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Viewpoint

The embodied energy of food: the role of diet

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The provision of food within a developed country requires the expenditure of large amounts of energy. This energy is used within the agricultural, transportation and retail sectors. Much of this will be energy derived from fossil fuels, implying a potential environmental impact. By using food consumption data from 2197 individuals an estimate is made of the width of the distribution of embodied energies for typical U.K. diets. The mean of this distribution is found to be surprisingly large, as is the standard deviation, indicating the potential for significant reductions in fossil-fuel-related greenhouse gas emissions by simple changes in diet.

Keywords: Embodied energy; Food; Global warming

Introduction

The production of food for the human population requires large amounts of energy. Some of this energy is naturally occurring and is required to fuel the bio-chemical processes within the relevant plant or animal; however, additional energy is required for the production and application of agricultural chemicals and the transportation, processing, retail and preparation of the food item in question. This second category of energy expenditure is likely to contain inputs from fossil-fuel sources and can therefore be connected with emissions of gases linked to global climate change. The amount of energy required by this anthroprogenic category is termed the embodied energy of the food, and ignores the calorific value of the product. The embodied energy differs not only between food items themselves but also between differing agricultural methods, transportation distances and other factors used in the production of otherwise identical items.

The origin of the embodied energy in a food, and thus the environmental damage caused by such energy expenditure, will depend firstly on the processes that were used in the production of the item, but also on the mix of fuels and processes used to produce the energy itself. Thus, just as in the case of products such as aluminium and other items, the environmental damage will vary between regions (see, for example, Bretz and Fankhauser, 1997; Erickson *et al*, 1996; Edwards and Schelling, 1996). This will be reflected in differing emission factors for similar items. Very little work appears to have been carried out on how the county of origin and the general energy mix within each country, together with the mix used within the relevant agricultural, industrial and retail conduits varies across the globe for common dietary items. However, the Dutch National Research Programme on Global Air Pollution and Climate Change have produced a database of energy intensities (in terms of MJ per Dutch Florin) for many common items found in a typical Western European diet (Biesot and Moll, 1995). The Dutch study related the energy used in the production of a product to household expenditure on that product, and analysed the result in terms of income group. At the core of this work was a list of energy intensities for the majority of household terms (and services) not just food.

In the work presented in this paper, the potential for reducing the average embodied energy of the U.K. diet is studied. This is done, not by considering direct changes in agricultural practices—such as restrictions on fertiliser use—nor by implementing direct changes in retail practice—such as planning restrictions on out-of-town shopping—but by encouraging direct dietary substitution of various items. This is achieved without a reduction in the calorific value of the diet. At the heart of the work is the estimation of the embodied energy content of 2197 real U.K. adult diets recorded over a single week. The diets themselves were taken from the Dietary and Nutritional Survey of British Adults 1986–1987 (Gregory *et al*, 1987). By extracting the amounts of each food in each individual diet, and using the results of Biesot and Moll (1995) and Vringer and Blok (1995) the embodied energy of each of the 2197 individual diets was estimated. In order to do this, the original energy intensity data had to be reduced to embodied energies expressed in units of MJ/kg. This embodied energy is the total energy used to produce 1 kg of final product. It encompasses the direct and indirect energy used in the production, transportation and retailing of the product. It is calculated over the entire life cycle of the product; including production, trade and waste disposal (see Engelenburg *et al*, 1994, for details). In the figures used here, it does not include the energy used in the preservation and preparation of the food within the household. As mentioned previously, the value used also does not include the calorific value of the food, nor the naturally provided energy source used by the bio-chemical processes during growth; for example solar energy used by photosynthesis within a plant.

If the average embodied energy of a population's diet can be reduced then it is axiomatic that the resultant level of fossil-fuel-related greenhouse gas production from the population will also fall, assuming the energy mix of this economic sector is largely unaffected. It is important that any such reduction does not impact negatively on the nutritional value of the diet.

Method

Using the energy intensities, quoted in MJ/Df1, in the appendix of Biesot and Mull (1995), the energy intensity in units of MJ/£ was calculated by assuming an exchange rate of 2.69 DFl:£. The embodied energy I_i of each food item i was then calculated using

$$I_i = A_i C_i$$

where A is the energy intensity in units of MJ/£ and C the cost in £/kg.

