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Article in *International Journal of Physical Distribution & Logistics Management* · February 2010

DOI: 10.1108/09600031011018055

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# Comparative analysis of the carbon footprints of conventional and online retailing

Analysis of the carbon footprints

## A “last mile” perspective

Julia B. Edwards, Alan C. McKinnon and Sharon L. Cullinane  
*Logistics Research Centre, Heriot-Watt University, Edinburgh, UK*

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Received March 2009  
Revised August 2009  
Accepted October 2009

### Abstract

**Purpose** – The purpose of this paper is to focus on the carbon intensity of “last mile” deliveries (i.e. deliveries of goods from local depots to the home) and personal shopping trips.

**Design/methodology/approach** – Several last mile scenarios are constructed for the purchase of small, non-food items, such as books, CDs, clothing, cameras and household items. **Official government data, operational data from a large logistics service provider**, face-to-face and telephone interviews with company managers and realistic assumptions derived from the literature form the basis of the calculations. Allowance has been made for home delivery failures, “browsing” trips to the shops and the return of unwanted goods.

**Findings** – Overall, the research suggests that, while **neither home delivery nor conventional shopping has an absolute CO<sub>2</sub> advantage, on average**, the **home delivery operation is likely** to generate **less CO<sub>2</sub>** than the typical shopping trip. Nevertheless, CO<sub>2</sub> emissions per item for **intensive/infrequent** shopping trips by **bus** could match online shopping/home delivery.

**Research limitations/implications** – The number of items purchased per shopping trip, the choice of travel mode and the willingness to combine shopping with other activities and to group purchases into as few shopping trips or online transactions as possible are shown to be critical factors. Online retailers and home delivery companies could also apply measures (e.g. maximising drop densities and increasing the use of electric vehicles) to enhance the CO<sub>2</sub> efficiency of their logistical operations and gain a clearer environmental advantage.

**Practical implications** – Both consumers and suppliers need to be made more aware of the environmental implications of their respective purchasing behaviour and distribution methods so that potential CO<sub>2</sub> savings can be made.

**Originality/value** – The paper offers insights into the carbon footprints of conventional and online retailing from a “last mile” perspective.

**Keywords** Carbon, Delivery services, Internet shopping, Distribution channels and markets, Air pollution

**Paper type** Research paper

### 1. Introduction

Some online retailers have been actively claiming that internet shopping yields environmental benefits (Smithers, 2007). Equally, consumers seem to have a widely held view that **online purchases and home delivery are beneficial to the environment** because they reduce personal travel demand (Royal Mail, 2007). Such opinions are also prevalent among researchers. For instance, Rotem-Mindali and Salomon (2007, p. 178) point out that:

[...] studies of the impacts of teleshopping on transport usually assume that the delivery trip, by the retailer or a third party, to multiple customers is more efficient than individual trips.



To date, however, little research has tested the claims that online retailing is environmentally superior. An early paper by Matthews *et al.* (2001), which compared the environmental impact of online and conventional book retailing in the USA, offered some support for this view. A review of the academic literature revealed little relevant research on this issue since the early 2000s.

This paper sheds new light on this subject. It focuses on the so-called “last mile” (i.e. the last link in the supply chain to the home) and compares the level of carbon emissions[1] from a conventional non-food shopping trip with those of delivering non-food items to the home. It is based on research in the UK, where online retailing has now captured around 17 per cent of total retail sales (IMRG/Capgemini, 2008). Transport at the local level is not just the most visible; it can also be the most energy-intensive. Browne *et al.* (2008) note for conventional shopping that personal shopping trips can use more energy than the entire upstream supply chain, even when production is included. Several past studies have examined the last mile delivery (European Information Technology Observatory, 2002; Abukhader and Jönson, 2003; Sarkis *et al.*, 2004; Farag *et al.*, 2006), although none have systematically compared consumer travel with freight delivery in terms of energy expenditure and CO<sub>2</sub> emissions per delivery drop/item bought.

This paper is structured as follows: first, we briefly examine previous work on the relative environmental effects of online and conventional shopping. This includes a comparison between the last mile and upstream supply chain activities to determine the importance of last mile operations relative to emissions from end-to-end supply chain activities. This is followed by a review of the data sources used and discussion of the assumptions underpinning our comparative model. Various home delivery and shopping trip scenarios are presented in the main results section. In addition to summarising the main findings, the conclusions explore some of the wider issues raised by the research.

## 2. The environmental effects of online versus conventional shopping

Probably, the greatest difference between online and conventional shopping can be seen in the fulfilment and distribution processes required to meet customer expectations (de Koster, 2002). In the traditional shopping model, customers do most of the labour-intensive work (such as order-picking and transporting the goods home), whereas in e-fulfilment, retailers must deliver personalised orders to highly dispersed locations within relatively narrow time windows.

Concerns have been expressed about the steep increase in home deliveries, some of them relatively inefficient, which reduce the net benefit of online retailing (Romm, 1999; Kröger *et al.*, 2003). Early research suggested that, although car-based shopping trips could be reduced by as much as 10 per cent as a result of internet shopping, more research was needed to assess possible environmental disbenefits (DTLR, 2002). These might result from:

- the fragmentation of the fulfilment process with consumers making more frequent purchases of relatively small quantities of goods, often from several different web-based companies;
- other car-based out-of-home activities being undertaken by either the car owner or other household member in the time saved by online shopping;

- the net increase in the total amount of material consumption; and
- additional transport created by failed deliveries, when no one is at home, and the return of unwanted goods.

