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Localisation of UK food production: an analysis using land area and energy as indicators

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Abstract

A variety of policy strategies have been proposed and argued as capable of delivering more sustainable food systems, and accompanying indicators have been developed to analyse the implications of these strategies for specific situations. This paper focuses on the policy strategy suggesting that localisation of food production leads to more sustainable societies. A case study of UK food production, and imports and exports of foodstuffs, is presented to explore the feasibility of operationalising this strategy, using land area and energy use as indicators. Novel features of the method used in the case study include: analysis at country level in specific foodstuff categories, and use of actual data on production and consumption of foodstuffs. The results show that, based on the land use indicator, localisation of UK food production is possible, although this would involve considerable changes in individuals' food consumption patterns. However, would implementation of such a strategy actually contribute to a more sustainable society? Using the indicators of land area and energy use, this question cannot be answered without additional consideration of the trade-offs between the UK and other countries in yields from equivalent crops, and energy requirements for agricultural production.

Keywords: UK food production; Localisation; Sustainable development

1. Introduction

Over the last 50 years there has been a major increase in the level of world trade: the 1997 level was fourteen times that of 1950 (WTO, 2000). This increase has been driven by steadily increasing liberalisation of the global economy, driven mainly by the General Agreement on Tariffs and Trade (GATT) and its successor, the World Trade Organisation (WTO). However, more recently there has been growing concern among a diverse range of citizens at this globalisation trend.

One trade sector where the benefits and disadvantages of the globalisation trend are actively being debated is that of food production and consumption. On the one hand, it can be argued that globalisation of food systems is beneficial to society as it encourages competition and so drives down the price of foodstuffs, and gives consumers greater choice at their food stores. However, on the other hand, it can be criticised because it reduces the food security of countries; increases the potential for exploitation of both the environment and human labour through minimising consumers' awareness about the upstream impacts of their food purchasing habits ("out of site, out of mind"); and contributes to a variety of transportation-related environmental impacts (for example, increased use of non-renewable resources, and global

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warming and photochemical smog formation due to emissions of pollutants). The alternative is localisation of food systems (where food consumed in a given country has been produced within that country). The emphasis here is upon reducing the distances between locations of food production and consumption.

In this paper, this globalisation/localisation debate is explored using the UK food sector as a focus. Obviously, a comprehensive analysis of this area would be more appropriate for a book than a journal paper, so here the analysis is focused by taking as a starting point the concept of sustainable development and then looking at two physical indicators to give some insights.

Sustainable development was articulated by the Brundtland Commission as development that "meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987). Its central concerns are with intra- and inter-generational equity: intra-generational equity is concerned with activities and their impacts that occur at different geographical locations, and inter-generational equity with activities and their impacts that occur on different time scales. The components of sustainable development can be represented as shown in Fig. 1, illustrating the importance of disciplines as diverse as ecology, economics and sociology in developing a sustainable development perspective.

The two physical indicators chosen for this analysis are land area and energy use. Choice of land area as an indicator is justified based on an argument that, from a sustainable development perspective, land area is a finite resource under increasing demand for alternative uses (see Section 3). Choice of energy as an indicator is justified based on the fact that generation of energy from fossil fuels contributes to a number of environmental impacts, that energy sources other than fossil fuels are still under development, and that these alternative sources are also likely to contribute to various environmental impacts (see Section 3).

The objective of this paper is thus to explore some of the issues surrounding globalisation versus localisation of food systems by analysing the UK food sector and using land area and energy use as indicators. In particular, the paper addresses two main aspects:

- The feasibility of localising food systems for the UK population (because there is little point in exploring localisation of food production as a policy strategy for the UK unless it is—at least theoretically—feasible).
- The trade-offs involved in importing foodstuffs versus local food production in the UK.

The paper begins with an overview of localisation of food systems as a policy strategy (Section 2). The choice to use land area and energy use as indicators in the subsequent analysis is explained in Section 3. In Section 4, the areas of land required for localisation of food production are calculated, alongside the transportation energy required for importing foodstuffs to the UK. The paper continues with a discussion of the

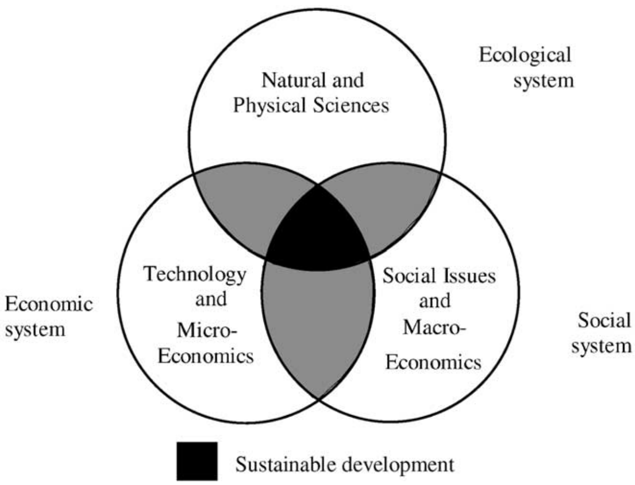

Fig. 1. Components of sustainable development. Source: adapted from Barbier (1987), Cowell et al. (1997).

desirability of localising food production and what it would mean in terms of UK food consumption patterns (Section 5). The conclusions are given in Section 6.

2. Localisation of food production as a policy strategy

Two main lines of argument have been developed in the literature on localisation of food systems as a policy strategy: one is concerned with food security, and the other with sustainable development.

2.1. Food security

Food security is concerned with availability of food and access to this food; it may be limited at any level from an individual within a household up to the global level (Pinstrup-Anderson and Pandya-Lorch, 1995, p. 90). At the national level, Mellanby (1975) published a book entitled "Can Britain Feed Itself?" which explored the ability of the agricultural industry in Great Britain to produce enough food to feed its population. Recommendations were made about agricultural production methods, alternative uses of land, and changes in peoples' diets in order to maximise the self-sufficiency of the country. At the regional and global levels, several land use studies have calculated the ability of different regions of the world to feed themselves under alternative future scenarios (Penning de Vries et al., 1995; WRR, 1995). Such studies are based on a belief that regional self-sufficiency of food production and consumption is more likely to increase the food security of individuals than a globalised food system. Therefore, failure to achieve regional self-sufficiency under any scenario is viewed as problematic and sufficient justification for action. Specific actions explored in the studies include changes in diets, changes in production methods, and changes in the size of the population under study.

2.2. Sustainable development

In the sustainable development literature, regionalisation, or even localisation, of food production and consumption is promoted based on several interconnected arguments:

1. It reduces the environmental impacts associated with transporting foodstuffs long distances. These include use of fossil fuels, and related pollution impacts such as acidification, global warming, and photochemical smog formation.
2. The potential for degradation of the environment and exploitation of human labour is reduced: it is more difficult to adopt an "out of sight, out of mind" attitude when activities are taking place in one's own backyard.
3. It leads to an increased sense of community by building up local networks of producers and consumers.

Such arguments form the basis of the "Food Miles" concept promoted by the UK pressure group, Sustain (Paxton, 1994; Sustain, 1999).

Support for such a strategy has gained ground recently through the success of initiatives such as the National Farmers' Union "New Season for British Food" campaign which encourages consumers to buy locally grown food in season, and farmers' markets. Farmers' markets promote local production for local consumption by making direct links between producers and growers, and the public.

