LCA Case Studies

The Relative Importance of Transport in Determining an Appropriate Sustainability Strategy for Food Sourcing

A Case Study of Fresh Produce Supply Chains

Sarah Sim[1,2]*, Mike Barry[1], Roland Clift[2] and Sarah J. Cowell[2]

[1] Marks and Spencer, Waterside House, 35 North Wharf Road, London, W2 1NW
[2] Centre for Environmental Strategy, University of Surrey, Guildford, Surrey, GU2 7XH

* **Corresponding author** (sarah.sim@marks-and-spencer.com)

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Abstract

Background, Aims and Scope. Over the last five decades, the nature of food retailing has undergone an enormous transformation. Macro level economic, structural and technological developments have led to a major increase in the level of world trade. These developments have helped retailers to meet modern consumer expectations, but benefits have not been achieved without some drawbacks. This paper seeks to explore the environmental impacts associated with fresh produce supply chains, in order to understand the relative significance of transport as compared to other supply chain activities.

Methods. Life Cycle Assessment was used to estimate the potential environmental impacts of three fresh produce items sourced from six countries and sold in Marks and Spencer stores: royal gala apples from Brazil, Chile, Italy and the UK; runner beans from Kenya (and extrapolated for Guatemala and the UK); and watercress from the UK and USA (and extrapolated for Portugal). Analysis was also conducted to evaluate the likely impacts of extending the storage period for UK apples thus negating the need to import, against the current strategy of importing fruit from the Southern hemisphere for six months of the year. In addition, the impacts of conventional as compared to organic cultivation were considered for watercress in both the UK and USA.

Results and Discussion. The results for all three products reveal similar dominating impacts. A clear distinction arises in terms of the activities which contribute most to environmental impact and the magnitude of this impact, depending on the country in which the product is cultivated; i.e. global, regional (European) or local (British) sources of supply.

Conclusion. Transport (or distance between production and consumption) is therefore an important factor in determining the environmental sustainability of food supply chains (though for long distance haulage, there is a significant distinction between airfreight and shipping). Electricity consumed for storage and packing operations is also significant, and the associated environmental impact is lower in countries where a large proportion of electricity is generated from renewable fuels. However, where this occurs in countries distant from the UK, transport impacts overshadow the environmental savings achieved from the more favourable electricity generation mix.

Recommendations and Perspectives. The results of this study suggest that when in season it is generally preferential, on environmental grounds, for UK consumers to buy British produce rather than produce imported from overseas. Cultivation overseas is necessary to ensure year-round availability and in these circumstances it is preferable that processing activities also occur overseas if environmental benefits can be derived from local factors (e.g. a favourable electricity generation mix). Overall, the findings should be evaluated in the context of managing wider sustainability interests (including social and economic issues), for which further research is required.

Keywords: Air freight; food sourcing; food supply chains; transport

Introduction

Over the last four to five decades, the nature of food retailing has undergone an enormous transformation. The World Trade Organisation (WTO) and its predecessor, the General Agreement on Tariffs and Trade (GATT) have mainly driven increased liberalisation of the global economy [1]. This, in combination with considerable investment in infrastructure, facilities and technologies at all levels of the supply chain [2,3] has led to a major increase in the level of world trade. Simultaneous with this global transformation in business have been a number of cultural and demographic changes within UK society, such as decreased family size, higher occurrence of single occupant households, greater numbers of working women and greater household disposable income. These societal changes have altered consumer needs and the value placed on meeting them. Modern food supply structures are better able to meet these needs, providing greater choice, lower prices (driven down by global competition), uniformly high quality and product safety and exceptional convenience.

However, more recently active debate has surrounded the disadvantages as well as the benefits of globalisation and the food industry [1]. Some authors have studied the environmental impacts associated with the increased distances travelled by foodstuffs between points of production and consumption, often dubbed 'food miles' [4,5]. However, the relative magnitude of transportation impacts as compared to other supply chain activities is not clear. Greenhouse gas (GHG) emissions from transporting food around the UK are estimated to contribute 3.5% to total UK GHGs [6], compared to a 12% contribution from agriculture (including emissions from animals' digestive processes, animal wastes, fertiliser use and the conversion of grass to arable land) [7]. However, emissions from the transportation of food destined for the UK market before it reaches UK shores is not accounted for in the UK's GHG inventory. The environmental impact of cross-boundary transport such as air-freighting is of particular interest as it is omitted from the GHG accounts of all countries, although air-freighted food is a growing phenomenon: food is the fastest growing air freight sector, accounting for 13% by volume of all air-freighted goods [8]. A recent publication by DEFRA [9] suggests that the transport of food by air has the highest CO_2 emissions per tonne and "although air freight of food accounts for only 1% of food tonne kilometres and 0.1% of vehicle kilometres, it produces 11% of the food transport CO_2 equivalent emissions". Thus it is clear that determining transport impacts relative to other activities in the supply chain is to some extent dependent on the modelling boundaries adopted, and their consistency across different products studied. Whether a full life cycle assessment is undertaken or not is also relevant, both in terms of including all the life cycle stages of a given food product as well as the range of environmental impacts that are considered [10].

The aim of this paper is to enhance understanding of the *environmental* impacts of food supply systems, up to the UK consolidation point, and the particular role of transport in contributing to these impacts. It is conducted from the perspective of a food retailer in the UK: Marks and Spencer. This study is therefore novel because it is shaped by this decision context, and focuses on the practical interpretation of LCA results for use in the business context. The work is part of a broader research project intended to enhance the overall sustainability of Marks and Spencer's food supply systems. The research outlined in this paper will inform the environmental element of a tactical sustainability decision-making framework for Marks and Spencer's food business. Subsequent research into socio-economic issues, as well as more traditional economic and quality considerations, will also inform the day-to-day decision-making process. It is imperative that all of these elements are managed simultaneously so that contradictions in operational strategy can be avoided, and the optimum balance of sustainability considerations can be sought.