Much of the previous research comparing online and conventional shopping has concentrated on the grocery retail sector (Cairns *et al.*, 2004; Cairns, 2005; Foley *et al.*, 2003; Gould and Golob, 1997). In the traditional grocery supply chain, goods are delivered to store where the customer picks the items before taking them home. For e-grocery, however, there are three scenarios: **picking and distribution** from existing stores; **direct home delivery from a dedicated fulfilment** (or “pick”) centre and **home delivery from a central warehouse via a satellite depot** (van der Laan, 2000; Agatz *et al.*, 2006). The most successful UK model to date has been order-picking and distribution from existing stores (Hackney *et al.*, 2006). Punakivi (2003) noted a considerable traffic reduction (of between 54 and 93 per cent depending on delivery method) when e-grocery replaced car-borne shopping trips to supermarkets in Finland. Further savings can be achieved when grocery reception boxes are used instead of attended delivery (where the consumer must be at home to receive the goods). Kämäräinen *et al.* (2001) recorded home delivery distance savings of over 50 per cent from the use of grocery reception boxes in Finland.

While most of the research to date has concentrated on the “last mile” stage, a few studies have compared the energy consumption of consumer travel and home delivery with energy use further upstream in the supply chain. Jespersen (2004) conducted telephone interviews to establish consumer travel behaviour when purchasing rye bread from shops. Assumptions were made about trip chaining[2] (50 per cent of an average 5 km trip was for shopping) and the weight of goods purchased (20 kg). His findings revealed that the amount of energy consumed by the customer’s trips to and from the shop was greater than the energy used in all the other transport associated with the production and distribution of the bread. Browne *et al.* (2006), in investigating the various stages of the production and distribution of jeans, observed that the energy used for a dedicated consumer shopping trip (of 11 km) was approximately the same as that used in transporting the product from the jeans factory (based in the USA or Turkey) to the UK port, despite the huge differences in journey lengths. Similarly, Weber *et al.* (2008), when comparing the energy use and CO<sub>2</sub> emissions generated by both the online and conventional distribution of an electronic flash drive, found that approximately 65 per cent of total emissions for traditional retailing came from the customer trip to and from the retail store.

These studies not only highlight the differences in carbon intensity across the “end-to-end” supply chain, but they also show how transport energy and emission calculations are dominated by last mile operations. They, therefore, provide justification for our decision to focus on this last link in the retail supply chain.

### 3. Research approach

This paper presents the results of a comparative study of the CO<sub>2</sub> emissions from home deliveries and conventional shopping trips in the non-food retail sector. The focus is on small non-food products such as books, CDs, clothing items and electronic devices, which, because of their physical characteristics, are responsible for very similar amounts of energy use and emissions when transported in freight vehicles, cars or public transport. In this analysis, they are considered to be identical in terms of their

transport-related carbon footprint. The paper examines the carbon emissions from transporting them solely at the “last mile” stage in the supply chain (from store to home or local depot to home). Using published UK Government statistics and primary data from one of the UK’s largest home delivery companies, it has been possible to model the amounts of CO<sub>2</sub> emitted by conventional and online purchases of small non-food items. An Excel spreadsheet was constructed for this purpose.

The emission factors for home delivery operations by diesel- and petrol-fuelled vans were obtained from four statistical sources and averaged:

- (1) Defra’s (2008) emissions factors for vans[3].
- (2) National Atmospheric Emissions Inventory (2008) emissions factors for vans: data for Euro II vehicles, and speeds of 40 kph (default speed), 20 kph (representative of average urban speeds) and 10 kph (worst-case scenario) are applied.
- (3) *RHA Cost Tables, 2008*: emissions factors are calculated from Defra values, based on average fuel consumption of 9.6 km per litre (27 miles per gallon) for a van (Road Haulage Association, 2008).
- (4) Freight Transport Association (2007) distribution costs 2008: emissions factors are calculated from Defra values, based on average fuel consumption of 8.9 km per litre (25 miles per gallon) for a van.

This averaging ensured both consistency and reliability in the calculations.

Several last mile scenarios are proposed based on publicly available data, face-to-face and telephone interviews with practitioners in industry and the results of previous studies. Sensitivity analyses have been performed to assess the impact of varying key parameters. Acquiring qualitative insight from practitioners helped to verify the robustness of data obtained from the home delivery company.

Average emission factors for car and bus journeys (expressed as CO<sub>2</sub> per km travelled) to the shops were found in Defra (2007). In the case of cars, additional calculations are made for specific vehicle exercise duty (VED) bands, particularly for low-emissions vehicle (Band A), a hybrid vehicle (Band B) and a high-emissions vehicle (Band G). Band-specific emissions have been sourced from the Vehicle Certification Agency’s records ([www.vcacarfueldata.org.uk](http://www.vcacarfueldata.org.uk)).

## 4. Modelling assumptions

### 4.1 Online shopping

*Methods of delivery.* The vast majority of online purchases result in the physical movement of a small package (or single item) to an individual address (typically a consumer’s home) by parcel carrier (RAC Foundation, 2006; Retail Logistics Task Force, 2001). In general, these deliveries are distributed from local parcel carrier depots and consist of mixed loads in the back of vans. Volumes delivered are high: the leading parcel delivery carrier in the UK delivers some 300,000 parcels daily. Concern has been expressed about the environmental repercussions of this expanding home delivery market (Webster, 2007). Total mileage travelled by vans has risen by 40 per cent over the past ten years in the UK, partly reflecting the growth in online retailing (Department for Transport DfT, 2009c). Vans also have relatively high carbon-intensity, expressed as g of CO<sub>2</sub> per tonne km (McKinnon, 2007), particularly as much of their mileage is run on urban roads. For this reason, there has been

increased interest in the use of electric vehicles for home delivery, especially in the online grocery sector. Sainsbury's (2007), for example, plans to convert its entire online grocery delivery fleet to electric vans by 2010.

