Incorporating preferences into a healthy and sustainable diet

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Abstract

Sustainable diets are defined as "nutrient-dense, affordable, culturally acceptable, and sparing of the environment" (Drewnowski, 2017). Whilst diets which cover the nutrient and environmental aspects have been studied in detail, there has been little work on also incorporating acceptability (i.e. consumer preferences). This study estimates sustainable diets using the Green et al (2015) dietary models (quadratic programming based) with the following data: national diet and nutrition survey, dietary reference values, Kantar Worldpanel prices and carbon footprints. The diet models were estimated for eight UK demographic groups alongside estimation of the respective demand systems in order to incorporate own price elasticities. The results suggest that sustainable diets for all the demographic groups are to an extent possible based on the nutrient constraints used, with the largest emission reductions (relative to the baseline diet emissions) of 45 per cent for males aged 19 to 50 and aged 50 plus.

Keywords [Food Consumption, Preferences, Nutrition, Sustainability]

JEL code [D12, Q56, Q18]

1. **Introduction**

The issue regarding sustainable diets is a particularly pertinent topic considering that food consumption in the UK represents 20 to 30 per cent of the country's consumption emissions (Audsley et al., 2009). With regards to the nutritional dimension of diets, the current UK average intake of nutrients such as non-milk extrinsic sugars and saturated fats exceed recommended levels (Food Standards Agency and Public Health England, 2016). Yet, prescribing a list of healthy sustainable diets as in the case of (Chalmers and Revoredo-Giha, 2017; Macdiarmid, 2013) is unlikely to result in a change of dietary habits given the lack of inclusion of consumer preferences. This acceptability/preference criteria is important for adhering to the domains of a sustainable diet as detailed by Drewnowski (2017): "Foods and food patterns need to be nutrient-dense, affordable, culturally acceptable, and sparing of the environment". As the definition includes "nutrient dense" this is taken as a measurement for health thus this paper will refer to healthy and sustainable diets as just sustainable diets.

This paper estimates a sustainable diet which meets dietary reference values, incorporates preferences (through the incorporation of own price elasticities) and is also low carbon emissions.

The structure of the paper is as follows: The background section highlights the motivation for sustainable diets and the previous work covering this area. The data section presents a description of the data required for the estimation of the diet model. The methods section details how the quadratic programme based diet models were estimated. The results and discussions section details the estimates of the diet model.

2. Background

The main motivation for estimating a sustainable diet is related to reducing carbon emissions and improving nutrient intake. Food emissions represent approximately 20 to 30 per cent of the UK's consumption greenhouse gas emissions (GHG) (Audsley et al., 2009). Climate change is a particularly important concern given recent evidence that the global average temperature for 2016 is the hottest since the preindustrial era of 1850-1899 (World Meteorological Organization, 2017). This combined with the widespread consensus on anthropogenic global warming (Cook et al., 2016) signifies the importance of trying to reduce carbon emissions. Therefore, it is clear why emissions associated with food consumption need to reduce given the concern associated with climate change.

The food products with the highest carbon emissions are those of red meats and dairy whilst those that are plant based tend to have lower carbon emissions (Garnett, 2011). Red meats are an important protein source rich in micronutrients such as iron (Heme iron) which can be more easily absorbed by humans than non Heme iron (Hunt, 2003), yet excessive consumption of red meats may result in bowel (colorectal) cancer and many red meats do contain relatively high levels of saturated fat (NHS, 2017a). This shows the importance of accounting for dietary reference values (DRVs) within diets.

The definition of sustainable diets as defined by the Food and Agriculture Organization (FAO) (2012) means that such a diet would cover at least 11 dimensions such as "low environmental impacts". Creating a diet which can fulfil the FAO's eleven sustainability dimensions (and the resulting constraints of each dimension) is considered unachievable given the lack of literature on such diets. However, Drewnowski (2017) have developed a framework which categorises such diets into four domains: "Foods and food patterns need to be nutrient-dense, affordable, culturally acceptable, and sparing of the environment". This framework therefore suggests that a sustainable diet is one that is measured by meeting dietary recommended values (DRVs), low monetary cost, incorporates preferences and has the lowest carbon emissions associated with the foods consumed. The diet models of Green et al (2015) and Milner et al (2015) have accounted for the aforementioned dimensions (except low monetary costs).

Green et al (2015) and Milner et al (2015) used quadratic programming within their diet models in order to estimate the change required from a current average male and female diet to one which meets the nutritional and GHG constraints. The model incorporated consumer preferences through the use of Marshallian own price elasticities and food expenditure shares. The limitation is the absence of cross price elasticities, however, the model does partially account for consumer preferences through the own price elasticities. The issue of low monetary cost is not directly addressed by the model. However, as the weighting of the quadratic function is the own price elasticities and food expenditure shares then there is to an extent a welfare measure of how willing consumers would be to change their diets (Milner et al., 2015).