1 Aim

Life Cycle Assessment (LCA) is currently one of the most sophisticated assessment approaches available to estimate the potential environmental impacts of a product or service. However, data requirements are significant and the food industry presents particular problems due to the complexity and scale of life cycles for different food products. Whilst a number of practitioners have sought to conduct full life cycle assessments of particular food products [11,12], many existing studies are often confined to one stage of a food product life cycle (usually cultivation) [13,14]. Relatively few studies address the issue of producing a specified food product in several alternative countries, intended for consumption in just one [15–18]. None appear to have examined products which have been air-freighted as well as transported by road or sea: in fact these alternative transport methods reflect the current sourcing strategy employed by many supermarkets to ensure year-round availability of fresh produce. Since supermarkets and major retail chains account for 76% of the UK fresh fruit and vegetable sales, and are responsible for most of the import of fresh vegetables into the UK [19], this study is highly relevant for the UK food system. Therefore, this research seeks to explore the impact of food transport relative to other supply chain operations for three fresh produce items cultivated in a variety of countries for consumption in the UK: royal gala apples (conventional), runner beans (conventional) and watercress (conventional and organic). The widespread seasonal cultivation of these products in the UK as well as overseas facilitates a comparison of alternative supply systems for these products (with varying distance between producer and consumer). The following research questions are addressed in this paper:

1. What are the dominating environmental impacts for each supply system and product?
2. What is the relative significance of transport, as compared to other supply chain activities?
3. To what extent does the country of origin dictate the environmental impacts of the three food products? Clearly impacts from transport will alter as a response to country of origin (determined by distance and mode of transport), but do impacts arising at other stages of the supply chain also depend on the country of origin?

2 Methodology

The functional unit assigned for all three product studies was the same: delivery to the UK consolidation point of 1 tonne of grade 1 product (runner beans / royal gala apples / watercress). This is consistent with the general function of a food supply chain from the perspective of a major retailer such as Marks and Spencer, and indeed with the functional unit for food products defined by other authors [3,14]. It acknowledges that direct human consumption is the main function of food products, without complicating this further by attempting to use nutritional value as a basis for comparison [20]. A supply chain perspective is incorporated (with the word 'delivery') and the quality requirements of supermarket retailers are also included with the term 'grade 1.' For each supply chain studied, the fore- and background systems are clearly defined (see Figs. 1, 3, 4, 8 and 9). All supply systems studied extend only to the UK consolidation point; it was not relevant to include stages of the supply chain beyond this point (regional distribution centres, stores and homes) because these life cycle stages are not influenced by the country of origin and may often be the same regardless of product.

Restrictions on the scope of the studies arose from difficulties involved in accounting for some inputs and limitations on data availability. Firstly, soil is omitted from the system boundaries (though technically it should be included to a specified depth [11,14,21]). Full crop rotations are likewise omitted given the reduced relevance of other crop types in the temporal crop planning for these products. However, if other crops were routinely rotated with those studied, the full crop rotations ought to have been included as inputs applied to one crop could affect the development of another in the same rotation, due to potential alterations in soil chemistry and quality [22]. The manufacture and construction of all buildings and infrastructure was also omitted, as is common in LCA studies. However farm machinery may often be included due to the relatively short life-span of this equipment and high maintenance requirements [14,22,23]. Data concerning the production and maintenance of farm machinery [24] were only included for watercress due to on-farm data availability issues. However, it should be noted that mechanisation in some watercress cultivation systems was substituted with manual labour. Interestingly this occurred as a consequence of the location of production (in the US labour is used for harvesting whilst in the UK this is mechanised) rather than the type of production (organic or conventional).

Both the apple and bean studies involved co-production, with products not reaching grade 1 quality sent for alternative commercial uses. A consistent approach to allocation between the main and co-products was used, following the partitioning approach advocated for prospective, comparative LCAs [25,26]. Some ancillary items are used beyond the temporal scope of all three product studies, such as harvest crates, which may last ten or more years. Allocation of these considered their life span, and the number of uses per year. With regard to transport, backhaul journeys were not allocated to the systems studied because logistics providers are frequently unconnected to these systems. Thus people involved in these product supply chains tend to have little knowledge of backhaul contents and utilised capacities. It is assumed that independent logistics providers will always seek to optimise capacity utilisation on backhaul journeys, as this will increase profitability.

Data related to the electricity mixes in different countries were taken from a variety of sources. Where available, data from the BUWAL 250 database were used (e.g. for the UK and Portugal) [27]. Other sources were used to establish the energy mix in Brazil, Guatemala, Italy and Chile as detailed in the references [28,29,30].

Most of the data relating to the production of pesticides were taken from Green [31]. Though these data are not recent, they have been used in many recent LCA studies of agricultural products due to the lack of available alternatives. Unfortunately, cause-effect modelling for pesticide use within LCA software and indeed the literature is not well developed and the effects of pesticide residues in crops and groundwater and of sprays on 'bystanders' continue to be matters for general debate, particularly in the UK [32]. It was therefore decided to omit assessment of the potential toxicity associated with active ingredients of pesticides. Again, for reasons of data availability, Integrated Pest Management strategies widely used in the bean and watercress production (in this case microbial insecticides) were not included in the study. No synthetic pesticides are used on watercress regardless of the location of cultivation.

Data for fertiliser production (production energy and heavy metal emissions to land, during the use phase) were similarly extracted from the literature; most were taken from Davis & Haglund [33], supplemented by data extracted from Audsley et al. [23]. Given that organic and conventional methods of cultivation were considered for watercress, a slightly different approach was taken to account for fertilisers used in these systems: data from the Ecoinvent database [24] were used as it contained more comprehensive listings to account for the relevant fertilisers. Estimates of site specific field emissions of nitrogen and phosphorus resulting from fertiliser use (for all three products) were not included because it is widely recognised that these emissions are highly variable and thus even estimated averages might be misleading. However, in order to gain some understanding of any potential significance of this omission, a sensitivity analysis was conducted for beans and apples, using nitrogen and phosphorus emission values associated with fertiliser use; values were taken from Cowell [22, derived from 34] and Audsley et al. [23] for emissions associated with agriculture in various European countries and the United States. The sensitivity analysis showed that eutrophication impacts could be between 12 and 60% higher than those presented in Figs. 2, 5, 6 and 7, but could even be five times higher in extreme examples (Chilean apples and Kenyan beans). Similarly, the potential global warming impacts could be between 0.5 and 10% higher than those represented in these graphs. However, when these higher values are normalised, eutrophication still remains relatively insignificant compared to some other impact categories. Therefore, the omission of site-specific field emissions from fertiliser application does not affect the conclusions presented in this paper. As such, it was thought unnecessary to repeat the sensitivity analysis for watercress as well.

The approach advocated by the IPCC for the assessment of climate change impact related to emissions from aircraft was used [35]. The IPCC suggest that "the total radiative forcing due to aviation is probably some three times that due to the carbon dioxide emissions alone. This contrasts with factors generally in the range of 1–1.5 for most other human activities" [35] and is attributable to complex cause-effect chains mainly associated with flying altitudes.

