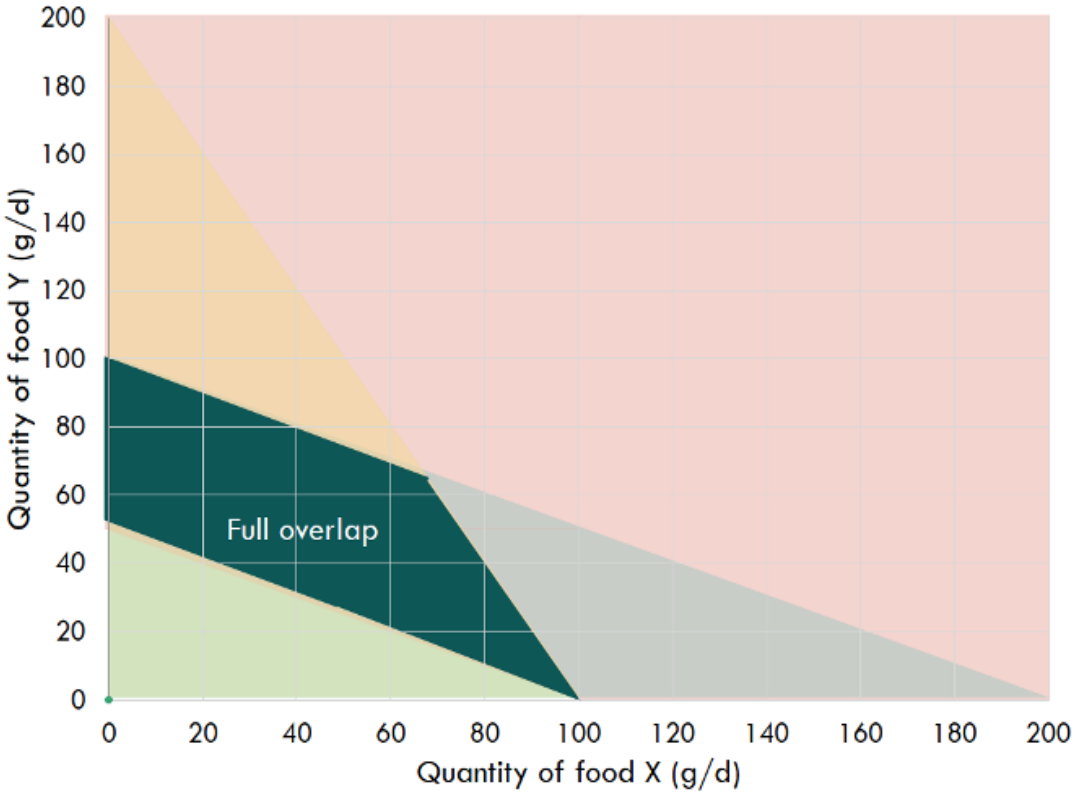

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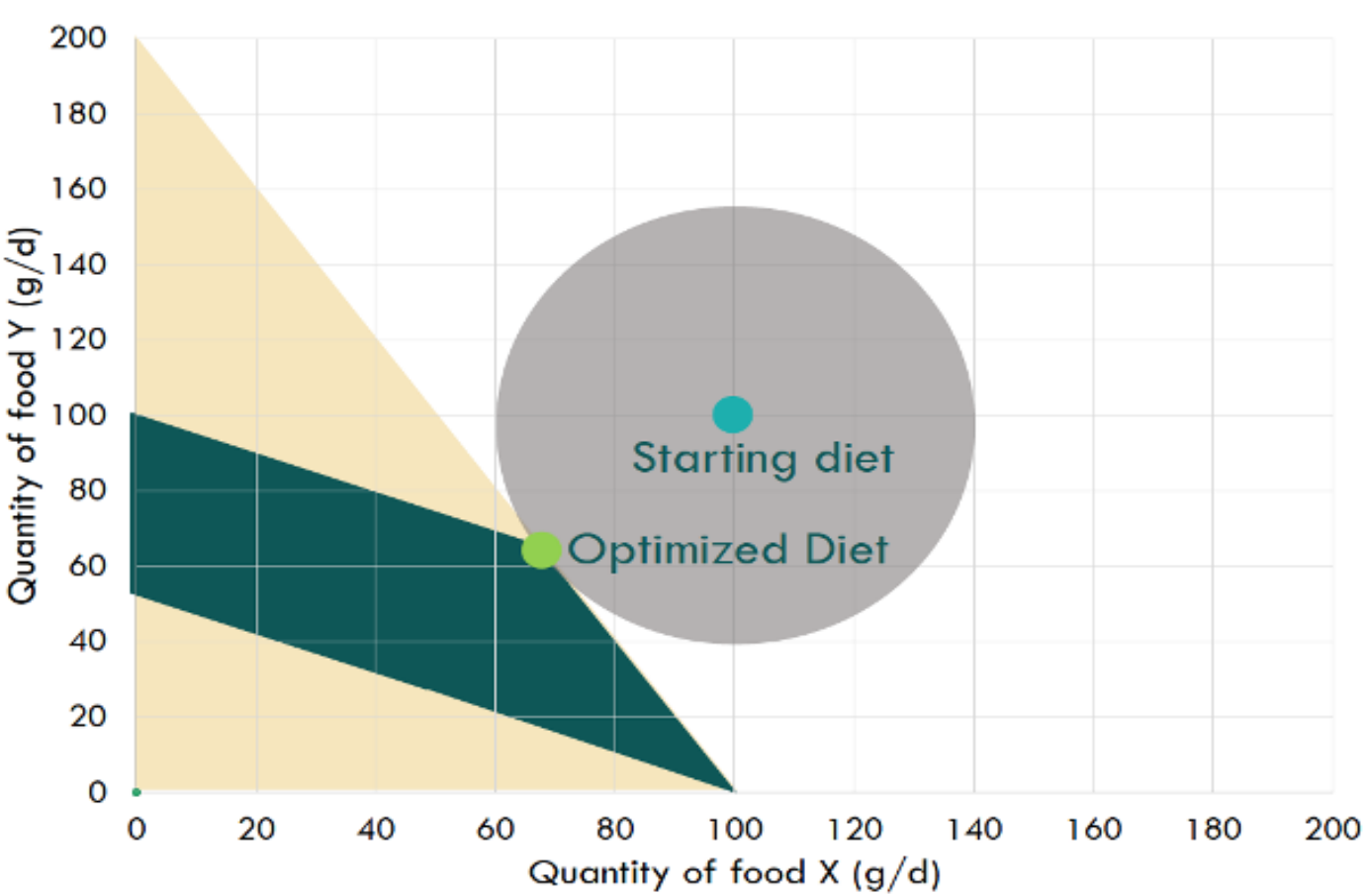
Requirements	Min	Max
Calories	500	1000
GHGe	0	5

Source: Blonk Sustainability Tools (2022)

How to find an optimized diet?

The optimized diet (green dot) is the most similar to the starting diet (blue dot) which fulfils all requirements.



Source: Blonk Sustainability Tools (2022)