Green et al (2015) found that a diet which reduced GHG emissions by 60 per cent relative to the baseline would likely require dietary change which would be unacceptable for adult males and females when accounting for preferences (Green et al., 2015). Green et al (2015) report that GHG reductions associated with a 60 per cent decrease would require men and woman to deviate from the existing average diet of 200 and 150 per cent, respectively. This means that there would be a very large change in current diet to meet this reduction. Green et al (2015) showed that diets with a 40 per cent reduction in GHG emissions are achievable for both genders. This resulting diet would require (for both genders) zero beef consumption, a slight increase in sugary food products and a slight reduction in fruit consumption.

However, the Green et al (2015) diet model is the use of household estimated price elasticities to represent the preferences of both males and females (i.e. individual demographic groups). It seems unlikely that these two demographic groups would have the exact same preferences for different food groups. The Green et al (2015) diet model only models a total of 14 nutrient and food groups and does not assess the overall diet quality of the subsequent sustainable diet. This is an issue as the diet could fail to meet other dietary reference values (DRVs).

3. Data

Four sources of data were required for this study: dietary recommendations, quantities of food products consumed (alongside nutrient availability) and carbon footprints. 16 food groups have been selected based on the National Diet and Nutrition Survey (NDNS) groupings and are shown in Table 1 along with information regarding the contents of each food group. The groups were formed based on the NDNS main food group codes and using these codes allowed somewhat similar food groups to be formed as in Revoredo-Giha et al (2018).

Table 1 Food groups

Food group number	Food group name	NDNS categories
1	Grains and grain-based products	Cereals and Cereal Products White bread Wholemeal bread Other breads High fibre breakfast cereals Other breakfast cereals Brown, granary and wheatgerm bread

Food group number	Food group name	NDNS categories
2	Vegetables and vegetable products	Salad and other raw vegetables Vegetables
3	Starchy roots, tubers, nuts and oilseeds	Chips, fried and roast potatoes and potato products Other potatoes, potato salads and dishes Nuts and seeds
4	Fruit, fruit products and fruit and vegetable juices	Fruit Fruit juice Smoothies
5	Beef, veal and lamb	Beef, veal and dishes Lamb and dishes
6	Pork	Pork and dishes Bacon and ham
7	Poultry, eggs, other fresh meat	Coated chicken and turkey manufactured Chicken and turkey dishes Eggs and egg dishes
8	Processed and other cooked meats	Other meat and meat products Liver, products and dishes Burgers and kebabs Sausages Meat pies and pastries
9	Fish and other seafood	White fish coated or fried Other white fish, shellfish and fish dishes Oily fish
10	Milk, dairy products and milk product imitates	Whole milk Semi-skimmed milk 1% Milk Skimmed milk Other milk and cream
11	Cheese	Cheese
12	Sugar and confectionary and prepared desserts	Sugars, preserves and sweet spreads Yogurt, fromage frais and other dairy desserts Puddings Sugar confectionery Chocolate confectionery

Food group number	Food group name	NDNS categories
		Ice cream
13	Soft drinks	Soft drinks, not diet Soft drinks, diet
14	Tea, coffee, cocoa, and drinking water	Tea, coffee and water
15	Snacks and other foods	Crisps and savoury snacks Biscuits Buns, cakes, pastries and fruit pies
16	Residual category	Miscellaneous Butter Margarine and other cooking fats and oils NOT polyunsaturated Polyunsaturated margarine and oils Low fat spread Reduced fat spread Spirits and liqueurs Wine Beer lager cider and perry Artificial sweeteners

Notes: Alcoholic products were removed for any age group below the age of 19. This is because 18 year olds (legal drinking age in bars) are included in a group with younger teenagers.

The most up to date dietary reference values (DRV) for eleven nutrients (Energy, Sodium, Non-milk extrinsic sugars (NMES), Fat, Protein, Iron, Copper, Zinc, Vitamin A, Vitamin C and Calcium) were obtained from: the Department of Health’s Committee on Medical Aspects (1991), Scientific advisory committee on nutrition (2011) and the Scottish dietary goals (Scottish Government, 2016). These nutrients were selected based on findings by Public Health England (2014) which suggested that on average Sodium and NMES were intakes for most demographic groups were greater than the respective DRVs. The following nutrients were not being met in terms of DRVs for some age demographic groups: Iron, Zinc, Vitamin A and Calcium (Public Health England, 2014). Whilst Public Health England (2014) did not report Vitamin C as an nutrient which lacks correct intake, it is being modelled as it is found in many fruit and vegetable products and as food groups are not forming any constraints, then this at least allows products rich in this vitamin to be constrained. A more detailed explanation of the source of each DRV is provided for in the appendix.

The quantities of food products consumed and the associated nutrients were obtained from the National Diet and Nutrition Survey (NDNS) (NatCen Social Research et al., 2017). Some products such as alcohol were only for the demographic groups of aged 19 plus. As this paper focusses on food and drink products only, supplements were therefore excluded. It should be highlighted that dietary supplements can be an important source of nutrients for some demographic age groups. “Equivalised household income tertiles”, “Age” and “Survey year” were used for the purposes of estimating the demand system. Despite the “Equivalised household income tertiles” existing for years 5 and 6 of the NDNS survey, the tertiles (i.e. 3 quartiles) were not present for years 1 to 4 and thus were created using the “Equivalised household income”. The “Equivalised household income” is based on estimating a McClements score (developed in the early 1970s) (NatCen Social Research et al., 2017).