Vans are not the only delivery vehicles employed by parcel delivery companies. The use of self-employed couriers has been on the increase recently (Beveridge, 2007). Several leading online retailers now use third-party courier networks for deliveries. These deliveries are generally made by private cars and are much shorter than typical van-based delivery rounds. As courier rounds have different delivery and vehicle characteristics, they have been excluded from the analysis.

Traditionally, vehicle load factors have been measured with respect to weight. For vans, in the home delivery sector, the number of drops per round is more representative of vehicle utilisation than the total weight of the consignments. Rather than considering vehicle fill as a percentage of maximum permissible weight, parcel delivery companies are concerned with achieving high-drop density rates per round by maximising the number of deliveries, a key productivity measure in the home delivery sector. The parameters of vehicle fill and empty running are not therefore included in this analysis. All delivery drops are treated equally, regardless of when in the round they are actually delivered. This approach may be criticised, as those deliveries dropped first, it could be argued, should be apportioned less CO<sub>2</sub> than those items delivered later in the round. While correct in theory, assigning emissions based on the sequencing of delivery drops would be an almost impossible task.

Home delivery companies do not normally adopt a strategy of dropping-off the heaviest (or bulkiest) loads first. It is clear from observations of loading practices by van drivers and discussions with depot managers that customer location is the main determinant of the loading/unloading sequence. Therefore, across the range of small, non-food consumer products typically bought online, the physical nature of the products has little effect on the energy intensity and carbon intensity of the delivery, i.e. weight/density are not significant. The main variable is the number of drops per round. Given the granularity of this analysis it is not necessary to distinguish between specific product types within the general category of small non-food items, which can be collected by consumers from high-street shops.

Two other factors are likely to have a greater influence on the level of CO<sub>2</sub> emissions: the chances of making a successful deliver first-time and the nature of the returns process for unwanted/damaged goods. These will be considered next.

*Incidence of first-time failed delivery.* It has become more common for people not to be at home during the working day when most home deliveries are made. Prologis (2008) reported that the number of working households increased by 22 per cent between 1992 and 2006. As a result, parcel carriers must cope with increasing incidence of failed delivery. Actual failed delivery rates among carriers vary considerably. Beveridge (2007), a leading consultant in the home delivery market with wide experience of managing last-mile delivery networks, indicated a range between 2 and 30 per cent, depending on the carriers' policies for dealing with "no-one-at-home". Some parcel delivery companies achieve very high first-time delivery rates as they are prepared to leave deliveries in alternative locations, such as with neighbours or in the garden shed (McKinnon and Tallam, 2003). While these places are often insecure, the use of dustbins is now generally avoided owing to earlier reported mishaps! Other carriers require proof-of-delivery signatures, and consequently have a much higher

delivery failure rate. As a result of different delivery arrangements, estimates of first-time delivery failure rates vary widely from six out of every ten small-package deliveries (Retail Logistics Task Force, 2001) to a more conservative one in eight (IMRG, 2006). This study uses three failed delivery ratios. First, a first-time failure rate of 25 per cent of deliveries, in line with findings by McLeod and Cherrett (2006) and Song *et al.* (2009); second, a 12 per cent failure rate (assumed by Weltevreden and Rotem-Mindali (2008), and based on IMRG (2006) findings), and finally, a very successful first-time failure rate of 2 per cent, achieved by parcel companies whose delivery drivers seek alternative locations at which to leave items.

*The return of unwanted goods.* Customers return items for a number of different reasons. They may, for instance, be the wrong product, because of errors in order picking, unsuited to the consumers needs, or damaged in transit. Online retailers also have widely varying returns policies from unconditional money back guarantees to store credit only to no refund whatsoever (Mukhopadhyay and Setoputro, 2004). Typically, between 25 and 30 per cent of all non-food goods bought online are returned (de Koster, 2002) compared with just 6-10 per cent of goods purchased by traditional shopping methods, though this varies widely among product groups and probably geographically (Nairn, 2003; Fernie and McKinnon, 2009).

The environmental implications of these online returns are strongly influenced by both parcel carriers' returns policies and consumers' preferred habits. Parcel carriers who collect returned items as part of their usual delivery round generate very little additional mileage. In these cases, an allowance is made for collections within planned delivery drop-rates, and any additional energy use is subsumed within the overall delivery round. On the other hand, some delivery companies send vans on separate pick-up runs dedicated solely to collecting returned items. Consideration of this dedicated collection process is treated separately.

The situation is complicated further by customers often having a choice of returns channels. For retailers with a high-street presence, customers may choose to return items to a physical store. The popularity of this method depends on the number of high-street stores operating such a returns policy. For instance, a high percentage of online supermarket clothing returns are handled through supermarkets, whereas some multi-channel retailers have very little returned to stores owing to their relatively sparse high-street presence.

Alternatively, customers can send items back through the standard postal service. Where there is a choice between parcel carrier or postal services, approximately half of returns are via carrier collection and half by post (Beveridge, 2007). Some high-street retailers find that half their returns are to stores, and the remaining half-split between carrier collection and the post. The model takes account of these different returns options.

#### *4.2 Conventional shopping*

There is no such thing as a "typical" high-street shopper. In creating characteristic shopper profiles consideration needs to be given to several key questions: how people travel to the shops, how frequently they shop, what they buy and in what quantities they purchase goods. Finding general answers to these questions is difficult owing to a lack of behavioural data at the consumer level (Rotem-Mindali and Salomon, 2007). Some retailers undertake their own customer surveys, but are usually reluctant to release the results. Our analysis has relied mainly on government statistics available at the national level.