In order to do this, the British diets were placed into context with the Dutch work by matching the individual items of each diet to their nearest Dutch equivalent. The mass of each item consumed per year was found simply by multiplying the weekly consumption (in kg) given by Gregory *et al* (1987) by 367.25/7 to give the annual consumption. The embodied energy, E_i, of one year's consumption (in units of MJ/person/annum) of any food item i is then given by

$$E_i = M_i I_i$$

where M_i is the mass of i consumed per person per annum.

The total energy requirement, T_d, of each diet d is then given by the summation:

$$T_d = \sum_{i=1}^{n} E_i$$

where the summation is carried out over all 85 food items in the study.

Results

The values of T_d estimated are likely to be far from precise. Along with all the more usual reasons for inaccuracies in embodied energy figures, inaccuracies arise here because the original energy intensities reflect Dutch, rather than U.K., agricultural and retailing practice. However, Holland and the U.K. are both geographically and culturally similar by international standards, implying that errors form this source will not be large.

Along with I_i, the appendix lists the embodied energy, I_i' for all i, expressed in terms of the embodied energy required to produce one dietary MJ (i.e. the ratio MJ(embodied)/MJ(food)). The results show that coffee has the highest value of I_i' and soft margarine the lowest. Figure 1 shows the frequency distribution of T_d drawn from all 2197 diets. It is believed (Gregory *et al*, 1987) that there is good general agreement between the dietary sample used and the U.K. adult population as a whole. Therefore, Figure 1 should be representative of the U.K. as a whole. The mean value of T_d is found to be 17.9 GJ/annum, with $\sigma = 6.6$ GJ/annum. Assuming a normal distribution, this implies that 68% of the adult population have diets with values of T_d in the range 11–24.5 GJ/annum. This is not a small range. Some of the variance can be explained by the differences in the amount of food consumed by various individuals. To avoid this bias, each value of T_d can be divided by the calorific value (in MJ) obtained from the diet to give the normalised dimensionless ratio T_d' (Figure 2). The mean value of which is 5.75. This implies that on average for every MJ of dietary energy obtained from the food 5.75 MJ needs to be expended. Most of this addition will be from the use of fossil fuels. This indicates, as has been noted before (Green, 1987) that modern food supply is in many ways a means of converting fossil fuels to edible forms.

Figure 2 contains a broad spread of values ($\sigma = 1.37$) and indicates that there might be great potential for reducing the total embodied energy of the source. Whether such reductions are realistically achievable is another question. As yet, we have been unable to pinpoint exactly what it is about certain diets, or food items, that lead to such a range in T_d'. Initial investigations indicate that the problem is a complex one with several interconnected factors. The question will require answering in some detail before recommendations could be made to individuals themselves and an estimation of the likelihood of success of any such campaign estimated.

Using published emission factors an estimate of the fossil-fuel-related CO_2 emissions implied by these embodied energies can be made. The assumption here is that the emission factors used accurately represent the energy mix used to produce the food items in question. On

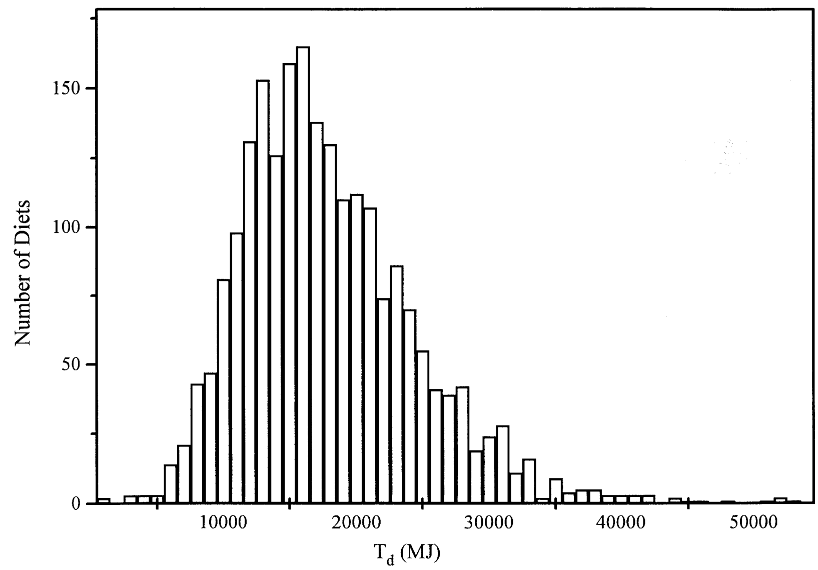

Figure 1 Frequency distribution of T_d, the embodied energy of individuals' diets

