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A comparative analysis of carbon emissions from online retailing of fast moving consumer goods

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ABSTRACT

Online retailing can lower the environmental impact of shopping under specific circumstances. As a result of the numerous variables involved, most of the studies that have compared the carbon footprints of online and conventional retailing only take a partial view. To make a more holistic assessment, this study develops a framework that accounts for all the relevant environmental factors relating to retail/e-commerce activities. Variables related to consumer shopping behaviour such as basket size, transport mode, trip length and trip frequency are included in the analysis. This framework is used to build a Life Cycle Analysis model. The model is applied to different online retail methods for fast-moving consumer goods in the United Kingdom. We find that, within the “last mile” link to the home, the nature of the consumer's behaviour in terms of travel, choice of e-fulfilment method and basket size are critical factors in determining the environmental sustainability of e-commerce. The nature and routing of van deliveries, the amount and type of packaging used, and the energy efficiency of shop and e-fulfilment centre operations are also identified as significant contributors to climate change potential. The results of this study indicate ways in which e-commerce can be made more environmentally sustainable, encouraging consumers to reduce complementary shopping trips and maximise the number of items per delivery. This study identifies the strengths and weaknesses of a range of e-retail channels and provides a basis for future research on the environmental sustainability of online retailing of fast-moving consumer goods.

1. Introduction

Online retailing of fast moving consumer goods (FMCG) is rapidly growing and in 2012 was worth € 300 billion in Europe (IMRG, 2012). The majority of this turnover was created in the United Kingdom, Germany and France. In the United Kingdom the share of online groceries is much higher than in other European countries. 19% of the UK population bought groceries online in 2011 (Eurostat, 2012a). This is expected to rise further to 40% by 2016 (Van Essen, 2012). While the relevance is growing, the effects on the environment remain unclear. Several studies have been conducted on the environmental impact of online retailing, but only a limited number of these perform an environmental analysis of the fulfilment of FMCG products that are ordered online. These studies have often a limited scope, comparing one online retail system with conventional shopping and ignoring important effects such as related consumer trips. Edwards and McKinnon (2009) show that failed deliveries, product returns, trip chaining (to what extent is the shopping trip embedded into another transportation goal, e.g. commuting back and from work, school drop-off, etc.) and browsing trips (a trip intended for product inspection before buying online) can make an important contribution to the

Abbreviations: PP1, pure player 1, centralised with van delivery; PP2, pure player 2, delivery through parcel network; PP3, pure player 3: drop-shipping from supplier through parcel delivery network; B&C1, brick and click 1, van delivery from local shops; B&C2, brick and click 2: collect in local stores; D2C1, direct to consumer, bypassing the retailer and use of parcel delivery network; B&M, brick and mortar conventional retailing in supermarkets; CDP, collect and delivery point; FMCG, fast moving consumer goods.

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environmental impact (estimated as the carbon footprint). Regrettably, these effects are often not included in Life Cycle Analysis studies (see for example Matthews et al., 2001; Weber et al., 2009). Abukhader (2008) also noticed that changes in consumer behaviour are often omitted in the environmental analysis of online retailing.

Different studies on the environmental impact of retailing show that consumer trips contribute significantly to the environmental footprint. Depending on the mode of transport, the distance, and the number of items in the shopping basket, the consumer trip can consume more energy than the total transport energy from factory to shop (Browne et al., 2005). Not surprisingly, a significant number of studies focus on the distance driven in the home delivery of groceries compared to physical shopping (Punakivi and Saranen, 2001; Siikavirta et al., 2003). In the case of complete substitution of the traditional shopping trip (consumer car travel) by van home delivery, the vehicle km can indeed be reduced by up to 70% (Cairns, 2005). However, complete substitution is unlikely (Erber et al., 2001; Hesse, 2002; Mokhtarian, 2004). In the case of consumer goods, and especially groceries, products are often bought as part of a larger shopping basket. It is likely that shopping trips will still be executed despite ordering certain products online for home delivery (Hand et al., 2009). Nevertheless, a reduction in consumer travel by car is essential if the environmental benefits of e-commerce are to be realised (Hesse, 2002; Matthews et al., 2002; Rizet et al., 2010). To calculate the real environmental impact of e-commerce, the influence of online shopping on consumer trips must be taken into account completely. Changes in consumer travel due to online shopping might include changes in shopping frequency, transport mode and changes in the distance between the shop and the consumer (Mokhtarian, 2004).

