

Review

Testing the assertion that ‘local food is best’: the challenges of an evidence-based approach

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Advocates of ‘local food’ claim it serves to reduce food miles and greenhouse gas emissions, improve food safety and quality, strengthen local economies and enhance social capital. We critically review the philosophical and scientific rationale for this assertion, and consider whether conventional scientific approaches can help resolve the debate. We conclude that food miles are a poor indicator of the environmental and ethical impacts of food production. Only through combining spatially explicit life cycle assessment with analysis of social issues can the benefits of local food be assessed. This type of analysis is currently lacking for nearly all food chains.

Introduction

Concerns about the environmental impacts of transporting food increasingly long distances prior to its consumption have focussed on the notion of ‘food miles’ (Smith *et al.*, 2005). This idea, popularly understood as the distance that food travels from farm gate to consumer, has generated considerable interest among environmental groups, academics, Government, the media, and the general public (see Frith, 2005; Hamilton, 2006; Kelly, 2004; Smith *et al.*, 2005). In response to these concerns, there is a growing advocacy for food systems that reduce food miles, popularly termed ‘local food’.

Positive claims about the environmental and social benefits of ‘local food’ systems are increasingly common (Morgan, Marsden, & Murdoch, 2006; Norberg-Hodge, Merrifield, & Gorelick, 2002). However, the concept of ‘local food’ remains ambiguous. Some 22% of respondents in an Institute of Grocery Distribution (IGD) survey (IGD, 2006) expected local food to be produced within 30 miles of where they lived, while others extended their notion of ‘local’ to country limits (e.g. England, Scotland or to Britain as a whole). For the majority of respondents, though, food was considered ‘local’ if it was produced in the same county as it was consumed.

However, distance from source is not the only attribute that consumers associate with local food. In the IGD survey,

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local foods were also strongly associated with freshness, and 60% of respondents gave this as the most important reason for buying local food. Other reasons included support for local producers (29%), environmental concerns (24%) and taste (19%) (IGD, 2006). These data are consistent with other studies which report that local foods are equated with safe, pure and natural foods, whilst imported foods are more likely to carry the connotation of being impure and unsafe (Draper & Green, 2002; La Trobe, 2001; Nygard & Storstad, 1998; Weatherell, Tregear, & Allinson, 2003; Winter, 2003).

Debates around local food have been given a new significance in the light of the responses of industry and Government to climate change and their desire to calculate the carbon footprints of goods and products. The carbon footprint of a food item is the total amount of greenhouse gases (GHGs) emitted during its production, processing and retailing (the most important GHGs derived from agriculture are carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O)). As these GHGs have different effects on the radiative forcing (global warming potential, GWP) of the atmosphere relative to the effect of CO₂, they are converted to CO₂ equivalents; with 1 kg of CH₄ being equivalent to 25 kg of CO₂, and 1 kg of N₂O equivalent to 298 kg CO₂ over a 100-year time horizon (IPCC, 2007).¹

Once the carbon footprint for a food item has been estimated, it is possible to use this to inform both food chain professionals and consumers about the relative impacts of different products. In the latter case, a carbon label could act in a similar way to other food labels (Kaiser & Edwards-Jones, 2006), on the assumption that concerned consumers will preferentially purchase goods with the desired characteristics, here a low carbon footprint.

In summary, the argument in favour of increased localisation of food chains assumes and reinforces an association between localness, taste, naturalness, safety, nutritional value, environmental quality and local economy. Thus, advocacy for 'local' food suggests that it is generally better overall to consume local food than food produced 'non-locally'. However, *a priori* reasoning would question the universality of such claims, as every location is local to someone, but all locations are non-local to most people. The local food argument implies that eating an English grown carrot in England is better for the environment, the consumer and society than eating a Moroccan grown carrot in England, and *vice versa*. But consider a hypothetical consumer, living on an island in the Atlantic Ocean equidistant between Morocco and England, who wants to buy carrots and has the choice of either English or Moroccan at the same price — which should she choose? A rational scientific outlook would suggest that

there must be an objective answer to this question, and that by collecting evidence, a rational decision could be made. This reasoning would be equally applicable to a London consumer faced with a choice between an Essex and a Kent grown carrot, and indeed could be extended to the general case of all consumers. That is to say, there must be a portfolio of evidence that could be collected which would indicate which food item is the 'best choice' in any given situation, where 'best' may variously be defined as the most ethical and/or that which maximises social welfare. If the evidence in this portfolio clearly showed that local food was best, then this would have profound implications for food production. However, if the opposite were true then some of the current marketing and media focus on local food may prove to be inconsequential.