*Dedicated shopping-only trips.* The National Travel Survey, undertaken by the DfT, collects data on personal travel behaviour over time, which allow comparison between food and non-food shopping trips. Table I lists the average distances travelled for shopping by different transport modes. The National Travel Survey defines a trip as a one-way journey with a single main purpose, with outward and return halves of a return trip treated as two separate movements (DfT, 2009b). Therefore, an average dedicated shopping trip would require a doubling of the distances shown in Table I. Average distances travelled for non-food purchases are longer than for food shopping trips, at 6.4 miles for car travel (car driver) and 4.4 miles for bus travel (DfT, 2009a). These distances are used to represent average shopping trips.

Car and bus travel are the two motorised transport modes most used by conventional shoppers, accounting for 72 per cent of all shopping trips (DfT, 2009a), and as such, are the only modes considered in this paper. Rail is omitted, as it is not a regular mode for shoppers (less than 1 per cent of shopping trips are by rail) (DfT, 2009a). **Walking and cycling have been also been excluded from the calculations, as both modes involve human effort** (a category excluded from typical life cycle assessments), and neither emits easily attributable CO<sub>2</sub> emissions. The environmental and social benefits of both are acknowledged, however.

*Combined and/or browsing-only shopping trips.* Trip chaining is a widely used term to describe a combined trip. Although having no agreed definition, it can be described as a household's tendency to combine different activities during a single trip (Popowski Leszczyc and Timmermans, 2001), with a trip segment representing the travel between a particular pair of activities (Primerano *et al.*, 2008). Often, minor detours to a store are incorporated into a trip made primarily for some other purpose, adding only marginally to the total distance travelled.

As Brooks *et al.* (2008, p. 29) state: "the high incidence of multi-stop trips in empirically observed behaviour makes the single-stop assumption unrealistic"; most trips for shopping involve multi-stop activities either between different stores or different activities, including shopping (i.e. from work to home, calling at shops on the way). In such cases, the allocation of energy consumption related to the purchasing activity needs to be reduced accordingly (Browne *et al.*, 2008).

Usually, consumers visit more than one shop per trip especially when shopping for non-food products (Brooks *et al.*, 2008). Establishing the number of items consumers buy on each trip is far more problematic as individual retailers only have information

Mode	Average distance (miles)
Walk	0.7
Car/van (driver)	6.4
Car/van (passenger)	8.3
Other private	4.3
Local bus	4.4
Other public	12.5
All modes	5.4

**Note:** 2005-2006 (one-way)

**Source:** **Derived from DfT (2009c)** Personal communications: National Travel Survey

**Table I.**  
Average trip length for  
non-food shopping by  
main mode



about the number of products bought in their own stores, and not as part of the shopping trip as a whole. It seems that no information is collected about the overall quantities of goods bought per shopping trip. Therefore, in the analysis reported here, we have had to estimate a range of values for this critical variable. It would clearly be preferable to have empirical data on the number and types of item bought on the shopping trips. In the absence of this information, however, calculations based on theoretical values still allow cross-channel comparisons of a “what if [...]” nature.

It must also be remembered that some shopping trips do not result in a purchase. Some trips to the high street may be for information-gathering purposes only. This “browsing” category has been largely ignored by researchers owing to a lack of data (Moe and Fader, 2001), yet frequently a fact-finding visit results in a later purchase (often online) (Skinner *et al.*, 2004).

#### 4.3 Specification of the model

*Online shopping: delivery rounds and drop characteristics for non-food.* From face-to-face and telephone interviews with logistics managers, local depot supervisors and delivery van drivers from four different leading parcel delivery companies, we established that a:

- highly efficient home delivery operation would have a drop density of approximately 150 drops on a 60 mile delivery round; and
- city centre-focused round would usually cover about 25 miles and comprise approximately 110 drops on average.

Given these operational characteristics and for ease of comparison, this study examines an average delivery round by a van, which we assume consists of 120 drops on a 50 mile round.

It is assumed that each package delivered as part of this representative home delivery round weighs less than 25 kg (the maximum permissible weight for a one-man delivery). Equally, no distinction is made between the different types of products delivered; as all items are treated equally in the delivery process.

Calculations of the number of items per drop have been performed. Initial results are shown for a single item per drop. However, a more realistic assumption, based on discussions with a leading book wholesaler, is for each drop to contain either 1.4 items in the case of deliveries containing books/DVDs/CDs or 2.5 items for other non-food goods (e.g. clothes and household items) (Beveridge, 2009). Therefore, additional calculations for multiple items per drop are also included. Some online retailers have a dispatch policy where they delay distribution until all items purchased are available for delivery, while others prefer to send one item per package regardless of the number of goods ordered at the time of transaction. For direct comparison with conventional shoppers’ behaviour, CO<sub>2</sub> emissions have been calculated on an item basis. The assumptions made about “last mile” delivery are listed in Table II and represent the expert knowledge of those working in the industry or are derived from previous work in this area.

*Conventional shopping: personal travel.* The average car driver makes a round trip of 12.8 miles for non-food shopping purposes (DfT, 2009a). For bus passengers, the average return journey to the shops for non-food items is slightly less at 8.8 miles (DfT, 2009a). The consumer travel behaviour characteristics assumed in the model are listed in Table III.