In this study, a Life Cycle Analysis (LCA) model is developed to compare the environmental impact of different fulfilment methods for FMCG in the United Kingdom. This includes the most utilised Business to Consumer (B2C) e-commerce models as well as the conventional brick & mortar retail channel. The research aim is to identify all relevant parameters for assessing the environmental impact of online retailing and then to determine which factors are most significant in determining the environmental sustainability of different fulfilment channels.

2. Methods

Following LCA guidelines this section begins by identifying the goal and scope of the analysis and describes the functional unit used to allow a comparative analysis of fulfilment methods. The model architecture, system boundaries, assumptions, and data sources are detailed thereafter.

2.1. Goal and scope definition

The primary aim of this study is to determine which factors play an important role in the environmental performance of different fulfilment methods for FMCG in the UK. The study also examines the relative extent of the impact of each factor and how the environmental impact of each fulfilment method might be reduced.

To achieve this we use the LCA software package SimaPro (Pré Consultants, 2011). The different fulfilment methods modelled are shown in Table 1. The various forms of e-commerce are defined by the structure of the delivery channel. Products can be distributed from a central e-fulfilment centre or from local stores (Scott and Scott, 2008). Retailers without physical stores, the so-called “pure players”, can deliver the products to the consumer via local van delivery. This often requires complementing vans with long haul truck transportation up to cross docking locations used to tranship goods into vans that execute a local delivery tour; this fulfilment method is called pure player 1 (PP1). Pure players can also use parcel companies for home delivery (PP2). Another possibility is the so called “drop-ship” approach, in which the products are sold by the retailer but shipped directly from the supplier to the consumer via a parcel network (PP3). Brick & click companies often deliver products to the consumer from a local store (B&C1). The concept of online ordering followed by consumer collection of items in store, the click & collect concept (B&C2), is growing in market share in the UK (Rimini, 2010). As yet there are few examples of producers bypassing the retailer and selling directly to the end-consumer, though this form of e-fulfilment may expand in the future.

2.2. Functional unit

The environmental impact of each fulfilment method is measured in CO_2-equivalents (CO_2-eq) emitted in the acquisition and fulfilment of one consumer item, i.e. the functional unit is a single item. This does not mean that only purchases of one item are considered. The item can be part of a larger shopping basket containing several items; the environmental impact (carbon emissions) is then divided by the number of items in the shopping basket to report the emissions per item fulfilled.

For the last mile delivery, emissions can be allocated with respect to the number of items and drops (Edwards et al., 2010). In most cases, the utilisation of the delivery van is limited by the number of orders in a delivery round due to the narrow delivery time windows and not by weight or volume (Siikavirta et al., 2003). Parcel companies, who deliver normally without pre-agreed time slots, are looking for high drop density rates per round to improve the delivery efficiency (Edwards et al., 2010). However, choosing one consumer item as the functional unit has its limitations. No distinction is made between the types of consumer item, the weight or volume of the product. This conflicts with the observation that the consumers' choice to shop via a specific retail channel depends on the nature of the products he or she intends to purchase. For example, online grocery shops are mainly used for stock-up orders containing a larger share of heavy and bulky products than shopping trips to a supermarket (Chu et al., 2008; Pozzi, 2009). Nevertheless, when appropriate caution is taken when interpreting findings, choosing the item as the functional unit is a suitable approach. The choice of ‘item’ enables allocation of the footprint at item level and reconstructing the footprint, on a bottom-up basis, for higher-level

Table 1
Fulfilment methods.

Method	PP1	PP2	PP3	B&C1	B&C2	D2C1	B&M
Explanation	Centralised pure player with van delivery	Centralised pure player through parcel delivery network	Drop-shipping from supplier through parcel delivery network	Van delivery from local shops	Click & collect in local stores	Bypass retailer and use parcel delivery network	Conventional retailing in local supermarkets

