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Procedia Social and Behavioral Sciences 2 (2010) 6154–6164

Procedia
Social and Behavioral Sciences

The Sixth International Conference on City Logistics

GHG emissions of supply chains from different retail systems in Europe

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Abstract

An approach has been developed to collect data and measure energy use and GHG emissions from logistics activities for product supply chains. This approach has been used to assess the GHG efficiency of several supply chains of the same product marketed through different types of retail systems in Europe. The retail types considered are hyper and supermarkets, corner shops, open-air markets, producer's basket direct sale, farm shops and e-commerce; Their GHG efficiencies are quantified and compared for food products, considering whole supply chains from the farm gate where they are grown to the consumer's home. This supply chain efficiency approach highlights the importance of the various operations carried out within the supply chains, such as transport, warehousing, the shop itself, and even consumer behaviour for the last mile. While supermarkets in towns, shops included in a delivery system, or open air markets in town centre appears to be very efficient, rural area and independent shops with lower turnover are less favourable. Indeed, the outcomes of an online consumer survey show large differences amongst the GHG efficiency values for all these retail systems. Therefore, potential logistics choices for improving the supply chain performance could be identified.

Keywords: Logistics; greenhouse-gases; supply chain; energy efficiency

1. Introduction

European consumers face several possibilities for buying their products: e.g. they can buy them in a supermarket, in a corner shop, at a trader at an open-air market, directly from a producer or they can order it through a web site and have it directly delivered to their home. These possibilities clearly correspond to different supply chain organizations and the energy and greenhouse gases (GHG) efficiencies of these retail types can be assessed and compared using a supply chain approach.

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doi:10.1016/j.sbspro.2010.04.027

This paper is based on research carried out by INRETS (France), the University of Westminster (UK) and the University of Namur [FUNDP] (Belgium), with a grant from ADEME, the French Environment and Energy Management Agency (Rizet et al., 2009). The objective of this supply chain approach was to provide a contribution to the discussion on the carbon footprint of a product by comparing different supply chains, measuring their energy consumption in a standardised way across many countries, quantifying the transport specific GHG emissions at each step of the considered supply chain and identifying potential strategic logistics choices and options which could lead to improved efficiency and reduced emissions. Importantly, the study also considers the consumer shopping trip as integral part of the chain and, if relevant, compares it to a home delivery alternative. The case studies presented here illustrate the comparison of most common retail systems used in Europe for food distribution. Since most retail activity takes place in or near to towns and cities the results have important implications for city logistics.

The quantification of energy consumption and GHG emissions along the supply chain 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 origins of the emissions to be taken into account, about the used methodology, and about the drawn system boundaries. In some cases like the Life Cycle Analysis (Browne et al., 2005), or the French carbon balance method (Ademe, 2007), the complete chain of all 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).

After the first section that describes the context of the research, this paper provides, in the second section, a brief description of our methodology. In the third section, we focus on the online survey conducted to analyse the consumer trips between shops and homes. Then the last sections highlight how the results of the analysis of supply chains could be used to compare GHG efficiency of different types of retail outlets: amongst several countries, different retail sizes in the Paris region versus a rural area and 'high street shop' versus e-commerce.

2. A Standardized Method for Logistics Analysis

Since the main objective of our research was to obtain a complete figure of the GHG emissions due to a "typical" supply chain by focusing on specific products, we considered fresh food products (apples, tomatoes and yogurt). Applying a standardised research method should lead efficient data collection, this means a relatively simple, one which would not be too time consuming for the companies involved. 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 to accommodate seasonality issues).

The applied method is quite comprehensive, different types of transport energy, used in the supply chains, have been included such as diesel for goods vehicles or bunker fuel oil for ships. Fuel, gas and electricity data have also been collected for storehouses, production plants, distribution centres and shops. Moreover, at all stages, data for tonnage of the products grown, manufactured, transported, stored or distributed were also collected. For this data collection, the time unit considered was one the year (i.e. how many tonnes had been shipped, sold or stored on an annual basis).

Concerning shops, the tonnage of the products considered (apples, tomatoes or yogurt) was taken as part of the total quantity sold by the establishment and therefore the same ration was applied on its global energy consumption (i.e. it was assumed that the energy consumption was in proportion to the volume of product sold); however, some difference in terms of total energy per kg was assumed between refrigerated and non-refrigerated products.

