CO_2 EMISSIONS OF EUROPEAN SUPPLY CHAINS: IMPACT OF LOGISTICAL CHOICES

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1 INTRODUCTION; ENERGY EFFICIENCY IN THE SUPPLY CHAIN

Freight transportation system is critical to economic activity but it carries significant environmental costs, notably GHG emissions: energy use and corresponding CO_2 emissions is increasing faster in freight transport than in other sectors and this increase is primarily the result of increased trade. This paper compares the transport activity, associated energy consumption and CO_2 emissions of different supply chains for selected products in three European countries: Belgium, France and United Kingdom. For each of these products, different supply chains, involving more or less transport activities and therefore associated energy consumption are analysed. We consider the whole supply chain, from production to consumption and attention is put on the mobility behaviours of consumers purchasing the studied products and taking them back home. The comparison of energy efficiency of alternative supply chains for the same consumers highlights some of the main factors that influence GHG emissions and illustrates how they vary according to product and country of final distribution. In more details, the paper addresses the main differences between the supply chains of these products namely, the origin of their sourcing, the logistical organisation between production and retail and different types of retail outlet. The origin of the sourcing impact is mainly related to distance. The impact on GHG emissions of the logistical organization between raw material and retail is mainly linked to mode and vehicle choices, to route and load factor. As for retail, the consumer's trip emissions, between his home and the retail outlet, are also an important part of the whole supply chain emissions.

The research is based on a comprehensive review of the various approaches to quantifying the energy and GHG impacts of supply chains together with data collection from a range of organisations including manufacturers, retailers and transport companies as well with an online survey regarding consumers' trip behaviours for purchase activities.

This paper is based on a two step research project on “Supply Chain, energy and GHG” carried out by INRETS (France), the University of Westminster (UK) and the University of Namur (Belgium) for ADEME (the French Environment and Energy Agency), through the French program on transport research (PREDIT).The products analysed in the first step of the project were yoghurts and jeans (Rizet & Keita 2005); in the second step, we dealt with furniture and fruits (Rizet & al. 2009).

The final objective of this supply chain project was to provide a contribution to the discussion on the carbon footprint of a product by comparing different supply chains, measuring their energy “expense” in a standardised way, quantifying the transport specific energy consumption steps in the considered supply chain and identifying potential strategic logistics choices and options which could lead to reduced energy use. Importantly, the study also considers the consumer shopping trip and, if relevant, compares it to a home delivery alternative.

The case study approach here presented highlights the need for good quality data from the various operations carried out within the supply chains, including factors such as distance travelled, weight carried, type of vehicle used, storage, handling and consumer behaviour. Therefore, the supply chain approach is potentially very complicated and time-consuming for the researcher. The complexity and the time required to complete the study of a supply chain is strongly influenced by decisions about the system boundaries. In some cases like the Life Cycle Analysis (Browne et al., 2005), or the French carbon balance (Ademe, 2007), the complete chain of all the suppliers of a company has to be assessed. However, the need for efficiency leads us to the choice of a survey method assessing the energy used from the producer to the consumer, so focusing more on freight transport movements than on other specific steps of the “complete” chain like agricultural production or recycling or product disposal (Rizet 2007).

In this paper, we will first present the developed methodology, and then the results corresponding to each studied product will be described. The company logistical choices and their impact on energy consumption and CO_2 emissions will be discussed, as well as the potential application of the research approach to the wider debate regarding the environmental impact of freight transport. The scope for GHG emissions reduction targets to be achieved will also be included.

More precisely, after this first section on the objective and context of the research, the paper provides a brief description of the methodology in section 2; then the results of the first phase on yoghurts (section 3) and jeans (section 4) will be presented. As already mentioned, the last leg of the chain, the consumer trip, was also an important focus of the project; Section 5 will present the web survey we have conducted to estimate the CO_2 emitted by this last mile part. Then Sections 6 and 7 will present the results for the products analysed in the second phase: fruits and furniture. Section 8 outlines the main results of these comparisons on the supply chains energy efficiency. Finally some conclusions on fitness for purpose of this supply chain approach will be discussed in Section 9.

2 METHODOLOGY OF THE RESEARCH

The main objective of the research was to obtain a complete figure of the energy “expense” of a “typical” supply chain by focusing on specific products: four types of products have been considered:

- Yoghurt consumed in France, a ‘domestic product’, mainly produced from milk produced in France,
- Jeans, a typically global product, internationally produced and traded.
- Fruits (apples and tomatoes), which can be either produced nationally or imported, including from very far countries.
- furniture (chest of drawers and book case), for which the consumer may have a very specific mobility behaviour.

The methodology has been slightly improved between the two phases; an important improvement was on the estimation of the consumer trip energy and CO_2 emissions (see below). In this synthesis paper, the results are discussed in relation with the detailed methodology.

The goal of choosing contrasting product types was, on one hand, to investigate the relative difficulties in data collection and analysis and, on the other hand, to identify whether the supply chain decisions which could lead to reduced energy consumption may be common across different product categories. Applying a standardised research method should lead to efficient data collection. This means using a relatively simple protocol that is not time consuming and represents a small burden for the involved companies. In line with these principles, the surveyed companies were mainly market leaders in the chosen product categories and the case studies focused on products sold in high volumes and generally available all the year round (although the sourcing may change for fresh produces to accommodate seasonality issues).

In the applied method, different types of transport energy have been included such as diesel for goods vehicles or bunker fuel oil for ships since such a range or fuels is used in the supply chains. Fuel, gas and electricity consumptions data have also been collected for storehouses, production plants, distribution centres and shops. Moreover, at each stage, data about tonnage of grown, manufactured, transported, stored or distributed products was collected together with these energy use data. The used calculation differentiates the energy consumed in buildings (warehouses, stores and shops) or for transport. For maritime transport, the principle is the same as for road but other specific indicators are needed: port calls and shipping line route, vessel load factor in TEU or % of nominal carrying capacity, average container load factor, etc. (Léonardi et al. 2009).

At each step of the supply chain, energy use is estimated and converted in “grams of oil equivalent” (goe); then GHG emissions are calculated in ‘grams of CO_2 equivalent’ (gCO_2e), using the coefficients given in Table 1. A ‘gram of CO_2 equivalent’ is a unit measuring the Global Warming Potential of different greenhouse gases (IPCC 2007); it measures the quantity of these other gases which would have the same Global Warming effect than one gram of CO_2. The used emission factors are 'from well to wheel', which means that they include the emissions which have been necessary to extract and transform the fuel, and to bring it to the vehicle.

Fuels	litre	= gram of oil equivalent	Emission factor = gCO_2e
Diesel	1	845	2951
Petrol	1	755	2841
Heavy fuel oil	1	1000	3553
Note: gCO_2e : gram of CO_2 equivalent			

Table 1 : Conversion factors for energy sources, fuel consumption and CO_2 emissions
Source: ADEME (2007).

In buildings (warehouses, stores and shops) the main energy source used is electricity. The quantity of GHG emitted per kWh highly depends on the primary energy from which electricity is produced: nuclear electricity emitted very few GHG, compared to fossil fuels power stations. ADEME (2007) estimated emission factors per country, using the share of nuclear electricity in each country and applying a different emission factor for nuclear or for other primary energies. The resulting coefficients for Belgium, France and UK are in Table 2.

Electricity produced	% nuclear energy in electricity production in 2001	Emission factor gCO_2e/kWh
in Belgium	60	268
in France	80	84
in UK	20	455

Table 2 Emission factors for electric energy per country
Source: ADEME (2007)

In order to be comparable between chains and across products, energy consumption and GHG emissions are divided per the total quantity of product sold: the units of comparison between chains are thus gram of oil equivalent per kg (of apples, etc.; goe/kg) and gram of CO_2 equivalent per kg (gCO_2e/kg).