Prices were obtained from the Scottish section of Kantar Worldpanel using Kantar food groups and then matched to the NDNS Databank data. There were approximately 508 food groups (does vary by year). As the products were categorised into similar groups then a median price of these groups can be estimated for each year and mapped to the NDNS data:

1. NDNS Year 1 – Kantar year 2008 data
2. NDNS Year 2 – Kantar year 2009 data
3. NDNS Year 3 – Kantar year 2010 data
4. NDNS Year 4 – Kantar year 2011 data
5. NDNS Year 5 – Kantar year 2012 data
6. NDNS Year 6 – Kantar year 2013 data

There were cases where the NDNS data described national brand or private label and subsequent searches could not locate these products within the Kantar food groups. Despite the limitation, this mapped NDNS data is considered to be the only UK source whereby a wide variety of nutrient data, food products, prices and carbon footprints are contained.

The number of respondents within each demographic group for the whole-time period of the NDNS years 1 to 6 of the mapped (food level dietary) data does vary with adults more represented than teenagers as shown in Table 2. It should be emphasised that this is cross sectional data.

Table 2 Number of respondents

Demographic group	Number of respondents for NDNS years 1 to 6
Female aged 50 plus	990
Male aged 50 plus	775
Female aged 19 to 50	1,365
Male aged 19 to 50	932
Female aged 15 to 18	478
Male aged 15 to 18	419
Female aged 11 to 14	424
Male aged 11 to 14	458

Source: Based on own elaborations of the mapped NDNS data

The carbon footprint data were matched to the NDNS data based on a University of Aberdeen (Rowett institute) project which mainly used the data of Tesco (2012). The project used carbon footprint data which were cradle to grave and in the public domain.

The median nutritional and carbon content of the food groups listed in Table 1 are shown in Table 3.

In order to allow a comparison of the results of the diet models against existing quantities consumed for the different demographic groups, it is important to estimate baseline diets. Table 4 shows the observed quartile three quantities of the different demographic groups. Whilst Table 5 shows the maximum quantities consumed of the different food groups. These tables are therefore useful in comparing to the diet models being estimated in this study.

In order to estimate weekly data on individual purchases (for the demand systems), the NDNS "Food level dietary data" were scaled up to seven days on the assumption that the same food and drinks consumed for the 3 or 4 days would also be consumed for the rest of the week. This assumption is based on the premise of weekly shops.

Table 3 Median nutrition and carbon content of food groups (units per 1 gram of food)

	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8	Group 9	Group 10	Group 11	Group 12	Group 13	Group 14	Group 15	Group 16
Energy (KJ)	12.080	3.320	8.140	2.000	6.350	8.330	7.250	9.950	7.020	2.960	12.490	9.170	1.080	0.700	16.780	5.700
Sodium (mg)	2.800	0.300	0.170	0.030	0.945	4.850	1.925	3.660	2.000	0.470	6.700	0.640	0.050	0.150	2.690	1.975
Free Sugars (g)	0.000	0.000	0.000	0.057	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.172	0.066	0.000	0.217	0.011
Fat (g)	0.034	0.018	0.094	0.001	0.075	0.104	0.092	0.135	0.090	0.036	0.235	0.050	0.000	0.000	0.164	0.032
Protein (g)	0.078	0.025	0.028	0.007	0.146	0.224	0.133	0.137	0.166	0.033	0.199	0.036	0.000	0.000	0.057	0.014
Iron (mg)	0.017	0.008	0.005	0.004	0.015	0.008	0.009	0.016	0.007	0.002	0.003	0.004	0.000	0.000	0.014	0.004
Copper (mg)	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.000	0.000	0.001	0.000	0.000	0.002	0.000
Zinc (mg)	0.010	0.004	0.004	0.001	0.028	0.021	0.009	0.019	0.006	0.005	0.021	0.004	0.000	0.000	0.007	0.002
Vitamin A (μg)	0.000	0.460	0.000	0.060	0.100	0.000	0.370	0.140	0.230	0.550	2.820	0.240	0.000	0.000	0.490	0.110
Vitamin C (mg)	0.000	0.075	0.087	0.110	0.000	0.000	0.000	0.005	0.000	0.016	0.000	0.003	0.070	0.000	0.000	0.000
Calcium (mg)	0.600	0.350	0.120	0.140	0.160	0.090	0.315	0.360	0.360	1.100	4.940	0.860	0.060	0.080	0.680	0.170
Carbon (g)	3.200	1.600	2.600	1.200	12.70	4.600	4.910	4.600	4.600	1.232	11.100	2.400	0.425	0.212	1.200	1.500

Notes: The food group number corresponds to the food group description of Table 1. Carbon content has grams greater than one gram for most food groups, this is a common result in life cycle assessments.