Assumptions	Type of delivery round	Total distance (miles)	Drop density (deliveries per round)
Van (<3.5-t)	Average	50	120
	Efficient	60	150
Failed first-time deliveries (per cent)	25		
	12		
	2		
Returns (percentage of orders)	25 (40 for clothing)		
Method of return	Collection		
	Postal services		
	In-store		

**Table II.**  
Freight “last mile”  
delivery: assumptions

Mode	Round trip (miles)
Car	12.8
Bus	8.8
Browsing (as percentage of all shopping trips)	10 (average)
	20 (clothes)
	33.3 (furniture)
Trip chaining (percentage of mileage attributed to shopping)	50
	25
	10 (only applies to trips by car)
Returns (percentage of all purchases)	8

**Table III.**  
Consumer travel and  
shopping behaviour:  
assumptions

## 5. Discussion

When focusing exclusively on the last link in the retail supply chain (from depot or shop to the home), home delivery by parcel carrier is often presumed to be more efficient than an individual travelling to the shops to buy the item in person. The results in Table IV appear to support this supposition. Typically, one drop of 120 such drops on a 50 mile delivery round is apportioned 181 gCO<sub>2</sub>. This figure has been derived from the four freight emissions factors outlined in Section 4 and is a drop’s “share” of the average emissions produced by the overall delivery trip (21,665 gCO<sub>2</sub>).

Delivery/collection method	Total gCO <sub>2</sub> per trip	gCO <sub>2</sub> per item delivered/ collected
Standard delivery van (<3.5-t) (120 deliveries per 50 mile round trip)	21,665 g	181 g (drop) 137 g (1.4 items) 72 g (2.5 items)
Car (dedicated shopping trip of 12.8 miles)	4,274 g	4,274 g (single item)
Bus (dedicated shopping trip of 8.8 miles, assuming average patronage <sup>a</sup> )	11,641 g	1,265 g

**Note:** Parcel carrier/car/bus

**Source:** [Defra \(2007\)](#)

**Table IV.**  
CO<sub>2</sub> per average trip and  
per drop/item

Assuming that a shopper, using a standard car, makes a round trip of 12.8 miles to the shops solely for the purpose of buying one item, the trip would generate 4,274 gCO<sub>2</sub> (all of which could be assigned to that one item). In this example, the CO<sub>2</sub> from personal car-based travel is 24 times greater than the CO<sub>2</sub> produced by a single drop within the average home delivery round.

An alternative way of interpreting these results is to say that a person would need to buy 24 non-food items in one standard car-based trip for this method of shopping to be less CO<sub>2</sub> intensive than having one non-food item delivered (on the first attempt) to their home by a parcel carrier. For a VED Band A vehicle (99 gCO<sub>2</sub>/km), 12 non-food items would need to be purchased and for a mid-range Band G vehicle 31 items (270 gCO<sub>2</sub>/km). A bus passenger, assuming average bus occupancy levels of 9.2 passengers for an 8.8 mile round bus trip, would need to purchase seven or more non-food items to compete favourably with a home delivery in terms of carbon emissions.

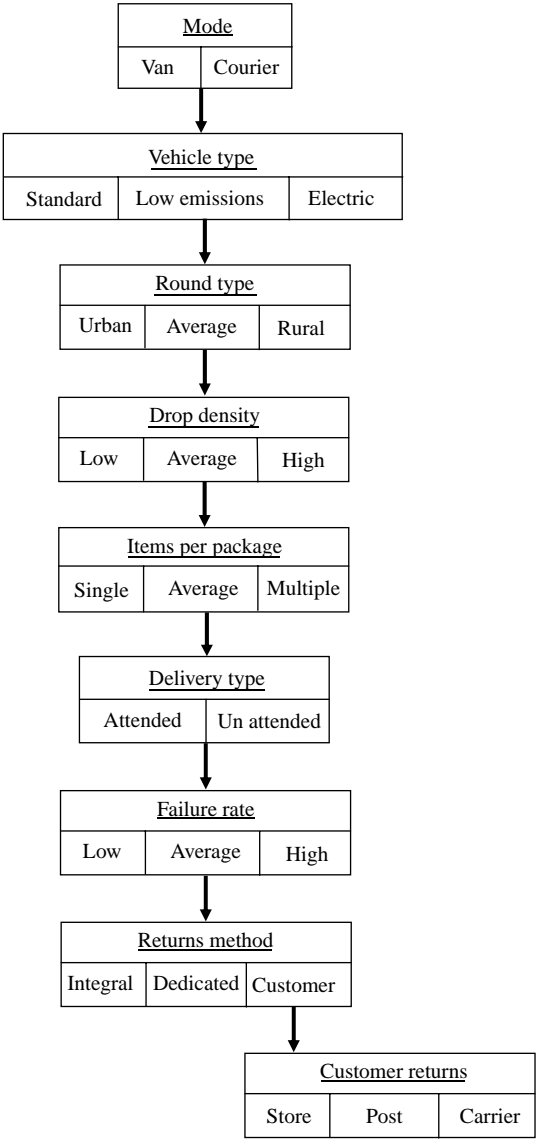
The above calculations assume one item per drop for home delivery and only one item per shopping trip. Although some deliveries to the home do only contain one item (some online retailers only send items out individually regardless of order size), it would be more realistic to increase the “items per drop” variable. With an average content of 1.4 items per drop (e.g. a typical book order) the CO<sub>2</sub> per item is reduced to 137 g for home delivery. When a home delivery (e.g. for clothing and household goods) consists of 2.5 items, the CO<sub>2</sub> per item is 72 g. These assumptions further increase the number of goods a conventional car-based shopper would have to buy in one trip to 32 or 59 non-food items, respectively, to contend with home delivery in terms of CO<sub>2</sub> efficiency. For bus travel, a shopper would have to carry ten or 18 non-food items, respectively.

Although home delivery appears to have a strong environmental advantage over consumers’ personal travel to the shops, this result requires several qualifications. The investigations only compare theoretical delivery trips based on average values. The last mile delivery is much more complex than these initial findings suggest (Figure 1). For instance, a standard home delivery will vary by failed delivery rates (the number of failed first-time deliveries); distances covered (including type of road network), and the method by which unwanted items are returned. These variants will be examined in the Section 5.1.