3 THE YOGHURT SUPPLY CHAIN IN FRANCE

Four types of yoghurt supply chains were analysed in France for years 2003 and 2004: one for hypermarket, one for supermarket, one for the small shops and the last one for the e-commerce supply chain with home delivery. They all had the same structure, i.e. the same stages in the same order, except for the two last stages (distribution and consumer trip). Starting from the farms producing milk, the successive common stages of the supply chains, are 1) transport of the milk to the yoghurt factory 2) production in the factory itself, 3) transport to the distribution centre of the yoghurt producers, 4) storage in the producer distribution centre, 5) transport to the retailer distribution centre and 6) storage in the retailer distribution centre, generally managed by a third party logistics provider responsible for supplying the yoghurt to retail outlets. From the retailer distribution centre, the yoghurt is distributed onto vehicles with other grocery products and this is the point where the chains are getting different. In the three chains corresponding to three types of retail outlet (hypermarkets, supermarkets and local shops) the next stages are still the same and they only differ by the various sizes and weights of goods vehicles, and also by the distances for the transport to retail outlet (7); the retail outlet itself (8) and the consumer shopping trip (9) also differ in energy efficiency. In the case of the e-commerce supply chain, the organisation is slightly different. Starting again from the retailer distribution centre (stage 6), there are 5 stages that we numbered with a digit plus a letter (7a to 9a) to distinguish them from the other supply chains (but keeping the same correspondence between legs of the chain and digits):

7a) transport from the retailer distribution centre to the e-commerce picking centre;

8a) handling in the picking centre, where the goods are picked according to the internet orders received

7b) transport to a local delivery point; the transport to the retail outlet in the 'traditional' retail chain should therefore be compared with the sum of steps 7a and 7b in the case of e-commerce

8b) storage and handling in the local delivery point from which deliveries to home are achieved; the sum of steps 8a and 8b replace the retail outlet of the 'traditional' chain.

9a) home delivery which replaces the consumer shopping trip (9)

Figure 1 here under shows these different stages considered when analysing the yoghurt supply chain. As already mentioned, these chains are identical up to the retailer distribution centre. The upper part of the diagram refers to supply chains in which yoghurt is sold via retail outlets, and the lower one refers to e-commerce and home delivery chain. This is discussed in more detail below.

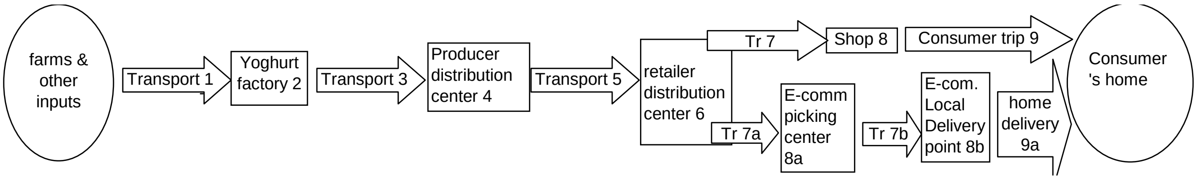

Figure 1: The yoghurt supply chain assessed in France

At stage 1, milk is collected from surrounding farms, using isothermal vehicles, to supply the yoghurt factory. When local milk is insufficient, a complement can be bought in and transported from regions that are more distant. As a result, the average distance for the round trip supply of milk is 354 km. The energy consumption for feeding the factory in milk is 6.2 goe and 22.2 gCO_2eq per kg of yoghurt. The factory is also supplied with packaging and other ingredients necessary for making yoghurt (fruits, containers, additives, sugar and cleaning materials). These products come from all around Europe, but in small quantities relatively to the milk.

At stage 2, the yoghurt factory is consuming natural gas for heating and electricity for cooling and processing the product. Total energy consumption related to total production results in 39 grams of oil equivalent (goe/kg) and the energy mix in 95 gCO_2e/kg of yoghurt.

Stages 3, 5, 7, 7a and 7b are road transport, made by third party companies. In stage 3, vehicles are semi-trailers, each containing 33 europallets; the load factor is very high and so is unitary energy consumption: around 27 goe/tkm, which gives 7 goe/kg of yoghurt for an average distance of 300 km per loaded trip. More downstream in the chain, shipments to the hypermarkets are sent by semi-trailer (refrigerated) and filled with standard pallets, while those to supermarkets and local stores are sent by smaller refrigerated vehicles filled with roll cages and some pallets. The quantities of yoghurt are smaller, many products are mixed in the vehicles, the load is less homogenous and lighter and the energy efficiency becomes worse. For example in step 7, energy efficiency varies between 75 and 140 goe/tkm which gives between 2 and 10 goe/kg of yoghurt and per trip. GHG estimated for these stages together, including the emission from the refrigerating fluid used to cool the trailer varies between 3 and 39 g CO_2eq per kilo of yoghurt and per trip. In Figures 2 and 3, the consumption of these different transport stages have been added, together with the one from stage 1 in global transport energy consumption per kilo of yoghurt.

For stages 4 and 6, the observed yoghurt producer distribution centres and retailer distribution centres are comparable according to energy efficiency. The consumption was calculated between 1 and 9 goe/kg of yoghurt. This energy is mainly nuclear electricity (we are in France) and results in rather low GHG emission: between 1 and 6 g CO_2eq per kilo of yoghurt.

Regarding stage 8, an average consumption per square meter of shop per year was estimated, multiplied per the surface of the yoghurt department; this gives a measure of the energy consumption in the shop due to yoghurt. The energy spent to cool the display units was added to this and the total was divided by the operated yoghurt tonnage per year. This computation lets us realise that retail outlets consume quite a lot of energy: 26 to 51 goe/kg of yoghurt, while the observed picking centre of the e-commerce chain only consumes 11.2 goe/kg.

Stage 9 (consumer transport) or 9a (home delivery) has been estimated using the information from the national transport surveys and other published data. In the case of traditional shopping, the share of consumers who drive their car, the distance they drive for shopping and the weight of the average shopping basket have been estimated as follows: for a hypermarket, 75% of the consumer come by car, they drive an additional distance of 14 km, and buy an average basket of 30 kg. These figures are respectively 50%, 9 km and 15 kg for a supermarket, and 7%, 3 km and 5 kg for a local shop. In the e-commerce supply chain, the transport from the picking centre to a local delivery point is performed by a semi-trailer on an average distance of 30 km; then lorries perform home delivery from the local delivery point. The typical round trip is 40 km long for 13.5 deliveries and each basket delivered has an average weight of 35 kg. The mean energy consumption of these two final transport segments for home delivery was estimated together at 19 goe/kg.

The results of the different stages for the four types of supply chains (hypermarket, supermarket, small shops and e-commerce) are summarised in Figure 2.