Table 4 Observed quantities (grams) consumed (third quartile)

Food group	Female 11-14	Male 11-14	Female 15-18	Male 15-18	Female 19-50	Male 19-50	Female 50 Plus	Male 50 Plus
Grains grain-based products	213.73	253.38	217.23	280.87	209.26	274.61	168.59	226.20
Vegetables and vegetable products	114.77	124.50	134.08	148.50	199.15	196.18	223.07	228.52
Starchy roots, tubers, nuts and oilseeds	114.24	121.13	122.56	158.00	121.88	144.50	125.00	155.94
Fruit, fruit products and fruit and vegetable juices	231.00	253.95	237.50	235.69	207.60	235.70	256.88	258.83
Beef, veal and lamb	60.91	54.07	55.48	74.94	65.68	87.00	64.38	90.89
Pork	32.25	40.00	30.38	48.88	35.19	54.16	37.50	53.75
Poultry, eggs, other fresh meat	78.29	82.26	84.05	108.13	95.31	113.75	74.37	91.83
Processed and other cooked meats	59.63	82.19	58.31	96.50	59.28	99.25	51.54	85.00
Fish and other seafood	42.28	38.80	47.18	61.01	54.93	68.00	62.50	75.00
Milk, dairy products and milk product imitates	212.50	303.93	174.71	300.00	202.80	244.19	255.15	275.15
Cheese	20.79	24.25	22.50	29.20	30.00	35.00	27.50	31.08
Sugar and confectionary and prepared desserts	95.48	115.72	78.75	88.94	90.00	96.17	116.23	110.01
Soft drinks	542.00	682.19	625.00	807.63	475.25	635.06	250.75	332.34
Tea, coffee, cocoa, and drinking water	563.06	553.13	804.63	784.00	1397.93	1383.34	1566.29	1391.00
Snacks and other foods	63.23	62.65	57.75	75.48	52.01	65.69	57.00	69.75
Residual category	66.73	70.45	79.81	74.35	244.92	638.19	191.22	582.64

Sources: Based on own elaborations of NDNS data

Table 5 Observed maximum quantities (grams) consumed

Food group	Female 11-14	Male 11-14	Female 15-18	Male 15-18	Female 19-50	Male 19-50	Female 50 Plus	Male 50 Plus
Grains grain-based products	472.79	847.79	496.83	606.25	607.50	736.94	386.78	548.15
Vegetables and vegetable products	402.88	477.46	395.50	520.00	743.27	1087.24	591.18	681.25
Starchy roots, tubers, nuts and oilseeds	319.33	335.00	526.50	415.00	565.25	367.38	480.00	986.25
Fruit, fruit products and fruit and vegetable juices	773.75	760.50	1243.75	1362.50	1970.25	1541.00	876.00	965.63
Beef, veal and lamb	177.00	256.10	254.15	264.85	304.15	461.25	350.00	426.25
Pork	152.00	130.00	141.53	182.33	197.53	300.00	133.00	193.90
Poultry, eggs, other fresh meat	348.60	225.08	249.37	383.38	321.38	1872.00	241.50	584.50
Processed and other cooked meats	155.25	282.67	259.75	310.25	198.00	337.50	205.50	320.51
Fish and other seafood	100.00	183.31	191.00	337.00	232.75	217.00	237.38	401.10
Milk, dairy products and milk product imitates	860.00	1783.85	772.50	2100.19	1740.24	1349.00	1097.20	975.00
Cheese	64.60	78.13	75.93	90.85	160.00	161.25	103.60	160.13
Sugar and confectionary and prepared desserts	287.93	321.20	265.63	402.63	612.91	433.03	553.20	541.00
Soft drinks	1520.00	2645.00	2635.00	2736.25	3434.50	3037.50	6459.00	3197.50
Tea, coffee, cocoa, and drinking water	3337.85	3250.00	3185.93	4307.33	5054.75	6385.00	5295.85	3665.50
Snacks and other foods	417.43	186.50	195.00	282.13	164.50	246.96	205.88	223.63
Residual category	305.63	370.49	711.75	343.16	4337.08	6189.00	1955.95	4527.50

Sources: Based on own elaborations of NDNS data

4. Methods

4.1 Diet modelling

Green et al (2015) used quadratic programming based diet models for estimation of sustainable diets and similar models were estimated for this study. The diet models required own price elasticities which were estimated for the eight demographic age groups using the Exact Affine Stone Index (EASI) demand systems. The conditional demand systems were estimated based on the food and drink groups of Table 1. Equation 1 shows the "approximate" model of the linear EASI demand which is based on the EASI introduced by Lewbel and Pendakur (2009) with the following parameters: w = budget shares, b = represents the Engel curve, $\tilde{y}$ = the stone price index, A = compensated price effects, p = log prices and the error term ε represented random utility parameter.

$$w = \sum_{r=0}^{r} b_r \tilde{y}_r + Cz + Dz\tilde{y} + \sum_{l=0}^{L} z_l A_l p + Bp\tilde{y} + \tilde{\varepsilon} \qquad (1)$$

The eight systems were estimated using R package Easi (Hoareau et al., 2013) with no interactions between price, implicit utility and demographic variables. The own price elasticities were also estimated using package Easi.