This paper discusses the portfolio of evidence that would need to be gathered in order to decide which type of food chain is 'best'. The paper primarily focuses on evidence related to biological and physical characteristics of food chains, and does not present any analysis of issues related to economics of comparative analysis and the benefits or disbenefits of international trade (for further information on these issues see Southgate, Graham, & Tweeten, 2007). The paper begins by considering the contribution of local and 'non-local' food to climate change, and then proceeds to consider other environmental and social issues. There is a particular focus on the case of fruits and vegetables, as this is a sector of high public interest. While most of the issues discussed are of generic interest, there may be important differences between fruits and vegetables and other foods, and any generalisations should be made with caution.²

Greenhouse gas emissions from the food chain

Between 1850 and 1990, worldwide changes in land use and management led to the release of an estimated 156 Pg C to the atmosphere (Houghton, 2003) (which is about half that released from the combustion of fossil fuels over the same period). Increasing public awareness of the consequences for climate change, as well as the media driven 'food miles' debate and the potential for commercial advantage, are propelling the introduction of carbon labelling in the food chain (PepsiCo *pers. comm.*). However, in the absence of an agreed framework for calculating a carbon label, there is the potential to draw the system boundary in different ways. System boundaries can be defined more or less narrowly: for example, to include only the transport

¹ These are the latest conversion figures given by the Intergovernmental Panel on Climate Change (IPCC). Previously IPCC (2001) had suggested that 1 kg of CH₄ was equivalent to 23 kg of CO₂, and 1 kg of N₂O was equivalent to 296 kg CO₂, while before that IPCC (1995) had suggested GWP conversion factors of 21 kg for CH₄ and 310 kg for N₂O.

² This paper arises from research conducted as part of the UK Research Councils' RELU Programme in a project entitled 'Comparative assessment of environmental, community and nutritional impacts of consuming fruit and vegetable produced locally and overseas' (RES-224-25-0044). RELU is funded jointly by the Economic and Social Research Council, the Biotechnology and Biological Sciences Research Council and the Natural Environment Research Council, with additional funding from the Department for Environment, Food and Rural Affairs and the Scottish Executive Environment and Rural Affairs Department.

element of the food chain; or slightly more widely to include on-farm activities only (cradle to farm gate); or more widely still to include on-farm activities, processing, retailing and consumption (cradle to plate); and ultimately from cradle to grave, which would also include waste disposal. Further, uncertainty arises as both different data and calculation methods may be used when incorporating data into integrative methodologies such as life cycle assessment (LCA). Thus, estimates of the amount of greenhouse gases emitted from a food system will depend on both the definition of the system boundary and the carbon accounting methodology utilised (Buckwell, 2005).

Working with a narrowly defined system boundary: transport only

It is relatively easy to estimate GHG emissions from within a narrowly defined system which includes only transport, as the levels of relevant emissions are well known (Table 1). Air freight is an area of particular public concern as it has a large global warming potential per tonne kilometer (i.e. the GHG emissions associated with moving 1 t of goods a distance of 1 km). Because of this, even when relatively low volumes of food are transported by air, their environmental impact may be relatively large (Marriott, 2005).

Widening the system boundary: life cycle assessment

A wider system boundary would consider all stages of the food chain, and LCA is a commonly used methodology for integrating and analysing material and energy flowing into and out of such a system (Fig. 1). When considering

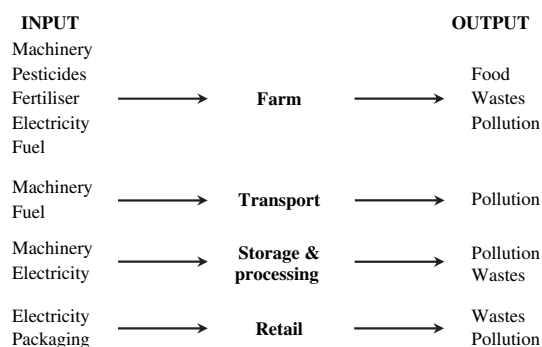


Fig. 1. Summary of typical inputs and outputs of different stages in the food production system. Standard life cycle assessment considers direct and indirect impacts of each of each of these inputs and outputs.