Evidence that localisation is gaining wider acceptance as a general sustainable development strategy can be found in other sectors of the economy. For example, the UK Government's Waste Management Strategy for England and Wales aims to set out the Government's policy for sustainable waste management over the next 20 years. It states that the proximity principle should be used to guide decisions, and that this principle "suggests that waste should generally be disposed of as near to its place of origin as possible" (DETR, 2000). This is in response to growing concern about the use of centralised landfill sites and waste incinerator plants.

Perhaps the most prominent support for localisation as a strategy for sustainable development comes from the Local Agenda 21 initiative, part of Agenda 21 agreed at the UN Conference on Environment and Development (UNCED, also known as the Earth Summit) in 1992. Recent initiatives in this area have led to a "World Charter for Local Self-Government", shortly to become a UN convention (IGFR, 2000).

It is, therefore, timely to reconsider the feasibility and trade-offs involved in a policy strategy of localising food systems for the UK.

3. Use of land area and energy as indicators

In this study, land area use has been selected as an indicator for examining the feasibility of localising food systems in the UK. It has been chosen because demands on land area are increasing with growing populations and growing consumption of material goods by individuals within these populations. Moreover, a more sustainable society implies that renewable resources must be used in place of finite reserves of resources like fossil oil, coal and natural gas. At present, oil, coal and natural gas are the basis of the energy economy, and also provide the feedstock for products ranging from plastics to synthetic textiles to paints. In many cases, their replacement by renewable resources implies growing crops such as short rotation coppice for energy, and oilseeds for plastics, textiles and paints. These will make extra demands on use of land in future, demands currently met by energy and materials derived from biomass which grew millions of years ago. Therefore, the demand for land is likely to be a central issue in defining more sustainable activities in the future.

Energy use has been selected as an indicator because, like land area, it is a fundamental limiting constraint on the human activities concerned with food production and consumption. In the context of sustainable development, the use of energy is a major factor in economic development and also a major contributor to environmental problems such as climate change, acidification, photochemical smog formation, deforestation and loss of biodiversity. A comprehensive analysis of energy use in the food system would require taking into account the full life-cycle of energy consuming activities including production, transportation, storage, preparation and waste management. However, the focus in this paper is on energy use related to transportation since this is a key factor in the globalisation versus localisation debate.

4. Method and results for analysis of land area and energy use

In order to calculate the changes in use of land area in the UK implied by localisation of food production, it is necessary to know the quantities of UK production, and of imports and exports, for different foodstuff categories. These values are presented in Section 4.1. They can then be used to calculate the net area requirements for localised production; the method and results are presented in Section 4.2.

There are several novel features to the approach used in this study compared with the land use studies most closely related to the work presented here (in particular, those by Penning de Vries et al., 1995; WRR, 1995):

- The country level is selected as an appropriate level for this analysis because much policy affecting food production and consumption is developed and implemented at this level of government.
- Rather than using grain-equivalents (GEs) to synthesise data on different foodstuffs, specific categories of foodstuffs produced and consumed are quantified in the analysis. This enables more detailed insights to be gained into the changes in land use and food consumption patterns implied by a greater focus on localisation of food production in the UK.
- Actual data on production and consumption of different foodstuffs are used rather than estimated values. This avoids criticisms about the accuracy of data used in predictive models (see, for example, Döös and Shaw, 1999), and provides a stable basis upon which to discuss alternative strategies for the future.

The purpose here has been to develop a model for exploring some of the implications for individuals and policymakers of implementing a localisation strategy for food production in the UK. In particular, in order to present the results in different foodstuff categories, it has been necessary to develop an approach for dealing with partitioning of land areas between the main products and by-products of some crops and livestock (see Appendix A).

In addition, the energy "credit" associated with avoiding international transport of foodstuffs has been calculated for the UK. The method and results are presented in Section 4.3.

4.1. UK production, imports, exports and consumption of foodstuffs

In order to examine whether the UK might satisfy its food requirements by local production, it is necessary to determine food consumption rates for the UK

Table 1
Food categories used in this study for UK foodstuffs

Food category	Foodstuffs
Cereals and products	Wheat, barley, oats, mixed corn, rye, triticale, rice, other cereals; imported prepared cereals (such as flour, meal, bread and cakes), pasta, malt extract
Vegetables and products	UK-grown and imported vegetables; imported prepared vegetables (dried, flaked, frozen, juice)
Fruit and products	UK-grown and imported fruit (fresh and dried); imported prepared and preserved fruit (peel, juice, frozen); imported sugar cane and products
Nuts, excluding oil nuts	Imported coconuts, brazil nuts, cashew nuts, almonds, hazelnuts, walnuts, chestnuts, pistachios, groundnuts and other edible nuts
Sugar beet and products	Sugar beet not for stockfeeding; molasses; natural honey; glucose/lactose/fructose and their syrups; sugar confectionery, other sugar products
Potatoes and products	Fresh and prepared potatoes
Oilseeds and products	Rapeseed, linseed, soya beans, sunflower seeds, palm nuts and kernals; defatted or wholly/partially refatted flour/meal of oilseeds/oleaginous fruits; margarine
Fodder crops[a]	Oilseed cake/meal; hay; residues from leguminous plants; meat and fish flour/meal/pellets; residues of starch and sugar manufacture; other food wastes and prepared animal feeds; dry peas, field beans, dried beans, maize, turnips/swedes, fodder beet/mangolds, kale, cabbage, savoy, kohl rabi, rape and other fodder crops
Meat	Beef and veal, mutton and lamb, pork, bacon, poultry
Other animal products	Milk, cream, yoghurt, buttermilk, ice cream, whey, butter, cheese, curd; bird's eggs
Fish	Fish, crustaceans, molluscs, other aquatic invertebrates
Beverages[a]	Non-alcoholic (mainly water-based); wine; fermented beverages, beer made from malt; spirits, liqueurs
Tobacco and products	Tobacco and products
Others	Coffee; cocoa, chocolate, other food preparations containing cocoa; tea, mate; spices; mustard/sesame/safflower/cotton seeds; hops; homogenised food preparations; soya and other sauces, mustard, vinegar; soups/broths; yeasts; infant food; other food preparations

[a] These two categories (fodder crops and beverages) do not include all UK production. In particular, fodder crops do not include grass, silage and straw in the absence of data on total quantities produced and consumed in the UK. Beverages do not include UK production because ingredients are already assessed under other categories (for example, the cereals used for brewing and distilling are already accounted for under "cereals and products").

population and the land areas required to produce this food. This has been done using data for 1992 on UK agricultural production (MAFF, 1994a,b; MAFF et al., 1994), and import and export data from the Central Statistical Office (CSO, 1993, 1994), with the exception of meat and meat products where data are from MAFF et al. (1994). The food categories used in the study are listed in Table 1.

For each foodstuff category, the quantity consumed by the UK population, C, was calculated using:

$$C = P_n + I - E - S \quad (1)$$

where P_n is the net production of foodstuff in the UK (i.e. excluding wastage at point of production) (t per year), I the imported food to the UK (t per year), E the exported food from the UK (t per year), and S the increase in farm and other stocks (t per year).