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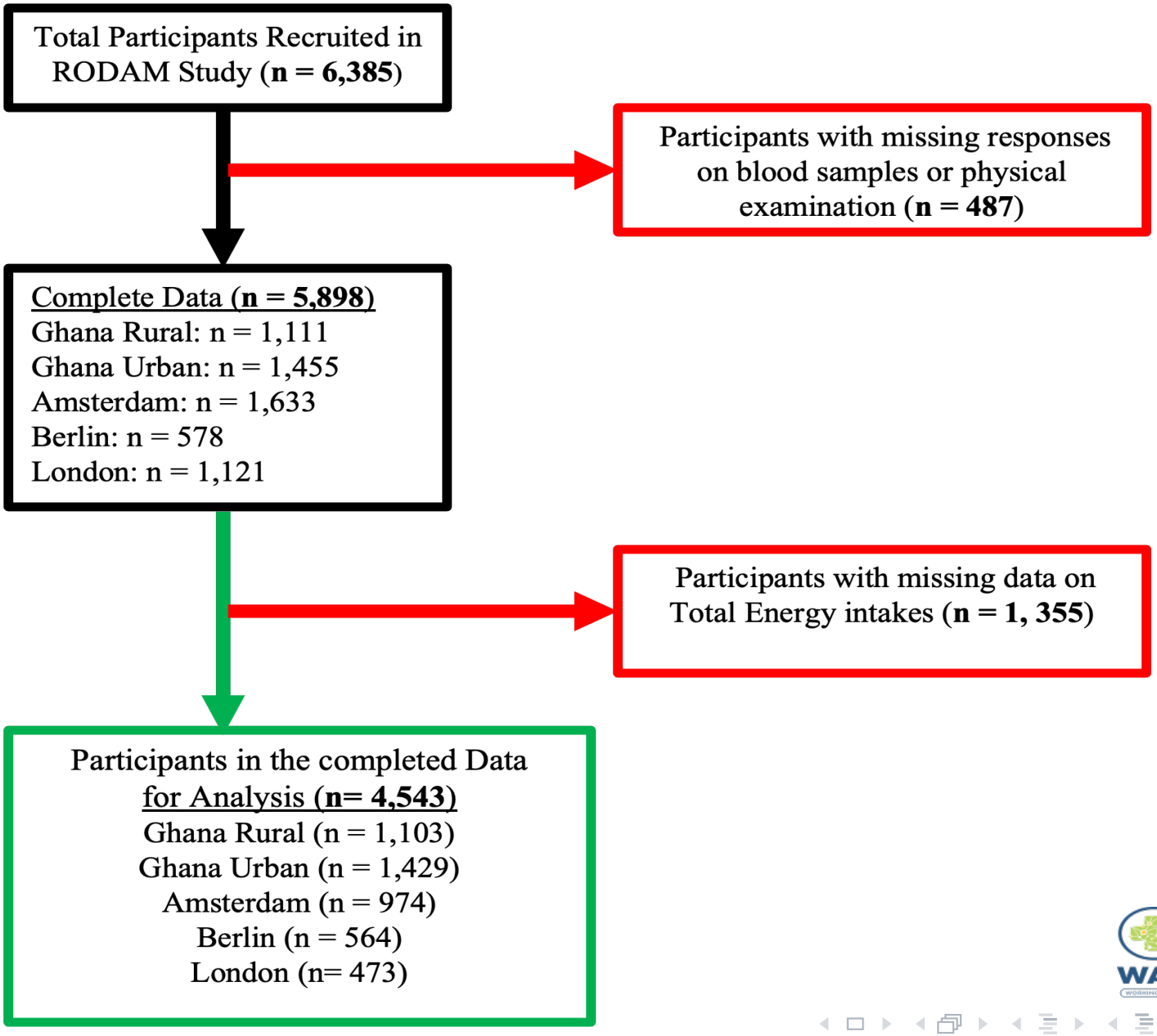
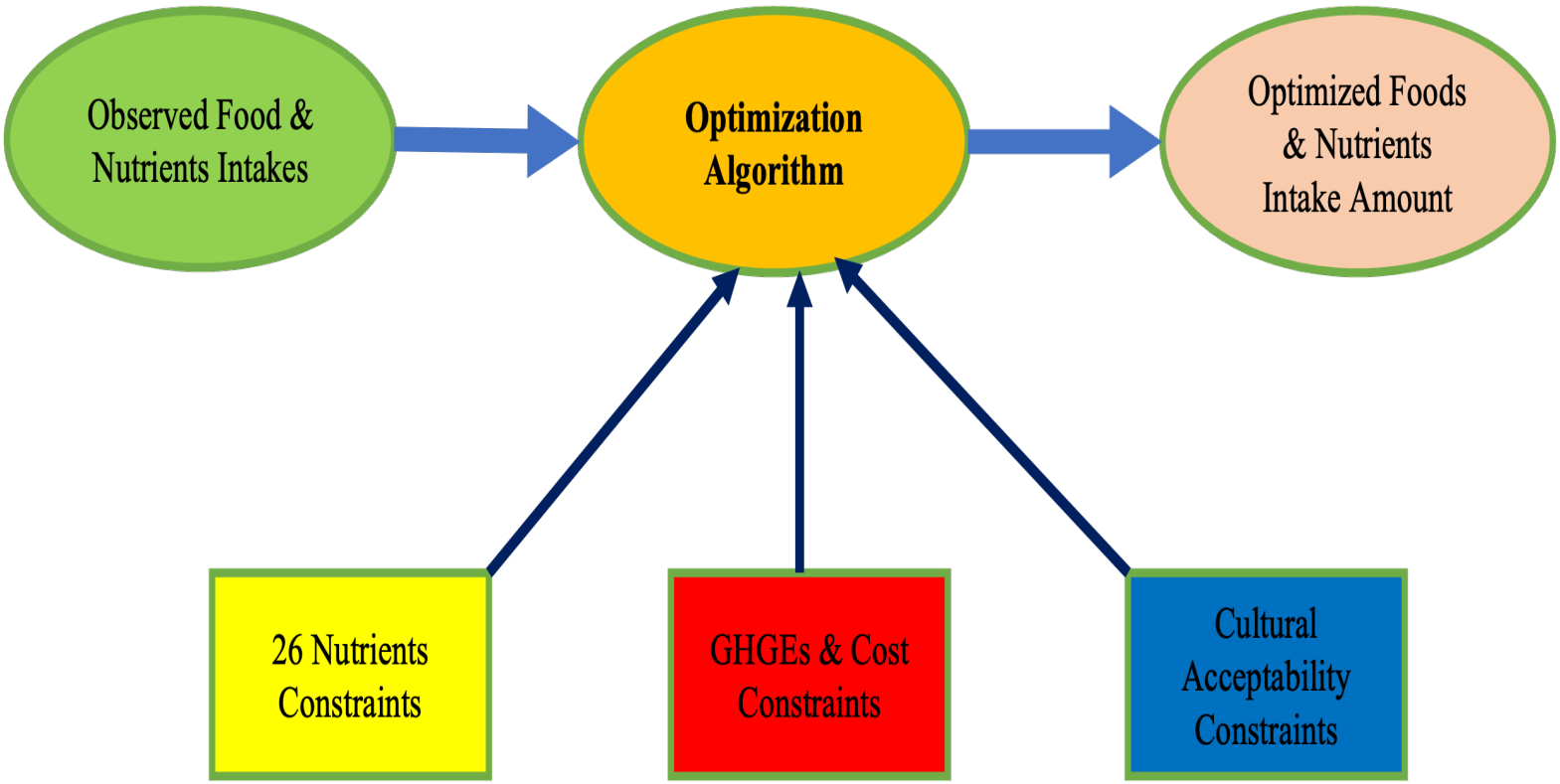
Optimization of sustainable diets for Ghanaian migrants

- The study seeks to identify the optimal combination of food groups and intake frequencies to achieve nutritious, climate-friendly, culturally appropriate, and affordable dietary patterns for Ghanaian adults living in rural Ghana, urban Ghana, and three European cities.
- Specific Objectives:
  1. Identifying optimal nutritious dietary patterns for the five study sites without any constraints on the GHG emissions and costs, that are culturally acceptable.
  2. Identifying optimal nutritious and climate-friendly (GHG-emissions) dietary patterns that are culturally acceptable for the five study sites without cost constraints.
  3. Identifying optimal nutritious dietary patterns, when considering climate-friendly, and costs (affordability) as constraints for the five study sites, that are culturally acceptable.

Study Population



Optimization Model



Flowchart for Optimization Algorithm of the consumed diets.