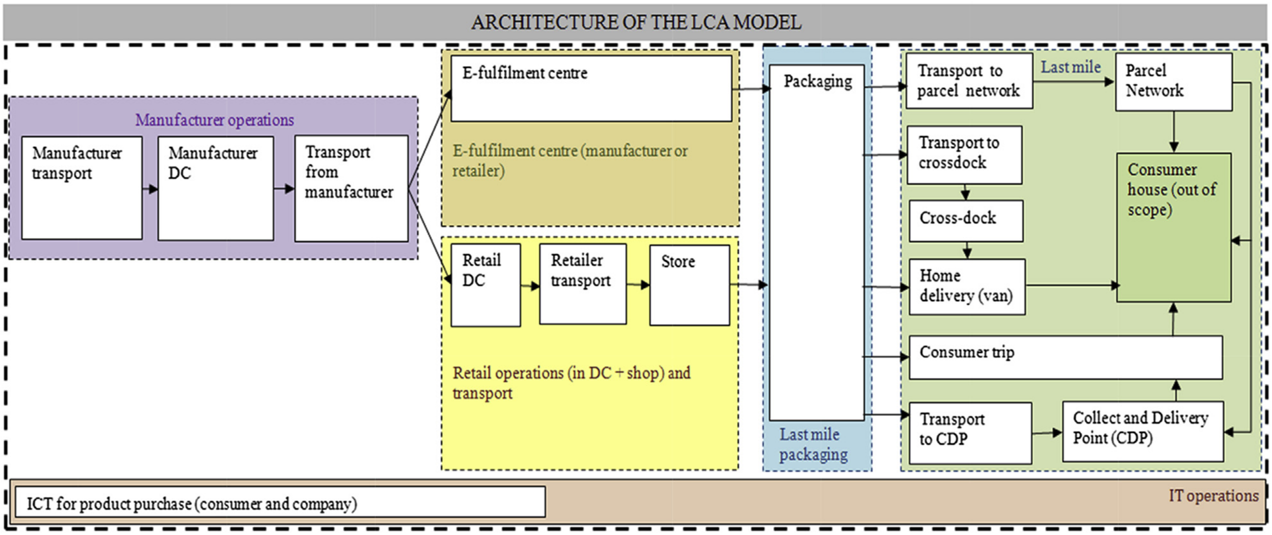

Fig. 1. Framework for environmental analysis of online shopping of consumer goods.

entities (basket, drop, order, and parcel) as a summation of items.

2.3. System boundaries

The environmental impacts of the fulfilment of one consumer item are compared from the point of divergence to the point of consumption, as suggested by Edwards et al. (2011). In the context of FMCG products, the point of divergence is the factory's outbound operation. Therefore all impacts due to the movement and storage of products from the factory to the consumer (and back in case of returns) are included in the model. Emissions associated with the actual creation and consumption of the item, i.e. raw material sourcing, manufacturing, product use and disposal, are excluded since these are independent of the fulfilment channel chosen by the consumer. Primary packaging[1] is considered as an indistinguishable part of the consumer item and is therefore also excluded from this environmental assessment.

2.4. Model architecture

The LCA model was built using a modular approach, such that different modules can be selected and parameterised to represent the supply chain of a specific retail/e-tail approach. The modules and possible relationships between them are shown in Fig. 1, following the flow of goods through the supply chain. Each of these modules (white boxes in Fig. 1) represent a number of activities including: manufacturer operations; e-fulfilment operations; retail operations; use of last mile packaging materials; last mile transportation, and the use of information communication technology (ICT). To facilitate interpretation and discussion, results are grouped together in each of these life cycle stages. The selected modules and data choices are explained in more detail in the following paragraphs.

[1] Primary packaging is defined here as all packaging directly used to pack products, excluding packaging added for transportation.

2.5. Data sources and assumptions

Although the results focus on few parameter variations within the context of several e-fulfilment scenarios, the model is highly parameterised and data intensive. To deal with different supply chain set-ups (e.g. unique to retailer/e-tailer) and consumer behaviours (e.g. representing region, time frame, the fulfilment method) over 400 parameters per fulfilment channel are defined, and substantiated with values, a few of which can be found in Appendix B.

Manufacturer and retailer transport (excluding last mile delivery) is modelled with data representing a 28t gross-weight truck. The truck operation includes the combustion of several types of fuel (diesel, biofuel, natural gas, and hybrid) representing a realistic mix for the region (Watkins, 2005). Manufacturer transport includes movements from continental Europe to the UK. In 2011 international freight transport in Europe covered an average distance of 596 km while freight to and from the UK was slightly lower (Eurostat, 2012b). Therefore in this research a distance of 500 km is assumed for manufacturer transport.

The utility consumption (electricity, fuel, gas, and water) of the different buildings in the modules (e.g. manufacturer and retailer distribution centres, e-fulfilment centre, supermarket, collection and delivery point, cross-dock facility and parcel hubs) is based on primary data for the manufacturer modules, while secondary data is used for the retailer modules. For the latter, the average electricity consumption data for the different buildings included in the model are taken from the Building Research Establishment (BRE) database (Pout et al., 2002). In allocating the use of utilities to individual items account is taken of the relevant building's throughput rate. The throughput rates and the distance and number of items in a truck are calculated from different retailer performance reports (Ocado, 2011; Watkins, 2005).