GHG emissions, LCAs generally consider both the direct emissions from activities like transport, alongside those generated during the manufacture of the relevant inputs, e.g. fertiliser, pesticides, electricity and machinery. It is evident from LCAs published in the peer reviewed literature (Table 2) that for many field grown crops the manufacture of fertiliser tends to be one of the on-farm inputs with the greatest energy demand and GHG emission factor (Roelandt, Van Wesemael, & Rounsevell, 2005). However, in glasshouse production, direct use of electricity for heating and lighting may represent the greatest energy input (Williams, Audsley, & Sandars, 2006).

When considering local food, several LCA studies report that local production can be more energy efficient than non-local production, largely because of transportation savings. For example, Stadig (1997) suggests that more energy is used in importing apples produced in New Zealand (NZ) to Sweden than in producing them in Sweden, even though apple production is more energy efficient in NZ. Interestingly, while Jones (2002), who is a UK-based researcher working on the LCA of apples, reports similar results for the UK situation, Saunders, Barber, and Taylor (2006) who are NZ-based researchers suggest the opposite. These contradictory results emphasise the need to utilise similar system boundaries and methodologies when making comparisons between different food systems. The full complexity of the apple LCA is revealed in a recent study by Milà i Canals, Cowell, Sim, and Basson (2007) (Fig. 2). This study compares the apples imported to the European Union (EU) from NZ and other southern hemisphere countries. Unlike the study of Saunders *et al.* (2006), Milà i Canals *et al.* (2007) consider the full calendar year and the energy inherent in storage of apples from time of production to time of consumption. Thus, an apple produced in a UK orchard which is consumed in October, uses less energy than one produced in the same orchard which is consumed in the following August. This difference is due to the energy used in storage between October and the following August. So while on average the consumption of EU grown apples in the EU uses less energy than consuming a NZ grown apple

Table 1. Direct emissions of carbon dioxide and the global warming potential (GWP) of all gaseous emissions for different modes of transport (expressed as kilogram CO₂ equivalent)

Transport type	kg CO ₂ (direct)/ t * km ^a	kg CO ₂ eq. (GWP)/ t * km ^b
Passenger car	0.191 kg/ passenger km	0.203 kg/passenger km
Van <3.5 t	1.076	1.118
Truck, 16 t	0.304	0.316
Truck, 32 t	0.153	0.157
Plane, freight ^c	1.093 ^c	1.142
Train, freight	0.037	0.038
Transoceanic freight	0.010	0.011
Transoceanic tanker	0.005	0.005

^a Includes all direct emissions of CO₂ and to provide 1 t km (i.e. including production and delivery of fuel and capital infrastructure).

^b Includes also radiative forcing of emissions of other greenhouse gases.

^c It should be noted that the Royal Commission on Environmental Pollution highlights that “the total radiative forcing due to aviation is probably some three times that due to carbon dioxide emissions alone” (RCEP, 2002). Source: Ecoinvent 1.2 database (Spielmann, Kägi, & Tietje, 2004).