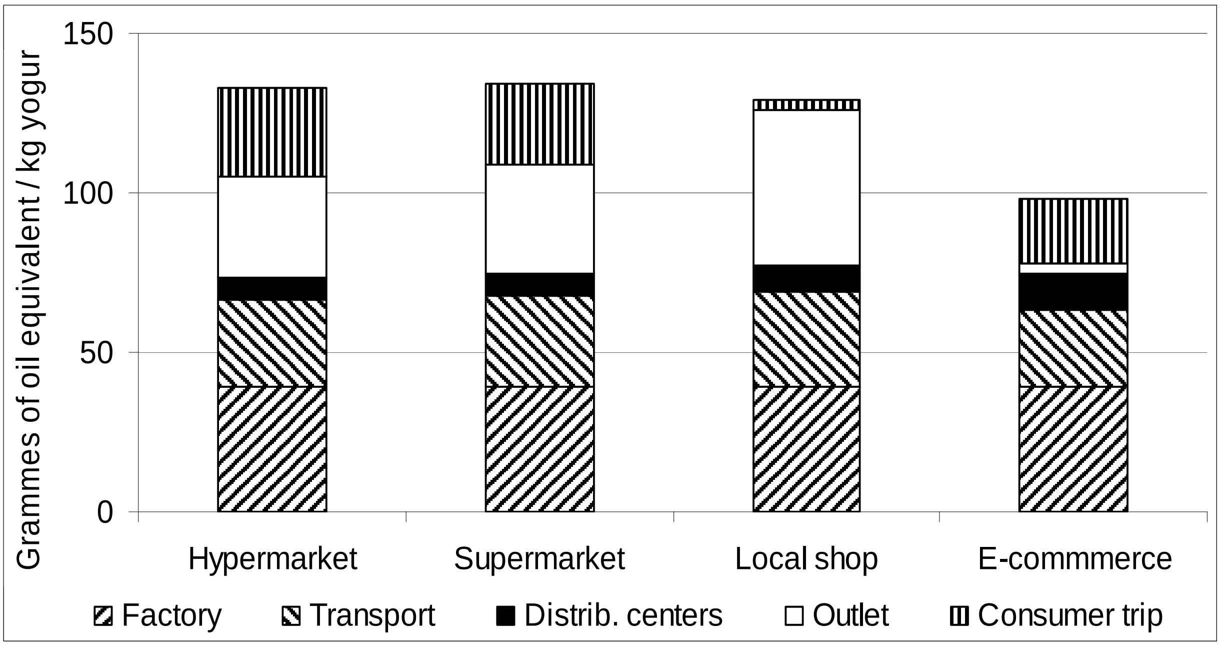

Figure 2: Energy consumption of the yoghurt supply chain according to the type of retail outlet

In the case of the hypermarket and the supermarket supply chains, the energy use applying to the consumer shopping trip is very significant and is approximately the same as the total commercial freight transport energy from farm to retail outlet. This is explained by the distance the consumer has to travel, due to the high level of car use by shoppers, the quantity of goods purchased and the hypothesis that the trip is mainly achieved for the purposes of food shopping. By comparison, the energy used in the consumer trip in the case of local shop is far less, due to the lower distance from shop to home and less use of cars. The observed e-commerce and home delivery supply chain generates a lower total transport energy consumption from farm to home than a chain where a consumer is shopping at a hypermarket or supermarket.

When the shop surface decreases, energy consumed in factory and good transport does not change, but the retail outlet consumption increases whilst the consumer consumption decreases nearly in the same amount; so, finally, there is not a great difference of total energy consumption per kilo of yoghurt among the three 'retail outlet' chains. By comparison, the e-commerce chain with home delivery seems to be more energy efficient.

In the following Figure 3, energy has been converted in greenhouse gases (ghg), using the coefficients of Table 1. The main differences with Figure 2 result from the different energy mixes and corresponding conversion factors of the different stages. Distribution centres and outlets mainly consume electricity, which, in France, produces very few GHG; this is favourable to the traditional retail outlets and mainly to the local shops. On the opposite, refrigerated transports not only emit greenhouse gazes for vehicle fuel use but also need more energy for refrigerating the load, and use cooling fluids, which are responsible for GHG. The consumer trip as well emits GHG, according to the fuel burnt, and this again is favourable to the small shops. Globally, when considering all the stages of the supply chains from the farm to the consumer home, the local shop supply chain are the more efficient for GHG emitted per kilo of yoghurt.

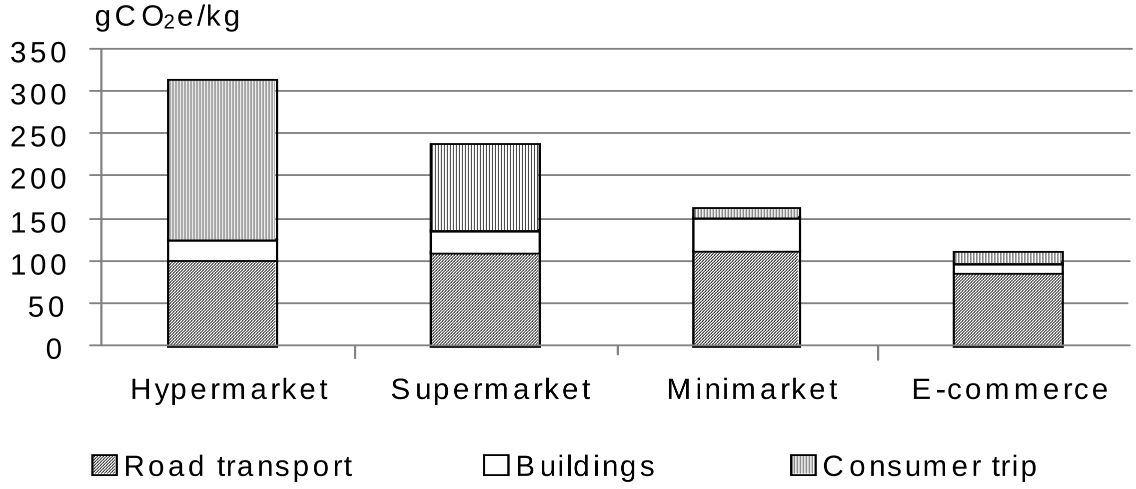

Figure 3: GHG emissions of the yoghurt supply chain according to the type of retail outlet

4 THE JEANS SUPPLY CHAINS

First of all, an initial stage for each case study has been the preparation of the supply chain map showing, as for yoghurt, the key physical movement details. Energy consumption in the UK and French jeans supply chains studied was calculated from the point at which cotton is grown to the point where jeans are arriving at the customer's home: cotton cultivation, spinning and dyeing, fabric manufacture, garment manufacture, importation of jeans to Europe, domestic distribution, and sale at retail outlet.

Jeans manufactured for sale in the UK: The supply chain for a pair of a relatively basic jeans involving few finishing processes, sold by a major UK multiple clothing retailer was analysed in the study. It involved six major transport stages from the cotton field to the retail outlet, with each stage involving up to three transport legs (e.g. road-sea-road). Cotton is sourced from both the USA and Turkey in this supply chain. On average, the total distance from cotton field to UK retail outlet when using American cotton is 17,950 km, and when using Turkish cotton is 7,600 km (Table 4)

The jeans manufactured for sale in France, whose supply chain have been analysed, are sold in hypermarkets. Two different cotton growing locations have been considered here: near Chenai in India and near Samarkand in Uzbekistan. The total distance from cotton field to the average retail outlet when using Indian cotton is 23,400 km, out of which 18,000 km is sea transport. In the case of cotton from Uzbekistan the total distance from cotton field to retail outlet is 27,200 km, with 20,000 km by sea. (Table 5)

From	To	Distance (km)	Vehicle (s)
Cotton plantation (USA)	Spinning mill (Turkey)	10750	Lorry & ship
Cotton plantation (Turkey)	Spinning mill (Turkey)	400	Lorry
Spinning mill (Turkey)	Garment make up (Morocco)	4150	Lorry & ship
Garment make up (Morocco)	Manufacturer’s warehouse (UK)	2450	Lorry & sea ferry
Manufacturer’s warehouse (UK)	Retailer’s national warehouse (UK)	300	Lorry
Retailer’s national warehouse (UK)	Retailer’s regional warehouse (UK)	(Average) 200	Lorry
Retailer’s regional warehouse (UK)	Retail outlets (UK)	(Average) 100	Lorry

Table 3: Summary of transport stage distances and mode used in UK jeans supply chain