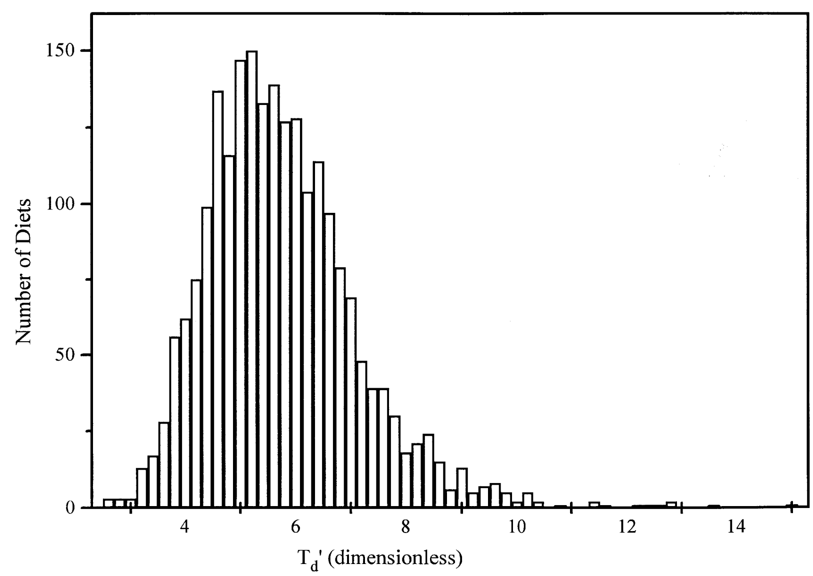

Figure 2 Frequency distribution of T'_d, the embodied energy of the diet divided by the dietary energy of the diet

average this is likely to be so. However, such an assumption is unlikely to be realistic for individual food items. Hence, it would be unwise to attempt to create a list of emission factors for individual foods in this way. Using a CO_2 emission factor of 0.0143 kg(C)/MJ (Government Statistical Service, 1996) implies that a food consumption within the U.K. is responsible for approximately 14.8 Mt(C) of CO_2 annually.* This is 9.9% of the U.K. total (Government Statistical Service, 1996), although, for imported items, some of this will have been emitted outside the U.K.

Conclusion

The range in values of embodied energies for typical U.K. diets has been estimated. This range is surprisingly broad which, together with the large mean, indicates that there is the potential to make savings in energy expenditure form this source. These savings are realisable without individuals being requested to consume less, but simply to switch consumed items. Nor is the need for government led changes to agricultural, transportation or retail practice implied. All changes can be made at the individual level. In order to allow this to happen the

*Assuming a U.K. population of 57.82 million (Redfurn and Brown, 1996). This value is most probably an over-estimate because of the lower consumption patterns of children and the elderly.

production of guidelines on individual food items will be required.

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Appendix

The following table lists the embodied energy (I_i) in MJ/kg together with the dimensionless ratio I'_i for the 85 food items used in the study. The reference numbers are those used in Biesot and Moll, and Gregory *et al*, respectively.

Table A1 Embodied energy (I_i) in MJ/kg of the food items considered, together with the dimensionless ratio I'_i