Results

Table 1a: Dietary patterns of the nutrients and cultural acceptability constraints for Ghana urban males (413 adults)

	Weight (g)			Energy (kcal)			GHGEs (kg CO_2eq)			Costs (GH Cedis)		
Food Group	Average	Optimized	Difference	Average	Optimized	Difference	Average	Optimized	Difference	Average	Optimized	Difference
Alcoholic Beverages	19.3	0.0	-19.3	6.8	0.0	-6.8	0.024	0.000	-0.024	0.106	0.000	-0.106
Cakes and Sweets	12.8	6.5	-6.3	64.8	32.7	-32.1	0.054	0.027	-0.027	0.063	0.032	-0.031
Coffee Tea	100.0	25.0	-75.0	386	96.5	-289.5	0.044	0.011	-0.033	0.040	0.010	-0.030
Condiments	64.8	30.4	-34.4	209	98.2	-110.8	0.259	0.122	-0.137	0.324	0.152	-0.172
Dairy Products	42.1	41.4	-0.7	28.9	28.4	-0.5	0.719	0.707	-0.012	0.126	0.124	-0.002
Eggs	5.0	3.9	-1.1	7.74	6.0	-1.7	0.022	0.017	-0.005	0.035	0.027	-0.008
Fermented Maize Products	120.0	103.0	-17.0	414	354.0	-60.0	0.126	0.108	-0.018	0.540	0.462	-0.078
Fish and Seafoods	83.7	69.3	-14.4	105	87.2	-17.8	0.321	0.266	-0.055	0.912	0.756	-0.156
Fruits	130.0	127.0	-3.0	155	151.0	-4.0	0.117	0.114	-0.003	0.260	0.254	-0.006
Legumes	69.3	57.0	-12.3	232	191.0	-41.0	0.069	0.057	-0.012	0.236	0.194	-0.042
Margarine	2.6	0.4	-2.1	18.8	3.2	-15.6	0.006	0.001	-0.005	0.009	0.002	-0.007
Meat mixed dishes	64.3	26.3	-38.0	84.9	34.7	-50.2	0.518	0.211	-0.307	0.913	0.373	-0.540
Nuts and Seeds	4.7	1.3	-3.3	16.8	4.8	-12.0	0.013	0.004	-0.009	0.030	0.009	-0.021
Olive Oil	1.2	1.5	0.3	10.7	13.6	2.9	0.003	0.003	0.001	0.013	0.017	0.004
Other Oils	4.0	4.3	0.3	35.9	38.9	3.0	0.009	0.010	0.001	0.040	0.043	0.003
Palm Oil	1.5	1.8	0.3	13.2	16.3	3.1	0.002	0.002	0.000	0.006	0.007	0.001
Potatoes	16.7	13.6	-3.1	19.2	15.7	-3.5	0.006	0.005	-0.001	0.050	0.041	-0.009
Poultry	12.5	5.0	-7.5	22.4	9.0	-13.5	0.074	0.030	-0.044	0.136	0.055	-0.082
Processed Meat	11.7	1.2	-10.5	32.9	3.4	-29.5	0.148	0.015	-0.133	0.166	0.017	-0.149
Red Meat	47.9	16.9	-31.0	139	49.1	-89.9	1.060	0.376	-0.684	0.838	0.296	-0.542
Rice & Pasta	182.0	170.0	-12.0	647	602.0	-45.0	0.240	0.223	-0.017	0.601	0.560	-0.041
Soft Drinks & Juices	55.0	41.5	-13.5	32.3	24.4	-7.9	0.060	0.045	-0.015	0.033	0.025	-0.008
Starchy Roots, Tubers & Plantain	169.0	165.0	-4.0	389	378.0	-11.0	0.090	0.088	-0.003	0.288	0.280	-0.008
Sweet Spread	1.3	0.1	-1.1	7.42	0.8	-6.6	0.003	0.000	-0.003	0.034	0.004	-0.031
Vegetable Soup, Stews and Sauces	304.0	300.0	-4.0	149	147.0	-2.0	1.130	1.120	-0.010	1.970	1.950	-0.020
Vegetables	268.0	263.0	-5.0	149	146.0	-3.0	0.143	0.140	-0.003	1.740	1.710	-0.030
Vegetarian mixed dishes	28.4	25.6	-2.8	37.1	33.4	-3.7	0.040	0.036	-0.004	0.185	0.166	-0.019
White Bread and Cereals	100.0	69.0	-31.0	253	175.0	-78.0	0.090	0.062	-0.028	0.700	0.483	-0.217
Whole Grain Bread Cereals	7.1	0.7	-6.4	17.7	1.8	-15.92	0.005	0.001	-0.005	0.050	0.005	-0.045
Total	1928.8	1570.9	-18.6%	3684.6	2742.0	-25.6%	5.39	3.80	-29.55%	10.44	8.05	-22.90%

Results

Table 1b: Dietary patterns of the nutrients and cultural acceptability constraints for Ghana urban females (1016 adults)

	Weight (g)			Energy (kcal)			GHGEs (kg CO_2eq)			Costs (GH Cedis)		
Product Group	Average	Optimized	Difference	Average	Optimized	Difference	Average	Optimized	Difference	Average	Optimized	Difference
Alcoholic Beverages	2.7	0.0	-2.67	0.9	0.0	-0.94	0.003	0.000	-0.003	0.015	0.000	-0.015
Cakes and Sweets	14.5	6.7	-7.83	73.2	33.7	-39.5	0.061	0.028	-0.033	0.071	0.033	-0.038
Coffee Tea	100.0	35.0	-65	386.0	135.0	-251	0.044	0.015	-0.029	0.043	0.015	-0.028
Condiments	60.7	28.5	-32.2	196.0	92.2	-103.8	0.243	0.114	-0.129	0.303	0.143	-0.160
Dairy Products	30.0	17.4	-12.6	20.6	11.9	-8.7	0.512	0.297	-0.215	0.091	0.053	-0.038
Eggs	12.9	2.0	-10.9	19.9	3.1	-16.8	0.057	0.009	-0.048	0.089	0.014	-0.075
Fermented Maize Products	120.0	83.3	-36.7	414.0	288.0	-126	0.126	0.088	-0.039	0.542	0.377	-0.165
Fish and Seafoods	87.0	65.0	-22	109.0	81.7	-27.3	0.334	0.249	-0.085	0.949	0.708	-0.241
Fruits	120.0	91.3	-28.7	143.0	109.0	-34	0.108	0.082	-0.026	0.236	0.179	-0.057
Legumes	44.2	15.0	-29.2	148.0	50.3	-97.7	0.044	0.015	-0.029	0.150	0.051	-0.099
Margarine	4.5	11.4	6.9	32.9	83.2	50.3	0.010	0.025	0.015	0.015	0.039	0.024
Meat mixed dishes	64.3	10.0	-54.3	84.9	13.2	-71.7	0.518	0.081	-0.438	0.913	0.142	-0.771
Nuts and Seeds	4.7	1.3	-3.34	16.8	4.8	-12	0.013	0.004	-0.009	0.030	0.008	-0.021
Olive Oil	0.2	2.0	1.8	1.8	17.7	15.93	0.000	0.004	0.004	0.002	0.021	0.019
Other Oils	3.8	14.2	10.4	34.2	128.0	93.8	0.008	0.031	0.023	0.023	0.085	0.063
Palm Oil	1.5	10.0	8.53	13.1	89.9	76.8	0.002	0.013	0.011	0.006	0.041	0.035
Potatoes	13.3	1.3	-12	15.3	1.5	-13.8	0.004	0.000	-0.004	0.040	0.004	-0.036
Poultry	10.0	5.0	-5	17.9	9.0	-8.95	0.059	0.030	-0.030	0.109	0.055	-0.054
Processed Meat	11.7	0.2	-11.5	32.9	0.6	-32.336	0.148	0.003	-0.145	0.166	0.003	-0.163
Red Meat	26.7	10.0	-16.7	77.3	29.0	-48.3	0.593	0.222	-0.371	0.467	0.175	-0.292
Rice & Pasta	163.0	126.0	-37	577.0	447.0	-130	0.214	0.166	-0.048	0.533	0.413	-0.120
Soft Drinks & Juices	33.8	18.1	-15.7	19.8	10.6	-9.2	0.037	0.020	-0.017	0.021	0.011	-0.010
Starchy Roots, Tubers & Plantain	169.0	124.0	-45	389.0	285.0	-104	0.090	0.066	-0.024	0.290	0.212	-0.078
Sweet Spread	0.5	0.1	-0.45	3.0	0.3	-2.673	0.001	0.000	-0.001	0.014	0.001	-0.012
Vegetable Soup, Stews and Sauces	307.0	236.0	-71	150.0	116.0	-34	1.140	0.880	-0.260	2.010	1.540	-0.470
Vegetables	281.0	162.0	-119	156.0	89.7	-66.3	0.150	0.086	-0.064	1.840	1.060	-0.780
Vegetarian mixed dishes	42.9	21.4	-21.5	55.9	27.9	-28	0.060	0.030	-0.030	0.281	0.140	-0.141
White Bread and Cereals	92.5	55.5	-37	234.0	140.0	-94	0.083	0.050	-0.033	0.647	0.388	-0.259
Whole Grain Bread Cereals	8.6	0.8	-7.82	21.3	2.0	-19.32	0.006	0.001	-0.006	0.060	0.006	-0.055
Total	1830.9	1153.4	-37.0%	3443.7	2300.2	-33.2%	4.67	2.61	-44.15%	9.96	5.92	-40.57%