The results are presented in Fig. 2 for total food consumption in the UK. Fig. 2 shows that the UK population in 1992 produced less than it consumed in all the categories except cereals and potatoes (although in meat and other animal products the UK was close to self-sufficiency). Table 2 shows *the self-sufficiency indices*, i.e. the ratios of production to consumption, for each foodstuff category. Other than nuts and tobacco which are not produced on any significant commercial scale in the UK, it can be seen that the UK in 1992 produced the smallest proportion of its own requirements in the categories of "other" foodstuffs (1% of total consumption), followed by fruit (15%) and then sugar (44%). Of course, economic considerations and operation of international markets have an important role in determining these patterns of imports and exports compared with local production. However, other factors are also relevant. In the case of "other" foodstuffs, the small percentage of local production is explained by the fact that the major imports in this category are coffee, cocoa and tea which are not produced in the

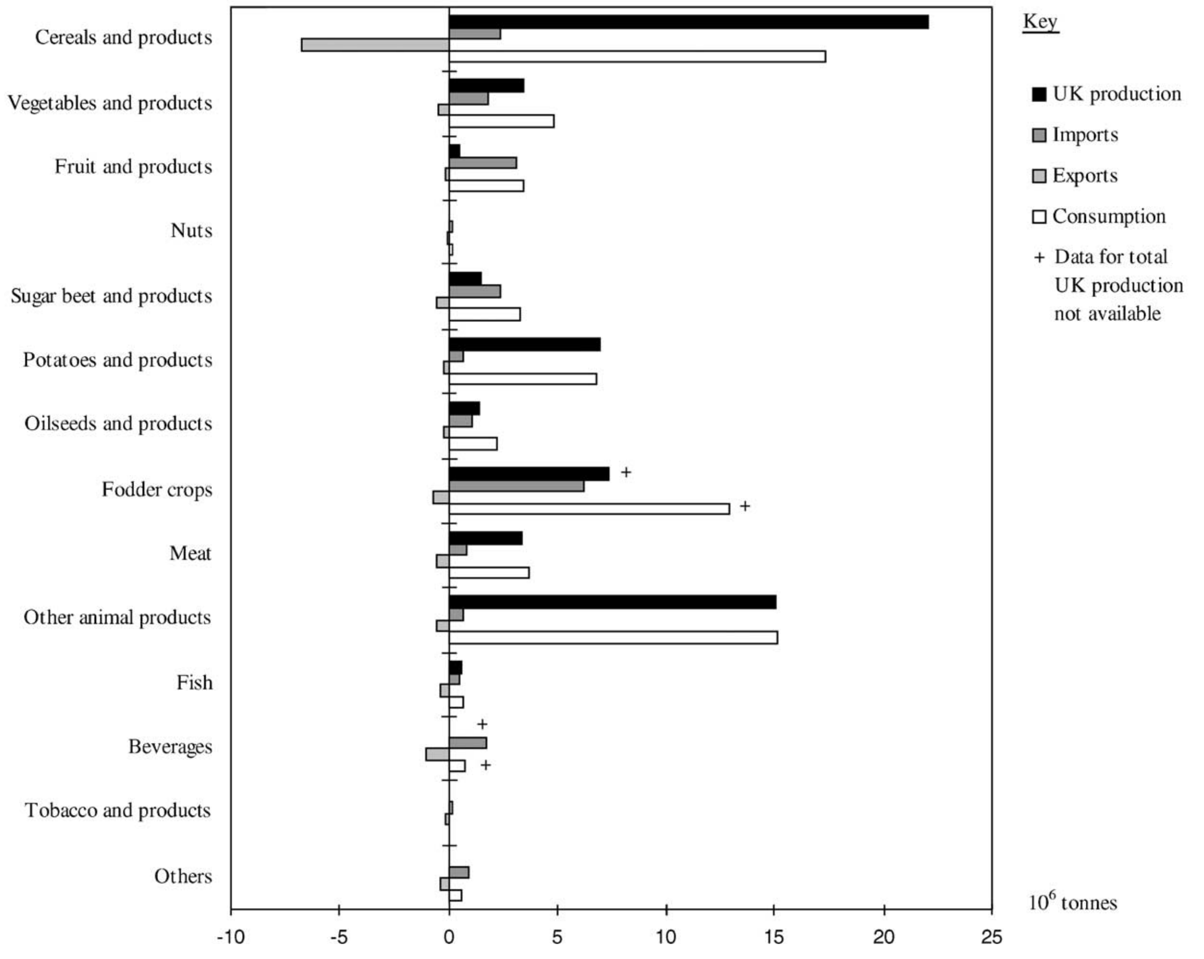

Fig. 2. UK production, imports, exports and overall consumption for different foodstuff categories (1992). Overall consumption calculated using Eq. (1).

UK. For oilseeds, some imported vegetable oils are particularly suitable for manufacturing products such as margarine and ice cream due to their chemical composition. For fruit and vegetables, gaps in fresh local supplies due to seasonality of production partially explain high imports, alongside consumer demands for variety. The issue of consumer choice is raised again in the discussion below (Section 5).

4.2. Area requirements for localised food production

If the UK were to meet its total food requirements by local production, a number of assumptions have to be made about changes in peoples' food consumption patterns. For example, obviously the UK is not suited to growing tropical fruit such as bananas and oranges, and so localised food production would require consumers to switch to locally produced fruits. In these calculations, it has been assumed that imported foodstuffs are replaced by the average range of locally produced foodstuffs in each category. Thus, bananas and oranges are replaced by the average mix of locally produced orchard fruit. For meat and animal products (not seafood), it is assumed that imports are replaced by products from intensive livestock production systems in the UK.

To calculate the area required, *A* (ha per year), to produce a given amount of a foodstuff, the following

Table 2
Self-sufficiency indices[a] for UK foodstuffs (1992)

Foodstuff category	Self-sufficiency index[a]
Cereals and products	1.27
Vegetables and products	0.71
Fruits and products	0.15
Nuts[b]	0.00
Sugar beet and products	0.44
Potatoes and products	1.03
Oilseeds and products	0.63
Fodder crops[c]	–
Meat and products	0.92
Other animal products	0.99
Fish	0.89
Beverages[c]	–
Tobacco[b]	0.00
Others	0.01

[a] Self-sufficiently index is defined as production divided by consumption.
[b] Nuts and tobacco are rated as 0% because these crops are not grown on a commercial scale in the UK (apart from small-scale production of Kentish cobnuts and walnuts).
[c] See footnote in Table 1.

simple equation is used:

$$A = \frac{C}{Y} \quad (2)$$

where C is the consumption of the foodstuff in the UK (t per year) and Y the yield of the foodstuff (t/ha).

Calculation of the yield for animal products is complex, and further details are given in Appendices A and B. A summary of these calculations are given in Table 3. For simplicity, variations in yield have not been considered in this preliminary analysis.

Using this approach, Fig. 3 shows the land requirements for localised food production in the UK, compared with actual use of land in each foodstuff category for 1992. Foodstuffs derived from freshwater and marine environments have been excluded from the study because they do not occupy terrestrial land areas. Fig. 3 shows that, in a situation of localised food production extrapolated from 1992 data, meat and other animal products require the largest land area in the UK, followed by cereals and then oilseeds.

Altogether the *additional* land area required in the UK for localised food production is between 350,000 and 3,020,000 ha. It can be argued that it is likely to be closer to the lower value due to assumptions made about low yields for fodder crops,[1] resulting in high area requirements per tonne of meat and other animal products.

In 1992, there was approximately 17,700,000 ha of land in agricultural production (including rough grazing but excluding land that is not used for crop production on agricultural holdings (such as woodland)) plus 165,000 ha of set-aside (MAFF Statistics, 1996, pers. comm.) and 53,000 ha of bare fallow (MAFF et al., 1994). These data suggest that the additional land requirement for localised food production is in the range from 1 to 16% of total current agricultural land, once set-aside and bare fallow have been brought back into production.

Of course, these calculations assume that yields remain constant with changes in land area under agricultural production. It can be argued that, in fact, yields will decrease as cropped areas are extended onto land less suitable for these purposes. Therefore the additional area requirement is, in practice, likely to be higher than the values calculated above. However, the variation due to different assumptions concerning land required for animal products is very likely to be much greater than the variation due to reduction in yield, therefore this aspect is not considered further in the analysis.