For last mile packaging, the use of cardboard boxes, filler materials and plastic bags are included. Cardboard packaging is often used in parcel deliveries, while plastic bags are used in van home deliveries. This implies that four types of packaging material are taken into account: LDPE film, corrugated board boxes, polystyrene, and starch. Re-usable plastic crates used for picking and delivering groceries are excluded due to their re-usable nature and long lifetime.

Table 2
Contribution analysis of different fulfilment methods (with industry average data).

	PP1	PP2	PP3	B&C1	B&C2	D2C1	BM
Last mile	42.9%	51.6%	66.8%	8.1%	18.9%	44.1%	25.6%
• Consumer trip	0%	18.3%	24.7%	0.3%	18.9%	5.5%	25.6%
• Parcel network	–	33.3%	42.1%	–	–	38.5%	–
• Home delivery (van)	19.8%	–	–	7.8%	–	–	–
• Transport to cross-dock	21.4%	–	–	–	–	–	–
• Cross-dock	1.8%	–	–	–	–	–	–
• Collection and delivery point	–	0.01%	0.02%	–	–	0.02%	–
Retail operations	–	–	–	44.2%	39.0%	–	35.7%
• Store	-	-	-	39.4%	34.7%	–	31.7%
• Retailer transport	–	–	–	4.5%	3.9%	–	3.6%
• Retail DC	–	–	–	0.4%	0.3%	–	0.3%
E-fulfilment centre	22.8%	13.6%	2.2%	–	–	30%	–
Manufacturer operations	29.9%	10.3%	4.2%	42.5%	37.5%	12.7%	34.3%
• Manufacturer transport	21.8%	3.9%	4.2%	33.7%	29.8%	12.7%	27.2%
• Manufacturer DC	5.0%	1.1%	–	3.1%	2.7%	–	2.5%
• Transport from manufacturer	3.1%	5.2%	–	5.7%	5.0%	–	4.6%
Last mile packaging	4.1%	23.7%	25.6%	4.9%	4.4%	12.8%	4.4%
ICT for product purchase	0.2%	0.7%	1.1%	0.2%	0.2%	0.4%	–

The last mile includes different transportation options. For delivery routes that are more distant from the fulfilment centre, long haul truck trips are combined with local van deliveries. Truck transport is then modelled from the centralised e-fulfilment centre to the cross-dock location, where the orders are shipped on to the consumer using in-house van delivery. Each drop includes on average 55 items (Ocado, 2011). The brick & click delivery round is estimated at an average of 22 drops in 50 km (Hailes, 2008; MacLeod, 2008). Important to note is that only attended delivery (with 2 h time slots) is assumed. When unattended delivery is used, the home delivery performance will increase significantly (Agatz, 2009; Grando and Gosso, 2005; Punakivi and Tanskanen, 2002; Yrjölä, 2003). In the brick & mortar situation, the consumer collects the items in the store. Based on the average shopping behaviour in the UK, a 12.5 km dedicated roundtrip with a basket size of 30 items is included (Future foundations, 2007; DfT, 2011). Much smaller drop sizes of between 1.4 and 2 items are used for parcel home deliveries depending on the fulfilment method. However, the last mile performance in terms of distance per order is higher for parcel deliveries, estimated at 80 km with 120 drops (Edwards et al., 2009). The life cycle impacts (including production, maintenance, and disposal) of the vehicles are included with a "burden factor", determined using the average total distance driven before disposal.

Four types of consumer trips are included in the analysis: trips to supermarkets in the conventional retail (B&M) channel, click & collect trips (B&C2), trips within e-fulfilment channels for picking up items after a failed delivery and those for returning unwanted items. The latter two types of trip can be either to a local shop, a carrier depot, or a collect and delivery point (CDP); all three options are included in the model. The dedicated distance and relative use of the transport modes (including walking, cycling and public transport) to a shop are taken from the national transport survey (DfT, 2011). Note that this study makes use of the average shopping behaviour of consumers in the UK. The average distance and transport modes used for travel to the other locations are taken from the study of Cherrett and McLeod (2005) and McLeod et al. (2006). Following the suggestion of Edwards et al. (2010), the environmental impact of the van and the consumer trip are allocated with reference to the number of orders and the number of items in the order to calculate the impact at item level. As a result, the impact due to the number of items purchased (2 in parcel delivery versus 55 in van home delivery) can significantly affect the study findings.