Results

Table 2a: Dietary patterns of the nutrients and cultural acceptability constraints for Ghana rural males (431 adults)

	Weight (g)			Energy (kcal)			GHGEs (kg CO_2eq)			Costs (GH Cedis)		
Product Group	Average	Optimized	Difference	Average	Optimized	Difference	Average	Optimized	Difference	Average	Optimized	Difference
Alcoholic Beverages	8.3	7.3	-1.0	2.9	2.6	-0.4	0.010	0.009	-0.001	0.046	0.040	-0.006
Cakes and Sweets	8.8	8.3	-0.6	44.6	41.7	-2.9	0.034	0.032	-0.002	0.043	0.040	-0.003
Coffee Tea	100.0	51.5	-48.5	386.0	199.0	-187.0	0.048	0.025	-0.023	0.043	0.022	-0.021
Condiments	45.0	23.3	-21.7	146.0	75.1	-70.9	0.140	0.072	-0.068	0.225	0.116	-0.109
Cooking Fats	0.5	0.0	-0.5	2.0	0.0	-1.9	0.001	0.000	-0.001	0.003	0.000	-0.003
Dairy Products	15.0	14.4	-0.6	10.3	9.9	-0.4	0.249	0.239	-0.010	0.046	0.044	-0.002
Eggs	12.9	9.1	-3.8	19.9	14.0	-5.9	0.050	0.035	-0.015	0.089	0.063	-0.026
Fermented Maize Products	200.0	196.0	-4.0	690.0	675.0	-15.0	0.215	0.210	-0.005	0.904	0.885	-0.019
Fish and Seafoods	59.5	54.8	-4.7	74.9	68.9	-6.0	0.212	0.195	-0.017	0.649	0.597	-0.052
Fruits	224.0	222.0	-2.0	267.0	264.0	-3.0	0.146	0.144	-0.002	0.440	0.435	-0.005
Legumes	74.3	39.2	-35.1	249.0	132.0	-117.0	0.072	0.038	-0.034	0.252	0.133	-0.119
Margarine	3.4	3.4	0.0	25.0	25.1	0.1	0.006	0.006	0.000	0.012	0.012	0.000
Meat mixed dishes	64.3	12.6	-51.7	84.9	16.6	-68.3	0.530	0.104	-0.426	0.913	0.178	-0.735
Nuts and Seeds	2.7	0.3	-2.4	9.6	0.9	-8.7	0.006	0.001	-0.005	0.017	0.002	-0.015
Olive Oil	0.0	2.5	2.5	0.0	21.8	21.8	0.000	0.004	0.004	0.000	0.026	0.026
Other Oils	2.3	4.8	2.5	20.7	42.9	22.2	0.004	0.008	0.004	0.014	0.029	0.015
Palm Oil	2.2	4.6	-3.9	19.4	41.7	22.3	0.002	0.005	0.002	0.009	0.019	0.010
Potatoes	14.9	11.0	-27.1	17.1	12.6	-4.5	0.006	0.004	-0.002	0.045	0.033	-0.012
Poultry	32.1	5.0	-4.0	57.5	9.0	-48.6	0.167	0.026	-0.141	0.351	0.055	-0.296
Processed Meat	5.0	1.0	-16.5	14.1	2.8	-11.3	0.062	0.012	-0.050	0.071	0.014	-0.057
Red Meat	31.7	15.2	-6.0	91.8	44.1	-47.7	0.694	0.334	-0.360	0.554	0.266	-0.288
Rice & Pasta	150.0	144.0	-1.5	533.0	510.0	-23.0	0.217	0.208	-0.009	0.492	0.472	-0.020
Soft Drinks & Juices	23.3	21.8	-4.0	13.7	12.8	-0.9	0.020	0.018	-0.001	0.015	0.014	-0.001
Starchy Roots, Tubers & Plantain	339.0	335.0	-0.5	780.0	771.0	-9.0	0.136	0.134	-0.002	0.580	0.574	-0.006
Sweet Spread	0.5	0.0	-5.0	3.0	0.1	-2.9	0.001	0.000	-0.001	0.014	0.000	-0.013
Vegetable Soup, Stews and Sauces	336.0	331.0	-8.0	165.0	162.0	-3.0	1.260	1.240	-0.020	2.200	2.170	-0.030
Vegetables	241.0	233.0	-6.9	133.0	129.0	-4.0	0.096	0.093	-0.003	1.570	1.520	-0.050
Vegetarian mixed dishes	21.4	14.5	-0.1	28.0	19.0	-9.0	0.031	0.021	-0.010	0.140	0.095	-0.045
White Bread and Cereals	98.6	98.5	-2.2	250.0	249.0	-1.0	0.089	0.089	0.000	0.690	0.689	-0.001
Whole Grain Bread Cereals	6.7	4.5	-2.2	16.5	11.2	-5.3	0.005	0.003	-0.002	0.047	0.032	-0.015
Total	2123.4	1868.5	-12.0%	4154.9	3563.8	-14.2%	4.51	3.31	-26.61%	10.47	8.57	-18.12%

Results

Table 2b: Dietary patterns of the nutrients and cultural acceptability constraints Ghana rural females (672 adults)

	Weight (g)			Energy (kcal)			GHGEs (kg CO_2eq)			Costs (GH Cedis)		
Product Group	Average	Optimized	Difference	Average	Optimized	Difference	Average	Optimized	Difference	Average	Optimized	Difference
Alcoholic Beverages	6.0	4.9	-1.1	2.1	1.7	-0.4	0.007	0.006	-0.001	0.033	0.027	-0.006
Cakes and Sweets	10.5	10.1	-0.4	53.0	51.1	-1.9	0.041	0.039	-0.001	0.051	0.049	-0.002
Coffee Tea	100.0	42.4	-57.6	386.0	164.0	-222.0	0.048	0.020	-0.028	0.043	0.018	-0.025
Condiments	39.9	20.7	-19.2	129.0	66.8	-62.2	0.124	0.064	-0.060	0.199	0.103	-0.096
Cooking Fats	0.5	0.0	-0.5	1.7	0.0	-1.7	0.001	0.000	-0.001	0.002	0.000	-0.002
Dairy Products	15.0	14.5	-0.5	10.3	10.0	-0.4	0.249	0.240	-0.009	0.046	0.044	-0.002
Eggs	6.0	2.7	-3.3	9.3	4.2	-5.1	0.023	0.011	-0.013	0.042	0.019	-0.023
Fermented Maize Products	163.0	159.0	-4.0	563.0	548.0	-15.0	0.176	0.171	-0.005	0.738	0.718	-0.020
Fish and Seafoods	64.3	58.8	-5.5	80.9	74.0	-6.9	0.229	0.210	-0.019	0.701	0.641	-0.060
Fruits	199.0	197.0	-2.0	237.0	234.0	-3.0	0.130	0.128	-0.002	0.392	0.387	-0.005
Legumes	64.3	32.4	-31.9	216.0	109.0	-107.0	0.063	0.032	-0.031	0.218	0.110	-0.108
Margarine	3.4	4.4	0.9	25.0	31.8	6.8	0.006	0.007	0.002	0.012	0.015	0.003
Meat mixed dishes	64.3	11.1	-53.2	84.9	14.6	-70.3	0.530	0.092	-0.439	0.913	0.158	-0.755
Nuts and Seeds	3.3	0.3	-3.0	12.0	1.1	-10.9	0.007	0.001	-0.007	0.021	0.002	-0.019
Olive Oil	0.0	1.0	1.0	0.0	8.8	8.8	0.000	0.002	0.002	0.000	0.011	0.011
Other Oils	2.3	5.9	3.6	20.7	53.2	32.5	0.004	0.010	0.006	0.014	0.036	0.022
Palm Oil	2.1	5.7	3.6	18.7	51.2	32.5	0.002	0.006	0.004	0.009	0.024	0.015
Potatoes	14.3	10.6	-3.7	16.4	12.2	-4.2	0.006	0.004	-0.001	0.043	0.032	-0.011
Poultry	32.1	5.0	-27.1	57.5	9.0	-48.6	0.167	0.026	-0.141	0.351	0.055	-0.296
Processed Meat	6.2	0.6	-5.6	17.5	1.7	-15.8	0.077	0.007	-0.069	0.088	0.009	-0.080
Red Meat	21.7	6.0	-15.7	62.8	17.4	-45.4	0.475	0.132	-0.343	0.379	0.105	-0.274
Rice & Pasta	150.0	143.0	-7.0	533.0	508.0	-25.0	0.217	0.208	-0.009	0.492	0.470	-0.022
Soft Drinks & Juices	23.3	21.7	-1.6	13.7	12.7	-1.0	0.020	0.018	-0.001	0.015	0.014	-0.001
Starchy Roots, Tubers & Plantain	312.0	308.0	-4.0	717.0	708.0	-9.0	0.125	0.123	-0.002	0.534	0.527	-0.007
Sweet Spread	0.5	0.1	-0.5	3.0	0.3	-2.7	0.001	0.000	-0.001	0.014	0.001	-0.012
Vegetable Soup, Stews and Sauces	347.0	342.0	-5.0	170.0	168.0	-2.0	1.300	1.280	-0.020	2.270	2.240	-0.030
Vegetables	237.0	230.0	-7.0	131.0	127.0	-4.0	0.095	0.092	-0.003	1.550	1.500	-0.050
Vegetarian mixed dishes	21.4	15.1	-6.3	28.0	19.7	-8.3	0.031	0.022	-0.009	0.140	0.099	-0.041
White Bread and Cereals	107.0	107.0	0.0	271.0	271.0	0.0	0.096	0.096	0.000	0.750	0.749	-0.001
Whole Grain Bread Cereals	8.6	6.1	-2.4	21.2	15.2	-6.0	0.006	0.005	-0.002	0.060	0.043	-0.017
Total	2024.9	1766.0	-12.8%	3891.7	3293.6	-15.4%	4.26	3.05	-28.32%	10.12	8.20	-18.92%