Food item	British reference	Dutch reference	I (MJ/kg)	I' (dimensionles)
Coffee	51A	113500	3.7	176.85
Tomatoes	36B	111510	35.07	49.28
Other salad vegs	36C	111520	54.59	44.97
Other whitefish and dishes	34B	117100	151.25	36.13
Tea	51B	113600	0.64	31.81
Green beans	37B	111310	32.21	30.78
Fortified wine	48B	114120	145.13	26.26
Canned fruit in juice	40D	112700	31.11	23.22
Other fruit	40R	112400	33.66	21.74
Diet soft drinks	46A	114030	17.55	19.97
Wine	48A	114120	62.4	19.88
Whole-grain and hi-fibre cereals	5R	110000	25.43	18.41
Cottage cheese	14A	118600	75.18	18.33
Shellfish	34A	117500	76.23	16.41
Fresh tomatoes (not raw)	37F	111510	35.07	15.51
Cider and perry	49R	11430	37.97	15.12
Other veg	37R	1111	49.02	14.64
Spirits	47B	114200	121.46	13.07
Fried whitefish in flour, batter, breadcrumbs	3R	117310	111.72	12.59
Canned fruit in syrup	40E	112700	31.11	12.18
Apples and pears	40A	112000	23.05	11.24
Liquers	47A	114200	121.46	10.4
Oranges, tangerines	40B	112200	14.26	10.02
Fruit Juice	45R	114020	14.64	9.99
Other soft drinks	46B	114030	17.55	9.98
Baked beans	37C	111710	32.99	9.98
Sausages	30R	116800	108.63	9.83
Savoury snacks	42R	112810	187.78	9.38
Carrots (cooked)	37E	111410	9.3	9.26
Leafy green veg	37D	111130	10.06	8.9
Coated chicken	26R	116920	88.33	8.72
Yoghurt	15R	118100	29.97	8.63
Liver and dishes	28R	116300	60.48	7.85
Beef, veal and dishes	23R	116000	101.13	7.74

Table A1 *continued*

Food item	**British reference**	**Dutch reference**	***I* (MJ/kg)**	***I′* (dimensionles)**
Burgers and kebabs	29R	116920	88.33	7.4
Oily fish (inclu. canned)	35R	117300	64.78	7.37
Other cheeses	14R	118600	101.34	6.98
Unsalted nuts, fruit and nut mixes	40F	112810	64.82	6.85
Chicken and turkey dishes	27R	117020	44.89	6.83
Carrots	36A	111410	9.3	6.73
Other puddings	9D	1105	83.47	6.49
Peas	37A	111300	21.59	6.37
Meat pies and pastries	31R	1166	102.57	6.23
Pork and dishes	25R	116100	107.37	6.23
Skimmed milk	12R	118000	8.33	6.03
Lamb and dishes	24R	1160	101.05	5.86
Other meat & meat dishes	32R	116800	49.06	5.83
Eggs	16R	118700	57.82	5.8
Bacon and ham	22R	116700	63.65	4.41
Semi-skimmed milk	11R	118000	8.33	4.33
Sponge type puddings	9C	1105	60.66	4.26
Preserves	41B	112500	34.24	4.26
Buns, cakes and pastries	8R	1105	60.66	3.91
Pasta	1A	1107	13.6	3.57
Fruit pies	8A	1105	34.94	3.34
Other milk and cream	13R	118400	34.37	3.34
Milk puddings	9A	118200	16.82	3.16
Misc	50R	1196	16.89	2.99
Rice	1B	110720	17.22	2.94
Low fat spread	19R	115	46.2	2.83
Whole milk	10R	118000	7.14	2.58
Biscuits	7R	1105	49.38	2.54
Other breakfast cereals	6R	110100	37.04	2.45
Bananas	40C	112300	9.25	2.33
Other	21R	115100	24.52	2.15
Chocolate confectionary	44R	1133	42.73	2.11
Other potato products	38R	1110	6.94	2.1
Other potato	39R	1110	6.94	2.1
Butter	17R	118500	54.68	1.77
Other	1R	110	17.44	1.67
Other sugars	41R	113	22.62	1.4
Block margarine	20R	115000	37.54	1.21
Sugar	41A	113000	15.4	1.16
Yellow spreads	21B	115	35.99	1.16
Other fried or roasted potatoes	38B	1110	6.94	1.08
Wholemeal bread	3R	110000	9.48	1.05
Other breads	4R	110200	11.6	1.03
Sugar confectionary	43R	113200	13.02	0.89
Polyun margarine	18R	115000	26.15	0.85
Potato chips	38A	1110	6.94	0.79
White bread	2R	110100	7.75	0.79
Ice cream	9B	119500	2.72	0.32
Soft margarine not polyum	21A	115000	4.01	0.13
Water	51R	114010	0	0