The objective function used in Green et al (2015) and Milner et al (2015) took the form of equation 2 whereby the difference between the current and the ideal consumption for food group i (Δx_i) is minimised using the ratio of the expenditure share of the food group (s_i) divided by the price elasticity of demand for the respective food group (ε_i), which is multiplied by the current consumption (X_i) squared (Green et al., 2015) . This ratio formed the acceptability (i.e. preference) weighting for the quadratic programme (Milner et al., 2015).

$$\underset{\substack{\Delta \boldsymbol{x_i} \\ \boldsymbol{s.t}}}{\boldsymbol{Min}} \quad \sum_{i=1}^{n} \left(\frac{\boldsymbol{s_i}}{\boldsymbol{\varepsilon_i x_i}^2} \right)^2 \Delta \boldsymbol{x_i} \qquad (\mathbf{2})$$

The nutritional constraints ($\boldsymbol{r_j}$) are shown below whereby equation 3 represents the nutrient coefficients (a_i) of the seven nutrients deemed as beneficial (Protein, Iron, Copper, Zinc, Vitamin A, Vitamin C and Calcium), in addition to quantity of the food groups (x_i).

$$\sum_{i=1}^{7} a_i x_i > r_j \qquad (3)$$

Equation 4 represents the four nutrients which are currently overconsumed: Energy, Sodium, Non-milk extrinsic sugars (i.e. free sugars) and fat.

$$\sum_{i=1}^{4} a_i x_i < r_j \qquad (4)$$

The GHG constraints are obtained through first running the diet model in order to estimate a diet. After this estimation, the next stage required decreasing the baseline carbon emissions until no solution could be found for the diet model. The carbon emission scenarios are shown in Table 10 of the appendix and the maximum reduction of 65 per cent (relative to the demographic baseline diet) were used based on the findings of Green et al (2015).

The quadratic diet models were estimated in Excel using VBA.

4.2 Assessing diet quality of the sustainable diets

As the diet models include eleven nutrient constraints, the overall effect constraining diets to meet the DRVs of these nutrients must also be assessed in order to understand the effects on nutritional diet quality. The Mean Adequacy Ratio (MAR) and Mean Excess Ratio (MER) developed by Vieux et al (2013) allow for assessing nutritional quality of diet. The MAR estimated the percentage of mean daily intake of 17 beneficial nutrients[1] with a value of 100 representing a diet which meets all of the nutritional requirements and a value less than 100 representing a diet which does not meet all the DRVs (2013). Equation 5 represents the estimation of the MAR whereby the intake of beneficial nutrients (*bn*) is weighted by the Dietary Reference Values (DRV) and is scaled by the number of nutrients used (in this case 17).

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[1] Protein, Calcium, Magnesium, Iron, Copper, Zinc, Vitamin A, Thiamin, Riboflavin, Niacin, Vitamin B6, Vitamin B12, Folate, Vitamin C, Iodine, Selenium and Fibre

$$MAR = \frac{1}{17} * \sum_{bn=1}^{17} \frac{intake_{bn}}{DRV_{bn}} * 100$$

5

The MER estimated the mean daily maximum recommended intake of three nutrients (Sugars, Saturated fats and Sodium) which is shown in equation 6 (harmful nutrients- *hn*) and are consumed in excess quantities. A value greater than 100 suggests excess consumption of these nutrients (Vieux et al., 2013).

$$MER = \left[\frac{1}{3} * \left(\sum_{hn=1}^{3} \frac{intake_{hn}}{DRV_{hn}} * 100\right)\right] - 100$$

6

5. Results and Discussions

This section discusses the results of the diet models with the initial focus on overall emission reductions as shown in Table 6. This is followed by a discussion of the reasons for the resulting quantities of the diet model as shown in Table 7.

The results of the diets in terms of carbon emissions indicate that the largest reductions of 45 per cent (relative to baseline) are possible for the males aged 50 Plus and males aged 19 to 50. It should be highlighted that these demographic groups did have the largest baseline carbon emissions and this outcome is likely to be welcomed by policymakers. Whilst the resulting diets are not as varied as those of Green et al (2015), the reduction in emissions for males aged 19 to 50 is very similar to the Green et al (2015) result of approximately 40 per cent reduction in adult males.

The lowest emission reductions of 10 per cent is attributed to the females aged 11 to 14 group. This group's relatively small reduction in emissions is largely a result of the baseline diet being relatively low in carbon emissions.

Table 6 Reductions in emissions associated with diets

Demographic Group	Baseline (Kg CO_2e)	New emissions (Kg CO_2e)	Emissions reduction Scenario (%)
Female 11-14	3.33	2.99	10
Male 11-14	3.76	2.63	30
Female 15-18	3.47	2.95	15
Male 15-18	4.44	2.89	35
Female 19-50	3.97	2.78	30
Male 19-50	5.27	2.90	45
Female 50 Plus	3.89	2.33	40
Male 50 Plus	5.08	2.80	45

Sources: Own elaborations

If the results of the diet model shown in Table 7 are compared to the baseline diets of Table 4 and Table 5, there is less variety in terms of the resulting food groups. With regards to the grains based group (products like bread and cereals) most of the demographic diet model results do not exceed the third quartile of the baseline diet for any of the groups. The exceptions to this are for all the demographic groups regarding the consumption of "Vegetables and vegetable products". However, it should be stressed that this vegetable group contains a wide variety of vegetable based products ranging from meals such vegetable curries to actual vegetable products such as carrots. Therefore, the resulting quantities do not only consist of vegetable products such as carrots but also of whole meals.