4.3. Energy consumption associated with imports and exports

Localisation removes the need for international transport of foodstuffs with its associated energy consumption. Therefore, localisation can be regarded as resulting in an energy "credit" equal to the energy consumed in transporting the foodstuffs. In practice, for each country, this "credit" will be based on the energy consumed only in the importing of foodstuffs, since it can be argued that a country is responsible

[1] For fodder crops, it is assumed that the average yield for livestock feed is 6 t/ha. This is the average from wheat, hay and oilseed production (7, 7 and 3 t/ha, respectively). However, the main constituents of many livestock feeds are by-products from cereal and oilseed processing (see MAFF Statistics, 1996). These will have a zero or small land area requirement per tonne by-product compared with the main products such as wheat grain and oil. The exact values depend on the method used to allocate the land area between the main product and by-product(s)—for example, oil and meal from oilseed crops, and grain and bran from cereal crops. See Appendices A and B for further details.

Table 3
Summary of main parameter values for calculation of land area requirements for production of animal products (see Appendix B for calculation details)

Livestock type	Area for feed during one breeding cycle, A_a (ha per year)	Number of offspring per female per year, n (per year)	Breeding lifetime, L_b (year)	Yield of meat per animal, y_t (t)	Area per tonne of meat, a_m (ha/t)
Cows	0.85[a]	0.92	5.0	0.36	4.7
Sheep	0.10[b]	1.45	6.0	0.021	3.7
Pigs	0.40[c]	20	2.4	0.072	1.2
Poultry	–[d]	–[d]	1.2	0.0017	0.50

[a] Includes 0.45 ha grazing. In addition, 0.39 ha is required for finishing, and 0.06 ha for maturation of the breeding cow, per offspring.
[b] Includes 0.09 ha grazing.
[c] In addition, 0.06 ha is required for subsequent feeding, and 0.001 ha for maturation of the breeding sow, per bacon pig.
[d] One breeder produces 119 chicks in its lifetime of 448 days. The area requirements are 0.00084 ha for subsequent feeding of broiler, and feeding of the breeder (per broiler).

for the demand for imports rather than exports. The inclusion of both imports and exports for each country in calculations of the total energy consumed in transportation would lead to double-counting.

The energy requirements for transporting foodstuffs from their country of origin to the UK have been calculated for 1992. For each trading partner country (p), the energy required for import, T_p (MJ), is simply

$$T_p = t_e D_p I_p \quad (3)$$

where t_e is the specific energy consumption for food transportation (MJ/t km), D_p the distance between the UK and trading partner, p (km), and I_p the imported foodstuff to the UK from trading partner, p (t).

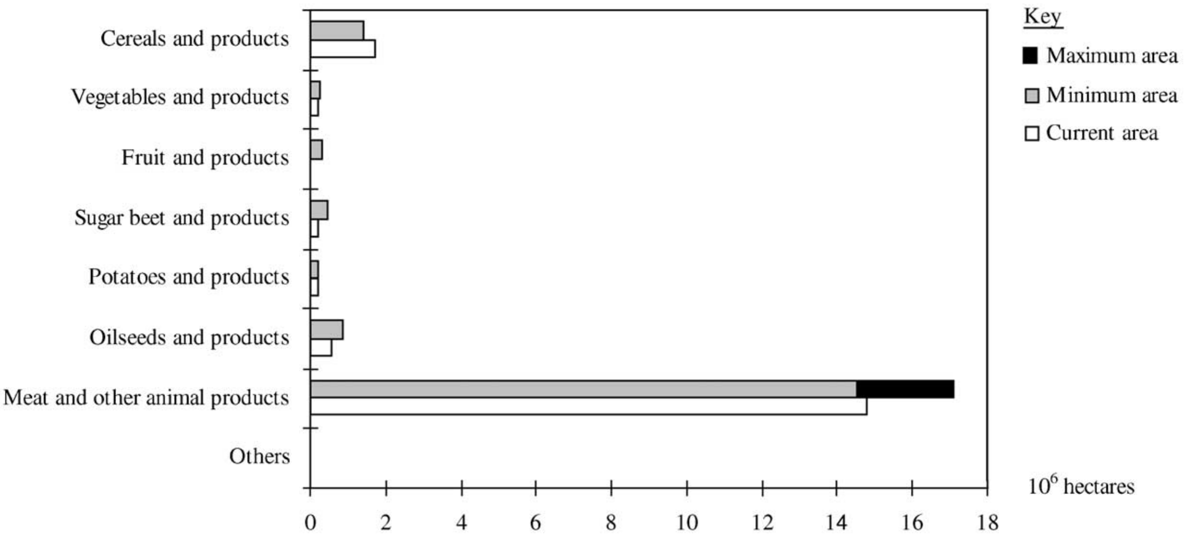

Fig. 3. Total land area requirements for localised food production compared with areas cultivated in the UK (1992). Areas required for meat and other animal products, fodder crops, and cereals used for animal feed have been amalgamated under "Meat and other animal products" because these categories overlap in their area requirements. Requirements for beverages and nuts have also been amalgamated under cereals (for beer and nuts) and fruit (for beverages such as cider and perry). It is assumed that there are no substitutes for imported coffee, tea, mate, cocoa, spices, soya and other sauces (except tomato sauces), mustard, vinegar, wine, spirits and liqueurs, and tobacco; therefore these products are excluded from the calculations. The difference between the minimum and maximum area requirements for meat and other animal products arises from different assumptions made about (a) the areas required to grow fodder crops replacing imported fodder crops, meat and other animal products, and (b) allocation of area between meat and other by-products. A fuller explanation of these assumptions is given in Appendices A and B.