### *5.1 Effects of varying home delivery parameters*

*Failed first-time delivery rates.* Failed delivery is both uneconomic for the carrier and inconvenient for the shopper. Various failed delivery scenarios are considered, based on the following:

- (1) A 2 per cent first-time failure rate, achieved by van-based parcel delivery carriers who accept alternative drop-off arrangements when no-one is at home for first-time delivery.
- (2) A 12 per cent first-time failure rate, quoted by IMRG (2008) and considered to be an average to good failure rate.
- (3) A 25 per cent first-time failure rate, often experienced by those carriers requiring proof of delivery signatures. It was also the proportion of failed first-time deliveries noted by McLeod and Cherrett (2006) and Song *et al.* (2009) (Table V).



**Figure 1.**  
The online retail channel:  
delivery options

	100% successful first-time delivery	2% failure rate	12% failure rate	25% failure rate
Van-based deliveries: gCO <sub>2</sub> per item	181 g	185 g	203 g	226 g

**Table V.**  
Emissions (gCO<sub>2</sub>) per item including failed delivery rates

Emissions of CO<sub>2</sub> per average drop increases from 181 g for a successful, first-time delivery to the worse-case scenario of an average 226 g per drop when one-in-four deliveries fail.

Most delivery companies schedule the repeat delivery for the next working day after the first-failed attempt, and as a result a high percentage of second attempts also fail, compounding the effects of the initial failed delivery. After a second failed attempt non-delivered goods are held at the local depot, and “carded” customers (those receiving a failed delivery card through the letterbox) have to visit the depot in person to collect the item. Around 3 per cent of home delivery recipients make a trip to collect an item left at a post-office, depot or outlet DfT (2009b).

*Returns.* The returns process for unwanted goods can take a number of forms. When a parcel carrier schedules collections into an outbound delivery round the gCO<sub>2</sub> per collection/item is effectively the same as per delivery. However, when alternative arrangements are made (either on the part of the consumer or the carrier) more complicated calculations are necessary. These are examined in Section 5.2.

### 5.2 Effects of varying shopping trip parameters

*Consumer travel and shopping behaviour.* The model also captures much of the variability in consumer shopping behaviour. Some shoppers make dedicated trips to shops when shopping is their only intention, while others may choose to combine shopping with other activities as part of a trip chain. Additionally, both online and conventional shoppers frequently choose to inspect items in stores (prior to buying either in-store or online), and may make several trips to do so. When shoppers wish to return unwanted items, they often have a choice of returns methods. Figure 2 shows an indication of some of the choices available to the conventional shopper.

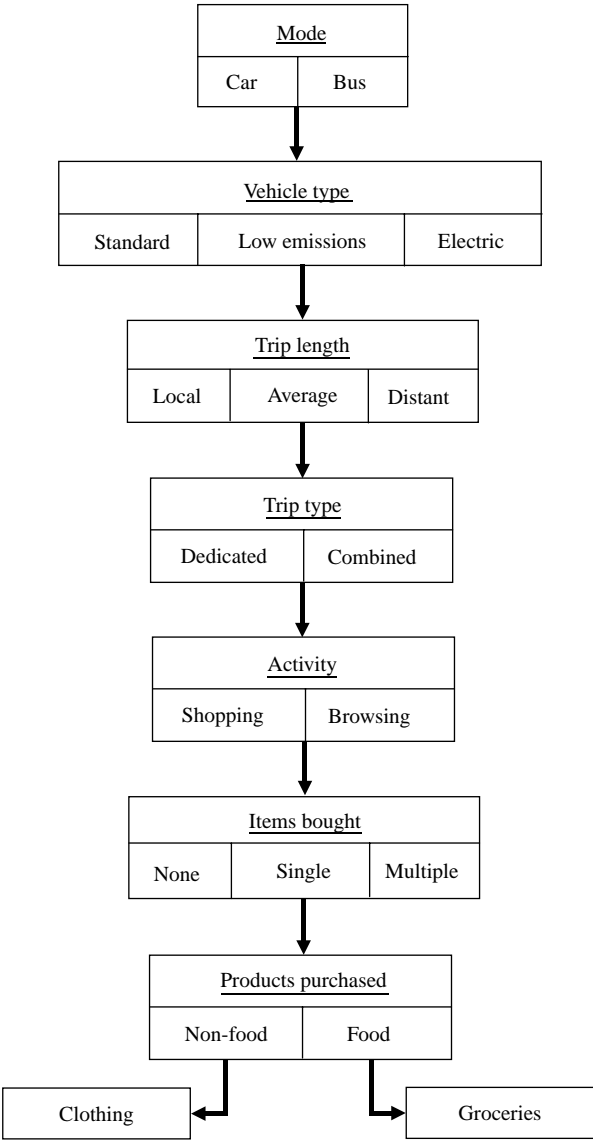
A certain number of shopping trips will end in no purchase, owing to the:

- consumer failing to decide which item to buy;
- particular good sought being unavailable; or
- consumer having no intention to purchase anything, using the trip for information gathering purposes only.

In these cases, the unsuccessful trip needs to be factored into the calculations. On the “realistic” assumption that one in ten shopping trips for a particular product results in no immediate purchase, the gCO<sub>2</sub> in each of the above-dedicated shopping trips would increase by a factor of 1.1. Nevertheless, at a personal level, a shopper’s CO<sub>2</sub> trip-related footprint would be twice the amount to take account of a second (later) journey to the shops. So, while total emissions for a “browsing plus purchase” average car trip would be 4,701 gCO<sub>2</sub> (4,274 gCO<sub>2</sub> × 1.1), for the individual undertaking the second journey it would be 8,548 gCO<sub>2</sub>.