At each step of the supply chain, energy use is estimated in "grams of petrol equivalent" and GHG emissions are calculated in 'grams of CO_2 equivalent' (gCO_2e) using the coefficients defined in ADEME (2007). 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. The used coefficients are given in Table 1.

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

Fuels	litre	gram	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

2.1. Estimating GHG emissions for transport

Estimating energy consumption and the GHG emissions of a road transport leg between two sites was fairly simple. The companies provided data on fuel use (miles per gallon in the UK, litres/100km elsewhere), distance, load, truck type and empty runs. From these data, emissions were calculated using:

$$EmpP = \frac{(L \times (D \div 100) \times E \times 2951)}{Q} \tag{1}$$

where:
EmpP = GHG emissions per product unit, in gCO_2e per kg
L = Average fuel use (diesel) computed from all vehicles in the fleet (in litres/100km)
D = Distance travelled between origin and destination of the supply chain leg
E = Empty running factor
Q = Load per trip in kg
2951 = Emission factor for diesel fuel (cf. Table 1)

For sea transport, the principle is the same. However, other specific indicators are needed: port calls and shipping line route, nautical miles between ports, vessel load factors in TEU or % of nominal carrying capacity, mean container load factors in tonnes on this route, motor fuel use per day at sea and days at ports, number of days at sea and at ports.

2.2. Estimating GHG emissions in buildings

In buildings (warehouses, stores and shops) the main used energy is electricity. Therefore, the quantity of GHG emitted per kWh highly depends on the primary energy from which electricity is produced: Nuclear electricity emits very few GHG's, 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 France, Belgium, and UK are shown in Table 2.

Table 2 Emission factors for electric energy in different countries

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

(Source : ADEME, 2007)

With all these elements, the formula for computing GHG emissions in buildings is given by

$$EmpP = \frac{(L \times 2951) + (E_e \times C_e) + (E_g \times 257) + (E_f \times 2951)}{V} \quad (2)$$

where:
EmpP = Emissions per product unit, in gCO_2e per kg
L = Annual fuel (diesel) use for all “handling” vehicles in litres
Ee = Annual electricity energy use in kWh
Ce = Country conversion coefficient from kWh to gCO_2e for electricity, see Table 2
Eg = Annual use of natural gas energy for heating or propulsion purposes in kWh
Ef = Annual fuel use for heating in litres
V = Annual volume of handled products in kg

3. A Web Survey for the Consumer Trip

A first part of this research (Rizet and Keita 2005) had shown that, at the end of the supply chain, the consumer trip implies some important effects on the emissions of GHG within the total chain. The calculation of the consumer trip emissions per kg of product will be strongly influenced by the type of product, the home-shop distance, and on the quantities transported by the consumer. This result was confirmed by (Weber and Matthews, 2008) in the US and (Edwards et al., 2009) in Europe. During our study, a web based survey was conducted in France, Belgium and the UK. It provided some interesting results which are outlined below. After that the implications drawn from these results for the research are then discussed.

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 and 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 these 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.

3.1. Consumer trip emission estimated from the online survey results

Table 3 summarizes emissions from consumer shopping trips, per kg fruit or vegetable, according to country and type of distribution.

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 addressing the same issues, we see that these results show far 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. This is mainly due to the German assumption that the purchase of coffee has a light load (250 gram bag) and is performed with a dedicated car trip. Our results shows again 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 consumers 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 highlights the importance of the assumptions used in the various studies into this topic.

Table 3 GHG emitted by the consumer's trip for purchasing fruits or vegetables (in gCO2e/kg)

	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

4. GHG Retail Performance in Large Cities in Europe

First of all, an initial stage for each case study has been the preparation of a supply chain map showing the key physical movement details. We will illustrate this with the apple chains which fit quite well for the comparison of hypermarkets located in Brussels, London and Paris. Then, after comparing these three capitals, we will compare different distribution systems within the Paris region, still focusing on apple supply chains. Finally, we shall consider another product, yogurt, for which we can compare the traditional market with e-commerce and home delivery, a growing type of distribution system.

4.1. A comparison between Brussels, London and Paris

Figure 1 shows the GHG emissions per kg of apples for 6 different supply chains: 3 capitals (Paris, London and Brussels) and, for each of these cities, two origins of sourcing, either apples imported from New Zealand or domestically grown are the variables differentiating these chains. This figure highlights two important issues:

Imported apples versus apples produced within the country. The differences in emission levels between the chains in Figure 1 is mainly due to the origin of the apples: the importance of GHG emitted by sea transport in the case of apples imported from New Zealand clearly reveals that, even though maritime transport is very energy efficient per tonne-kilometre, the distance involved when apples are sourced in New Zealand results in much higher emissions than in the case of locally produced apples.