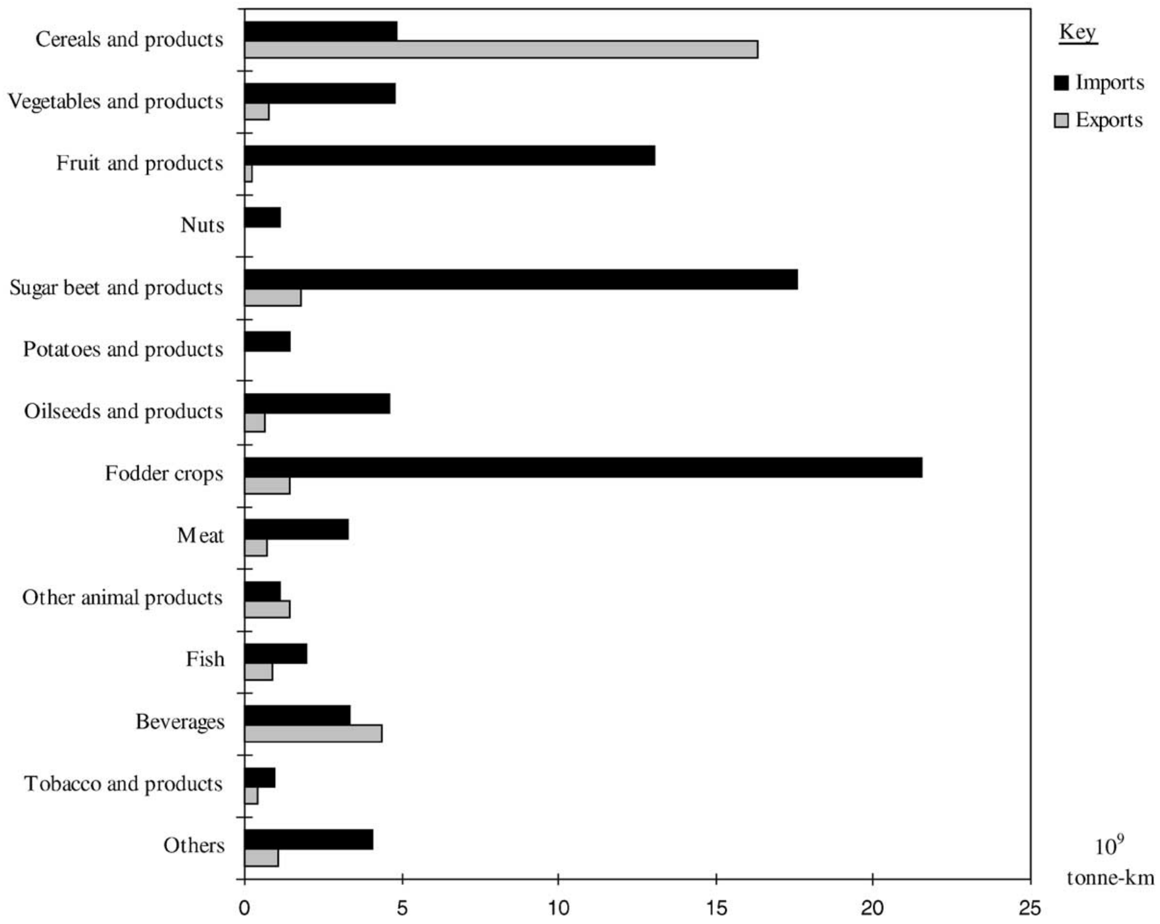

Fig. 4. Import and export distances travelled by different foodstuff categories (1992, tonne-kilometre values).

To explain further how this equation was applied, the discussion is broken into two parts. The first is the derivation of the "tonne-kilometre" values for each foodstuff category, i.e. D_p multiplied by I_p. The second is the issue of specific energy consumption, t_e.

4.3.1. "Tonne-kilometre" values

Fig. 4 shows the tonne-kilometre value for each imported foodstuff category. For comparison, the export values are also shown in this diagram. These values were obtained using trade data on countries of origin and destination listed in the Overseas Trade Statistics of CSO (1993). In this Figure, distances between countries have been measured "as the crow flies" between London and the capital of each importing/exporting country; in other words, the most direct transportation distances. In reality, these distances are likely to be considerably larger because goods are transported via roads, waterways, or sea and air routes that do not provide direct links between countries of origin and destination. However, in the absence of detailed data on transportation modes and routes, these values are used as a conservative estimate. It can be seen that the greatest tonne-kilometre values for imports are linked with fodder crops, mainly concentrates (21,500 million t km), followed by sugar beet and products (17,500 million t km), and fruit and products (13,000 million t km). The greatest tonne-kilometre values for exports are linked with cereals and products (16,000 million t km): these are mainly exports of wheat and barley to the European Community and former USSR.

Table 4
Energy consumed by transportation during the importation of foodstuffs into the UK (1992)

Foodstuff category	Transportation energy for importation (PJ)
Cereals and products	2.9
Vegetables and products	2.9
Fruits and products	7.8
Nuts	0.7
Sugar beet and products	105
Potatoes and products	0.9
Oilseeds and products	2.8
Fodder crops	129
Meat and products	2.0
Other animal products	0.7
Fish	1.2
Beverages	2.0
Tobacco	0.6
Others	2.4
Total	50.3

4.3.2. Specific energy consumption

In order to estimate the specific energy consumption, t_e, i.e. the energy required to transport 1 t of foodstuff by 1 km, information is required about the mode of transportation used. As mentioned above, a variety of modes may be used but, in practice, the bulk of the journeys are likely to be by truck and/or ship. A value of 0.6 MJ/t km has, therefore, been used which is simply the mean of the values for long-distance truck and ocean ship (Tillman et al., 1991; PEMS, 1995). The results are shown in Table 4: it can be seen that localisation of food production for these foodstuff categories results in an energy "credit" of approximately 50 PJ. This primary energy requirement is equivalent to that of a large (approximately 1 GW) power station (based on average values for conversion efficiency (37%) and load factor (53%) for power plants in the UK (DTI, 2000). It is important to note that the energy consumed in the transportation of food within the UK is assumed to be unchanged between the current situation and the localised case.

5. Discussion

Whilst it should be recognised that this is only a preliminary study based on just two indicators, some interesting insights are apparent which are relevant at a broad policy level.

5.1. Land use analysis

The analysis of land area requirements shows that localisation of UK food production would require extra land in addition to set-aside land, equivalent to between 1 and 16% of the area in agricultural production in 1992 (and likely to be towards the lower end of this range—see Section 4.2). In order to calculate this range, assumptions were made concerning certain changes in the UK diet. For example, it was assumed that a mixture of locally produced alternatives would have been substituted for imported tropical fruits and vegetables. It is clear, therefore, that in order for a localised UK agriculture system to meet current food demand, not only would local alternatives need to be found for non-indigenous crops, but some substitution of agricultural products with lower yields by those with higher yields would also needed.

Since plant products can be produced more efficiently (mass per hectare) than animal products for human consumption, a reduction in consumption of animal products in favour of plant products is likely to facilitate the localisation of food production. As an example, meat products have yields as low as 0.2 t/ha (see Table 3), whereas grain yields range from 4.4 to 6.8 t/ha. Further weight is given to this argument by the fact that supplying the current demand for meat and other animal products would require between 82 and 97% of the area used for UK food production in 1992. Moreover, about 50% of the UK consumption of cereals is by livestock (MAFF et al., 1994, 1998). However, on the other hand it must be remembered that many livestock are fed on the by-products of agricultural production and food processing operations, such as straw, oilseed meal and wheat bran (thereby making production of the main product more economic), or grazed on land that is unsuitable for other food production. In these cases, a reduction in the consumption of animal products would not make extra land available for production of other foodstuffs for human consumption.[2] However, in general, it can

[2] It can be argued that such a situation would lead to increased quantities of agricultural waste and degradation of wildlife habitats currently maintained by low intensity grazing regimes (for example, meadows). However, the waste could be useful as biofuel, and meadows could be replaced by forest which has advantages such as timber production and carbon sequestration. Such issues quickly become complex.

be concluded that a reduction in current levels of UK consumption of meat and other animal products could facilitate localisation of food production by replacing some of the crops grown for livestock feed with cereals and horticultural crops for direct human consumption.

So would UK consumers be willing to make such major changes in their diet? On the issue of eating more UK grown produce, a recent survey (MORI, 1999) has found that 74% of the UK public would buy British fruit and vegetables when they are in season, suggesting that some changes in consumption would be welcomed. On the issue of reducing meat consumption, another survey (BBC, 2001) shows that the percentage of vegetarians in the UK has grown to 7%, a doubling in the last 10 years, demonstrating the flexibility over time in peoples' dietary choices.

From a sustainable development perspective, however, one must consider the consequences for other countries in addition to the UK of implementing a policy of localising food production (because sustainable development is concerned with intra-generational equity). More specifically, in the context of this study, the relative land area requirements of equivalent crops grown in different countries should be considered as yields often vary between countries. Therefore, analysis of the desirability of localising food production should be on the basis of total land areas for the production of foodstuffs in countries exporting foodstuffs to the UK compared with production in the UK. This has been outside the scope of the present study but is recognised as a relevant point in refinement of the model.