From	To	Distance (km)	Vehicle (s)
Cotton plantation (India)	Spinning (India)	1600	Lorry
Spinning & dyeing (Ahmed.)	Garment factory (Bangladesh)	2500	Lorry
Cotton plantation (Uzbekistan)	Spinning (India)	4700	Train, ship, train
Spinning & dyeing (India)	Garment factory (Bangladesh)	3200	Lorry
Garment make up (Bangladesh)	Warehouse (Bangladesh)	25	Lorry
Warehouse (Bangladesh)	Warehouse (France)	18800	Train, ship, barge, lorry
Warehouse (France)	Hypermarket (France)	(Average) 380	Lorry

Table 4 : Summary of transport stage distances and mode used in French jeans supply chain

The energy consumption for the manufacturing and transport stages in the jeans supply chain from the cotton field to the consumer’s home was calculated. The transport data reflects the specific distribution systems used in the two chains. The results indicate that product manufacture is the most energy intensive procedure in the UK and French jeans supply chains studied (approximately 70%). This is followed by cotton fibre production, which accounts for approximately 25% of total energy consumption in the supply chain. Energy used in finished product stockholding and retailing (i.e. the energy used to run the warehouses and shops in which jeans are stored and displayed) accounts for only approximately 1% of total energy. The transport activities (i.e. commercial freight transport from field to shop, and consumer transport to home) account for 4-5% of the total energy used in both the French and UK jeans supply chains.

If the commercial transport is considered in isolation, then it can be seen that, in the UK supply chain, the transport stages from the point of product manufacture to UK port is responsible for the greatest proportion of transport energy use per kg of jeans in the UK supply chain (see Figure 4). Most of this energy is consumed in the transport stage in which the product is moved from the factory at which the jeans are finished to the UK port. The transport stage from the UK port to the store accounts for approximately 20% of the total commercial transport energy in the case of cotton from the USA, and 25% in the case of cotton from Turkey. The transport leg from the retailer RDC to the shop (the final commercial transport leg in the supply chain with an average distance of 100 km) accounts for approximately 4% of total commercial transport energy use.

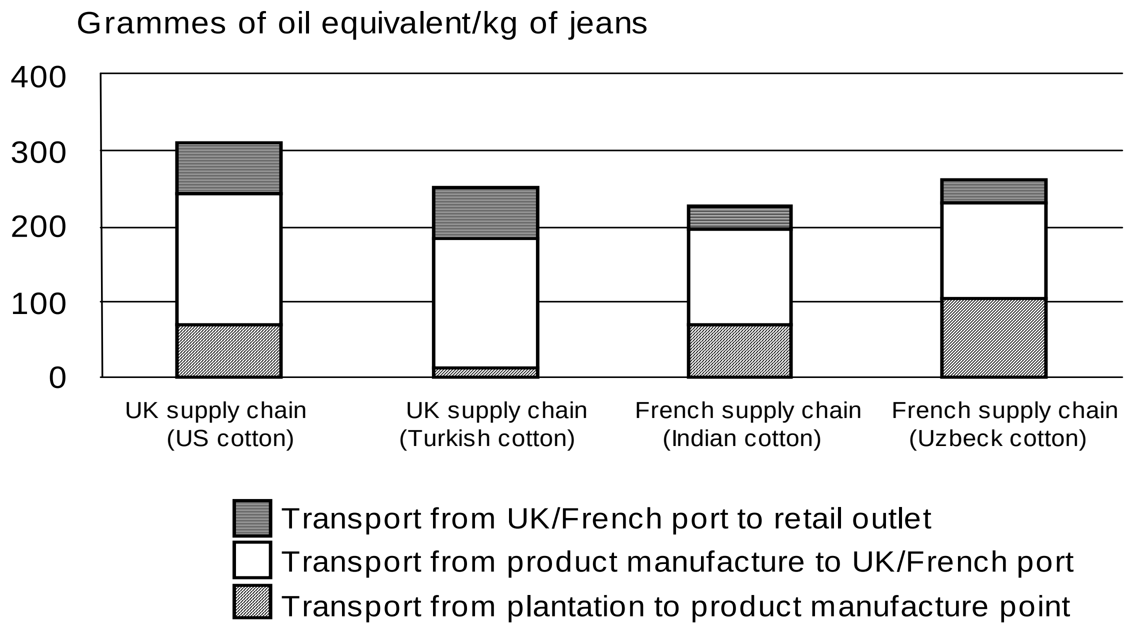

Figure 4: Transport energy consumed from cotton field to retail outlet in UK or France

In the commercial transport stages in the French supply chain, the stages from the point of jeans manufacture to the French port is approximately as important as in the UK chain but the legs between the cotton fields and the manufacturing point are more important, especially in the case of Uzbek where the cotton is carried a long distance by road (this represents 40% of total commercial transport energy). Though energy efficiency (in goe /tkm) is higher for sea transport than for land transport, the sea legs are the most energy consuming in the French case because of very long distances to the European ports. The transport stage from the French port to the store accounts for approximately 12% of the total commercial transport energy in the case of cotton from Uzbekistan, and 14% in the case of cotton from India. The last commercial leg of the supply chain, from the retailer's warehouse to the shop (average distance of 381 km) accounts for 10 % of total commercial transport energy use (1 % of total supply chain energy use).

Comparing the UK supply chain using local Turkish cotton and French supply chain using Uzbek cotton that is transported 4,700 km to a mill shows that the distance over which cotton is transported for spinning, weaving and dyeing has an important effect on the proportion of total commercial transport energy used during this first transport stage. In the case of Uzbek cotton, transporting the cotton from the field to the spinning mill accounts for 40% total commercial transport energy use, while in the case of grown cotton in Turkey that is transported to a domestic mill this accounts for 5% of total commercial transport energy use. However, given the relatively small contribution of commercial transport activities to total energy use in the supply chain, using more locally produced cotton has a very small impact on the total energy used in supply chain. For example, in the UK supply chain commercial transport alone accounts for 3.3% of total energy use when using Turkish cotton and 4.0% when using American cotton.

Concerning the transport stage carried out by the final consumer in the UK and French supply chains, it is assumed to take place by car. From information supplied by the UK retailer, it has been assumed that the round trip distance travelled is 11 km and that an average weight of 5 kg of goods are purchased on consumer clothing shopping trips in the UK. The trip is assumed to have two purposes (i.e. shopping and one other) and therefore only half the energy use has been allocated to the shopping activity. This consumer transport stage in the UK uses one third of the energy per kg of jeans transported that is used in the total commercial transport stages. It uses approximately 50% more energy than that used in transporting the jeans from the UK port to the retail outlet. In the French case the jeans are sold in hypermarkets. It has been assumed that car trips take place solely for shopping and have an average distance of 15 km and an average basket weight is 18 kg (i.e. consumers buy clothes and groceries). Therefore both the distance and the weight of goods purchased are greater than that assumed in the UK case (15 km compared with 11 km, and 18 kg compared with 5 kg). The results indicate that this greater weight of purchases leads to a sizeable reduction in the GHG emissions per kilogramme of jeans transported.

5 A WEB SURVEY FOR THE CONSUMER TRIP

During the first phase of the research, it appeared clearly that the consumer trip was responsible for an important part of the whole chain emissions. The calculation of the consumer trip emissions per kg of product is strongly influenced by the type of product, the home-shop distance, and on quantities transported by the consumer. To get a better view of the consumer mobility and quantify all these variables, a web based survey was conducted in France, Belgium and the UK during the second phase of the project (Cornélis & al. 2009). In the results presented in the following sections, all the consumer trip emissions have been calculated with this survey, including those which had been done in phase 1.