Results

Table 3a: Dietary patterns of the nutrients and cultural acceptability constraints for Amsterdam males (391 adults)

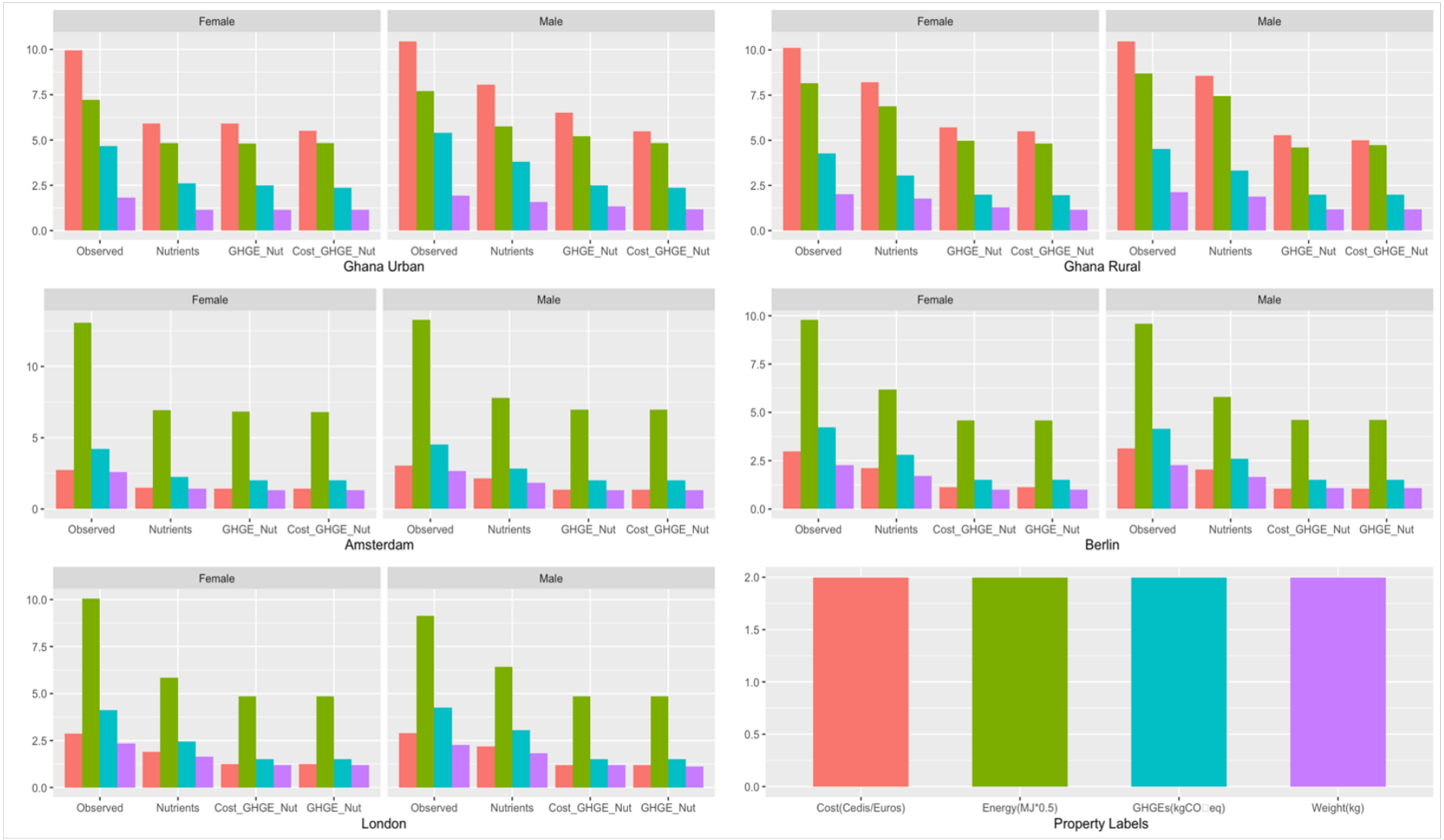
	Weight (g)			Energy (kcal)			GHGEs (kg CO_2eq)			Costs (Euros)		
Product Group	Average	Optimized	Difference	Average	Optimized	Difference	Average	Optimized	Difference	Average	Optimized	Difference
Alcoholic Beverages	34.7	29	-5.7	12.2	10.2	-2.0	0.042	0.035	-0.007	0.347	0.290	-0.057
Cakes and Sweets	16.2	8	-8.2	81.7	40.4	-41.3	0.068	0.034	-0.034	0.022	0.011	-0.011
Coffee Tea	900	463	-437.0	3470	1790	-1680.0	0.522	0.269	-0.253	0.107	0.055	-0.052
Condiments	113	53	-60.0	364	171	-193.0	0.541	0.254	-0.287	0.563	0.265	-0.298
Cooking Fats	0.24	0.0	-0.2	0.904	0.0	-0.9	0.001	0.000	-0.001	0.000	0.000	0.000
Dairy Products	52.9	51.1	-1.8	36.3	35.1	-1.2	0.282	0.273	-0.009	0.142	0.137	-0.005
Eggs	5	3.65	-1.4	7.74	5.65	-2.1	0.022	0.016	-0.006	0.005	0.004	-0.001
Fermented Maize Products	32.7	18	-14.7	113	62.1	-50.9	0.040	0.022	-0.018	0.009	0.005	-0.004
Fish and Seafoods	55.9	26	-29.9	70.3	32.7	-37.6	0.293	0.136	-0.157	0.106	0.049	-0.057
Fruits	192	183	-9.0	228	217	-11.0	0.288	0.274	-0.014	0.185	0.176	-0.009
Legumes	38.8	15	-23.8	130	50.3	-79.7	0.050	0.019	-0.030	0.105	0.040	-0.065
Margarine	4	3.7	-0.3	29.2	27	-2.2	0.014	0.013	-0.001	0.004	0.004	0.000
Meat mixed dishes	37.5	8	-29.5	49.5	10.6	-38.9	0.262	0.056	-0.206	0.101	0.022	-0.080
Nuts and Seeds	4	1.33	-2.7	14.4	4.8	-9.6	0.008	0.003	-0.005	0.022	0.007	-0.015
Olive Oil	0.02	0.12	0.1	0.177	1.06	0.9	0.000	0.000	0.000	0.000	0.000	0.000
Other Oils	5.83	5.86	0.0	52.5	52.7	0.2	0.020	0.020	0.000	0.018	0.018	0.000
Palm Oil	0.35	0.38	0.0	3.15	3.42	0.3	0.002	0.002	0.000	0.000	0.000	0.000
Potatoes	31.7	22	-9.7	36.4	25.3	-11.1	0.011	0.007	-0.003	0.053	0.037	-0.016
Poultry	37.5	14	-23.5	67.1	25	-42.1	0.341	0.127	-0.214	0.075	0.028	-0.047
Processed Meat	6.67	0.6	-6.1	18.8	1.69	-17.1	0.039	0.003	-0.035	0.018	0.002	-0.016
Red Meat	30	12	-18.0	87	34.8	-52.2	0.341	0.136	-0.205	0.101	0.040	-0.061
Rice & Pasta	157	117	-40.0	556	415	-141.0	0.240	0.179	-0.061	0.147	0.110	-0.037
Soft Drinks & Juices	128	119	-9.0	74.9	69.6	-5.3	0.196	0.182	-0.014	0.022	0.021	-0.002
Starchy Roots, Tubers & Plantain	107	91.9	-15.1	246	211	-35.0	0.082	0.071	-0.012	0.212	0.182	-0.030
Sweet Spread	0.5	0.05	-0.5	2.97	0.297	-2.7	0.003	0.000	-0.003	0.002	0.000	-0.002
Vegetable Soup, Stews & Sauces	206	193	-13.0	101	94.7	-6.3	0.529	0.497	-0.032	0.242	0.228	-0.014
Vegetables	358	343	-15.0	198	190	-8.0	0.173	0.166	-0.007	0.422	0.404	-0.018
Vegetarian mixed dishes	5	0.5	-4.5	6.52	0.652	-5.9	0.008	0.001	-0.007	0.006	0.001	-0.005
White Bread and Cereals	35	16.4	-18.6	88.6	41.6	-47.0	0.035	0.016	-0.019	0.010	0.005	-0.005
Whole Grain Bread Cereals	75	40	-35.0	186	99	-87.0	0.060	0.032	-0.028	0.014	0.008	-0.007
Total	2670.5	1838.6	-31.2%	6332.4	3722.7	-41.2%	4.51	2.84	-36.97%	3.06	2.15	-29.83%