There a two reflections on the vegetable based group, which help to justify this result, firstly vegetable based products contain many important nutrients and are usually low carbon emission based, thus the diet model will select these groups. The final point is the own price elasticity (as shown in Table 9 of the Appendix) of the vegetable group is inelastic relative to other food groups such as processed meats and fish (the initial budget is similar) for all the demographic groups.

There may be concern that the diet models returns zero grams of the fruit group for all the demographic groups. However, this is likely as most of the nutrients selected for this study appear in higher quantities for the vegetable based group (shown in Table 3). Therefore this helps to explain from a nutritional perspective why fruit does not appear in the study. With regards to the consumer preference perspective, the own price elasticities for the vegetables are relatively inelastic when compared to those for the fruit group for all demographic groups (except Males 19-50 where fruit own price elasticity is not statistically significant). In addition to this, the budget share of the two groups is relatively small but similar. Therefore the vegetable own price elasticities created a larger preference weight in the quadratic programme when compared with fruit.

The results of all the models showed zero consumption for the Beef, veal and lamb group and are likely due to the high carbon emissions. Also the own price elasticities within the different demographic groups were relatively more elastic for the meat group relative to the other groups. The exceptions were: Males 50 plus where cheese had a slightly higher value, Males 19 to 50 where meat were not statistically significant and females 19 to 50 whereby the pork group had a slightly higher value.

The results also indicate that for the diet models of the respective demographic groups, milk products (Milk, dairy products and milk product imitates) would form part of the resulting sustainable diet. The likely reasoning behind this, is firstly milk products have a relatively smaller carbon content compared to cheese. The nutrients which are dominant in milk such as Calcium are also found in cheese (as shown in Table 3), yet the currently overconsumed nutrients such as saturated fat (thus contributing towards overall fat) and sodium are found in larger quantities in the cheese group compared to the milk group. With regards to the consumer preference perspective, the own price elasticities for the cheese group are relatively more elastic when compared to those for the milk group for all demographic groups (except Males 19-50 where the cheese group own price elasticity is not statistically significant and Males 50 plus where milk is not statistically significant). In addition to this the budget share of the two groups are relatively small but similar. Therefore the milk own price elasticities create a larger preference weight in the quadratic programme when compared with cheese.

Table 7 Green et al Diet model results

Food group	Female 11-14	Male 11-14	Female 15-18	Male 15-18	Female 19-50	Male 19-50	Female 50 Plus	Male 50 Plus
Grains grain-based products	306.89	237.64	303.19	323.23	0.00	0.00	0.00	81.87
Vegetables and vegetable products	985.22	505.64	891.59	480.10	1599.02	1007.88	1132.60	759.92
Starchy roots, tubers, nuts and oilseeds	0.00	0.00	44.02	0.00	0.00	0.00	0.00	0.00
Fruit, fruit products and fruit and vegetable juices	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Beef, veal and lamb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pork	21.33	0.00	0.00	0.00	0.00	161.20	26.68	0.00
Poultry, eggs, other fresh meat	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Processed and other cooked meats	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fish and other seafood	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Milk, dairy products and milk product imitates	194.21	726.73	222.10	845.39	42.70	306.66	188.38	934.88
Cheese	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sugar and confectionary and prepared desserts	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Soft drinks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tea, coffee, cocoa, and drinking water	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Snacks and other foods	81.60	138.18	138.18	14.60	137.32	138.18	138.19	138.17
Residual category	0.00	0.00	0.00	18.19	0.00	0.00	0.00	0.00

Source: Own elaborations

With regards to the MAR, it can be shown that only three age demographic groups (Female aged 19 to 50, Male aged 19 to 50 and Female aged 50 plus) experience a relatively small reduction or no change. The other groups experience an increase in MAR ranging from two percent to eleven percent which is considered beneficial. It should be stated that none of the resulting MARs equal 100 which suggests that the resulting diets whilst largely offering an improvement in terms of nutritional quality, do not equate to all DRVs being met. There is a strong possibility that studies which estimated the sustainable diet using linear programming would likely meet a MAR of 100. Though linear programming does not incorporate consumer preferences hence not meeting the Drewnowski (2017) domains of a sustainable diet.

The MER offers a very different perspective whereby all age demographic groups experience relatively large reductions. This may be considered beneficial though the large reductions equate to some nutrients being consumed in quantities which are in some cases nearly half of the respective DRVs.