The results presented for all product studies have undergone a normalisation step which relates them to the total impact, for the categories considered, of economic activities in Western Europe (i.e. the 2003 EU plus Switzerland and Norway). With this normalisation it becomes possible to see when impacts caused by the product are large in relation to total impacts in the region where the product is consumed [25]. Theoretically it may be desirable to normalise the impacts in relation to the countries of production, rather than the region of consumption. However this would require splitting the data between those supply chain activities occurring abroad and those occurring in the UK: normalisation data for this level of specificity are not available.

3 Results

3.1 Runner beans

Runner beans sourced from Naivasha, Kenya and transported on a freight plane to the UK (**Fig. 1**) were studied. The packaging materials referred to in Fig. 1 includes in-flight boxes used for in-transit protection and insulation of the product, as well as retail packaging. In-flight boxes are manufactured from heavy corrugated cardboard to provide the necessary insulation: temperatures in aircraft holds are usually warmer than is preferable for fresh produce items. They are currently recycled into other products; the impacts of the recycling process have been allocated to this system. A subsequent scenario analysis was undertaken to assess the impact of changing transport and lighting requirements (artificial lighting is employed at the growing stage in Kenya due to insufficient daylight hours for growing beans) in line with sourcing from Guatemala and the UK. The normalised results for the runner bean systems suggest that three impact categories are of particular significance to the Kenyan and Guatemalan supply chains. In order of significance these are: global warming, marine aquatic ecotoxicity and abiotic depletion. When using the IPCC methodology for climate change, the results suggest that the global warming potential of beans sourced via the Kenyan or Guatemalan supply chains is between 20 and 26 times the potential estimated for UK beans. This is mainly attributable to emissions from air transportation which account for 89% of the global warming potential illustrated for the Kenyan supply chain and 91% of the global warming potential illustrated for the Guatemalan supply chain (**Fig. 2**).

Of the other impact categories shown to be significant for the Kenyan and Guatemalan supply chains, abiotic depletion is also mostly attributable to the use of kerosene in air transportation (77–80% of the total result for the supply chains), though non-renewable fuels used for the production of electricity used in the manufacture and recycling of in-flight boxes (corrugated card) also contributes to the po-

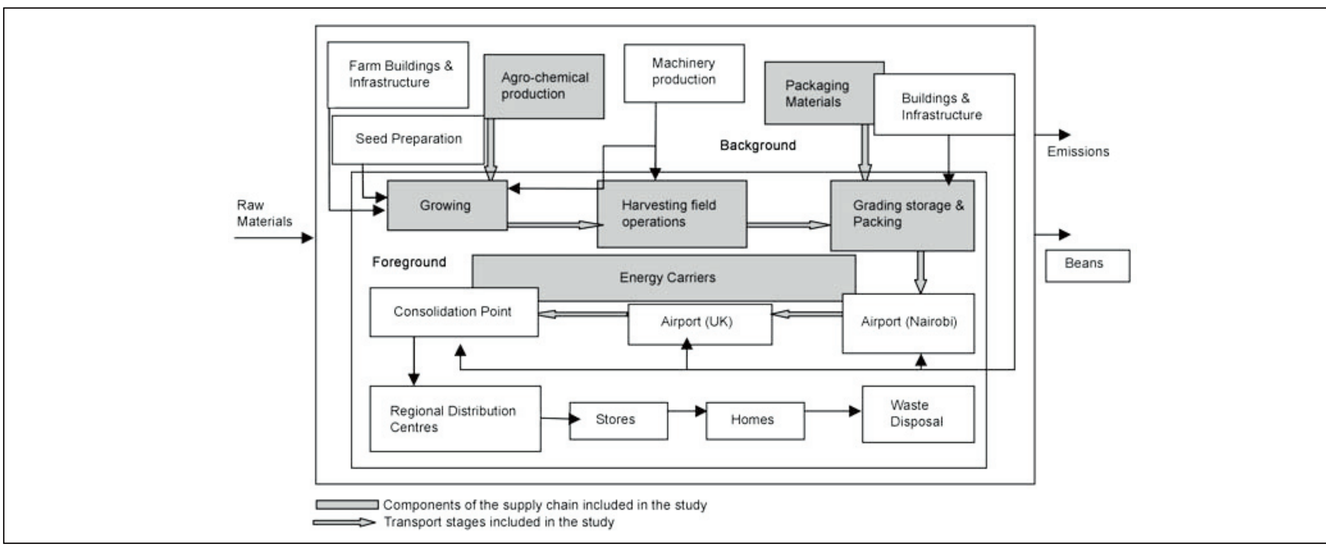

Fig. 1: Schematic Diagram of the Kenyan runner bean system under study

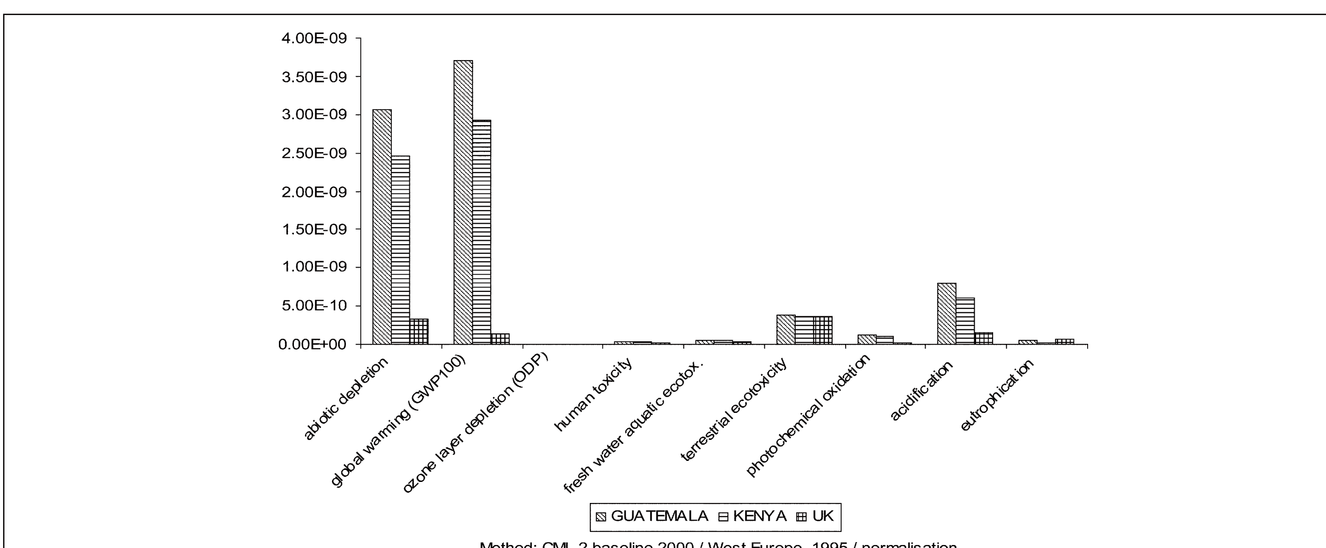

Fig.2: Normalised impact assessment for runner beans sources from Kenya, Guatemala and the UK – accounting for radiative forcing of aircraft emissions for the Kenyan and Guatemalan supply chains