These results based on the collection of primary transport and logistics data confirm the importance of maritime transport, found in previous results of this research (Browne et al., 2005) as well as in other researches (Canals et al., 2007). They are also in line with the findings of Blanke and Burdick (2005) which included farm production and cooking for a full life cycle approach of imported versus domestic apples for Germany.

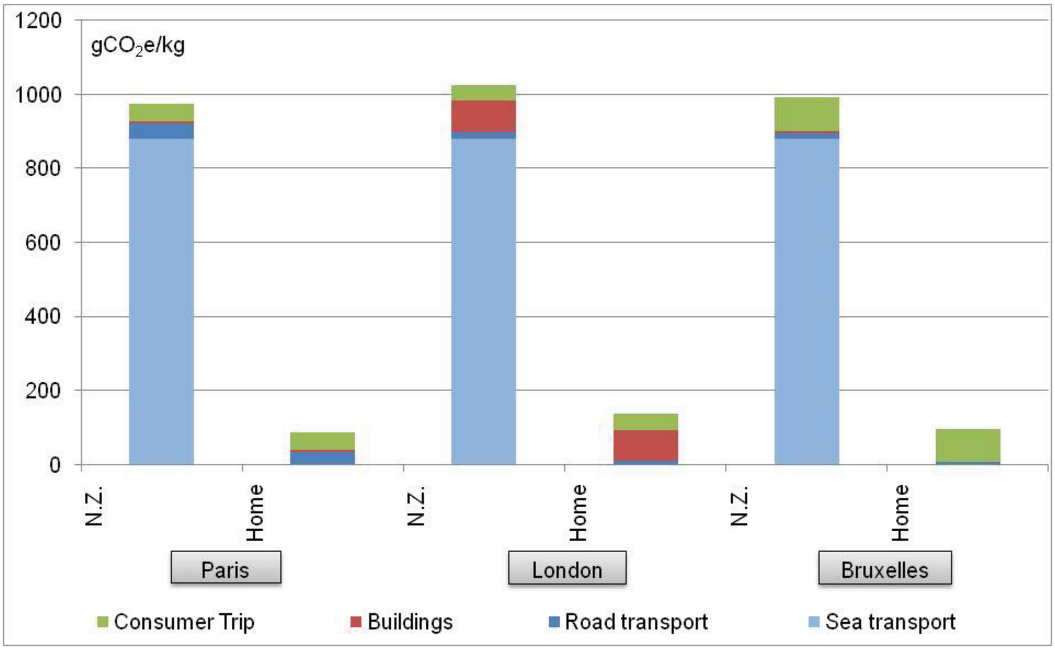

Figure 1 GHG emission of different apples supply chains sold in hypermarket in Europe

4.1.1. Similarities and differences between supply chains of the three countries

When comparing 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 weak performance and in Belgium it is the consumer trip.

Some possible reasons for this is that 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 factors 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 in Paris and London.

4.2. A comparison between different retail types within the Paris region

In order to compare the GHG efficiency of different distribution systems within the Paris region we first focused on the chains of apples grown in France. The distribution systems compared are the following: hyper and super market, a small 'corner' shop, an open air market, and a dedicated fruit and vegetable shop. Unlike the previous figure, all the supply chains in Figure 2 are for apples grown in the same orchard in Limousin, a region located 400 km SW of Paris, and sold in the Paris region. Apples are transported from the orchard to the shop by different road vehicles and the differences in road transport emissions between the different chains mainly result from vehicle loads and vehicle types for the different legs. Energy consumed in the 'buildings' (shops and warehouses) is electricity; differences between chains energy consumption result from the apple turnover in the warehouse or the shop. The consumer trips emissions are included according to the results of the online survey.