The on-line survey provided information on consumer travel behaviour and, among other things, details of the distance travelled to view products and to shop. In addition, information was obtained about the average weight of purchases and the mode of transport used for shopping. A filter selected only the respondents who have bought the specific products included in the research (apples, tomatoes …) during the previous week. In total 965 usable responses were obtained and this allowed us to compute significant evaluations for the energy consumption and the GHG emissions due to the shopping trip. It should be noted that the diffusion of the on-line questionnaire through a 'viral dissemination' strategy, means that there could be some bias in the responses and therefore care needs to be taken about generalising from the results. Nevertheless the results provide some interesting and useful insights into the relative importance of consumer trips in terms of energy use within the overall supply chain. Table 3 summarizes emissions of the consumer shopping trip, per kg of fruit (apples or tomatoes), according to country and type of distribution.

	Belgium	France (rural)	France (towns)	United-Kingdom	*All-together*
Supermarket in town	46	56	14	44	36
"Round the corner" shop	1	274	10	2	50
Hypermarket	84	129	47	73	80
Open air market	104	77	29	87	47
Direct sale from producer	104	370	-	255	136
Greengrocer shop	53	165	24	-	88
Outlying supermarket	90	77	34	39	75
"Minimarket" in town	21	35	12	9	21
All together	75	105	28	48	64

Table 5 : GHG emitted by the consumer's trip for purchasing fruits or vegetables (in gCO_2e/kg)

The consumer's trip emissions are quite different according to the type of distribution: (from 21 gCO_2e/kg for a minimarket in town, up to 88 for dedicated fruit & vegetable shops and even 136 gCO_2e/kg for direct producer sales). We also note an important difference between rural (105 gCO_2e/kg) and urban (28 gCO_2e/kg) consumers in France. So, in forthcoming analyses, we shall consider GHG efficiency separately for retailers settled in the Paris region or in a rural area.

When comparing these results with the few other studies aimed at the same topic, we could see that these results are quite comparable with the estimations made for the first stage of the project and presented on the yoghurt case. The survey results show lower emissions for the last mile than another recent German case study on the carbon footprint of coffee (PCF 2009). With 1.9 gCO_2e for 7 grams of coffee, corresponding to 271 gCO_2e/kg, the German case study result for a small shop in city centre is more than five times higher than our average value of 50 gCO_2e/kg for this type of retail. This is mainly due to the German assumption that the purchase of coffee has a very light load weight (250 gram bag) and is performed with a dedicated car trip. Our results shows again a far lower level than Edwards' study (2009), which estimates at least 650 gCO_2e/kg emissions for a book purchased in UK. The main reason for this difference is also the assumption of a dedicated purchase of only one book item of 450 grams, while our online consumer survey results highlight a basket load weight of more than 7 kg for city centre shopping and up to 20 kg for a hypermarket shopping trip. This tends to confirm again the importance of the assumptions made and the limits of the system of observation set in the various studies into this topic.

6 FRUIT SUPPLY CHAIN: THE CASE OF APPLES

First of all, an initial stage has been, as for other products studied, the preparation of a supply chain map showing the key physical movement details. Figure 5 summarizes this map for apples sold in hyper or supermarkets. A large number of apples supply chains have been analysed and are figured in this map: for each country, we consider two possible sourcing (domestic apples or apples imported from New-Zealand) and, in France, we have analysed two types of consumer zone: the Paris region (Ile de France), densely populated and 'rural zone', where the density of population is much lower. Figure 6 presents some of these chains for apples distributed in hypermarkets, in France, UK and Belgium showing their GHG emissions per kg of apples.

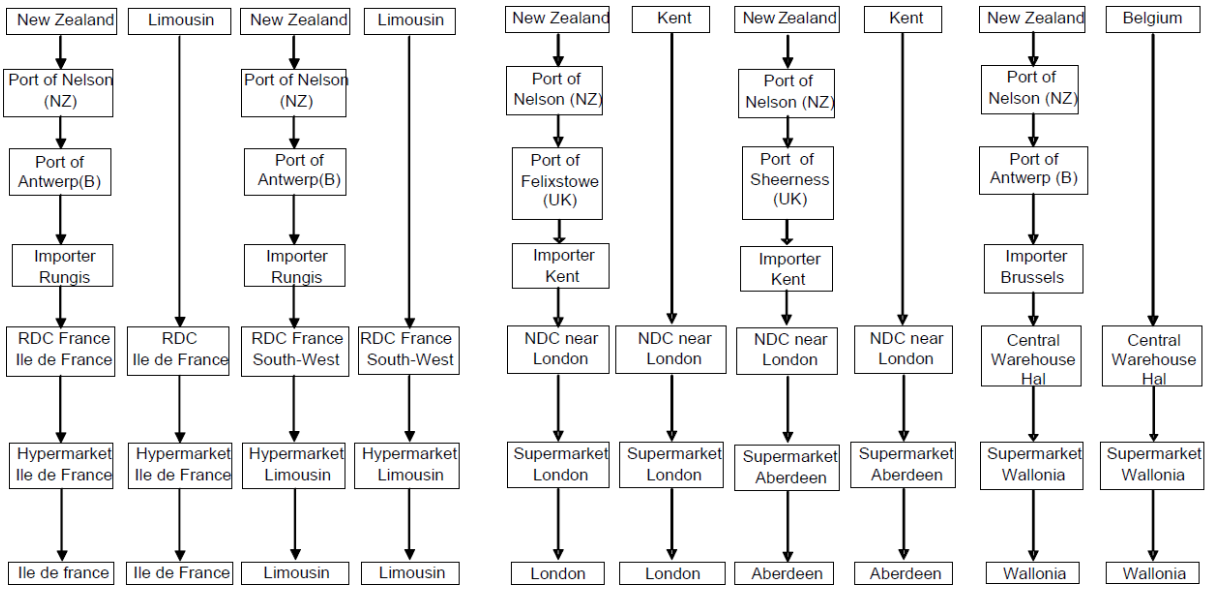

Figure 5: Apple supply chains examined in the study

In figure 6, six different supply chains are presented for hypermarkets located in Paris, London and Brussels, with two origins of sourcing for each of these cities. The most important result highlighted in this figure is the important difference in CO_2 emissions between apples imported from New-Zealand and those produced within the country where they are consumed. It is clear that even though maritime transport is very energy and carbon efficient per tonne-kilometre the distance involved when New Zealand apples are bought results in much higher transport energy use and CO_2 emissions for imported apples than in the case of locally produced apples

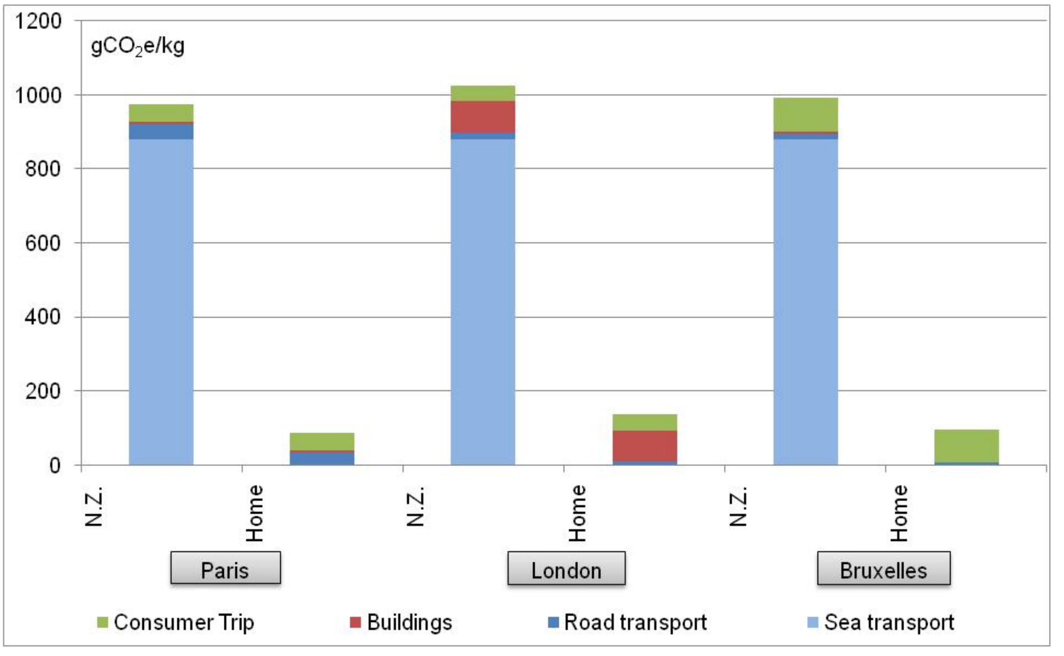

Figure 6 : GHG emission of different apples supply chains sold in hypermarket in Europe