5.2. Energy use analysis

The next set of points concerns the desirability of localising food production when focusing on energy use rather than, or in addition to, land use. In Section 4.3, the approximate transportation energy "credit" from displacing imports of foodstuffs to the UK was calculated. It was shown that this energy credit was equivalent to 50 PJ. However, it must be remembered that energy is used in production and storage of foodstuffs as well as their transportation. In particular, it is used for production of ancillary materials such as fertilisers and pesticides, and farming activities. It may be that, based on energy use, imports are desirable when foodstuffs produced locally using energy-intensive practices can be replaced by imported foodstuffs produced using less energy-intensive practices.

This can be illustrated by an example from some research on wheat production, suggesting that conventional, intensive wheat production in the UK uses approximately 3300 MJ/t wheat grain up to the farm gate (including production of fertilisers, pesticides and farm machinery; and cultivation, harvesting and drying of the grain) (Cowell, 1998). This energy value is equivalent to a transportation distance of 5500 km (using a transportation energy value of 0.6 MJ/t km—see Section 4.3), suggesting that wheat should not be imported further than this distance (and, in practice, significantly less than this distance) when taking account of energy used in the production in different countries, and energy used in transportation to the UK.

However, a key issue here is the source of energy used for production and transportation. Using fossil fuels, for instance, would contribute to climate change or local air pollution; nuclear power, to the production of radioactive waste; and hydro-electric dams, to possible land use and water resource conflicts. In deciding the trade-offs between growing crops more locally and importing them over a large distance, wider issues obviously need also to be considered. Nevertheless, the calculation above does raise important questions about the efficiency of transporting foodstuffs over large distances.

5.3. Broader issues

Three additional points are also relevant. Firstly, improvements in crop yields and crop management systems are likely to have a large influence on these data. It has been suggested that genetically modified crops may be useful in this role; however, controversies concerning the impact on ecological systems and human health continue to be debated (Brown et al., 2000).

A second point, as discussed in Section 2 of this paper, is that it is important to remember that sustainable development implies different things to different people. Therefore, insights from the approach described above must be seen in the context of a wider analysis of the sustainability of food production systems involving issues as diverse as social justice, pollution, conservation of biodiversity and economic costs.

Finally, although localisation of food production appears to be feasible, it is important to consider the consumer's role. Carried to its logical extremes, localisation suggests elimination of food items such as coffee, tea, bananas, oranges and lemons from the diet. Clearly, this type of behavioural change is unlikely to be popular with the British public! Indeed, it strikes at the heart of the sustainability debate: the interaction between lifestyles, consumption of goods and services, and the quality of life experienced by individuals. Practical progress towards sustainable societies is only likely to take place on a large scale when stronger connections are made between individual and community lifestyles, the environmental impacts associated with human consumption of goods and services, and quality of life. The analysis in this paper can make a contribution to this process, since through the metrics of land area and energy some of the environmental demands made by food systems can be represented in a meaningful way.

6. Conclusions

The analysis above has shown the value of single indicator approaches in providing some insights into the sustainability of a localised versus a globalised food production and consumption system, although it should be remembered that this is a preliminary analysis. The work shows that, although localisation of food production appears to be feasible on the basis of land areas for production of foodstuffs, it is important not to draw conclusions about the desirability of import substitution in the absence of data on crop yields and energy used in the production of equivalent foodstuffs. Indeed, it may be preferable to import foodstuffs produced from crops with high yields using less energy-intensive production processes, in preference to local production of crops with low yields using more energy-intensive production processes. However, the distances over which foodstuffs can be transported without offsetting any potential energy savings arising from less energy-intensive production processes, are limited (and can be calculated). Using the approach described in this paper, it is possible to make these comparisons between different foodstuffs. The answers can provide insights into the wider question of how farming systems and food consumption patterns can contribute to the evolution of sustainable societies.

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Appendix A. Treatment of by-products

A number of by-products are produced during agricultural production. These include meal from oilseed crops; straw from cereal crops; products such as hides, bonemeal and tallow from livestock production; and meat from dairy herds and battery hen systems. It could be argued that a proportion of the total area requirement for these crops and livestock should be allocated to by-products. Allocation may be in relation to mass, financial or some other physical parameter of the various by-products compared with the main product. All the approaches have weaknesses and this issue, which also arises in Life Cycle Assessment studies, is discussed elsewhere (see, for example, Cowell, 1998).

The rationale behind the approach used in this study for allocation of area requirements between the main product and by-products is that the actual area requirement for imported by-products, and additional production of by-products in the localised production scenario, lies somewhere between two extremes. At one extreme, all by-products are assumed to have a zero area requirement because the total area requirement is allocated to the main product; according to this view, the by-products are viewed as bonus, "free" outputs from the system under analysis. At the other extreme, each by-product is assumed to have an area requirement equivalent to the total area requirement for cultivating the crop or livestock yielding the main product; according to this view, the so-called main product is viewed as the bonus, "free" output from the system under analysis. In fact, the real situation lies somewhere between these two extremes but there is no consensus at the present time about modelling this situation. (In LCA, a hierarchy of approaches to allocation has been agreed (ISO, 1998) but the preferred approach, avoiding allocation by "system extension," is unrealistic for this type of analysis due to the large number of assumptions and additional data required for such an analysis.)

For agricultural crops in this analysis, the area requirements for by-products are calculated as follows.

A.1. Current area requirement in UK—maximum and minimum areas

For by-products produced in the UK (including those subsequently exported), the area requirement is set to zero because the total area used for cultivation of the main and by-products is already accounted for under main products. Hence there is no need to distinguish between maximum and minimum areas because the actual areas are included in the analysis.[3]

A.2. Additional area requirement for localised production—maximum area

The area requirement to produce any additional by-product is calculated as the total area requirement for cultivating the crop yielding the main product. For example, the area requirement for additional oilseed meal is taken as the area requirement for cultivating an oilseed crop yielding the additional oilseed meal. This value is added to the total additional area requirement.

A.3. Additional area requirement for localised production—minimum area

The area requirement to produce any additional by-product is set to zero. For exported by-products (i.e. those by-products where there is currently a net surplus in the UK), the area requirement to produce the surplus quantity is calculated as the total area requirement for cultivating the crop yielding the main product. This value is deducted from the total additional area requirement.

For livestock production, meat, milk and eggs (and their derived foodstuffs) have been accounted for in the analysis. Two aspects related to by-products must be taken into consideration: (a) by-products of meat production systems such as hides, bonemeal and tallow, and (b) crop by-products used in livestock feed (such as oilseed meal, miller's offals and straw). Taking into account both aspects, the *maximum* additional area requirement is calculated as the total area requirement for rearing the livestock yielding the meat, milk or eggs, and assuming an average yield of 6 t/ha for by-products used in feedstuffs. With respect to aspect (a), the *minimum* additional area requirement does not account for by-products because it is extremely unlikely that additional meat requirements would be met by meat produced as a by-product of livestock systems. The exception is milk and egg production systems where meat is the main by-product. Therefore, for milk and egg production systems, the maximum additional area is calculated as the area required solely for milk and egg production (see Appendix B). However, the minimum additional area for milk and egg production systems is calculated as the area required for milk and egg production minus the area required to produce an equivalent quantity of meat from meat production systems. With respect to aspect (b), the minimum additional area requirement is calculated assuming that all crop by-products in livestock feedstuffs have zero area requirements, i.e. they are surplus, "free" outputs from crop production systems. This follows the approach described above for agricultural crops.