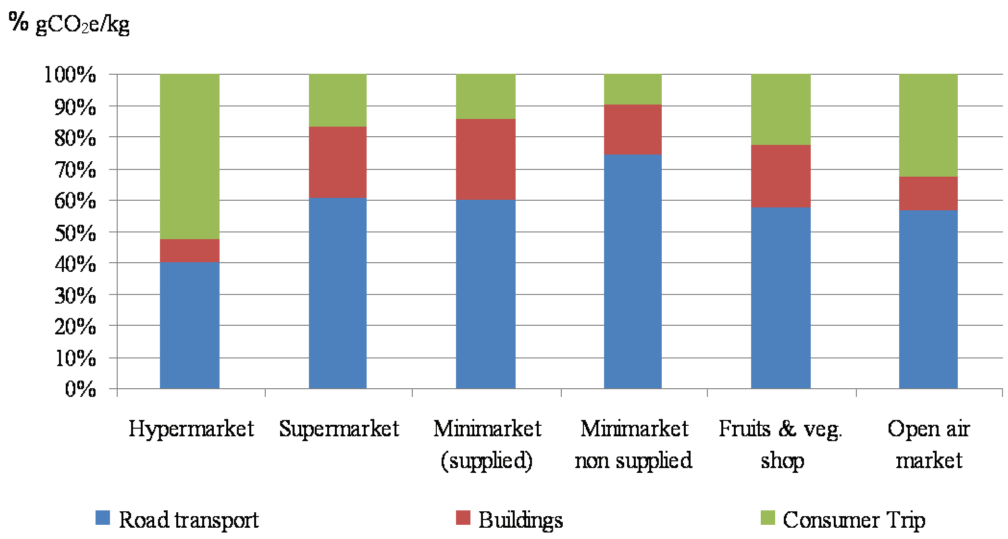

Figure 2 GHG emissions for different apples supply chains in the Paris region

In Figure 2, the 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. The two types of retailers are somewhat above this average value: 'non-supplied minimarket', where the shop owner used to drive themself 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 'fruit & vegetables shop' case, the main 'GHG inefficiency' is in the consumer trip: the emissions of the supply chain up to the shop are not very different from the supplied minimarket but our online survey reveals that the consumers are coming from further away and buy less products.

Since we have seen that the relative importance of the different parts of the supply chains in the GHG emissions is quite different, we split the emissions of considered chains due to each of these parts in percentages of the total emissions (Figure 3).

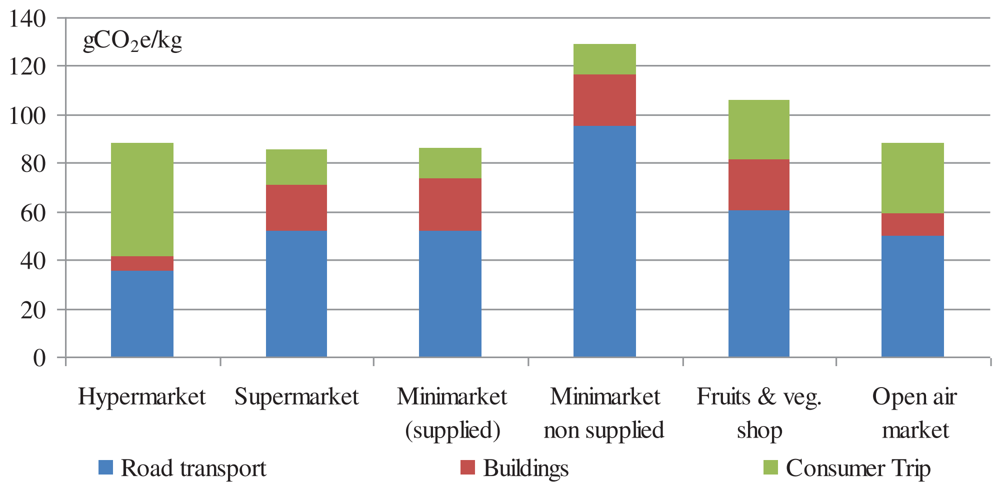

Figure 3 Structure of GHG emissions for different apples supply chains in the Paris region

From Figure 3, we can deduce that the share of each emissions category (road transport, buildings, consumer trip) are distributed differently for each type of retail activity: for hypermarkets, the consumer trip is responsible for more than half the total emissions of the chain, road transport for only 40% whilst, for non-supplied minimarkets, where the owners pick up their supplying with their own trucks, road transport is responsible for three quarters and the consumer trip only for 10% of the whole supply chain emissions. Compared with a small shop, hypermarkets have a very high performing supply chain (regarding GHG efficiency) up to the retail point and a low efficiency for the downstream part (consumer trip): this situation could be explained by the fact that it is generally located out of the densely populated area and hence the consumers mainly go there by car and travel longer distances.