7 FURNITURE SUPPLY CHAIN: THE CHEST OF DRAWERS

Within the research two types of furniture product were investigated – namely a chest of drawers made of pine and a book case made of particle board but in the following discussion the focus will only be on the pine chest of drawers, imported from Brazil in maritime containers.

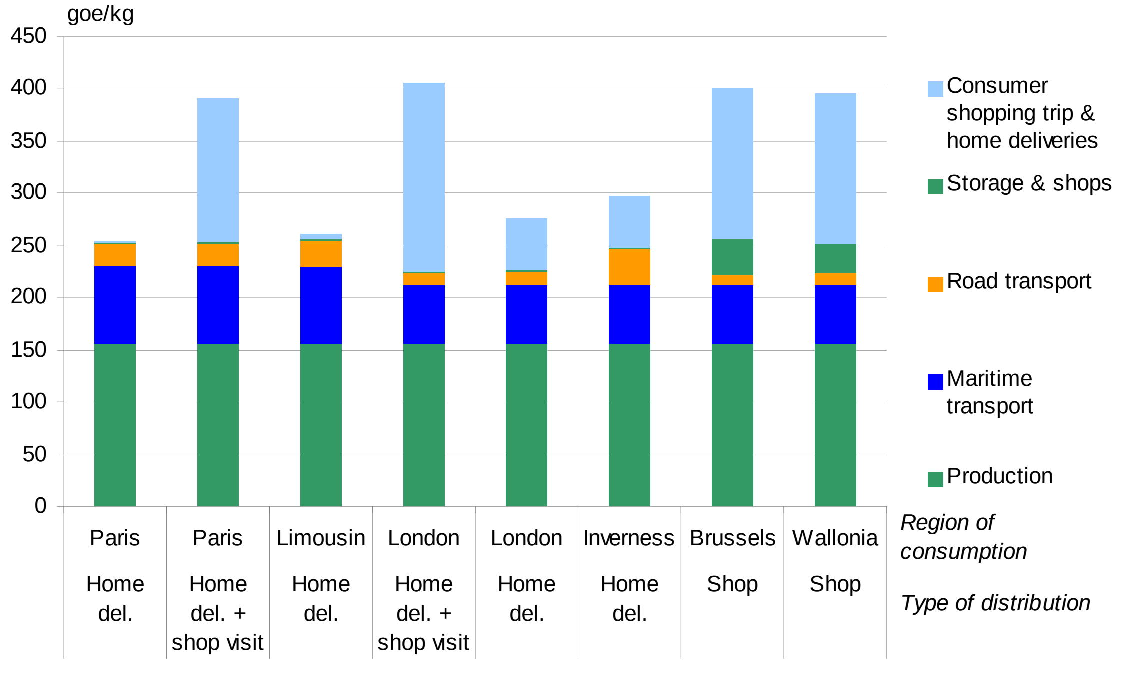

Figure 7: Comparison of the supply chains for a pine chest of drawers

Figure 7 highlights the importance of the final consumer trip in the whole supply chain emissions for furniture. Indeed, this part of the chain could be more complicated than for food purchases: for example, the consumer may travel to have a look on the product in several stores before the final purchase, which makes this case interesting for the supply chain analysis. At the opposite, he may buy the product on the internet, which will be delivered at home. The home deliveries analysed in Paris were very carbon efficient, compared with all types of consumer trip and even with other home deliveries.
In this Figure 7, an estimate of the energy consumed in production has been introduced, which is normally not included in our supply chain approach but which illustrates a key point of the life cycle consumption: energy consumed in production is somewhat more important than the logistical part of the supply chain (transport + storage and shops) up to the shop.
On another hand, some of the supply chains include a consumer shopping trip, which has been estimated with our online consumer survey and, when relevant, summed up with the home delivery (and presented in the Figure). For those chains with a consumer trip, this upper part in the Figure is the most important of the whole supply chain.
And finally, even with a maritime intercontinental transport, the logistical part of the supply chain, i.e. transport and storage and shops consumption, is generally not the most important part of energy consumption in the whole production and supply chain.

8 IMPACT ANALYSIS

8.1 CO_2 efficiency and sourcing: impact of distance versus volume

Distance is clearly the main factor for energy consumption of the supply chain, as illustrated in Figure 8 below. Sea transport and rail are more energy efficient but, on the whole, the distance is determinant.

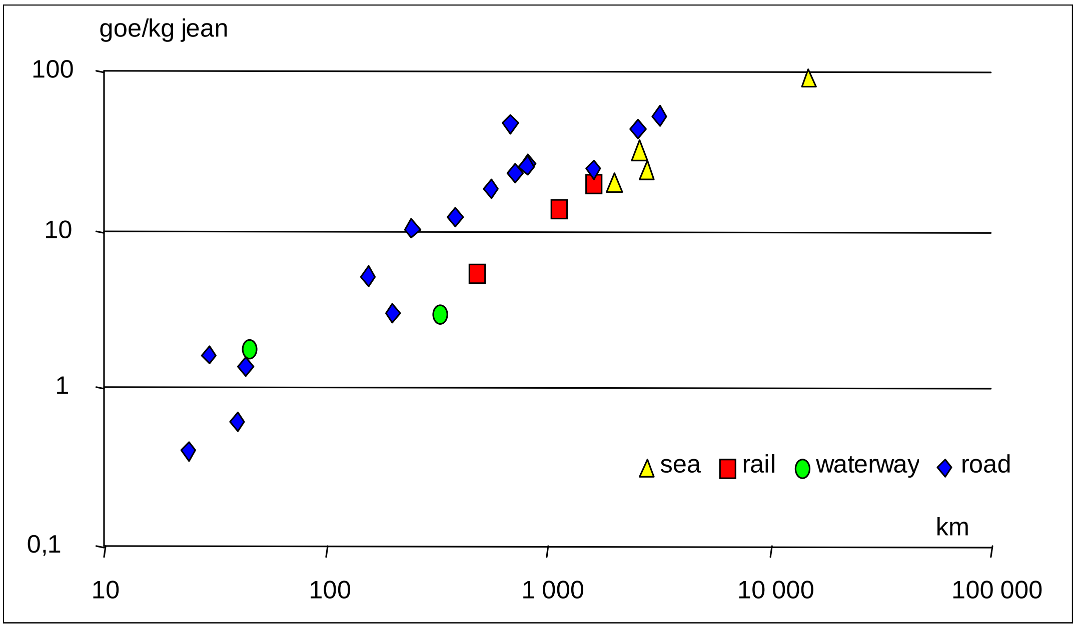

Figure 8: energy consumption per kg of product and per leg, according to distance (the case for jeans)

But distance is not the only dimension of energy consumption and GHG emissions: load factor, transport mode and other parameters are also important. Another parameter highlighted by the yoghurt case is the refrigeration. Refrigerated products consume a little more energy than non refrigerated ones and furthermore emit another type of GHG: the refrigerant liquid/gas used to produce the cold. Similarly the buildings consume more energy for the yoghurt than for apples, mainly because yoghurt has to be kept refrigerated.