It should be noted that this treatment of livestock production means that non-food by-products such as hides, bonemeal and tallow are omitted from the analysis. This amounts to an assumption that the existing demands for by-products can be satisfied under the localised production scenario. This is a reasonable assumption for the UK because the analysis shows that localised production requires increased livestock production—hence all existing demands for by-products would be more than satisfied under this scenario. However, it would have to be re-evaluated for countries where some livestock production systems exist primarily to produce outputs other than foodstuffs. (An example is the Merino sheep in New

[3] This leads to some distortion between foodstuff categories due to allocation of the area to the main product category rather than to any by-products. For example, meal from oilseed crops grown in the UK and subsequently used in livestock feed is accounted for under "Oilseeds and products" rather than "Meat and other animal products". This distortion is only relevant for the data presented in Fig. 3 and Table 3, where it should be remembered that the areas for each foodstuff category include by-products produced in the UK.

Zealand where wool is the main product and meat a by-product. In this case, ceasing export of meat derived from Merino sheep would not necessarily be associated with a decreased area requirement for livestock production in New Zealand.)

Appendix B. Calculating area requirements for livestock production

This appendix gives details on the method used to calculate the areas required for livestock production in the UK. In light of the discussion in Appendix A on the treatment of by-products, the calculations relating to maximum and minimum area requirements for livestock are also included.

In order to calculate the areas, it has been necessary to (a) calculate the total area requirements to produce the feed of the animal from birth to slaughter; and (b) take account of the feed requirements for maintaining the breeding stock.

B.1. Meat production

Data exist on the different feed requirements of livestock during growth and the reproductive cycle (Agro Business Consultants Ltd., 1995; Federation of UK Milk Marketing Boards, 1993; MAFF et al., 1994; MLC, 1993a,b; NFU, 1994a,b; Nix, 1994; SAC, 1995; Spooner, 1991, 1992). In general, a given animal requires an area, A_a (ha per year), to feed itself over 1 year, calculated thus:

$$A_a = A_g + \sum_{\text{all}\_i} \frac{C_i}{Y_i} \tag{B.1}$$

where A_g is the grazing area (ha per year) and C_i the annual consumption (t per year) of feed i (cereals, silage, etc.) and Y_i the yield for feed i (t/ha). Taking the case where A_a is the area needed to feed one breeding animal and its offspring over 1 year (where the offspring are slaughtered before they reach 1-year-old), the area required for rearing one offspring from birth to slaughter, A_{bs} (ha), is calculated by dividing A_a by the number of offspring per mother per year, n (per year), thus

$$A_{bs} = \frac{A_a}{n} \tag{B.2}$$

This equation applies for sheep. For cattle, it is necessary to take account of the extra time (and feed) required to achieve slaughter weight after suckling. Hence a further term must be added to Eq. (B.2), thus

$$A_{bs} = \frac{A_a}{n} + \sum_{\text{all}\_i} \frac{c_i w_g}{Y_i} \tag{B.3}$$

where c_i is consumption of feed i per unit weight gain (unitless) and w_g the weight gain from suckling to slaughter (t).

However, in order to calculate the total area requirements for a given animal reared and slaughtered to produce livestock products, A_t (ha), an area additional to area A_{bs} is required to account for production of breeding stock, thus

$$A_t = A_{bs} + f_r A_{bs} \tag{B.4}$$

where f_r is the replacement factor (unitless). This factor represents a proportion of the feed requirements for rearing a breeding female.[4] The proportion is calculated from the number of offspring produced by each breeding female in its lifetime, thus

$$f_r = \frac{1}{nL_b} \tag{B.5}$$

where L_b is the breeding lifetime of the animal (year) (i.e. its lifetime minus the time taken to mature).

The area required to produce 1 t of a given type of meat, a_m (ha/t), is then:

$$a_m = \frac{A_t}{y_t} \tag{B.6}$$

where y_t is the total yield of meat per animal (t) corrected, as in Eq. (B.4), to include the final meat yield from the breeding female, thus

$$y_t = w_o + f_r w_b \tag{B.7}$$

where w_o is the dressed carcass weight (dcw) of the offspring (t), and w_b the dcw of the breeding animal (t).

The data calculated for each type of livestock using this method are given in Table 3 (Section 4.2).

[4] The data have been simplified by excluding an allowance for the breeding male. This is because the male generally makes a small contribution (<1%) to the final area requirement per slaughtered animal because one male will serve many females in its lifetime (typical examples are one ram per 41 ewes and one bull per 33 cows each year).

B.2. Dairy production

For milk production, the area requirement to produce 1 t of milk, a_{milk} (ha/t), is

$$a_{\text{milk}} = \frac{1}{\rho_{\text{milk}} y_{\text{milk}}} \left[A_{\text{g}} + \sum_{\text{all}\_i} \frac{C_i}{Y_i} + A_{\text{df}} \right] \quad \text{(B.8)}$$

where a_{milk} is the density of milk (t/l) and y_{milk} the annual milk yield of one cow (l per year). A_{df} (ha per year) is an allowance for the dairy follower (the time between suckling and before the cow produces its first offspring) and is calculated as

$$A_{\text{df}} = \left[\left(\frac{1}{N_{\text{cow}}} \right) \left((A_{\text{g}})_{\text{df}} + \sum_{\text{all}\_i} \frac{(C_i)_{\text{df}}}{Y_i} \right) \right] \quad \text{(B.9)}$$

where $(A_{\text{g}})_{\text{df}}$ is the grazing area (ha) and $(C_i)_{\text{df}}$ the consumption of feed i (t) for the dairy following period and N_{cow} the number of years of milk production by the cow (year). For $\rho_{\text{milk}} = 0.00103$ t/l and $y_{\text{milk}} = 5500$ l per year, a_{milk} is 0.22 ha/t.

As discussed in Appendix A, there is a meat by-product associated with milk production which needs to be considered in estimates of maximum and minimum area requirements for livestock production. Assuming a cow weighs 0.6 t, and the carcass weights 0.33 t (at 55% killing out) then, since each cow produces approximately 28 t milk in its lifetime, 1 t of milk is associated with an equivalent meat yield, y_{m}, of $0.33/28 = 0.012$ t of meat per tonne of milk. This meat, under the minimum area scenario given in Appendix A, would displace an area, A_{ob} (ha per year), of beef farming, calculated thus:

$$A_{\text{ob}} = y_{\text{m}} \frac{C_{\text{milk}}}{Y_{\text{beef}}} \quad \text{(B.10)}$$

where y_{m} is the yield of meat from dairy cattle per tonne of milk (unitless), C_{milk} the consumption of milk products (t per year) and Y_{beef} the yield of beef (t/ha).

B.3. Egg production

For egg production, an equation similar to (B.8) applies:

$$a_{\text{egg}} = \frac{1}{w_{\text{egg}} y_{\text{egg}}} \left[\sum_{\text{all}\_i} \frac{C_i}{Y_i} + A_{\text{pu}} \right] \quad \text{(B.11)}$$

where a_{egg} is the area required for egg production (ha/t), w_{egg} the weight of one egg (t) and y_{egg} the annual egg yield of one hen (per year).

As in the case for milk production, where there is an area requirement for the dairy follower, in the case of egg production, there is one for the pullet, A_{pu} (ha per year), calculated thus:

$$A_{\text{pu}} = \left[\left(\frac{1}{N_{\text{hen}}} \right) \left(\sum_{\text{all}\_i} \frac{(C_i)_{\text{pu}}}{Y_i} \right) \right] \quad \text{(B.12)}$$

where $(C_i)_{\text{pu}}$ is the consumption of feed i (t) for this period and N_{hen} the number of years of egg production by the hen (year). Since N_{hen} is approximately 1 year, it cancels out of the equation.