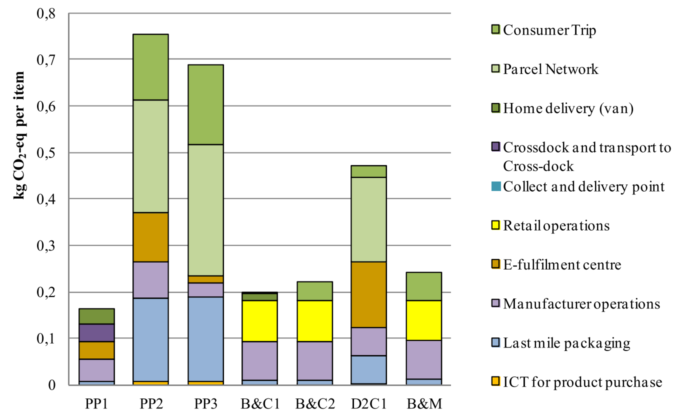

Fig. 2. Base case scenario- CO_2-eq emissions for different fulfilment methods, assuming complete trip substitution.

For the e-tail channels the ICT-operations for product ordering are included. This means that the electricity consumption of PC's, laptops, smart phones, or tablets is included as well as the life cycle impacts of the computers, infrastructures, routers etc., is allocated with a burden factor (as suggested by Sivaraman et al., 2007). Based on previous LCA studies (Collins and Aumônier, 2002; Scott and Scott, 2008; Sivaraman et al., 2007; Weber et al., 2009), it is assumed that placing an online order takes between 15 and 30 min.

For all "background processes" including the production of electricity and the life cycle impacts of vehicles, IT-equipment and packaging material, the EcoInvent Database (Frischknecht et al., 2007) is used as provided in SimaPro.

2.6. Impact assessment

In order to analyse relevant environmental impacts from the life cycle system as described above, ReCiPe impact assessment methodology (Goedkoop et al., 2009) was used in the Simapro software. More specifically, via "endpoint" normalisation (ReCiPe Endpoint H) of 17 environmental midpoint indicators, we have identified a small set of environmental indicators that represent the highest relative contribution to worldwide damage/endpoint indicators. The results (see Appendix A) show a relative high contribution of 1) fossil resource depletion, 2) climate change potential, 3) particulate matter formation and 4) human toxicity potentials. Given the relevance of climate change potential in the life cycle system modelled in this study[2] and its overall importance as an externality, the analysis is confined to the measurement of CO_2-eq. Since the "IPCC 2007 GWP 100a V1.02" methodology is still the most widely recognised impact method for measuring climate change impact potentials (over 100 years), it is the one applied here (developed by the Intergovernmental Panel on Climate Change, Solomon et al., 2007). In more popular terms, the climate change potential is also referred to as global warming potential and/or the "carbon footprint".

[2] Following normalisation, climate change is the second most relevant indicator and is contributing to two damage categories (ecosystem loss and human health). Also, fossil resource depletion (first most relevant indicator) is a result from the same unit processes in the life cycle systems, and will therefore lead to the same conclusions.

3. Results and discussion

In our first scenario (base-case scenario) we include differences in the supply chain between the fulfilment methods plus the differences in consumer behaviour that are unique to the different fulfilment methods in the UK. For example, when ordering FMCG products at an online grocery retailer an average of 45 (B&C1) to 55 (PP1) items are ordered. FMCG products at a pure player with parcel delivery (PP2) have an average basket size of only 2 items (see Appendix B). In this scenario, a complete substitution of consumer trips to the supermarkets due to online shopping is assumed. The carbon footprint results are presented in Fig. 2 and Table 2 for each of the e-retail and conventional retail methods.

From Fig. 2 and Table 2 we can identify the key contributors to climate change potential; these include consumer transport, parcel network, the physical store, and the transport between the factory and the manufacturer's distribution centre (DC). By contrast the DC facilities, the CDP and cross-dock facilities have a limited impact on the total greenhouse gas emissions. As expected from previous research, ICT operations have also a minor impact.

In this scenario, where complete consumer trip substitution is assumed, large differences in the total footprint between the different fulfilment methods occur. Taking into account the average number of items purchased, the carbon footprint of van home deliveries and consumer pick-up methods (PP1, B&C1, B&C2 and B&M) is ~200 g CO_2-eq per item. PP2, PP3 and D2C1 (parcel delivery) methods all lead to substantially larger carbon footprints (~500–800 g CO_2-eq per item).