tential for this environmental impact (4–10% of the total result for the supply chains). Electricity used for other activities is less significant in Kenya or Guatemala, benefiting from a high proportion of renewable sources. The potential for marine aquatic ecotoxicity in the Guatemalan and Kenyan supply chains mainly results from electricity used in cardboard manufacture and recycling (used for in-flight boxes). In particular emissions of Cobalt (Co), Hydrogen Fluoride (HF), Vanadium (V) and dioxin (TEQ) to air respectively, and emissions of Selenium, Vanadium and Barium (Ba) to water, result from electricity production. Marine aquatic ecotoxicity is the most significant environmental consequence of the UK supply chain as a result of the electricity used in the growing, harvesting, grading, storage and packing phases. The UK relies rather more heavily on non-renewable fuel resources for its electricity production with only 3% [27] generated from renewable sources as compared to approximately 40% in Guatemala [36] and 65% in Kenya [37].

However, one should consider the uncertainty involved in cause-effect modelling for toxicity impacts as compared to that for other impact categories. Particularly significant problems are associated with assumptions in the CML fate modelling for oceans (marine aquatic eco-toxicity) in the Simapro software [38]. For instance, discounting has not been applied for future impacts, so stable elements have a very long life time coupled with the fact that the sink in the ocean is slow. This assumption is of particular importance with regard to HF for which a mean oceanic residence time (MORT) of 80million years is calculated, while 1 million years is suggested to be a more realistic value [38]. In addition some parameters are missing from the normalisation data which affects estimates of marine aquatic ecotoxicity. This means that the method gives very strange results, for which there is currently no agreed solution [39]. As such, the results for marine aquatic toxicity are omitted from Figs. 2, 5, 6, 7, 10 and 11 as they diverted attention from the other significant impact categories, a step considered reasonable given the uncertainties in modelling methodology for this impact category.

3.2 Royal gala apples

Cultivation of apples in the UK (three orchards) and in Italy, Chile and Brazil (one orchard in each country) determined the different apple supply systems studied (**Fig. 3** and **Fig. 4**). Where apples are imported (shipped) they are graded in the country of origin, and packed in travel boxes. On arrival in the UK, they are subsequently repacked for retail. UK apples are packed directly for retail after grading. The retail packaging element represents all types of retail packaging (trays, bags and loose) in proportions relative to their popularity. Data required for allocating the electricity used for packing and storage of imported apples in the UK were incomplete and thus omitted. This should be considered when comparing UK with imported apples, as supply chain electricity use and the associated environmental impacts are perhaps significantly underestimated for imported apples.

A subsequent scenario analysis was conducted in order to determine whether it is environmentally preferable to store apples grown in the UK for the whole year, thus negating the need to import; or to sell UK apples only when in season, and source apples from the Southern hemisphere when out of season. A period of 10 months for storage of UK apples to cover year-round supply was used as an example (assuming a staggered harvest).

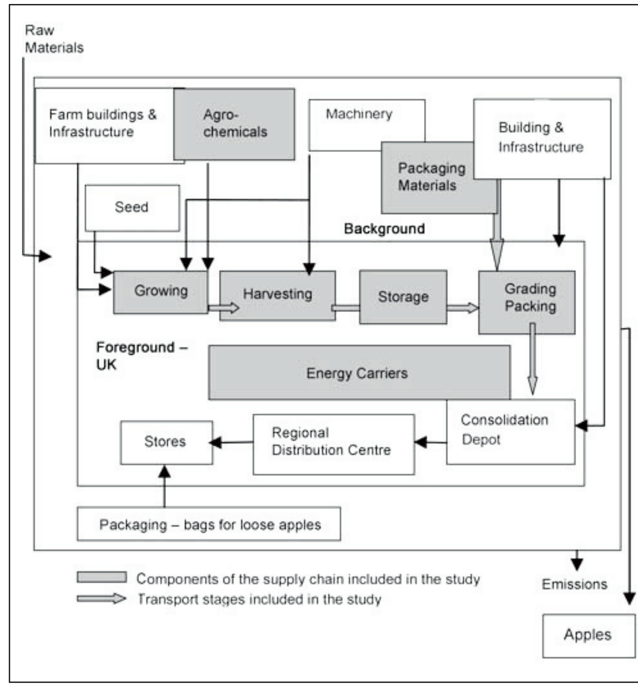

Fig. 3: Schematic diagram of the supply chain system for apples grown in the UK

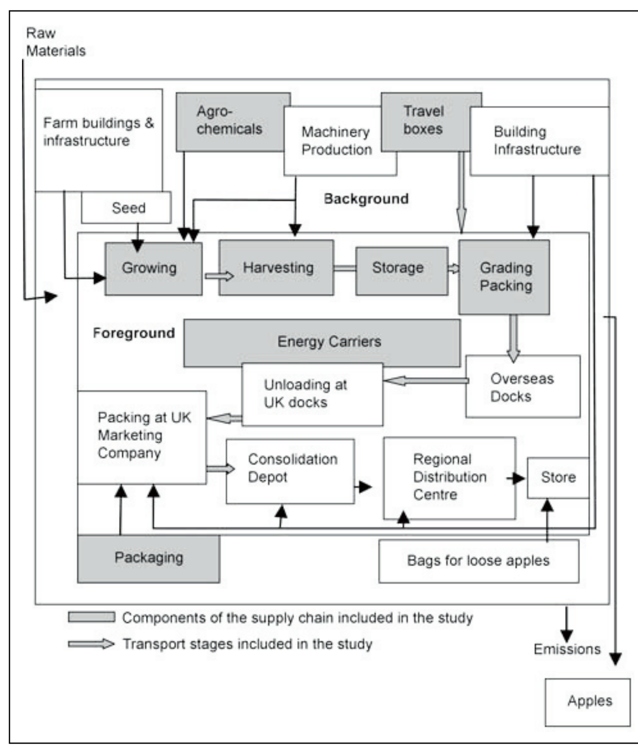

Fig. 4: Schematic diagram of the supply chain system for apples grown overseas

The results were again normalised with reference to the total impact of activities in Western Europe (1995). The domi-