Results

Table 3b: Dietary patterns of the nutrients and cultural acceptability constraints for Amsterdam female (583 adults)

	Weight (g)			Energy (kcal)			GHGEs ($kgCO_2eq$)			Costs (Euros)		
Product Group	Average	Optimized	Difference	Average	Optimized	Difference	Average	Optimized	Difference	Average	Optimized	Difference
Alcoholic Beverages	8.33	0	-8.3	2.93	0	-2.9	0.010	0.000	-0.010	0.083	0.000	-0.083
Cakes and Sweets	17	7.9	-9.1	85.9	39.9	-46.0	0.071	0.033	-0.038	0.023	0.011	-0.012
Coffee Tea	900	467	-433.0	3470	1800	-1670.0	0.522	0.271	-0.251	0.107	0.056	-0.051
Condiments	120	70	-50.0	389	226	-163.0	0.577	0.336	-0.241	0.601	0.350	-0.251
Cooking Fats	0.34	0	-0.3	1.28	0	-1.3	0.002	0.000	-0.002	0.000	0.000	0.000
Dairy Products	39.9	30	-9.9	27.4	20.6	-6.8	0.213	0.160	-0.053	0.107	0.080	-0.027
Eggs	5	2	-3.0	7.74	3.1	-4.6	0.022	0.009	-0.013	0.005	0.002	-0.003
Fermented Maize Products	32.7	18	-14.7	113	62.1	-50.9	0.040	0.022	-0.018	0.009	0.005	-0.004
Fish and Seafoods	59.4	26	-33.4	74.7	32.7	-42.0	0.311	0.136	-0.175	0.112	0.049	-0.063
Fruits	177	115	-62.0	211	137	-74.0	0.266	0.173	-0.093	0.170	0.111	-0.059
Legumes	39.2	19	-20.2	131	63.7	-67.3	0.050	0.024	-0.026	0.106	0.051	-0.055
Margarine	4.8	4.32	-0.5	35	31.5	-3.5	0.016	0.015	-0.002	0.005	0.004	0.000
Meat mixed dishes	20	8	-12.0	26.4	10.6	-15.8	0.140	0.056	-0.084	0.054	0.022	-0.032
Nuts and Seeds	4.67	1.33	-3.3	16.8	4.8	-12.0	0.010	0.003	-0.007	0.026	0.007	-0.019
Olive Oil	0.02	0	0.0	0.177	0	-0.2	0.000	0.000	0.000	0.000	0.000	0.000
Other Oils	3.56	17.5	13.9	32	157	125.0	0.012	0.060	0.047	0.011	0.053	0.042
Palm Oil	0.01	2	2.0	0.09	18	17.9	0.000	0.012	0.012	0.000	0.002	0.002
Potatoes	26.7	16	-10.7	30.7	18.4	-12.3	0.009	0.005	-0.004	0.044	0.027	-0.018
Poultry	37.5	14	-23.5	67.1	25	-42.1	0.341	0.127	-0.214	0.075	0.028	-0.047
Processed Meat	3	0.3	-2.7	8.46	0.846	-7.6	0.017	0.002	-0.016	0.008	0.001	-0.007
Red Meat	25	10	-15.0	72.5	29	-43.5	0.284	0.114	-0.170	0.084	0.034	-0.050
Rice & Pasta	157	41	-116.0	556	146	-410.0	0.240	0.063	-0.177	0.147	0.039	-0.108
Soft Drinks & Juices	114	91.1	-22.9	66.8	53.5	-13.3	0.175	0.140	-0.035	0.020	0.016	-0.004
Starchy Roots, Tubers & Plantain	100	41	-59.0	230	94.2	-135.8	0.077	0.031	-0.045	0.198	0.081	-0.117
Sweet Spread	0.5	0.05	-0.5	2.97	0.297	-2.7	0.003	0.000	-0.003	0.002	0.000	-0.002
Vegetable Soup, Stews & Sauces	206	105	-101.0	101	51.4	-49.6	0.529	0.270	-0.259	0.242	0.124	-0.118
Vegetables	388	280	-108.0	215	155	-60.0	0.188	0.135	-0.053	0.457	0.330	-0.127
Vegetarian mixed dishes	5	0.5	-4.5	6.52	0.652	-5.9	0.008	0.001	-0.007	0.006	0.001	-0.005
White Bread and Cereals	35.9	10	-25.9	90.9	25.3	-65.6	0.036	0.010	-0.026	0.010	0.003	-0.008
Whole Grain Bread Cereals	71.3	42	-29.3	176	104	-72.0	0.057	0.034	-0.023	0.014	0.008	-0.006
Total	2601.8	1439	-44.7%	6248.4	3310.60	-47.0%	4.23	2.24	-46.96%	2.73	1.49	-45.21%