The 'proximity commerce' highlights the fact that short distances are not necessarily carbon efficient. The product used for the comparison of different types of distribution in figure 9 is tomatoes grown in France and consumed in a low density region of France. The compared distributions systems are a 'bio basket' (a producer dispatch each week a vegetables basket to 'his' consumers, through his own logistical organisation); a direct sale at the farm, where the consumer goes to the farm and buys the locally produced tomatoes from the farmer; these are two types of 'proximity commerce' where the product is grown and consumed locally, within a beam (rayon) of less than 100 km. They are compared to more traditional retail outlets: a supermarket, an open air market and a minimarket. The GHG emitted by the consumer shopping trips have been assessed for these chains from our online consumer survey.

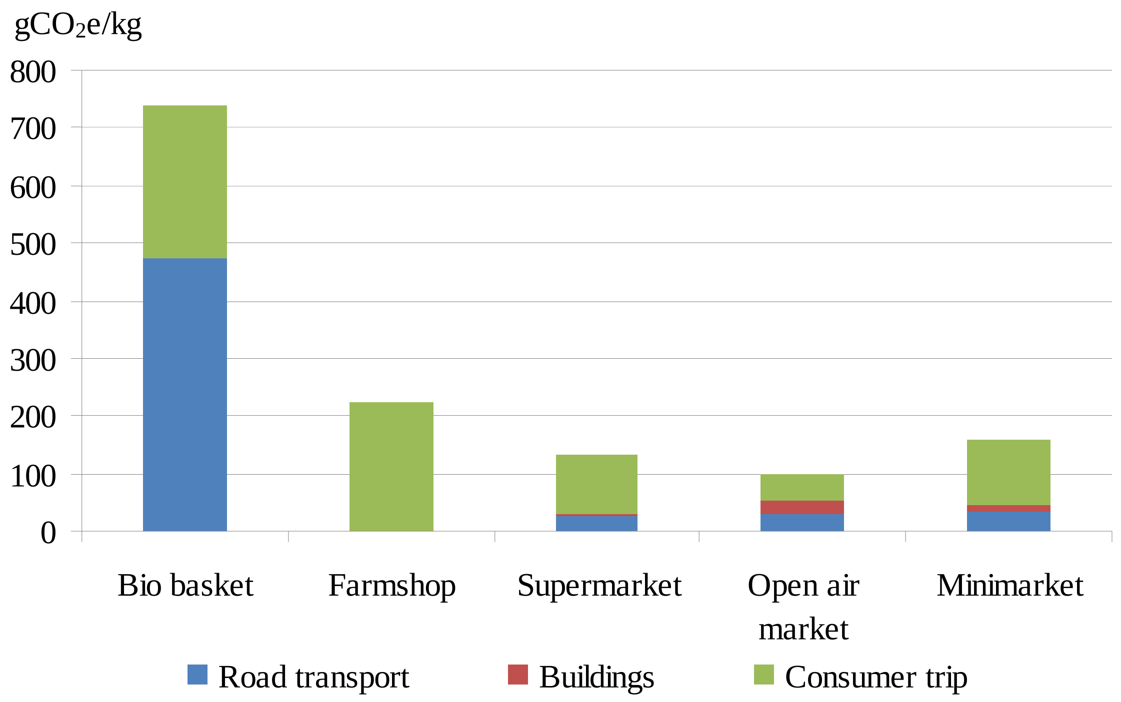

Figure 9 : GHG emission of different tomatoes supply chains in a rural region

Bio basket and farm shop were found to be the shortest supply chains, however they were the least efficient, because of the low quantities of sales and therefore of products transported, leading to a rather inefficient load factor. .

8.2 Importance of the: consumer purchasing trip or home delivery in GHG emissions of the supply chain

These case study results have shown that consumer shopping trips can consume as much energy as commercial transport activities (per kilogramme of jeans). This implies that when considering how best to reduce transport energy use in these jeans supply chains, it should be given as much consideration to consumer shopping trips as to commercial freight transport operations. This is an important point since consumer shopping trips are often not included in freight transport data collection exercises and freight transport research, even though the consumer shopping trip is an integral part of the supply chain for jeans. Companies do not necessarily perceive consumer transport as being part of their supply chain; however their decisions about shop location and home delivery services have a major impact on consumer transport behaviour. Further research to investigate the split between consumer and commercial transport energy use in other supply chains would be extremely beneficial.

8.3 GHG efficiency of different types of retail

GHG efficiency of the distribution systems will be analysed through different comparisons. We will start with the comparison of different distribution systems within the Paris region, through the apples supply chains. Then, we will compare the GHG efficiency of different distributions systems located in a French rural region, to analyse the impact of population density. Finally we shall comment previous comparisons between the traditional retail outlet versus e-commerce and home delivery, a rising distribution system.

The traditional distribution outlets: Figure 10 compares different supply chains on the case of apples grown in France and sold in the Paris region. The distribution systems compared are: hyper and super market, a small ‘corner’ shop, an open air market, and a

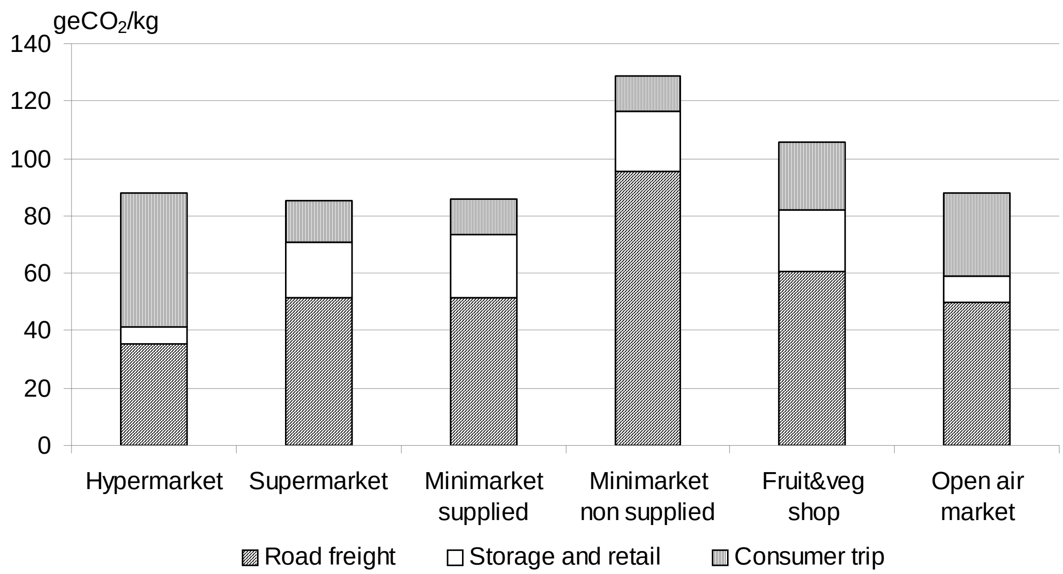

Figure 10 : GHG emissions for different apples supply chains in the Paris region

dedicated fruit and vegetable shop. In this figure, four types of retail supply chains show very similar GHG emission levels, nearly 90 gCO_2e per kg of apples sold in hypermarket, supermarket, supplied minimarket and open air market. Two types of retail are somewhat above this average value: 'non supplied minimarket', where the shop owner uses to drive himself to the wholesale market (and look at the product quality before buying it), and 'fruit and vegetable shop', specialised in the sales of fresh products of high quality. Non supplied minimarkets have the highest emissions and this is due to frequent deliveries with small quantities carried. In the 'fruits & vegetables shop' case, the main 'GHG inefficiency' is in the consumer trip: the emission of the supply chain up to the shop is not very different from the supplied minimarket but our online survey reveals that the consumers are coming from further and buy less products.