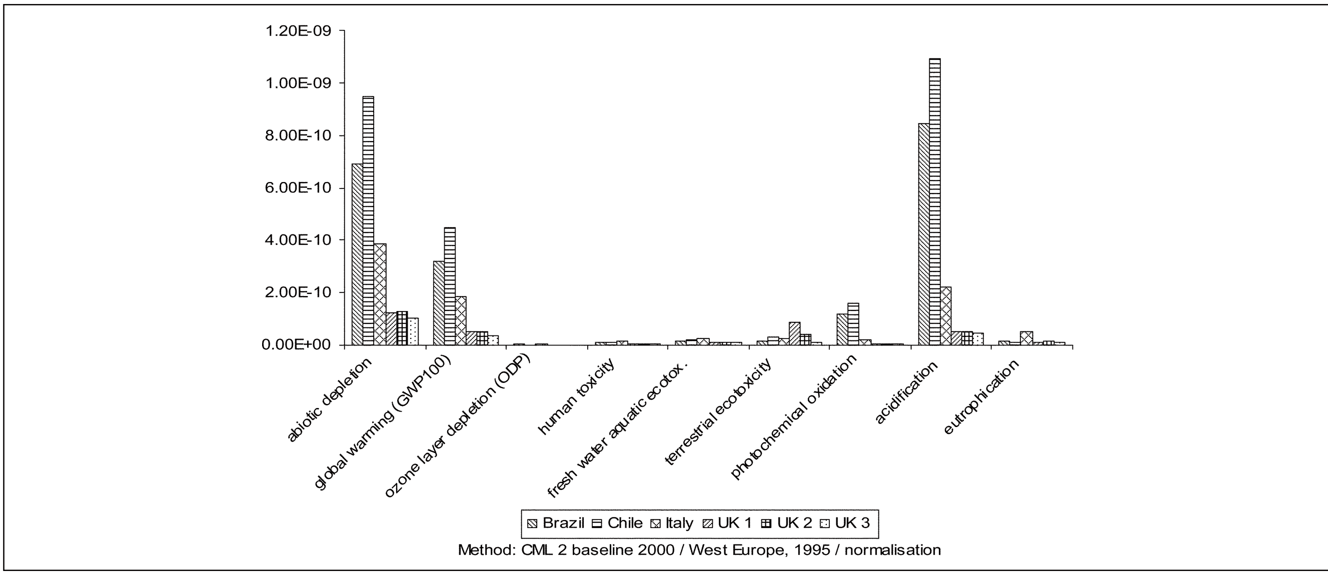

Fig. 5: Normalised impact assessment for royal gala apples sourced from Chile, Brazil, Italy and the UK

nating impact categories are similar to those identified in the runner beans LCA; marine aquatic ecotoxicity, acidification, abiotic depletion and global warming (**Fig. 5**). Electricity consumption is the root cause of marine aquatic ecotoxicity in all these apple supply chains. The activities associated with electricity consumption are grading, packing and storage, agrochemical production and transport (recovery and refining of petrochemical fuels). For apples sourced from Chile and one of the UK supply chains, agrochemical use is a dominant contributing activity. This illustrates how the impacts caused by cultivation activities, as well as transport, vary according to country of origin (**Fig. 6**). Abiotic depletion is mainly attributable to fuel use (particularly coal and gas for the generation of electricity and diesel used in vehicles). The activities contributing to this impact category are the same as those for marine aquatic ecotoxicity. However, transport is particularly significant for apples imported from the Southern hemisphere. Global warming and acidification are significant impacts mainly for imported apples. Transport is the dominant activity contributing to global warming potential for Chilean and Brazilian apples (72% and 90% respectively, as compared to 6–21% for UK apples), whilst both agrochemical use (contributing 49% of global warming potential) and transport (contributing 30% of global warming potential) are significant for Italian apples.

Results of the scenario analysis suggest that storing apples for ten months of the year in order to maintain total year round supply incurs significantly lower impact for half of the impact categories considered. When the results are normalised, the UK scenario appears preferable for three of the four dominating impacts (**Fig. 7**). The UK & Southern Hemisphere scenario shows twice the global warming potential of the UK scenario, 1.7 times the abiotic depletion potential and 4.3 times the acidification potential. However,

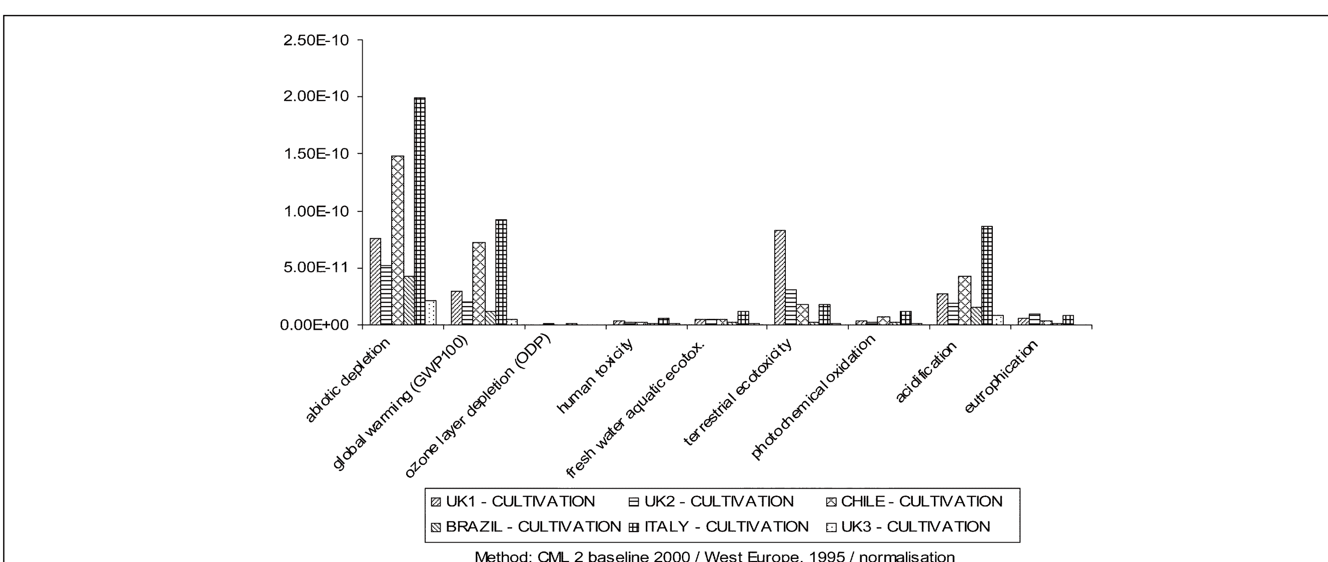

Fig. 6: Normalised impact assessment for the cultivation stage only of royal gala apples sourced from Chile, Brazil, Italy and the UK