Table 2. Examples of life cycle assessment analyses of horticultural products which have been published in the peer reviewed literature			
Country of production	Product	Main findings	Reference
Europe, South America and New Zealand	Apples	<ul style="list-style-type: none"> Primary energy requirement for production in: Europe and South America was 0.4–3.8 MJ kg⁻¹, and in New Zealand was 0.4–0.7 MJ kg⁻¹ Storage for 5–9 months in Europe increases energy requirements by 8–16% Specific farming practices introduce significant differences in energy consumption Season of production and consumption and storage losses affect total energy consumption 	Milà i Canals <i>et al.</i> (2007)
New Zealand	Apples	<ul style="list-style-type: none"> Specific farming practices introduce significant differences in energy consumption (30–50%) and other environmental impacts Fuels, fertilisers and pesticides have an important impact on many environmental variables and careful selection of products can reduce environmental impacts Direct energy inputs for field operations represent 64–71% of total energy consumption; most environmental impacts are related to energy-related emissions Percentage of total energy consumption for different inputs were: pesticide production (10–20%), machinery manufacture (7–12%), fertiliser production (5–11%) 	Milà i Canals <i>et al.</i> (2006)
UK	Apples	<ul style="list-style-type: none"> Transportation accounts for a considerable percentage of total energy consumption in the life cycle of fresh apples Transportation in most cases exceeds the energy consumed in commercial apple cultivation Development of local production and marketing systems can help reduce transport demand 	Jones (2002)
Switzerland	Apples	<ul style="list-style-type: none"> Apple production is represented by 37.6 GJ eq. ha⁻¹ for energy use, 4.7 kg Zn eq. ha⁻¹ for aquatic ecotoxicity and 1.0 kg PO₄ eq. ha⁻¹ for aquatic eutrophication Potatoes, sugar beet and carrots have similar energy consumption and aquatic ecotoxicity Aquatic eutrophication caused by apple production is much lower than all arable crops because of low P-fertiliser needs Area-related energy use is 50% higher for apple growing compared to arable crop rotation The key impact categories energy use, aquatic ecotoxicity and aquatic eutrophication can be managed by keeping the inputs of machinery, pesticides and fertilisers low 	Mouron <i>et al.</i> (2006)
Sweden	Potatoes	<ul style="list-style-type: none"> Agricultural production accounted for almost all the emissions contributing to eutrophication and acidification Agricultural production, production of packaging materials and the household phase were the main contributors to global warming Energy use was evenly distributed among life cycle stages 	Mattsson and Wallen (2003)
UK and Spain	Greenhouse tomatoes	<ul style="list-style-type: none"> Importing tomatoes from Spain to the UK during the winter is more energy efficient than growing them in heated glasshouses in the UK 	Smith <i>et al.</i> (2005)
Spain	Greenhouse tomatoes	<ul style="list-style-type: none"> Main negative impact derives from the waste of biomass and plastics 	Anton, Munoz, and Castells (2005); Anton, Munoz, Castells, Montero, and Soliva (2005)
Spain	Greenhouse tomatoes	<ul style="list-style-type: none"> Relative impacts of pest control depend on the selection of specific pesticides and crop stage development at the time of application Both integrated pest management and chemical pest management could be improved by a careful selection of pesticides 	Anton, Castells, Montero, and Huijbregts (2004)
The Netherlands	Greenhouse tomatoes	<ul style="list-style-type: none"> Substrate cultivation with recirculation of the drainage water results in less environmental effects per kilogram of tomatoes than soil cultivation and free drainage Reusing the drainage water leads to a lower emission of N and P and consequently to a much lower score for nitrification The lower consumption of phosphate fertilisers in crops with recirculation results in much lower scores for toxicity to water and soil organisms These conclusions are also valid for other fruit and vegetable crops grown on substrate The energy consumption at the glasshouse holding of natural gas and electricity has a great share in the total environmental pressure 	Nienhuis and de Vreede (1996)
UK	Sugar beet	<ul style="list-style-type: none"> Mean impacts per hectare were 21.4 GJ of energy consumption, emission of 1.4 t of CO₂ equivalents, 3.3 kg nitrogen leached and 15.2 kg nitrogen lost to denitrification 	Tzivilakis <i>et al.</i> (2005)
Switzerland	Several arable crops	<ul style="list-style-type: none"> Energy use dominated by mechanization, use of mineral fertilisers and grain drying Eutrophication is mainly caused by nitrogen compounds Field emissions are of decisive importance for many environmental impacts 	Nemecek and Erzinger (2005)