E-Commerce: The debate concerning the environmental impacts of online shopping, compared with traditional shopping is growing with the development of E-commerce and the two main issues in this debate are the trade-off between consumer car trips and home deliveries by vans and the efficiency of fulfilment centre where the orders are prepared in the E-commerce case, compared with the traditional retail outlet. All over Europe, E-commerce companies are claiming the benefits of their online operations. But these benefits are very difficult to assess because of the complexity of the "last mile" issues involved in comparing conventional and online sales.

Figure 3 (in section 3) has compared GHG emissions for traditional yoghurt supply chains (hypermarket, supermarket and minimarket) versus an E-commerce chain. The chains are identical from the farm gate down to the regional distribution centre (RDC) of the retailer. From this RDC, the products follow different steps in the conventional shopping and in the e-commerce. In the traditional market system, the products are transported by refrigerated trucks up to the shop, where they are bought by the consumer who bring them home. The main differences amongst the three types of classical markets are due to the consumer trip (distance, mode and quantity bought), to the GHG efficiency of the shop itself (nearly no difference in the platforms, which are sometimes common to different types of markets) and to the last leg of the road transport, where the load is lighter for minimarket than for hypermarket.

In the e-commerce chain, from the RDC, the products are transported to an online fulfilment centre where the orders are prepared and then to another distribution RDC and finally, from this last depot, the baskets are delivered by vans, either directly to the consumer home (95% of the drops) or to a 'service point' where the consumer collects it. Hence, the trip consumer of the classical distribution should be compared to the home delivery or to a sum of the delivery to service point plus a delta of distance for the consumer who collects the product from that point. Furthermore, the GHG emissions of the classical shop should be compared to the sum of emissions of the fulfilment centre and of the last depot in the e-commerce.

We have seen that the main difference between the different types of yoghurt distribution is clearly in the last mile: the trip consumer emissions are directly related to the size of the shop; in the e-commerce case, the delivery is very efficient: an average load of 0.7 tonnes and an average delivery round of 6 km (plus the final truck leg). The shops are less GHG efficient than the online fulfilment centre; they are lighted, air conditioned and often include escalators and many electrical equipments while the online fulfilment centre remains a rather simple 'platform'. Finally, among the observed yoghurt supply chains, the e-commerce seems to be the more efficient for greenhouse gases.

8.4 A comparison between Belgium, France and UK.

Similarities and differences are observed and analysed between supply chains of the three countries. If we compare the import chains or the domestically grown apples chains, then the overall amount of emissions are comparable between the three countries. Nevertheless there are differences amongst countries, each one having its 'bad performance': in France, road transport emissions are higher than in the two other countries; in the UK it is the 'buildings' step which has a weak performance and in Belgium it is the consumer trip. Let us try to explain this.

Road transport emissions are higher in France than in Belgium clearly because distances are longer in France than in a small country like Belgium. In UK, inland distances could be as long as in France but, in the case of apples consumed in London, the distances are shorter, either for apples imported via Felixstowe or Sheerness or for apples grown in Kent. The buildings in UK have higher emission than the two other countries: this is mainly due to the emission factor for electricity in UK (455 gCO_2e/kWh), compared with the lower factors in Belgium (268) and especially in France (84, see Table 2). The consumer trip emissions are more important in Belgium; this could be explained by longer distances, and perhaps also related to the rather lower density of population in Belgium, compared to those from Paris and London.

9. FITNESS FOR PURPOSE OF THE SUPPLY CHAIN APPROACH

The different case studies have illustrated that the supply chain approach is useful in comparing the energy use implications of different logistics strategies. It can readily be used to consider options such as sourcing and distribution centre locations, the number of stockholding points in the chain, transport modes, road freight vehicle types and weights, and transport to the consumer's home. How does this approach compares with other results?

The results presented here not only rely on the assumptions presented in the methodology (perimeter of the supply chain, emissions coefficients …), they also result from the observation of a small number of operators. And we know that the variation may be very large between logistical performance of different operators in the same market. The tests of sensibility developed in Rizet & Keita (2005) suggest that, in some cases, the specific implementation of individual transport legs may matter as much as which configuration of the supply chain is chosen: for example, the consumer trip emission is clearly very sensible to the consumer behaviour (load factor, distance, driving style, etc.).

Obviously, energy comparisons between different studies need to be treated with caution due to potential differences, in assumptions made in the work, in the data sources used and mainly in systems boundaries. On the one side, the ‘carbon balance’ developed by ADEME gives a picture of the total energy consumption and GHG emissions of a company but no detail on the products. On the other side, Life Cycle Analysis or ‘carbon footprint’ gives much more information than the supply chain approach on the product, so that it can help the consumer to choose between different products. The supply chains approach developed here is mainly for logisticians and for public sector decision.

In the jeans LCA, the total energy consumed in all consumer and commercial freight transport activities only accounts for 4-5% of the total energy used in making and supplying jeans in the cases studied. Therefore, although there may be opportunities to reduce energy consumed during transport activities, a greater absolute reduction in total energy used in these supply chains may be possible by targeting non-transport activities. The case study results can be compared with some of the previous studies that have been reviewed. The proportion of energy accounted for by commercial freight transport in the case of jeans manufactured in another country and sold in the UK and France was found to be approximately 3-4% of the total energy used to manufacture the product. Previous research calculated that commercial freight transport represented 2% the total energy used in producing a pair of polyester trousers and 6% of the total energy for a pack of cotton briefs (Environmental Resources Management, 2002). Research into in producing, supplying and cooking a hamburger in a fast-food restaurant calculated that freight transport accounted for between 5-9% of the total energy used (Carlsson-Kanyama and Faist, 2000). Another study of the transport energy used in the supply and cooking of a selection of foods found that freight transport ranged from approximately 7% of the total energy used in the case of mashed potato, to 32% in the case of rice (Carlsson-Kanyama, and Boström-Carlsson, 2001). These results reflect the energy-intensive manufacturing and processing activities that are required to produce denim and finished jeans compared with some foods.

Previous studies that have used LCA to investigate energy consumption in product supply chains vary in the extent to which they attempt to study the entire chain. Some studies have concentrated on only the transport activities in the supply chain, while other studies have examined both production and transport activities. Studying only part of the supply chain or only specific activities can lead to greater difficulties in terms of the acceptance of the results and their interpretation. This issue about how much of the supply chain to include in the study is closely related to the complexity of the LCA technique. Studying more of the product supply chain in a greater level of detail will have important implications for the data requirements and the project resources required. Also, the greater the supply chain coverage of the LCA, the greater the difficulties that are likely to be encountered in terms of how best to handle system boundary and allocation considerations.

The supply chain approach is time efficient for companies, compared with LCA, once all the partners of the chain have agreed on the objective and on the methodology.
Finally, the possible CO_2 abatement measures that appeared in this research, either for the logisticians or for public decision, are the following:

- Reduce the distance, mainly by a more local sourcing
- Reduce energy consumption within retail outlets which are dramatically inefficient

The last mile is an important issue that needs more research but, already, the more energy efficient type of commerce should be preferred, e.g. in the planning of a city.
Energy and GHG indicators should be harmonized and spread among companies as a starting point for carbon accounting and benchmarking. And this is clearly another point where more research is needed.

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