Results



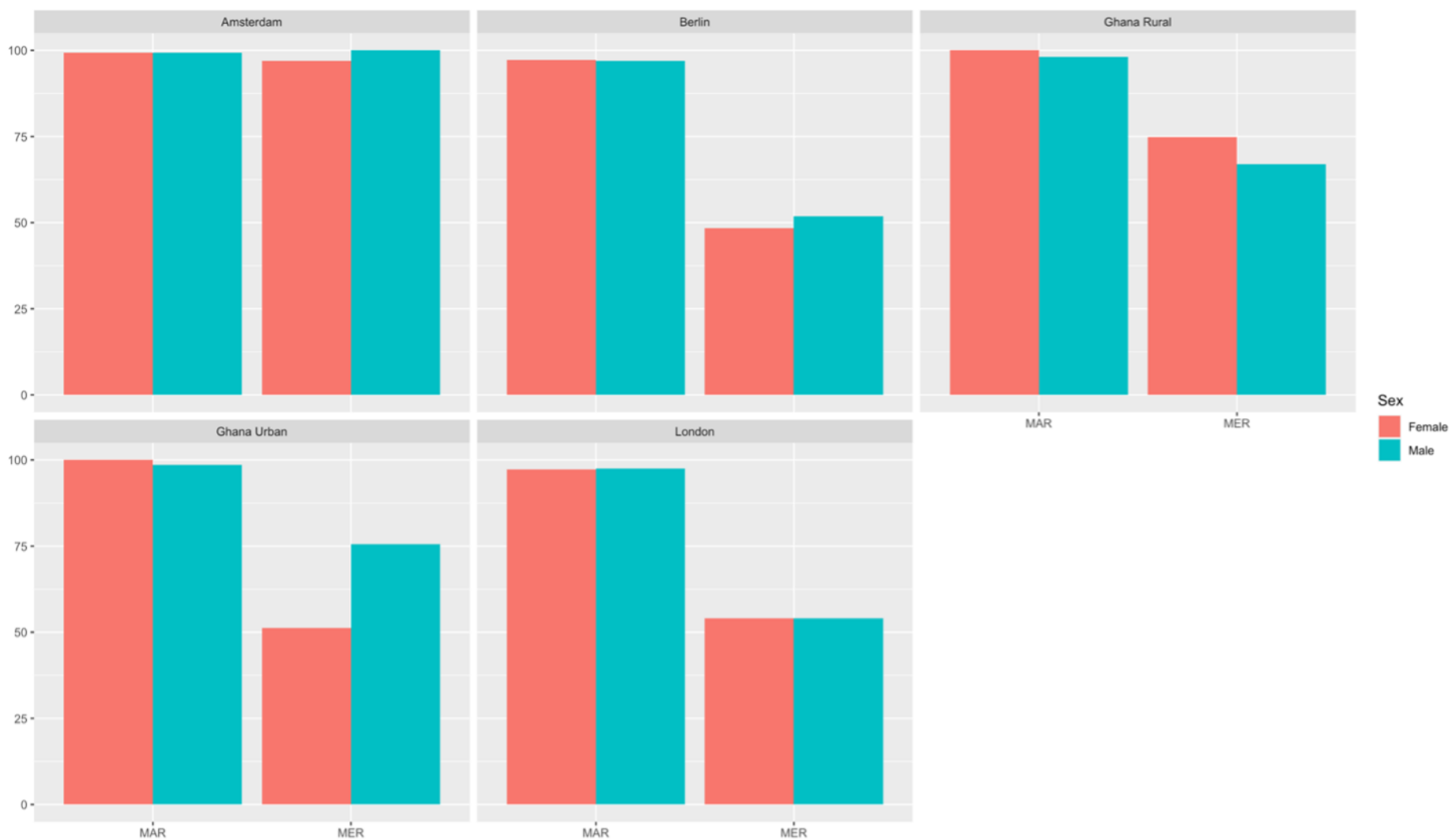
Summary of the results illustrating the differences in cost, energy use, GHGEs, and weight after three subsequent cycles

Results

Table 16: Food portions for the five study sites of the after three cycles of optimal nutritious dietary patterns per day in grams

		Portion Sizes Weight		Amsterdam		Berlin		London		Ghana Urban		Ghana Rural	
Food Group	FPQ	Europe	Ghana	Women (g)	Men (g)	Women (g)	Men (g)	Women (g)	Men (g)	Women (g)	Men (g)	Women (g)	Men (g)
Cakes and Sweets	1 piece	100	100	8	8	7	1.6	8	8	7	5.5	3.3	1.3
Coffee Tea	1 cup	350	500	470	479	225	222	169	185	36	46	70	59
Condiments	a handful	100	100	70	53	38	23	32	37	29	30	33	33
Dairy Products	150ml or 150g	150	150	10	16	24	15	17	17	10	10	5	5
Eggs	whole	60	60	2	2	2	2	2	2	2	2	2	2
Fermented Maize Products	large orange size	280	280	18	18	15	9	18	18	70	68	69	69
Fish and Seafood	one portion	100	125	26	26	14	14	14	15	55	50	31	25
Fruits	whole /a handful/ 1 piece	150	150	88	80	51	69	177	120	94	104	144	151
Legumes	one portion	150	150	19	15	15	15	10	15	15	31	15	22
Margarine	1 teaspoon	8	8	0.4	0.4	9.2	12	9.8	0.2	12	7	10	19
Meat mixed dishes	one portion	250	300	8	8	8	11	7	8	10	10	10	10
Nuts and Seeds	a handful	40	40	1.33	1.33	1.33	0.3	1.33	0.4	1.3	1.3	0.3	0.3
Olive Oil		20	20	0.0	0.01	0.1	0.01	0.08	0.33	0.02	0.12	0.0	0.0
Other Oils		20	20	21	25	15	12	13	23	11	2	9	3
Palm Oil		20	20	1.75	0.04	0.01	0.01	0.02	0.04	10	9	10	10
Potatoes	3 pieces	200	200	16	15	10	16.2	9.7	10.1	1.3	1.6	0.5	1.4
Poultry	one portion	175	150	14	14	14	5.8	14	14	5	5	5	5
Processed Meat	one portion	20	20	0.3	0.6	2	0.67	0.6	0.3	0.2	1.2	0.6	0.5
Red Meat	one portion	150	200	10	12	10	10	10	10	10	12	6	12
Rice & Pasta	one portion	300	300	41	70	70	76	76	87	136	147	52	25
Soft Drinks & Juices	200 ml	200	200	30	35	20	77	41	76	27	48	7	7
Starchy Roots, Tubers & Plantain	3 pieces, finger size or slices	150	150	41	37	22.5	29.9	62.2	46	163	156	262	289
Sweet Spread	1 Tablespoon	15	15	0.05	0.05	0.01	0.1	0.05	0.1	0.1	0.1	0.1	0.01
Vegetable Soup, Stews and Sauces	3 Sp.Sp	300	300	105	100	100	130	114	122	206	197	230	216
Vegetables	one portion or whole	150	150	280	278	277	243	275	214	147	162	125	138
Vegetarian mixed dishes	one portion	150	100	0.5	0.5	5	3	0.5	5	21	15	2	3
White Bread and Cereals	one slice or piece	50	50	10	10	17	32	56	33	53	53	52	51
Whole Grain Bread Cereals	one slice or piece	50	50	42	40	42	54	50	57	0.8	0.7	0.8	0.6

Results



MAR and MER nutrient adequacy measurements.

Results

Table 17: Ghana Urban males and females nutrient properties after the three cycles constraints were considered

		Female				Male			
Property/Nutrients	Units	Min	Max	Average	Optimized	Min	Max	Average	Optimized
Protein	g	50.0	123.0	143.0	69.0	50.0	127.9	154.0	89.0
Energy	kcal	2300.0	3570.0	3440.0	2300.0	2300.0	3972.4	3680.0	2750.0
Fats	g	35.0	138.2	52.9	43.5	38.5	154.2	57.5	38.5
Carbohydrates	g	160.0	500.0	504.0	330.0	164.8	602.1	531.0	425.0
Fiber diet	g	20.5	52.9	64.5	37.5	25.0	70.0	69.1	50.9
Alcohol	g	0.0	2.0	3.0	1.3	0.0	2.0	5.4	2.0
Calcium diet	mg	520.0	2000.0	1890.0	1100.0	530.0	2000.0	1940.0	1180.0
Iron (Ferritin) diet	mg	15.0	40.0	49.9	25.0	15.6	50.0	53.0	30.8
Magnesium diet	mg	245.8	1000.0	1170.0	621.0	228.4	1000.0	1240.0	813.0
Phosphorus diet	mg	721.4	4000.0	2440.0	1310.0	705.7	4000.0	2620.0	1680.0
Potassium diet	mg	2260.5	10000.0	9360.0	4650.0	3000.0	10000.0	9790.0	5680.0
Natrium diet	mg	1000.0	5030.0	2560.0	1200.0	1020.0	5533.6	2740.0	1250.0
Zinc diet	mg	5.9	40.0	18.8	9.5	5.8	40.0	20.9	12.7
Copper diet	mg	1.0	8.0	5.8	2.5	1.0	8.0	6.4	3.2
Vitamin A retinol eq. diet	µg	834.0	4769.3	3890.0	1960.0	810.8	5049.1	4010.0	1560.0
Vitamin A retinol diet	µg	34.1	1000.0	2330.0	517.0	31.0	1000.0	2460.0	485.0
Vitamin A beta carotene diet	µg	8824.5	55411.5	18400.0	17200.0	7540.6	58925.8	18300.0	12700.0
Vitamin B1 diet	mg	0.6	3.0	2.6	1.5	0.6	3.0	2.8	2.1
Vitamin B2 diet	mg	0.7	3.0	3.7	1.7	0.7	3.0	3.9	1.9
Vitamin B3 diet	mg	9.0	26.1	58.7	26.1	8.9	30.0	61.6	30.0
Vitamin B6 diet	mg	1.3	5.0	4.2	2.4	1.2	5.0	4.5	2.9
Vitamin B9 diet	mg	165.1	600.0	1150.0	600.0	157.6	1000.0	1270.0	836.0
Vitamin B12 diet	mg	3.2	67.0	33.6	7.1	2.2	68.6	35.8	7.3
Vitamin C diet	mg	81.5	500.0	341.0	227.0	75.0	493.4	343.0	237.0
Vitamin D diet	mg	2.0	10.3	14.5	8.8	1.4	11.2	14.0	8.0
Vitamin E diet	mg	11.0	30.0	15.5	12.0	9.2	29.1	15.7	11.5
Grams	g	1000.0	-	1830.0	1170.0	1000.0	-	1930.0	1330.0
GHGEs	kgCO_2eq	0.0	2.5	4.7	2.4	0.0	2.5	5.4	2.4
Costs (Cedis)	₵	3.0	5.5	10.0	5.5	3.0	6.0	10.4	6.0