Table 8 Mean Adequacy Ratio (MAR) and Mean Excess Ratio (MER) Results

	MAR Baseline Diet	MAR Sustainable Diet	Percentage Change MAR	MER Baseline Diet	MER Sustainable Diet	Percentage Change MER
Female 11-14	84	94	11	132	57	-56
Male 11-14	90	99	10	148	76	-48
Female 15-18	83	92	10	134	73	-45
Male 15-18	91	96	6	155	45	-71
Female 19-50	89	88	-2	141	56	-60
Male 19-50	95	95	0	174	71	-59
Female 50 Plus	92	90	-1	138	62	-55
Male 50 Plus	95	97	2	161	73	-55

Source: Own elaborations

6. Conclusions

Diet modelling is challenging given that economic consumer behaviour modelling tends to focus on households whilst nutrition focusses on populations of demographic groups. However, this study has estimated demand systems at demographic age group level in order to improve the diet models. The results of the Green et al (2015) diet model suggest that more nutritious and lower carbon emission diets are possible for all demographic groups. The carbon emission reduction scenarios indicate that the largest reductions of 45 per cent (relative to baseline) are likely for the Male 50 Plus and Males 19 to 50 groups. Whilst the lowest emissions reduction of 10 per cent are attributed to the female 11 to 14 group. The latter group's relatively small reduction in emissions is largely a result of the group's baseline diet (in terms of low carbon emissions) being relatively low.

The results indicate that for most age demographic groups only four of the food groups need to be consumed for the selected DRVs (and carbon emissions to be reduced) to be met. It should be remembered that food groups such as vegetables encompass a variety of different products ranging from complete meals to individual vegetables. The resulting diets do result in consumers having to alter their diet by large measures as some food groups should have zero consumption. However, the weighting of the diet model (i.e. quadratic programme) using the budget shares and own price elasticities does at least incorporate partial consumer preferences which makes the resulting diets more realistic relative to a linear programme-based diet.

The resulting diets largely offer an improvement in the mean adequacy ratio (MAR) which suggests that diet nutritional quality will improve. However, none of the age demographic groups meet all of the dietary reference values (DRVs) hence no group has a MAR of 100. The very large decreases in the mean excess ratio (MER) do suggest that currently overconsumed nutrients would decrease to a larger extent than the actual respective DRVs, this may not necessarily be positive considering that DRVs should be fully met.

Whilst modelling more food groups may initially appear advantageous, the NDNS main food group codes make this a difficult task. Future work could consider disaggregating these codes though specialist knowledge from a nutritionist would likely be required in order to ensure future food groups are categorised by similar food characteristics such as nutrients.

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Appendix

Table 9 Own price elasticities of the demographic groups

Food group	Female 11-14	Male 11-14	Female 15-18	Male 15-18	Female 19-50	Male 19-50	Female 50 Plus	Male 50 Plus
Grains grain-based products	-0.21	-0.15	-0.14	0	-0.18	-0.32	0	-0.14
Vegetables and vegetable products	-0.60	-0.46	-0.23	-0.81	-0.14	-0.32	-0.33	-0.36
Starchy roots, tubers, nuts and oilseeds	-0.27	-0.27	-0.40	-0.41	-0.27	-0.19	0	0
Fruit, fruit products and fruit and vegetable juices	-1.14	-1.26	-1.29	-1.50	-0.94	0	-0.60	-0.97
Beef, veal and lamb	-1.73	-1.74	-1.73	-1.74	-1.74	0	-1.72	-1.70
Pork	-1.69	-1.68	-1.73	-1.71	-1.76	0	-1.66	-1.72
Poultry, eggs, other fresh meat	-0.55	-0.59	-0.61	-0.60	-0.49	0	-0.44	-0.59
Processed and other cooked meats	-1.51	-1.39	-1.60	-1.46	-1.56	0	-1.58	-1.47
Fish and other seafood	-1.64	-1.65	-1.69	-1.65	-1.51	0	-1.34	-1.38
Milk, dairy products and milk product imitates	-0.98	-1.19	-0.87	-1.53	-0.29	-0.08	-0.76	0
Cheese	-1.76	-1.74	-1.72	-1.70	-1.73	0	-1.68	-1.72
Sugar and confectionary and prepared desserts	0	0	0	0	-0.11	-0.12	-0.34	-0.35
Soft drinks	-1.36	-0.94	-1.26	-1.31	-1.35	0	-1.35	-1.46
Tea, coffee, cocoa, and drinking water	0	-0.11	-0.26	-0.26	-0.60	0	-0.66	-0.65
Snacks and other foods	-0.54	-0.43	-0.78	-0.96	-0.70	0	-0.37	-0.71
Residual category	-0.18	-0.08	-0.37	0	-0.75	-1.16	-0.87	-0.87

Notes: Non-statistically significant price elasticities are designated by “0”

Table 10 Emission reduction scenarios for the demographic groups

Emission reduction scenarios	Female 11-14 (Kg CO_2e)	Male 11-14 (Kg CO_2e)	Female 15-18 (Kg CO_2e)	Male 15-18 (Kg CO_2e)	Female 19-50 (Kg CO_2e)	Male 19-50 (Kg CO_2e)	Female 50 Plus (Kg CO_2e)	Male 50 Plus (Kg CO_2e)
Baseline 0%	3.33	3.76	3.47	4.44	3.97	5.27	3.89	5.08
5%	3.16	3.57	3.30	4.22	3.77	5.01	3.69	4.83
10%	2.99	3.38	3.12	4.00	3.57	4.74	3.50	4.57
15%	2.83	3.19	2.95	3.78	3.37	4.48	3.30	4.32
20%	2.66	3.01	2.78	3.56	3.17	4.21	3.11	4.07
25%	2.50	2.82	2.60	3.33	2.97	3.95	2.92	3.81
30%	2.33	2.63	2.43	3.11	2.78	3.69	2.72	3.56
35%	2.16	2.44	2.26	2.89	2.58	3.42	2.53	3.30
40%	2.00	2.25	2.08	2.67	2.38	3.16	2.33	3.05
45%	1.83	2.07	1.91	2.44	2.18	2.90	2.14	2.80
50%	1.66	1.88	1.74	2.22	1.98	2.63	1.94	2.54
55%	1.50	1.69	1.56	2.00	1.78	2.37	1.75	2.29
60%	1.33	1.50	1.39	1.78	1.59	2.11	1.56	2.03
65%	1.16	1.32	1.21	1.56	1.39	1.84	1.36	1.78