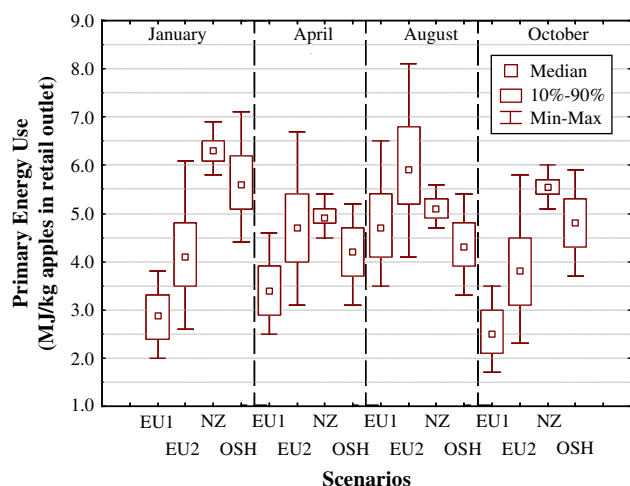


Fig. 2. Primary energy use per kilogram of apples from European and southern hemisphere suppliers for the different seasons. EU1 indicates an apple produced in a country within the European Union (EU) and eaten in the same country. EU2 indicates an apple produced in a country within the EU and eaten in another EU country. NZ indicates an apple produced in New Zealand and eaten in an EU country. OSH indicates an apple produced in another country within the southern hemisphere, not NZ, and eaten in an EU country (Milà i Canals et al., 2007).

in the EU, the relative benefits of so doing vary with the season.

The results of LCAs may also be influenced by different scales of production at the local/global level. Sundkvist, Jansson, and Larsson (2001) studied bread production with locally sourced flour versus bread produced in other regions of Sweden, and concluded that the smaller scale of the local mills results in reduced energy efficiency. However, when considering other impacts apart from energy use, Andersson and Ohlsson (1998) find lower emissions per kilogram of bread in smaller bread-making facilities compared to a large industrial bakery. Interestingly, Schlich and Fleissner (2005) suggest that the energy efficiency of global food systems is greater due to the increased size of producers (i.e. 'ecology of scale'), which counters the increased energy use for transportation. However, this study is contested by Jungbluth and Demmeler (2005), who highlight some of the critical – and controversial – decisions made during the analysis (e.g. direct energy consumption instead of primary energy requirements; non-representative data for regional production; inconsistent system boundaries for the two compared systems). Further, the production practices of producers servicing local distribution networks may differ substantially from those of more 'globalised' producers servicing large retailers, and this should also be considered in any analysis.

These studies serve to demonstrate several important issues related to LCAs. Firstly, there is inherent variation at the farm level, within a country and between seasons, which leads to different levels of environmental impact even for the same product. Secondly, it is only when the system

boundary of the LCA includes all phases of the food chain that accurate estimates of impact can be obtained. Thirdly, the outputs from LCAs may not give simple messages to those consumers who are seeking to make informed but uncomplicated purchasing decisions.

Widening the system boundary further: spatially specific emissions from agro-ecosystems

Standard LCA methodologies have been largely developed within the context of engineering and physical systems, and are not well adapted to deal with the variation inherent in biological systems. So if LCA is to contribute to the local food debate, it will be necessary to utilise spatially explicit coefficients which reflect the reality of production in different localities. While this is theoretically possible in some of the newest LCA methodologies, severe difficulties remain in practice, as discussed below.

Greenhouse gas emissions from on-farm activities

Emissions of CO₂ from soils represent one of the major fluxes in the global carbon cycle, and through the biological and chemical processes that occur within them, agricultural soils are responsible for releasing significant amounts of GHGs into the atmosphere (Schlesinger & Andrews, 2000). Gaseous emissions from soil are not considered by consumers when making food choices, and even when they are accounted for in LCAs, the assumptions made are often incorrect. The discussion below highlights the uncertainties which surround GHG emissions from soils and the difficulties inherent in representing these emissions in integrative analyses.

The release of CO₂ from soil occurs mainly from respiring plant roots and from soil microbes decomposing organic matter in soil (Farrar, Hawes, Jones, & Lindow, 2003). A second GHG, N₂O, is produced naturally in soils by microorganisms through the processes of nitrification or denitrification. Nitrification is the aerobic oxidation of ammonium to nitrate; denitrification is the anaerobic reduction of nitrate to nitrogen gas. Both processes are enhanced by the increased availability of nitrogen in the soil, such as through additions of fertilisers, faeces, slurries, manure, ploughed in leys, arable residues etc., all of which have the potential to increase N₂O emissions. As large quantities of nitrate fertiliser are added to most agricultural systems, the potential for emissions is large. There are also indirect emissions of N₂O due to the volatilisation, leaching and run-off of nitrogen from managed soils. Major sources of emissions of the third main GHG, CH₄, are animal wastes and severely anaerobic soils (e.g. rice paddies), although in most agricultural systems CH₄ is much less important as a GHG than CO₂ and N₂O (Conrad, 2002).