3.1. Consumer trips

Although complete substitution is assumed in the base-case scenario the consumer trip contributes significantly to the total climate change potential of certain e-fulfilment methods. In this scenario consumer trips arise due to returning unwanted goods, picking up failed deliveries or collecting deliveries at a CDP. The relative importance of these trips is not equal across the different fulfilment methods. In parcel deliveries, the failed deliveries result in 62–89 g CO_2-eq per item (PP2 and PP3 respectively), assuming 40% failed deliveries of which 90% is redelivered and 10% is picked up by the consumer at a local CDP or at the carrier's depot. Another 66 g CO_2-eq is emitted due to consumers returning unwanted items, which occurs in 3.5% of the cases. In van based models the incidence of consumer trips is much lower. Due to the delivery windows agreed with the consumer, the proportion of failed deliveries is much lower. Also when failed deliveries occur, the consumer can pick up items at a local shop, leading to a shorter distance (12.5 km dedicated roundtrip) than when the consumer has to pick up items at a carrier depot (19.95 km) as is the case with failed parcel deliveries. In van based deliveries (B&C1), failed deliveries lead to just 0.004 g CO_2-eq, assuming that 99% can be redelivered and 1% of the failed deliveries are picked up in the local store. This shorter distance and lower return percentage also leads to a lower footprint for returns in the van based models, emitting only 0.5 g CO_2-eq per item. The lower return percentage can be explained by the different nature of the products. Van based models mostly deliver grocery products, which have typically a very low return rate (Cairns, 2005), while parcel models deliver proportionally more high value FMCG products, like consumer electronics, which have higher return rates.

A complete substitution of the consumer trip to the store due to home deliveries is, however, unrealistic. It is argued that the home delivery of groceries reduces the shopping trips to the supermarket by as little as 25% (Forrester 2001 cited by Foley et al., 2003). For other online retail channels this is likely to be even lower. To include this moderate effect on existing shopping trips, a second scenario was developed in which the percentage of remaining shopping trips is included in the environmental impact calculations of online retailing. Depending on the fulfilment method, 75% or 90% of the consumer trip to a physical store is included on top of the online retail emissions (see Appendix B). An average of 30 items is assumed for these physical shopping trips. Other rebound effects, such as increased spending or travelling due to e-commerce (see for example Mokhtarian, 2004) are considered out of scope because they lack data-based evidence. Fig. 3 shows a comparison including consumer representative shopping trips in each fulfilment method.

A trip to the local store emits on average 62 g CO_2-eq per item, assuming a dedicated round-trip distance of 12.5 km and 30 items in the shopping basket. However, only 75% or 90% of this trip is included in the e-retail models to take into account the limited reduction in the shopping trips due to online shopping. Depending on the online retail model, the additional consumer shopping trips add between 28.7% (PP1) and 7.3% (PP2) to the total climate change potential.

Including these remaining supermarket shopping trips leads to a shift in the environmental ranking of the fulfilment channels. In this scenario calculation, brick & click (B&C1) now has a higher environmental impact than the click and collect option (B&C2) and is on par with conventional retailing (B&M). Influencing consumer behaviour to minimise the occurrence of these complementary shopping trips is therefore an important factor to be considered in reducing the environmental impact of e-commerce. To better understand the impact of one fulfilment method over another, and how consumer choice might influence the carbon footprint of different e-fulfilment channels, the sensitivity of the results to basket size is investigated.

3.2. Shopping basket size

A critical parameter in the LCA model is the number of items in the shopping basket (Browne et al., 2006). Previously we have shown results comparing the different retail situations, based on the average UK basket sizes typical for the particular fulfilment channel. However, when a consumer buys a single product, which is often the case when purchasing high value FMCG products, the situation looks very different. Results for a third

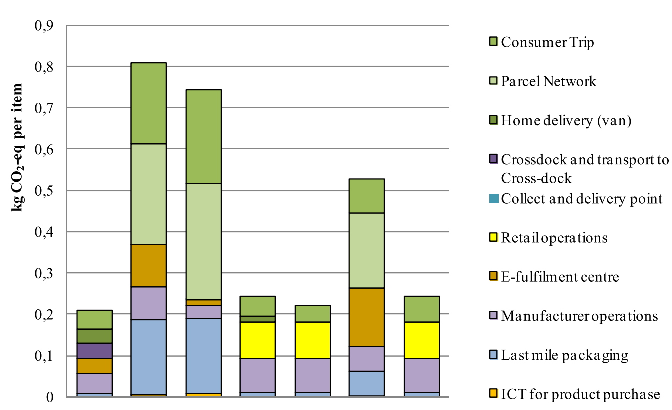

Fig. 3. Scenario two-climate change potential of different e-retail methods based on industry average shopping basket sizes, complementary shopping trips, returns and failed deliveries.