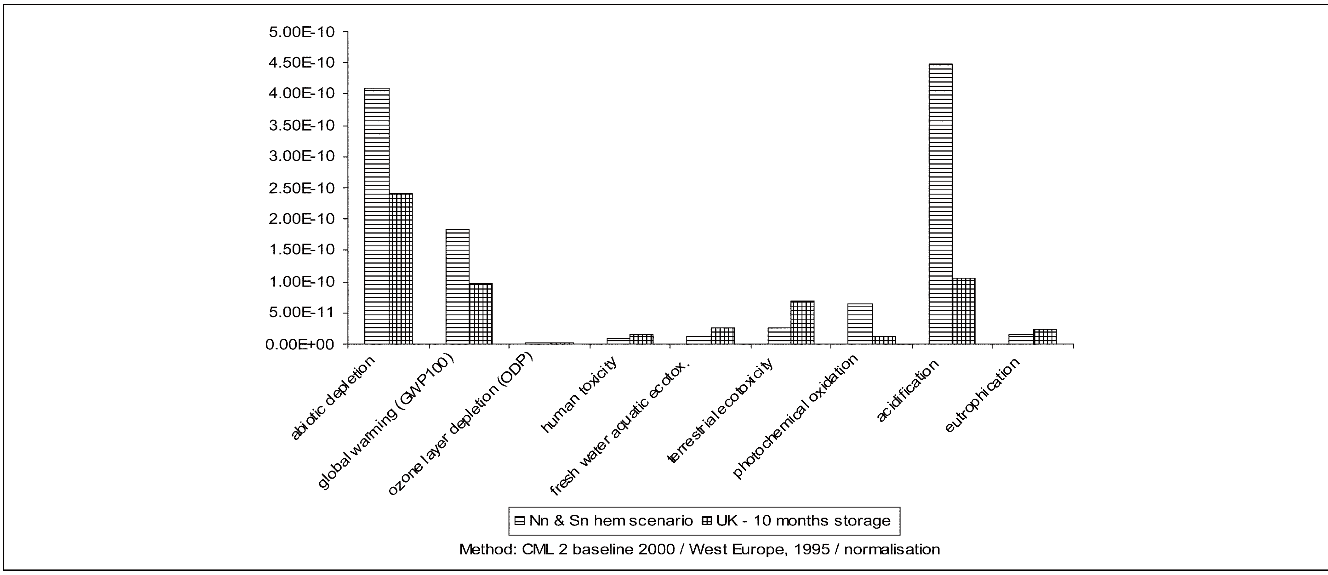

Fig. 7: Normalised impact assessment for two supply scenarios intended to cover year round availability – UK apples only as compared to UK and Southern hemisphere apples

the UK-only scenario shows 3.1 times the marine aquatic ecotoxicity potential of the UK & Southern Hemisphere scenario due to emissions from the production of the electricity used. This difference is less meaningful than the comparisons for the previous three impact categories given the uncertainty involved in the cause-effect modelling for marine aquatic ecotoxicity. The scenario analysis considers product quality only by accounting for apple wastage in the UK scenario due to lengthy storage (40%). However, the 60% of apples which remain, whilst still edible, will have a significantly lower quality than fresher apples imported from the Southern Hemisphere instead [40]. Quality is an important consideration for Marks and Spencer and offers one example of contradictory sourcing strategies that could potentially be advocated if all elements of product sustainability are not considered.

3.3 Watercress

The countries considered for this study are the UK and the USA (organic and conventional for both countries of origin), with a scenario analysis to consider the supply chain impacts if cultivation occurs in Portugal (conventional only) (**Fig. 8** and **Fig. 9**). Data were not readily available for the Portuguese example and the UK (conventional) crop data

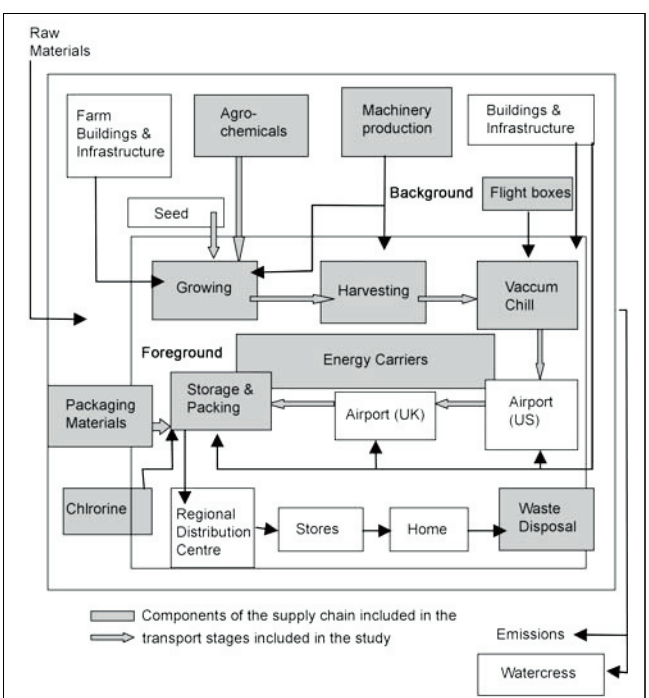

Fig. 8: Schematic diagram of the supply chain system for watercress grown in the US

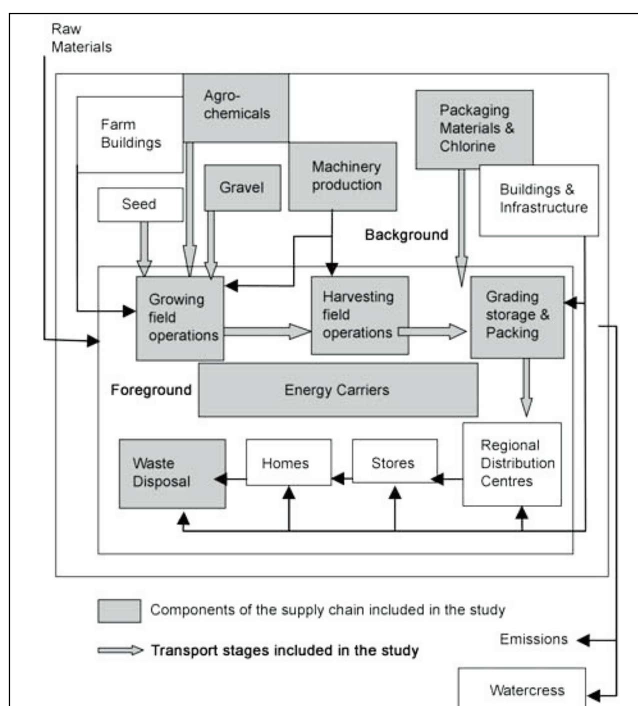

Fig. 9: Schematic diagram of the supply chain system for watercress grown in the UK