The magnitude of GHG emissions from soil depends on an extremely diverse range of biological, chemical, physical and management variables making measurement or prediction of the net GHG budget for agricultural soils extremely

difficult (Christopher & Lal, 2007; Kebreab, Clark, Wagner-Riddle, & France, 2006). This also implies that single GHG emission values cannot be ascribed to broad agricultural system types but are moreover likely to be highly context specific and dependent upon local conditions. This contrasts strongly with the relatively fixed carbon emissions associated with subsequent food processing and transport/distribution.

One major issue which is rarely appreciated, and which fundamentally remains poorly understood, is that soils can also be major sinks for greenhouse gases. In the case of CO₂, all crop plants sequester atmospheric CO₂ in photosynthesis. Some of this is returned to the soil when roots die and at the end of the season in crop residues left behind in the fields. Both of these are important in replenishing soil organic carbon stores. In addition, soils can also act as sinks to significant quantities of both N₂O and CH₄ (Castaldi, Costantini, Cenciarelli, Ciccioli, & Valentini, 2007; Chapuis-Lardy, Wrage, Metay, Chotte, & Bernoux, 2007; Suwanwaree & Robertson, 2005).

The net release of GHGs from agricultural soils is therefore a delicate balance of CO₂, N₂O and CH₄ gains and losses across an entire growing season. Consequently, it is important to measure all three of these gases simultaneously to reliably estimate GHG emissions. Further, it can be expected that over a cropping cycle an agricultural field will fluctuate from being a source to a sink for these gases. Studies have demonstrated that these net fluxes can change dramatically within a day depending upon the prevailing weather conditions and management regime (Wagner-Riddle, Thurtell, King, Kidd, & Beauchamp, 1996). Therefore, accurate estimates of GHG emissions from food production systems require measurements to be made over long time periods (ideally a full calendar year) on a continuous, or very regular, basis (e.g. hourly). This intensity of measurement poses severe practical challenges and is rarely undertaken. Even if it were undertaken for a whole calendar year, variation in weather between years may render the results from a single cropping cycle unrepresentative of long-term GHG emissions.

The IPCC approach to this problem was to undertake a meta-analysis of all the available experimental data and to produce standard emission factors, which describe, for example, the proportion of nitrogen fertiliser that is emitted as N₂O from crop production (Bouwman & Taylor, 1996). This emission factor approach is based on a limited number of data points and is applied worldwide for agricultural soils regardless of variations in soil characteristics, land management or climate (Roelandt *et al.*, 2005). This is obviously a crude approach that can have little relevance to local conditions (Smith *et al.*, 2002). To address this issue, many researchers have developed mathematical modelling approaches that attempt to simulate net GHG emissions from soil at a range of temporal (days to decades) and spatial scales (field to continental level) (Levy *et al.*, 2007; Vuichard *et al.*, 2007). Ultimately, however, these models

are only as good as the knowledge that underpins them (Tonitto, David, Li, & Drinkwater, 2007). Although scientific knowledge of carbon and nitrogen dynamics is far from complete for many agro-ecosystems, simulation models of GHG emissions from soil such as DNDC (Li, Frolking, & Frolking, 1992) and soil carbon stocks CENTURY (Sanford, Parton, Ojima, & Lodge, 1991) have been widely accepted and partially validated. However, in many situations there may be poor agreement between modelled outputs and actual measured emissions, and further refinement of these modelling approaches is required before they can be used to make informed judgements pertinent to the local food debate.

Conclusion on LCA and GHG emissions from local food production

It is clear from the above discussion that in order to quantify the GHG emissions from local and non-local food, it is necessary to conduct spatially explicit LCAs which include emissions from agricultural systems alongside those emanating from food processing, transport and retailing. Unfortunately, due to the many different definitions of the phrase 'local' it remains difficult to identify the precise scale of analysis which would best inform consumers and/or policy-makers. Given the paucity of studies published at any scale which analyse emissions from across the entire food chain, it is currently impossible to state categorically whether or not local food systems emit fewer GHGs than non-local food systems.