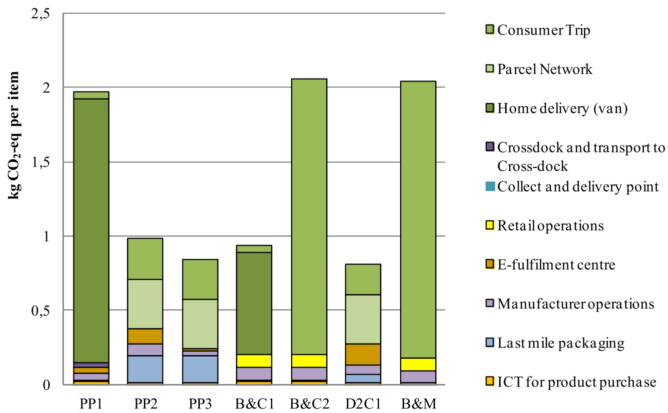

Fig. 4. Scenario three-climate change potential of different e-retail methods for the acquisition of one FMCG product.

Table 3
Kg CO_2-eq emissions for different fulfilment methods and basket sizes.

Method/number of items in basket	PP1	PP2	PP3	B&C1	B&C2	B&M
1	1.97	0.9	0.81	0.94	2.06	2.04
5	0.54	0.77	0.68	0.37	0.56	0.55
20	0.27	0.75	0.65	0.26	0.27	0.27
100	0.19	0.74	0.65	0.23	0.20	0.20

scenario representing a basket size of one product are shown in Fig. 4.

A consumer trip to the supermarket and a van based delivery over a long distance (from a centralised warehouse) show a result of around 2 kg CO_2-eq per item. E-fulfilment channels where the consumer order is consolidated with other orders/deliveries for a long period of time, e.g. parcel deliveries and deliveries from local stores, demonstrate lower emissions. The basket size is clearly a significant factor in determining climate change potential. The total environmental impact of the different fulfilment methods for different basket sizes is calculated and presented in Fig. 5 and Table 3.

From Table 3 it can be concluded that parcel based fulfilment methods are suitable for delivering specialised items which are not part of a larger basket. The short distance per delivery, due to the combination of deliveries in the same neighbourhood, makes them suitable for small packages. Larger orders are sometimes split into separate consignments to speed up delivery, which makes this system less attractive than fulfilment methods that can combine many different products into one delivery.

Where 2 to 22 items are ordered, van based deliveries from local shops (B&C1) result in the lowest amount of CO_2-eq emissions per item. This can be explained by the long consolidation with other products followed by a short delivery distance combined with the ability to deliver the items in one delivery. Van based deliveries from centralised warehouses (PP1) are preferred for larger shopping baskets (22 items or more). The efficiency of the e-fulfilment centre outweighs the additional emissions from the longer last mile distance. However, the difference with conventional shopping is only small in this case.

Regardless of the fulfilment method, the environmental footprint per item fulfilled varies inversely with the basket size. Therefore maximising the shopping basket size is always beneficial. However, larger environmental benefits can be achieved when the right fulfilment method is chosen for the maximised shopping basket.

3.3. Retailer's operations and e-fulfilment centre

The retailer operations comprise the modules retail DC, retailer transport and store. From the results it appears that the retail DC and retailer transport emits only a limited amount of CO_2-eq, accounting together for less than 5% of the total CO_2-eq emissions. The supermarket's utility consumption contributes 77 g CO_2-eq per item, of which the majority comes from the production of electricity. The e-fulfilment centre for groceries is estimated to emit on average 37 g CO_2-eq per item. This difference was expected due to the higher efficiency and throughput rate that can be reached in e-fulfilment centres,