5. GHG Retail Performance in Rural Areas

Now we compare the GHG efficiency of distribution systems in a French rural region, which is among the less densely populated regions of France. The product used for comparison is tomatoes grown in France. The distributions systems compared 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; a supermarket; an open air market and a minimarket in a small town (4000 population.). As before, the GHG emitted by the consumer shopping trips has been assessed for these chains from our online consumer survey.

Here again, the low efficiency values observed for the organic tomato producer are all explained by the rather low quantities of sales and therefore of products moved/transported per kilometre travelled.

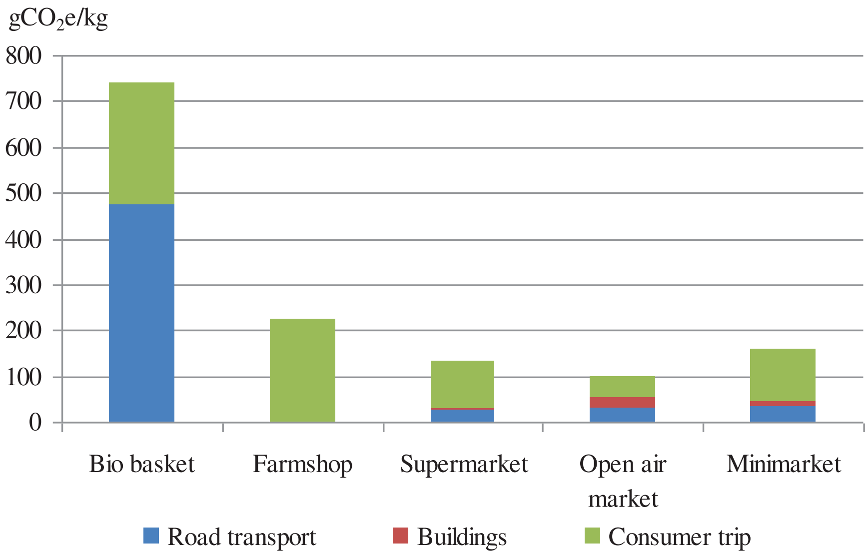

Figure 4 GHG emission of different tomatoes supply chains in a rural region

6. E-commerce versus Supermarket GHG Performance

The debate concerning the environmental impacts of online shopping, compared with traditional shopping is growing with the development of e-commerce and one of the main issues in this debate is the trade-off between consumer car trips and home deliveries by vans. 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 5 compares GHG emissions for yogurt supply chains in France, with one chain corresponding to classical distribution (hypermarket, supermarket and minimarket) and the other e-commerce. These supply chains are identical from the farm gate down to the regional distribution centre (RDC) of the retailer. From the RDC, the products follow different steps in conventional shopping and in e-commerce. In the classical market system, the products are transported by refrigerated trucks to the shop, where they are bought by the consumer who brings 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 minimarkets than for hypermarkets.

In e-commerce chains, 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 consumers home (95% of the drops) or to a 'service point' where the consumer collects it. Therefore, we could suppose that the main difference between E-commerce and the traditional market, lies in the 'last mile'; Hence, the consumer trip of classical distribution should be compared to the home delivery or to a sum of the delivery to service point plus the difference in 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 e-commerce.

For the yogurt case, the emissions from road transport as well as the emissions of the buildings of the logistics establishments are notably more important than in the case of apples. For road transport this is due to the fact that the distances are much longer in that case: the yogurt supply chain starts at the farm gate where the milk is collected and then goes to the yogurt factory before starting the distribution part of the chain, while, for apples, it goes directly from the orchard into the distribution system. Another difference is that yogurt has to be carried in refrigerated vehicles, which consume a more energy than non-refrigerated ones. Similarly the buildings consume more energy for the yogurt than for apples, mainly because yogurt has to be kept refrigerated.