Other environmental hazards in the food chain

The impact of food production on climate change is not the only environmental issue that needs to be considered when comparing 'local' and 'non-local' food. For example, in some locations horticulture can have aesthetic impacts on the landscape through the use of glasshouses, poly-tunnels, field scale mulches and fleeces, particularly when there is a clustering of horticultural farms in one area. Buying food from such areas may support these production methods, and thereby perpetuate the visual impact.

Another potentially polluting practice relates to the use of pesticides, and again the hazard arising from pesticides may vary with location. The types and amounts of pesticide used on a given crop relate to the pest and disease pressure which vary between growing regions (BCPC, 2007). Different pesticides have their own toxicological profiles, and therefore pose different levels of hazard. In general, herbicides tend to pose low hazards to human health, while insecticides demonstrate higher hazards (Cross & Edwards-Jones, 2006). For these reasons, the actual hazard posed to the environment and society from the use of pesticides varies with location.

In addition, there are a range of other potential environmental hazards posed by agriculture whose severity may also vary with location. These include gaseous emissions, e.g. ammonia (Havlikova & Kroeze, 2006), pollution of

surface and ground water (e.g. nitrate leaching, phosphate pollution (Almasri & Kaluarachchi, 2007; Powers, 2007)), soil erosion (Van Oost, Govers, de Alba, & Quine, 2006) and impacts on biodiversity (Butler, Vickery, & Norris, 2007). These hazards are not discussed in detail here, but they do serve to highlight that growing the same crop in different places will pose different environmental hazards, which may result in different levels of impact. Further, the importance of these impacts can only be assessed in the context of the locality in which the impact occurs. There is currently no study which has quantified and mapped the full range of environmental impacts arising from fruit and vegetable production at a local, national or global level. To do so would be a mammoth task, and while such a dataset may have some value to Governments it is unclear how consumers and producers would react to such a mass of information.

Local food, quality and nutritional value of fruit and vegetables

Determinants of quality

The commercial and nutritional quality of fruits and vegetables is determined by a range of characteristics, attributes and properties (Schröder, 2003). Commercial quality standards include cleanliness, firmness, lack of damage, freedom from disease, colour, size and shape, freshness, appearance, texture, aroma, consistency, origin and use-by-date (UN-ECE, 2007). Nutritional quality relates to essential nutrients (carbohydrates, amino and fatty acids) and biologically active compounds (vitamins, dietary fibre, flavonoids, carotenoids, phytosterols, phenolic acids and glucosinolates). Both of these aspects of quality may be affected by the various activities that occur along the supply chain. For example, fresh vegetables can experience deterioration in their marketing quality during transportation due to mechanical damage caused by handling and transit vibrations (Hinsch, Slaughter, Craig, & Thompson, 1993). Storage can also reduce vegetable quality due to microbial spoilage and nutritional losses, with the most susceptible nutrient compounds being ascorbic acid, niacin, folic acid, phenolics, carotenoids and flavonoids (Goldberg, 2003).

Preservation methods such as refrigeration, gas and controlled modified atmosphere, chlorination, electrolyzed water treatments, ionizing radiation, application of film packaging and surface coating aim to reduce the nutritional losses and to increase the shelf-life of fresh vegetables (Alzamora, Tapia, & Lopez-Malo, 2000). While consumer knowledge of these processes may be limited, preservation by freezing is familiar to most Western consumers. The application of quick freezing technologies combined with blanching, a thermal treatment, can minimise both nutritional losses and physical damage of frozen vegetables. Unfortunately though, freezing is not suitable for all vegetables and cannot be used effectively to preserve salad items such as endives, cucumbers and radish. However, although frozen vegetables retain most of their

nutrients and vitamins (including ascorbic acid, folic acid and thiamine), the freezing process does not guarantee retention of the full nutritional quality of the produce. The major risk of nutrient loss for frozen vegetables occurs during blanching prior to freezing (Puupponen-Pimiä *et al.*, 2003). Nevertheless, blanching is a necessary activity as it deactivates the enzymes responsible for undesirable changes in odour, flavour and colour during defrosting and reduces the microbial activity and oxidation processes that cause spoilage.