Furthermore, a consumer may choose to acquire the item as part of a larger shopping expedition when many items are bought, and/or to combine the shopping trip with other activities (Table VI). The combined trip, in this instance, realistically assumes that shopping-related mileage is a quarter of the overall trip mileage (25 per cent).

In Table VI, it can be seen that the most efficient ways to purchase and collect a product would be either as part of a much larger shopping trip when many items are bought at the same time or where shopping is incorporated into trips made principally for another purpose. Any consolidation of shopping activities clearly reduces their carbon intensity.



**Figure 2.**  
The conventional retail channel: consumer choices

Bus travel can compete with home delivery in terms of CO<sub>2</sub> efficiency. During peak leisure times (e.g. on a Saturday afternoon), when occupancy levels are high and most non-food shopping occurs, from an environmental point of view, bus travel is an effective method of collecting shopping. For example, assuming a shopper travels the average distance (8.8 miles) by bus, in the company of 29 other passengers, and buys five items, each purchase would be allocated a share of just 78 gCO<sub>2</sub>, less than half that

**Table VI.**  
Implications of shopping  
trip type on CO<sub>2</sub>  
emissions

Trip type	Items bought	Mode of transport	gCO <sub>2</sub> per item
Dedicated	Single item (one item)	Car	4,274
		Electric car	1,586
		Bus	1,265
	Multiple purchase (five items)	Car	855
		Electric car	317
		Bus	253
Browsing (two trips to shops: one for browsing, one for purchase)	Single item (one item)	Car	8,548
		Electric car	3,172
		Bus	2,530
Combined (shopping 25 per cent of trip mileage)	Single item (one item)	Car	1,069
		Electric car	397
		Bus	316
Combined then dedicated (25 per cent of mileage: initial browsing followed by dedicated trip to buy an item)		Car	5,343
		Electric car	1,983
		Bus	1,581
Combined (grocery shopping: distance 7.12 miles <sup>a</sup> )	Multiple (50 items)	Car	48
<b>Note:</b> <sup>a</sup> Average round trip distance to a supermarket (Future Foundation, 2007)			

for a typical home delivery (181 gCO<sub>2</sub>). Encouragingly, from an environmental point of view, most shoppers (63 per cent) state that they would have no difficulty getting to the shops by public transport (DfT, 2005).

*Returns.* The actual gCO<sub>2</sub> per online order is very sensitive to the proportion of products returned and the method of return. Two scenarios are considered:

- (1) *Where the unwanted item is collected on a subsequent delivery round.* In this case, the integrated returns collection is allocated 362 gCO<sub>2</sub> (twice the CO<sub>2</sub> of an outbound drop), as the unwanted item has the combined emissions of an outbound and return trip (in effect two outbound deliveries).
- (2) *Where the consumer returns the item to a high-street store.* In the case of an online shopper making a separate car trip to return the item, the CO<sub>2</sub> would be 4,522 gCO<sub>2</sub> (181 gCO<sub>2</sub> + 4,341 gCO<sub>2</sub>), calculated on an average car-based round trip (13 miles). This is clearly the worst-case scenario. The marginal CO<sub>2</sub> impact could be greatly reduced by returning the item as part of another shopping trip or by “trip chaining”.

5.3 CO<sub>2</sub> emissions: last mile versus upstream activities

It is not only on the last link that the online and conventional retail channels vary, but the structure of their upstream supply chains also differ and this too will affect their relative carbon footprints. Ideally, one should compare the carbon intensity of the two channels as far back as the point in the supply chain at which they diverge because up to this point the amount of CO<sub>2</sub> emitted will be common to both channels (Figure 3). This would allow us to put differences at the carbon intensity of last mile operations into context.



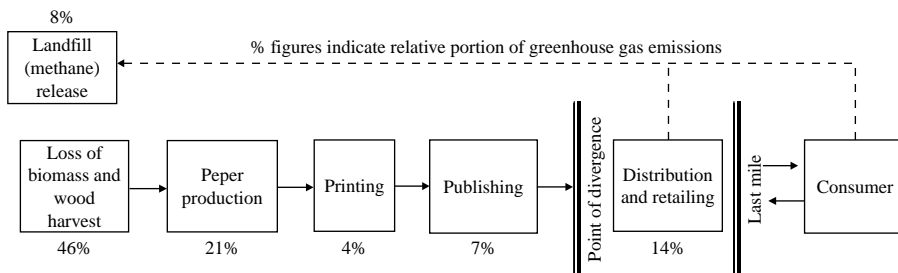
The calculations in this paper and available published evidence suggest that emissions from car-based shopping trips can far exceed those from distribution operations back along the supply chain. It is likely, therefore, that the environmental comparison of online and conventional shopping channels will be dominated by what happens at the local level. Differences in CO<sub>2</sub> emissions between car-borne shopping trips and home deliveries are likely to be much more important determinants of the respective carbon footprints of online and conventional shopping than differences in upstream logistical operations as far back as the point at which the two distribution channels diverge.

## 6. Conclusions

This study summarises the results of a comparative study of CO<sub>2</sub> emissions for the home delivery and conventional shopping trips. While this so-called “last mile” has received considerable attention from researchers, none of the previous studies have attempted such a comparison on per trip, drop or item basis. Several scenarios were investigated, and wherever possible representative values, derived from national statistics, previous research or industry practice, were applied to different freight and consumer trips.