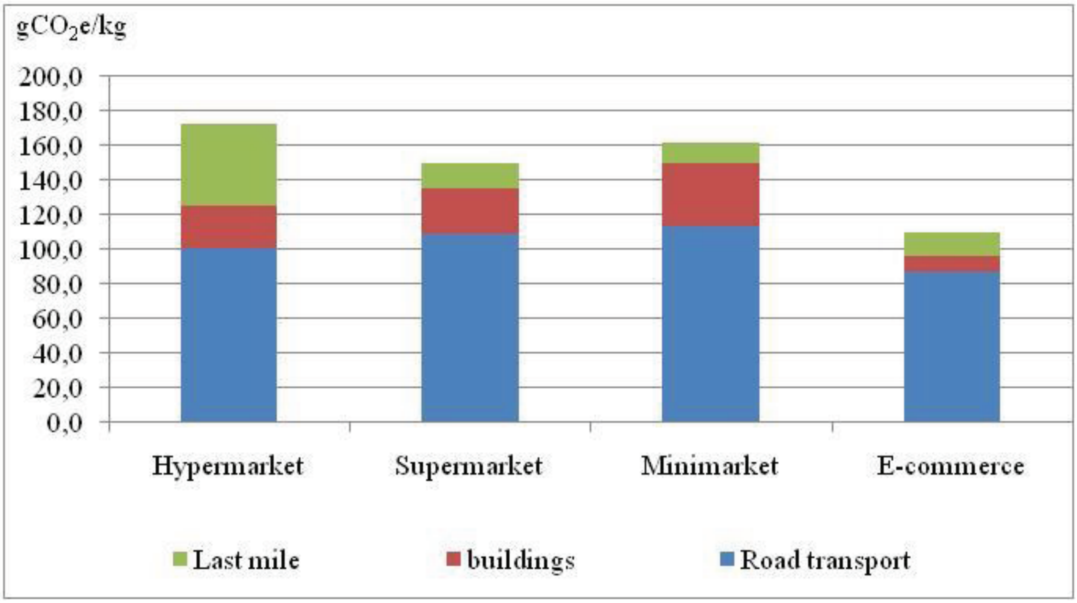

Figure 5 GHG emission of different yogurt supply chains in the Paris region

In Figure 5, the main difference between the different types of yogurt distribution is clearly in the last mile: in the classical distribution, the consumer trip emissions, estimated from our online survey, 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).

Shops are less GHG efficient than the online fulfilment centres; they are lighted, air conditioned and often include escalators and much electrical equipments while an online fulfilment centre remains a rather simple 'platform'. Finally, among the observed yogurt supply chains, e-commerce seems to be the more efficient for greenhouse gases.

7. Conclusion

The best performing supply chains observed in this paper are for domestic apples sold in the capitals (less than 100 gCO_2e/kg). Within the Paris region, similar GHG emission levels, around 90 gCO_2e/ \kg, were found for different types of retail supply chains: supermarket and supplied minimarket in the town centre and open air markets. A 'non-supplied minimarket', where the shop owner drives himself to the wholesale market, and 'fruit and vegetable shop', specialised in the sales of fresh products of high quality, had somewhat above this average value, because of their less efficient supplying systems.

The most emitting supply chain observed is for the apple sourced in New-Zealand, with 1000 gCO_2e/kg, because of the very long distance. This does not mean that a distribution system which sources its products in the vicinity of its consumers is efficient: the most GHG emitting chain for domestic products (700 gCO_2e/kg) we found was a very local 'producer basket' where very short distances did not compensate the very small quantity of products transported per vehicle. Furthermore the 'direct sale at the farm' observed, with over 200g, is also relatively inefficient though the distances are very short.

For the different distribution systems, the GHG directly emitted by the final consumer shopping trip is generally an important part of the total supply chain transport emissions. It is clear that the nature of the assumptions about this trip and the way in which energy allocations are made have a major impact. Therefore, if the consumer achieves a 'combined' trip (doing at least two activities on the same tour) and energy use is apportioned according to the various trip purposes then the emissions attributable to the purchasing activity will be reduced. In some cases it could be argued that this figure could be zero (for example when a consumer purchases an item on their way home from work with no additional transport requirements). This highlights the need for greater understanding of consumer shopping trips and the extent to which trip behaviours could be influenced by providing more information about the energy and emissions implications. In a recent Logistics Director Forum meeting (LDF, 2008) the lack of ability to directly influence the consumer was noted. Clearly there is the opportunity for collaborative work between travel behaviour researchers and those more directly concerned with the supply chain.

The benefits of common measures, models and standards are clear. In such a direction, the approach described in this paper enables comparisons between different supply chain configurations in terms of GHG emissions and across options for reducing energy use within transport activities in the chain. By identifying the most important transport activities in terms of emissions it helps to ensure that attention can be focused on the key transport related decisions. There is a need to balance the amount of management time and the cost of data collection with the potential opportunity for changing the supply chain and thereby reducing total energy requirements.

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