Results

Table 18: Ghana Rural males and females nutrient properties after the three cycles constraints were considered

		Female Adults				Male Adults			
Property/Nutrients	Units	Min	Max	Average	Optimized	Min	Max	Average	Optimized
Protein	g	45.2	160.1	145.0	78.9	42.1	182.4	152.0	67.3
Energy	kcal	1438.8	6680.2	3890.0	2670.0	1527.5	7348.4	4150.0	2470.0
Fats	g	46.0	161.3	50.5	46.0	47.7	188.5	54.0	47.7
Carbohydrates	g	188.2	1241.4	610.0	422.0	196.2	1254.4	652.0	391.0
Fiber diet	g	21.0	110.0	71.6	53.2	20.6	100.0	77.1	42.4
Alcohol	g	0.0	3.5	3.5	1.6	0.0	3.9	3.9	1.4
Calcium diet	mg	306.1	2000.0	1890.0	1280.0	289.5	2000.0	1930.0	1230.0
Iron (Ferritin) diet	mg	1.0	40.2	48.8	30.9	1.0	43.5	51.9	27.7
Magnesium diet	mg	275.0	1235.4	1230.0	802.0	278.5	1362.3	1300.0	734.0
Phosphorus diet	mg	700.0	4000.0	2520.0	1520.0	735.4	4000.0	2660.0	1320.0
Potassium diet	mg	3634.7	11765.3	10000.0	6950.0	2548.0	12612.4	10400.0	7020.0
Natrium diet	mg	1289.8	5621.6	2010.0	1290.0	1355.0	5650.4	2120.0	1360.0
Zinc diet	mg	6.0	40.0	19.3	10.8	6.0	40.0	20.8	8.9
Copper diet	mg	1.0	8.0	6.0	3.1	1.0	8.0	6.4	2.7
Vitamin A retinol eq.	µg	900.0	5657.3	4240.0	2050.0	900.0	5769.3	4330.0	2060.0
Vitamin A retinol diet	µg	22.6	500.0	2620.0	500.0	24.6	600.0	2690.0	600.0
Vitamin A beta car. diet	µg	11000.0	64673.9	19000.0	18500.0	11000.0	66322.7	19300.0	17300.0
Vitamin B1 diet	mg	0.7	15.0	2.8	1.9	0.8	15.0	3.1	1.4
Vitamin B2 diet	mg	0.6	15.0	3.7	1.9	0.6	15.0	3.9	1.7
Vitamin B3 diet	mg	8.7	34.1	60.0	34.1	8.7	38.3	61.6	38.3
Vitamin B6 diet	mg	1.3	50.0	4.4	2.7	1.2	50.0	4.6	2.3
Vitamin B9 diet	mg	187.5	854.4	1210.0	824.0	174.1	917.1	1290.0	630.0
Vitamin B12 diet	mg	1.0	66.3	32.8	6.0	1.0	69.1	33.7	6.4
Vitamin C diet	mg	75.0	805.9	381.0	285.0	75.0	801.8	399.0	251.0
Vitamin D diet	mg	1.2	11.4	10.9	5.0	1.2	14.3	10.3	4.1
Vitamin E diet	mg	10.2	100.0	16.7	14.0	10.2	36.2	17.5	13.7
Grams	g	1000.0		2025.0	1182.6	1000.0		2123.4	1260.4
GHGEs	kg CO_2eq	0.0	2.1	4.3	2.0	0.0	2.2	4.5	2.0
Costs (Cedis)	₵	3.00	5.50	10.12	5.50	3.00	5.50	10.47	5.00

Results

Table 19: Amsterdam Male and Female properties after the three cycles constraints were considered

		WOMEN				MEN			
Property/Nutrients	Units	Minimum	Maximum	Average	Optimized	Minimum	Maximum	Average	Optimized
Protein	g	49.2	159.8	250	125	49.1	160	255	125
Energy	kcal	1290.2	4970.5	6250	3250	1330	5570	6340	3320
Fats	g	37.2	209.2	56.6	46.6	35.6	216	60.1	47.6
Carbohydrates	g	164.6	895.8	1030	508	161	956	1030	520
Fiber diet	g	21.1	100.0	68.9	37.8	18.3	168	67.5	33.5
Alcohol	g		5.0	4.23	1.75		7.3	7.31	1.48
Calcium diet	mg	349.1	2500.0	3280	1800	465	3000	3240	1730
Iron (Ferritin) diet	mg	9.6	50.0	92.3	49.8	9.16	61.5	91.7	46.6
Magnesium diet	mg	274.7	2070.0	3750	1950	281	2090	3750	1950
Phosphorus diet	mg	835.3	3960.0	4760	2410	819	3860	4800	2400
Potassium diet	mg	4500.0	20600.0	38800	20400	2710	21200	38800	20400
Natrium diet	mg	1563.9	5200.0	4170	2260	1420	5240	4100	1870
Zinc diet	mg	8.0	34.4	23.2	11.4	7.18	40	24	11.2
Copper diet	mg	1.5	8.0	7.9	4.01	1.47	8	8.41	3.89
Vitamin A retinol equivalent diet	µg	1363.8	7812.3	3040	1640	1000	8440	3550	1500
Vitamin A retinol diet	µg	154.6	3000.0	1400	533	126	3540	1960	547
Vitamin A beta carotene diet	µg	5607.5	45653.1	19300	13200	3920	46300	18900	11400
Vitamin B1 diet	mg	1.0	5.1	2.64	1.35	0.81	10	2.65	1.28
Vitamin B2 diet	mg	1.0	5.9	4.16	2.17	0.92	10	4.4	2.1
Vitamin B3 diet	mg	13.6	150.0	286	148	13.6	150	287	150
Vitamin B6 diet	mg	1.7	50.7	4.59	2.45	1.3	50.9	4.61	2.35
Vitamin B9 diet	mg	238.5	973.9	1370	764	206	982	1350	679
Vitamin B12 diet	mg	2.7	12.6	15.1	5.94	2.4	15.2	23.2	6.2
Vitamin C diet	mg	146.7	1000.0	431	263	116	1500	425	254
Vitamin D diet	mg	1.4	9.3	9.86	4.27	1	11.6	9.51	4.3
Vitamin E diet	mg	11.4	100.0	14.8	11.4	11.4	100	15	11.4
Grams	g	1000.0		2600	1330	1000		2670	1340
GHGEs	kg CO_2eq		2.0	4.23	2.0		2.0	4.51	2.0
Costs (Euros)	€	1.0	3.0	2.73	1.4	1.35	3.0	3.06	1.35

Thank You

Questions and Discussions