Sources: Based on own elaborations

Sources of dietary reference values

The sources of the nutrients listed in Table 11 are detailed in this section with the letters in the brackets of each nutrient denoting the year 6 National Diet and Nutrition Survey (NDNS) databank name. All the sources were based on dietary reference values (DRV) which were provided for in absolute form, except for total fat whereby the absolute value were estimated based on guidelines as detailed in this section.

Table 11 Dietary reference values for demographic groups

Nutrients	Female 11-14	Male 11-14	Female 15-18	Male 15-18	Female 19-50	Male 19-50	Female 50 Plus	Male 50 Plus
Energy (KJ)	9100.00	9850.00	10175.00	12575.00	8950.00	11225.00	8300.00	10250.00
Sodium (mg)	1600.00	1600.00	1600.00	1600.00	1600.00	1600.00	1600.00	1600.00
Free Sugars (g)	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00
Total Fat (g)	67.39	73.13	61.16	90.61	59.13	87.92	54.66	81.06
Protein (g)	41.20	42.10	45.00	55.20	45.00	55.50	46.50	53.30
Iron (mg)	14.80	11.30	14.80	11.30	14.80	8.70	8.70	8.70
Copper (mg)	0.80	0.80	1.00	1.00	1.20	1.20	1.20	1.20
Zinc (mg)	9.00	9.00	7.00	9.50	7.00	9.50	7.00	9.50
Vitamin A (µg)	600.00	700.00	600.00	700.00	600.00	700.00	600.00	700.00
Vitamin C (mg)	35.00	35.00	40.00	40.00	40.00	40.00	40.00	40.00
Calcium (mg)	800.00	1000.00	800.00	1000.00	700.00	700.00	700.00	700.00

Energy (KJ[2]): The main issue of averaging the EAR is that the energy value fluctuates with the most energy required for late teenagers while younger children (regardless of gender) require the least energy.

Sodium (NA): The reference nutrient intake (RNI) for those aged 11 upwards takes on COMA (1991) values in terms of milligrams (mg) which are 1,600 mg.

Free sugars (NMILK)**:** The National Health Service (2017b) suggests those aged 11 plus should consume no more than 30 grams of free sugars per day. It is accepted that free sugars and Non milk extrinsic sugars (NMES) are very similar.

Total Fat (FAT): The absolute values for total fat were estimated using the Scottish Dietary Goals (Scottish Government 2016) “Average intake of total fat to reduce to no more than 35%

[2] As denoted in year 6 NDNS databank

food energy”. One gram of fat provides 37KJ of energy (NHS, 2015). This was estimated using the “food energy (FoodEkJ)” variable from NDNS year 1 to 4 “Person level dietary data” using equation 7:

$$absolute\ fat\ in\ grams = \frac{(0.35 * \ food\ energy)}{37} \tag{7}$$

Protein (PROT): The RNI for protein is listed in the appendix tables and COMA (1991) advise that adults should avoid an intake which is double the RNI for protein.

Iron (FE): The RNI ranges from 8.7 mg/day (7 to 10 year olds) to 14.8 mg/day (Female 11 to 18 years group) (COMA, 1991).

Copper (CU): The RNI ranges from 0.7 mg/day (7 to 10 year olds) to 1.2 mg/day (Both male and female 19 and plus age groups) (COMA, 1991).

Zinc (ZN): The RNI ranges from 7 mg/day (7 to 10 year olds) to 9.5 mg/day (males aged 15 years and plus) (COMA, 1991).

Vitamin A (VITA): The RNI ranges from 500 µg/day (7 to 10 year olds) to 700 µg /day (Male age groups of 15 years and plus) (COMA, 1991). The revisions made to the vitamin A advice did not affect the existing RNI of the vitamin though the report did emphasise “that consumption should not be reduced to levels below the” RNI (SACN, 2005).

Vitamin C (VITC): The RNI ranges from 30 mg/day (7 to 10 year olds) to 40 mg/day (males and females aged 15 years plus) (COMA, 1991).

Calcium (CA): The RNI ranges from 550 mg/day (7 to 10 year olds) to 1000 mg/day (Male 15 to 18 years old) (COMA, 1991). COMA (1991). Despite the RNI nearly doubling for teenagers (relative to the age 7- 10 group) thus affecting the overall average, COMA (1991) have advised that due to body calcium metabolism “overconsumption is virtually unknown”.