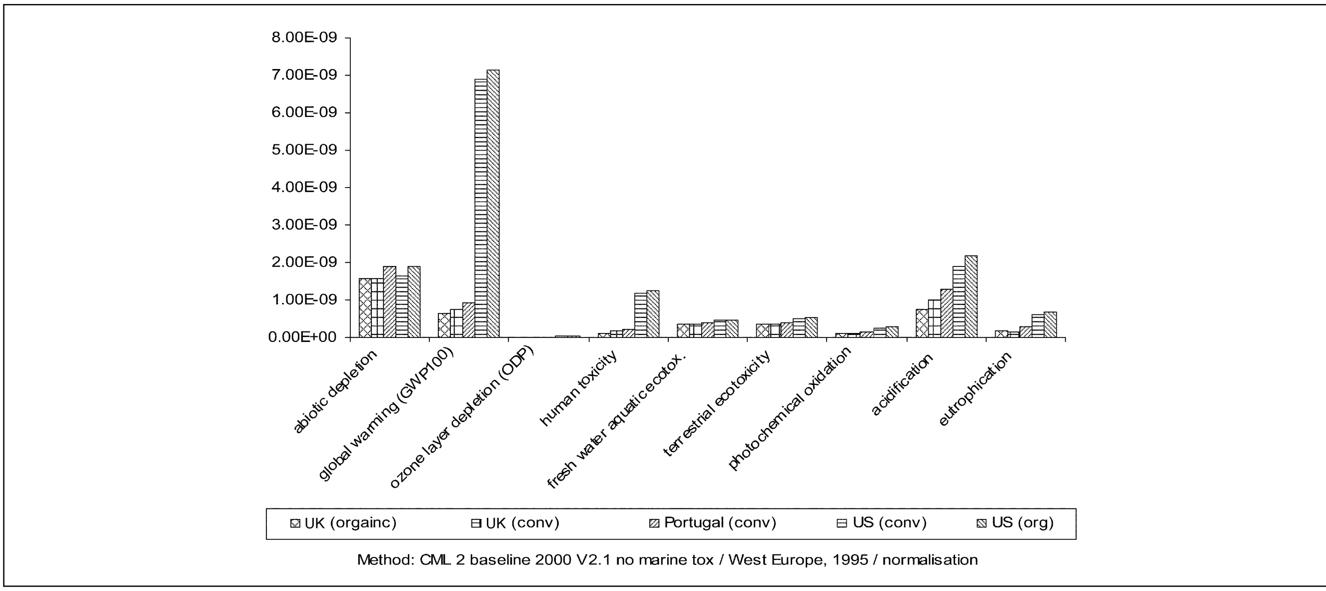

Fig. 10: Normalised impact assessment for watercress sourced from the UK (organic and conventional), the USA (organic and conventional) and Portugal (conventional) – marine aquatic ecotoxicity removed

were used as a proxy, with transport requirements altered in line with sourcing from Portugal. The normalised results for the watercress systems are shown in **Fig 10**. Four of the impact categories included in the assessment are of particular significance to these supply chains: marine aquatic ecotoxicity, global warming, abiotic depletion and acidification. Human toxicity is also significant for the US supply chains as air freighting (manufacture, maintenance and use) results in emissions of sulphur dioxide, ethylene oxide, formaldehyde, nitrogen oxides and particulates to air, and barium and lead to water. The method of estimating the global warming impacts of air freight is again consistent with the IPCC research and these results suggest that watercress sourced from the USA may result in up to 15 times the global warming potential of the UK sourced watercress (transport contributing 89% of the global warming potential from both the organic and conventional watercress supply chains). For the UK and Portuguese supply chains, global warming potential ranks third in terms of dominant environmental impacts and is mainly attributable to electricity consumption in the packing phase (this is the second biggest contributing activity in the US examples). The potential for marine aquatic ecotoxicity from all watercress supply systems studied occurs mostly from emissions released in the production of the electricity used.

Acidification ranks as the 2nd most significant impact for all supply systems studied. For the US and Portuguese systems, transport and packing are the main contributing activities whilst packing (and fertiliser use for conventional) are significant for the UK examples. Emissions of SO_2, NO_x, HCL or NH_3 from the combustion of kerosene in aircraft and particularly coal in the generation of electricity (from which nearly 60% of UK national grid electricity is generated) are the causal factors. Abiotic depletion is the dominant impact attributable to the UK and Portuguese supply systems (ranking 3rd for the US). Non-renewable fuels used for electricity generation (and transport for the Portuguese system) are again significant.

Interestingly, the US organic system appears to have a greater potential environmental impact for all impact categories considered when compared to the US conventional system. This is explained by a number of factors. For every tonne of watercress produced via the organic system, there is a greater degree of crop discarded at the packing facility in the UK. Therefore, more organic crop is transported to the UK for every tonne of product as compared to conventional watercress sourced from the USA. All the resources associated with producing and transporting this waste crop are allocated to the system. In addition, the yield of watercress from the US organic system is lower than from the US conventional system. Thus, where resource inputs (machinery) are similar on an area basis, they are in fact higher for the organic system when allocated to 1 tonne of watercress, due to the lower yield per hectare (**Fig. 11**). Conversely, watercress from the UK organic system is associated with better environmental performance than watercress from the UK conventional system. This is due to the use of organic fertilisers which compare favourably to the synthetic ones used in the conventional system, particularly in terms of global warming and acidification potential.