If consumers collected produce from a farm within a few hours of its harvest, then it could be expected that its nutritional quality would be high. However, if quality was only related to time since harvest, then given that produce grown in Kenya can be available for sale in some parts of northern Europe 24–30 h after harvest, this produce too may be of high nutritional quality. For these reasons, it is not possible to state categorically that locally produced fruits and vegetables will always be of higher nutritional quality than non-local produce. Rather their quality will depend on time since harvest and the type of processing to which they are subjected. Thus, the characteristics of the supply chain are probably more important in determining quality of fruits and vegetables than is the distance between producer and consumer.

Assessing impacts on health

Scientific evidence of quality differences between local and non-local food could be derived by measuring the chemical constituency of food from different supply chains throughout the year. If the health status of consumers who ate food from the different supply chains were also assessed, then any changes in their health status could, in theory, be related to the chemical constituency of their food. However, such an approach faces several challenges. Firstly, a large amount of analytical effort would be needed in order to chemically characterise all food items from the different supply chains. Secondly, despite a large amount of information being available on this topic, the nutritional quality of all fruits and vegetables has not yet been defined. To date, around 50,000 chemical compounds have been elucidated in plants (Fiehn, 2002), most of which have unknown function in humans. Thirdly, the actual health impact on individuals who choose to consume either local or non-local produce could only be assessed in relation to the rest of their diet. So any nutritional advantage gained by eating one type of produce could be enhanced or counteracted by the quality and quantity of other elements of the diet. Finally, the relevance of this type of chemical information to consumers is unclear. While some consumers seem to value the claimed health benefits associated with certain food products, sociological research suggests that consumers normally have a multidimensional concept of quality which goes beyond chemical and physical variables, and may include a range of social factors relating to the traditions and experiences of people in the food chain (see Parrott, Wilson, & Murdoch, 2002).

Overall discussion and the role for interdisciplinarity in the local food debate

The previous discussion has largely taken a natural science perspective to the impacts of purchasing local and non-local food. However, there are also a range of social and economic factors which have not been discussed in detail here. For example, an issue of concern to some consumers is the impact that their purchasing decisions will have on individual farmers, and also on the local and regional economies in which the farmer is located (witness the growth of Fairtrade produce). Whilst many consumers may have the desire to use their purchasing decisions to help poorer regions and nations, others may explicitly decide not to buy produce from some countries for political reasons (e.g. movements to boycott South African goods in the 1980s as a protest against apartheid). So, when a consumer decides to preferentially purchase local food, they may explicitly be making a decision to benefit local farmers, the local economy and the local political status quo. However, simultaneously they are implicitly deciding not to support farmers, regions and political systems beyond their locality. The cumulative impact of these decisions may have implications for the wealth of producers and the development of regions, which may in turn have wider environmental and political impacts.

The interaction of the impacts of consumer choice on natural and socio-economic systems highlights the inherent interdisciplinarity of food chain analysis. If research is to contribute to understanding the advantages and disadvantages of alternative food supply chains, then social and natural scientists must work closely together. However, both sets of scientists need to recognise each other's perspective.

For example, natural scientists may argue that it would be almost impossible to develop a scientific dataset which would enable formal testing of the hypothesis that local food is better than non-local food. The difficulties associated with this task relate firstly to difficulties in defining each locality in a spatially explicit manner — which is a necessary step if relevant environmental data are to be collected — and secondly to the large volume of data needed to enable all locality–locality comparisons to be made for all relevant variables. However, social scientists may not be surprised that reductionist natural science cannot resolve the local food debate, as for many consumers the attractions of local food do not relate to measurable differences in its embodied energy or nutrient status, but rather they relate to sense of place, trust and experience.

The role of natural science in the local food debate will probably focus around informing the wider societal debate about technical issues (e.g. energy use of different technologies) and in highlighting emerging issues (e.g. GHG emissions from soil). Social science will also play a role in knowledge discovery in fields such as risk perception, consumer behaviour and social attitudes. In addition, social scientists will have an important role in understanding how

decision-makers, be they consumers, the media, food chain professionals or politicians, can best use the emerging knowledge to guide their actions. This does not mean that there is no role for natural scientists in communicating knowledge, but rather that by working together, the inherent synergies in natural and social science approaches can help bring about real change in food supply chains — be they local or otherwise.

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