As in the case of dairy cows, there is a meat by-product of egg production which can be used as a basis for an estimate of maximum and minimum area estimates for poultry production. Assuming a battery hen weighs 2.0 kg, and the carcass weights 1.48 kg (at 74% killing out), then, since each battery hen produces 278 eggs, one million eggs are associated with an equivalent meat yield, y_{m}, of $1.48/278 \times 1\,000\,000 = 5.3$ t of meat per one million eggs. In this case the offset area, A_{op} (ha per year), per one million eggs is given by

$$A_{\text{op}} = \frac{y_{\text{m}}}{w_{\text{megg}}} \frac{C_{\text{egg}}}{Y_{\text{poultry}}} \quad \text{(B.13)}$$

where y_{m} is the yield of meat from battery hens per million eggs (t), w_{megg} the mass of one million eggs (t), C_{egg} the annual egg consumption (t per year) and Y_{poultry} the meat yield of poultry (t/ha).

References

Agro Business Consultants Ltd., 1995. The Agricultural Budgeting and Costing Book, No. 41. Agro Business Consultants Ltd., Twyford.

Barbier, E.B., 1987. The concept of sustainable economic development. Environ. Conserv. 14 (2), 101–110.

BBC, 2001. http://news.bbc.co.uk/hi/english/uk/newsid_1246000/1246817.stm(accessed 28/3/01).

Brown, L., Renner, M., Hailweil, B., 2000. Vital Signs 2000–2001. Worldwatch Institute, Earthscan, pp. 118–119.

Cowell, S.J., 1998. Environmental life cycle assessment of agricultural systems: integration into decision-making. Ph.D. Dissertation. Centre for Environmental Strategy, University of Surrey, Guildford, UK.

Cowell, S.J., Hogan, S., Clift, R., 1997. Positioning and applications of LCA. In: Udo de Haes, H.A., Wrisberg, N. (Eds.), Life Cycle Assessment: State-of-the-art and Research Priorities. Eco-Informa Press, Bayreuth, pp. 33–57.

CSO (Central Statistical Office), 1993. Overseas Trade Statistics of the United Kingdom, 1992. HMSO, London.

CSO (Central Statistical Office), 1994. Annual Abstract of Statistics 1994. HMSO, London.

DETR (Department of the Environment, Transport and the Regions), 2000. Waste Strategy 2000. England and Wales. Part I. DETR, London.

Döös, B.R., Shaw, R., 1999. Can we predict the future food production? A sensitivity analysis. Global Environ. Change 9, 261–283.

DTI (Department for Trade and Industry), 2000. UK Energy Sector Indictors 2000. DTI, London.

Federation of UK Milk Marketing Boards, 1993. United Kingdom Dairy Facts and Figures. Federation of UK Milk Marketing Boards, Thames Ditton, Surrey.

IGFR, 2000. World Charter for Local Self-Government. Global Futures Bulletin, 106. Institute for Global Futures Research, Earlville, Australia, April 15.

ISO (International Standards Organisation), 1998. Environmental Management—Life Cycle Assessment—Goal and Scope Definition and Inventory Analysis. ISO Standard 14041. ISO, Geneva.

MAFF, 1994a. Agricultural and Horticultural Census: June 1, 1993. United Kingdom and England. Final Results. Stats 21/94. MAFF, Guildford, February 1, 1994.

MAFF, 1994b. Basic Horticultural Statistics for the United Kingdom Calendar and Crop Years 1984–1993. MAFF, London.

MAFF Statistics, 1996. Results of the Survey into the Composition of Main Compound Feed Rations as Used in Great Britain during the Six-month Period: July–December 1995. MAFF Statistics (Commodities and Food) Branch, York.

MAFF, Scottish Office Agriculture and Fisheries Department, Department of Agriculture for Northern Ireland, Welsh Office, 1994. Agriculture in the United Kingdom 1993. Produced by MAFF, Scottish Office Agriculture and Fisheries Department, Department of Agriculture for Northern Ireland and Welsh Office. HMSO, London.

MAFF, Scottish Office Agriculture and Fisheries Department, Department of Agriculture for Northern Ireland, Welsh Office, 1998. Agriculture in the United Kingdom 1997. Produced by MAFF, Scottish Office Agriculture and Fisheries Department, Department of Agriculture for Northern Ireland and Welsh Office. HMSO, London.

Mellanby, K., 1975. Can Britain Feed Itself? Merlin Press, London.

MLC, 1993a. Sheep Yearbook. Meat and Livestock Commission, Milton Keynes.

MLC, 1993b. Beef Yearbook. Meat and Livestock Commission, Milton Keynes.

MORI, 1999. British Public ‘Hungry’ For Seasonal Food. Market and Opinion Research International Ltd., London, May 10. http://www.mori.com/

NFU, 1994a. Broilers Quarterly Bulletin 88, April. National Farmers’ Union, London.

NFU, 1994b. Egg Production Quarterly Bulletin, April. National Farmers’ Union, London.

Nix, J., 1994. Farm Management Pocketbook, 25th Edition. Wye College, University of London.

Paxton, A., 1994. The Food Miles Report: The Dangers of Long Distance Food Transport. SAFE Alliance, London.

PEMS, 1995. PEMS.3 Life Cycle Inventory Analysis Computer Model. Pira International, Leatherhead.

Penning de Vries, F.W.T., van Keulen, H., Rabbinge, R., 1995. Natural resources and limits of food production in 2040. In: Bouma, J., Kuyvenhoven, A., Bouman, B.A.M., Luyten, J.C., Zandstra, H.G. (Eds.), Eco-regional Approaches for Sustainable Land Use and Food Production. Kluwer Academic Publishers, Dordrecht, pp. 65–86.

Pinstrup-Anderson, P., Pandya-Lorch, R., 1995. In: Bouma, J., Kuyvenhoven, A., Bouman, B.A.M., Luyten, J.C., Zandstra, H.G. (Eds.), Eco-regional Approaches for Sustainable Land Use and Food Production. Kluwer Academic Publishers, Dordrecht.

SAC, 1995. Farm Management Handbook 1995/1996, 16th Edition. Scottish Agricultural College, Edinburgh, UK.

Spooner, W.F., 1991. By-product yields from pigs. Meat Research Report 2/91. Division of Food Processing Meat Research Laboratory, CSIRO, Cannon Hill, Qld, Australia.

Spooner, W.F., 1992. By-product yields from sheep and cattle. Meat Research Report 2/92. Division of Food Processing Meat Research Laboratory, CSIRO, Cannon Hill, Qld, Australia.

Sustain, 1999. Food Miles—Still on the Road to Ruin? Sustain, London.

Tillman, A.-M., Baumann, H., Eriksson, E., Rydberg, T., 1991. Life-cycle Analyses of Selected Packaging Materials. Chalmers Industriteknik, Goteborg.

WCED (World Commission on Environment and Development), 1987. Our Common Future. Oxford University Press, Oxford.

WRR, 1995. Sustained Risks: A Lasting Phenomenon. Scientific Council for Government Policy (WRR), The Hague.

WTO, 2000. The Multilateral Trading System—Past, Present and Future. World Trade Organisation. http://www.wto.org/wto/inbrief/inbr01.htm

Further Reading

Bouma, J., Kuyvenhoven, A., Bouman, B.A.M., Luyten, J.C., Zandstra, H.G. (Eds.), 1995. Eco-regional Approaches for Sustainable Land Use and Food Production. Kluwer Academic Publishers, Dordrecht.