4 Discussion

All three product studies reveal similar dominating impacts, though the magnitude of these differs considerably. The dominant impact categories are global warming, abiotic depletion, acidification and marine aquatic ecotoxicity. Given the dubious cause-effect modelling for marine aquatic ecotoxicity, it seems appropriate to exclude this impact category from further consideration. Though it is acknowledged that the delineation of system boundaries may have a bearing on the results obtained, the relative dominance of these

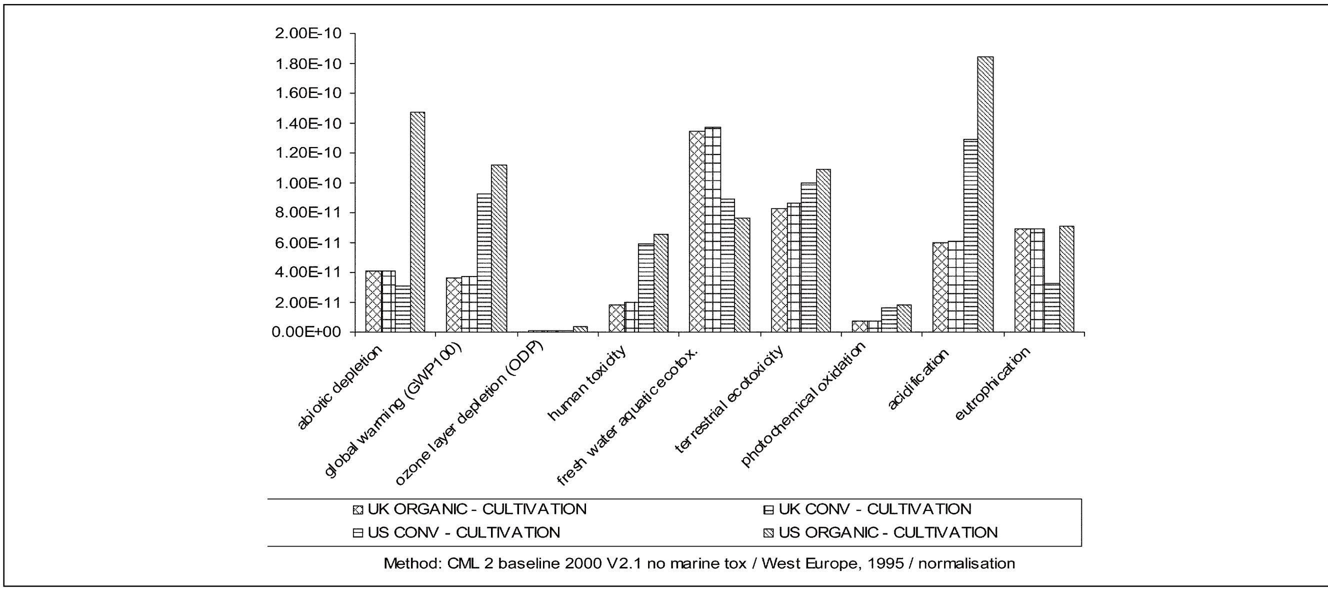

Fig. 11: Normalised impact assessment for the cultivation stage only of watercress sourced from the US and UK

three impact categories, for all the products studied, suggests that the results are indeed an accurate reflection of the supply chain environmental impacts. For the global supply systems studied (Kenyan and Guatemalan beans; Brazilian and Chilean apples; and American watercress) transport contributes most to the dominant environmental impacts, whereas activities which consume electricity, such as grading, packing and storage are most significant in the UK supply systems. Italian apples and Portuguese watercress represent regional sourcing systems. They show combined dominance of transport and activities consuming electricity (particularly the manufacture of agrochemicals for the Italian example, and packing in the Portuguese example).

Thus a clear distinction arises in terms of the activities which contribute most to the three dominating environmental impacts, depending on the country in which the product is cultivated; i.e. global, regional (European) or local (British) sources of supply. The overall magnitude of each impact also appears to depend upon country of origin, primarily due to the dominance of transport impacts, though there is a significant distinction between products that are air-freighted and those that are shipped. For air-freight, the impacts are so overwhelming that they would also dominate for other products unless their production is highly energy-intensive. Electricity consumption for storage and packing operations is also significant and the magnitude of impacts from these activities is similar for all supply systems of the same product, except where significant differences in the electricity generation mix for national grid electricity occur. There is no consistent pattern when relating the magnitude of environmental impacts of the cultivation stage to sourcing regions (global, regional or local), or cultivation systems (organic or conventional) and one should consider that the particular farms studied may not be representative of other farms in these geographical locations. It is likely that farm-specific management behaviour is a more important determinant of on-farm environmental impact than location [13]. It is also observed that regardless of the existence of any pattern, variations in on-farm environmental impact are generally disguised in the overall assessment of supply chain impact due to the dominance of transport, packing and storage activities (with the exception of eutrophication).

The dominant impact categories and contributing supply chain activities revealed in these studies should be prioritised in the environmental management of fresh produce buying strategies. This conclusion is significant because Life Cycle Assessment is not a practical approach for the assessment of all food products offered by Marks and Spencer, due to time and cost constraints. However, this study illustrates that, used strategically, LCA can aid the development of a more targeted approach to environmental management of product supply chains. The results of this paper suggest a particular management strategy in terms of country of origin; i.e. it is advisable that the distance between production and consumption be minimised. However, this is stated with extreme caution, for a number of important reasons. Firstly, if fresh produce items are to be offered to consumers all year round, two sourcing strategies are essentially available in the winter where sufficient quality cannot be maintained through storage: import produce from overseas, or create an artificial environment to replicate summer growing conditions (usually through heating and lighting greenhouses) and source produce more locally. This paper does not compare the environmental impacts associated with these alternative strategies. Indeed it may be in some cases that the energy used for greenhouse production mitigates the energy used in transportation thus justifying a strategy of overseas sourcing [9,41]. The UK examples presented in this paper represent produce grown in the UK season, and from this we can conclude only that when in season, it is preferential on environmental grounds to buy locally grown (British) produce rather than produce air-freighted from overseas. Should cultivation occur overseas in order to ensure year-round availability in the UK (providing greater choice and potential health benefits, particularly in winter), it is preferable that processing activities (grading and packing) also occur overseas if environmental benefits can be derived from local factors such as a more favourable electricity generation mix. Overall, the findings should be evaluated in the context of managing wider sustainability interests (including social and economic issues), for which further research is required.

5 Conclusions and Perspectives

This research suggests a clear strategy for the environmental management of fresh produce supply chains. However, additional environmental issues which are not currently included in the LCA method (e.g. land use including biodiversity, water use and toxicity impacts related to the use of pesticides) also require further examination. In addition, the environment must be considered as only one part of a wider sustainability management process, which should include socio-economic impacts of food sourcing decisions, consumer health and business drivers. Further research is required to equip decision-makers within Marks and Spencer with information in these other areas of sustainability, in order to introduce a reasoned and logical system of prioritisation. This is particularly important for the management of sustainability issues which appear contradictory.

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