Numerous factors influence emissions from home deliveries. They include: drop densities; the distance and nature of the delivery round; the type of vehicle used; and the treatment of failed deliveries and returns. On average, when a customer buys fewer than 24 items per shopping trip (or fewer than seven items for bus users) it is likely that the home delivery will emit less CO<sub>2</sub> per item purchased. These findings require several qualifications, however. They assume:

- the car-based trip was solely for the purpose of shopping (no other activity was undertaken during the course of the trip);
- the product ordered online was delivered successfully first time;
- the shopper was satisfied with the purchase and did not return the item;
- home deliveries and shopping trips were made over average distances; no allowance was made for different types of road network or traffic conditions; and
- only the last mile and not the upstream supply chain has been considered in the analysis (although reference has been made to previous studies of the relative environmental impact of upstream activities).



Source: Derived from green press initiative (2008)

**Figure 3.**  
Stages of book production and distribution

The environmental implications of consumer behaviour have been illustrated by a series of different shopping scenarios. Having already established that a standard home delivery for a non-food item would be allocated 181 gCO<sub>2</sub> various dedicated, combined and browsing-only shopping trips were then compared. From the modelling evidence presented here and from the results of previous research, it seems that emissions from the average shopping trip, particularly by private car, can be greater than emissions from all upstream logistical activity irrespective of the distribution channel. Further work is underway to examine this issue in greater detail. The mode of personal travel is particularly important. When a shopper travels by bus at busy times and makes several purchases, the emissions per item are lower than when a home delivery van delivers just one item to a consumer's home.

It is acknowledged that people appear to regard shopping as a social, recreational or even hedonistic activity to be enjoyed in a physical store. Given increasing concern for climate change, however, it is important that they are made aware of the CO<sub>2</sub> consequences of their chosen shopping behaviour. With a little planning and thought on both the part of consumers and carriers/retailers, emissions related to the transport element of any shopping activity could be minimised through a few simple actions. Carriers should aim to maximise drop densities (something that is likely to happen anyway as a consequence of the growth of online retail sales), avoid dedicated collection trips when picking-up returned items and where possible use low emissions vehicles, e.g. electric vehicles. The use of reception boxes at people's homes and separate collection points would eliminate failed deliveries, the consolidation of orders to a particular address in a single delivery would cut vehicle-kms and wider adoption of variable delivery pricing would promote off-peak/out-of-hours deliveries, allowing delivery vans to run more of their mileage at fuel-efficient speeds.

Conventional shoppers meanwhile should ensure that when they go shopping wherever possible they should combine their shopping trip with other activities and thus avoid making a dedicated journey to buy a single item.

The relative carbon intensity of the different forms of retail distribution depends on their particular circumstances. Neither has an absolute environmental advantage. Some forms of conventional shopping behaviour emit less CO<sub>2</sub> than some home delivery operations. On average, however, in the case of non-food purchases, the home delivery operation is likely to generate less CO<sub>2</sub>. This environmental advantage can be reinforced in various ways if online retailers and their carriers alter some of their current operating practices.

Analysis of the emissions from the distribution of products with very different characteristics, such as refrigerated food or bulky items (> 25 kg) that require a two-man delivery, may yield very different results. The methodological approach outlined in this paper could be applied to a comparative carbon analysis of these other sectors of the retail market. Further research is also required to refine the analysis for small non-food items. This could explore the impact on carbon emissions of other behavioural responses to the growth of online retailing not considered by the present study. Some online customers, for example, may continue to shop as much by conventional means, but merely buy less on each trip, effectively increasing the carbon intensity of each item purchased by this means. Others may use the internet not just for purchasing goods but to inform their conventional shopping decisions, allowing them to select products and shops in advance and thereby rationalise their shopping-related travel. This future

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research, like the present study, will require an extension of logistics' traditional focus on the transport of goods in dedicated freight vehicles to include the various forms of personal travel associated with the movement of goods on the "last mile" to the home.

## Analysis of the carbon footprints

### Notes

1. The carbon footprint of a product is the sum of all the carbon emissions for that product from raw materials through manufacturing, distribution, use and disposal, taking account of all related activities and materials. The calculations in this paper are for CO<sub>2</sub> emissions for the last stage in the distribution only.
2. Trip-chaining occurs when a person visits several locations for different purposes in the course of a single trip.
3. A van denotes a light goods vehicle up to 3.5 tonnes maximum permissible gross vehicle weight of van-type construction on a car chassis that operates on diesel fuel unless specified otherwise.

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### About the authors

Julia B. Edwards is a Research Associate in the Logistics Research Centre at Heriot-Watt University, Edinburgh. She joined the Group in 2006 as part of the multi-university "Green Logistics" project. Prior to that, she was a Senior Lecturer of Environmental Management at the University of Wales, Newport. She has been researching and teaching in the areas of transport and environmental issues for the last fifteen years. Currently, her research interests include carbon auditing of supply chains, e-commerce and the environment and consumer travel and shopping behaviour. Julia B. Edwards is the corresponding author and can be contacted at: [j.b.edwards@hw.ac.uk](mailto:j.b.edwards@hw.ac.uk)

Alan C. McKinnon is a Professor of Logistics and a Director of the Logistics Research Centre at Heriot-Watt University, Edinburgh. A graduate of the universities of Aberdeen, British Columbia and London, he has been researching and teaching logistics for 30 years and has published extensively on many different aspects of the subject. He has conducted studies for numerous public and private sector organisations and been an adviser to several UK Government departments, parliamentary committees and international agencies. Much of his current research relates to the decarbonisation of logistical activity.

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Sharon L. Cullinane has continued to lecture, research and publish in the field of transport policy and the environment around the world, since gaining her PhD in logistics 20 years ago from Plymouth University. Previous to that she has been employed at the University of Hong Kong, Oxford University, the Egyptian National Institute of Transport, the École Supérieur de Rennes and Plymouth University. She is now an independent consultant. She is widely published internationally. She has lectured, researched and published in logistics and transport around the world. Her most recent post was as a Senior Lecturer at Heriot-Watt University in Edinburgh, UK.

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