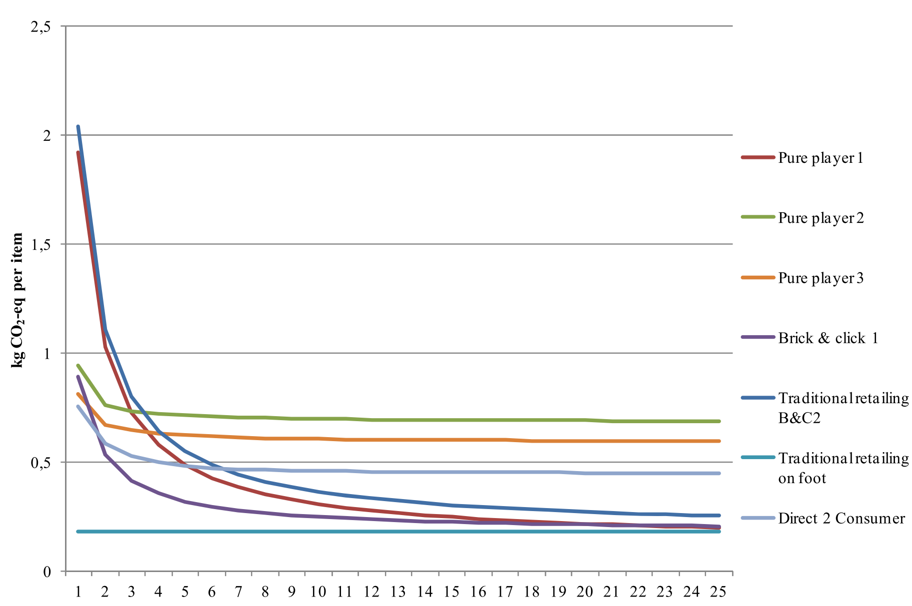

Fig. 5. CO_2-eq emissions for different fulfilment methods and basket sizes.

resulting in less energy per item (Romm et al., 1999; Kämäräinen et al., 2001).

3.4. Packaging

Packaging can account for a significant portion of the greenhouse gas emissions if cardboard packaging is used. 100 g of corrugated cardboard plus limited amounts (33 g in total) of filling material, results in 181 g CO_2-eq per item. The impact of shopping bags, used in van based home deliveries and consumer shopping trips, is relatively limited resulting in less than 11 g CO_2-eq. This is because the amount of packaging is much lower, i.e. an average of 9–15 bags, weighing as little as 8 g per bag, are used for a typical purchase of 30 items (Barrow, 2010; Green, 2008).

4. Conclusions

Previous research on the environmental impact of online retailing has regularly omitted consumer travel behaviour effects due to, for example, failed deliveries, product returns and trip chaining. This study includes these effects and further recognises that online ordering does not completely eliminate consumer shopping trips. Our results show that the nature of the consumer's behaviour in terms of travel, choice of e-fulfilment method and basket size are critical factors in determining the environmental sustainability of e-commerce. Emissions per item for a particular fulfilment method are strongly influenced by the method of execution. For example, in the absence of a pre-agreed appointment or time-slot, the probability of non-delivery is much higher. Where this results in a proportion of consumers having to drive to a collection point to pick-up their order, average emissions per item rise steeply. We have also found that basket size is a critical factor in determining the most suitable distribution channel. Regardless of the fulfilment method, the emissions per item increase inversely with basket size. Large pure players distribute their products from different supply points and often split large consumer orders into several packages, reducing the environmental benefit of maximised basket sizes. A better strategy here would be to maximise the utilisation of the space within the package. Parcel deliveries are especially efficient for delivering products that are not part of a large shopping basket, while van based deliveries are more suitable for larger baskets. Encouraging consumers to increase the number of items per delivery (i.e. to reduce the number of trips/deliveries) offers a significant opportunity to improve the environmental impact of B2C e-commerce. The amount and type of packaging used, and the energy efficiency of shop and e-fulfilment centre operations are also identified as significant contributors to climate change potential.

Even though this research looked at the most utilised e-fulfilment methods, other options are possible, sometimes involving variants of the main methods. For example, brick & click companies are now opening "drive-throughs" where consumers can collect items they have ordered online. The impact of this and other trends should be further researched in order to understand the environmental implications of new forms of online retailing. Furthermore, recent research suggests that online grocery shoppers are likely to visit the supermarket even more often than those who do not shop online (Hartman group, 2013). This erodes the potential environmental benefit of online shopping. Future studies could investigate ways to minimising this adverse effect.

The results obtained in this study are limited by the assumptions and system boundaries applied. We have assumed average data, ignoring the random behaviour evident in real systems. A probabilistic model could have been constructed to indicate the statistical significance of any differences between the climate change potentials of the factors identified. However, as the purpose of this research was to quantify the key climate change potential impact factors of online FMCG retailing in general, average industry data were deemed appropriate. Use of FMCG data for the UK also limits the geographical applicability of the findings. The characteristics of traditional and online retailing in other countries may be quite different to those seen in the UK and this could lead to different results and conclusions. For example, in the Netherlands a much higher proportion of consumers walk or cycle to the shop than in the UK. We would therefore expect the carbon footprint of traditional retailing to be lower, making online retail methods less attractive there in terms of relative emissions. For a wider understanding of the environmental impact of online retailing and the role of consumer behaviour, scenarios should be constructed that are relevant to consumers and retailers/e-tailers in different regions. Nevertheless, this study provides important insights into the relative importance of different factors contributing to the carbon footprint of a range of e-fulfilment methods for FMCG products.

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Appendix A. Normalisation results

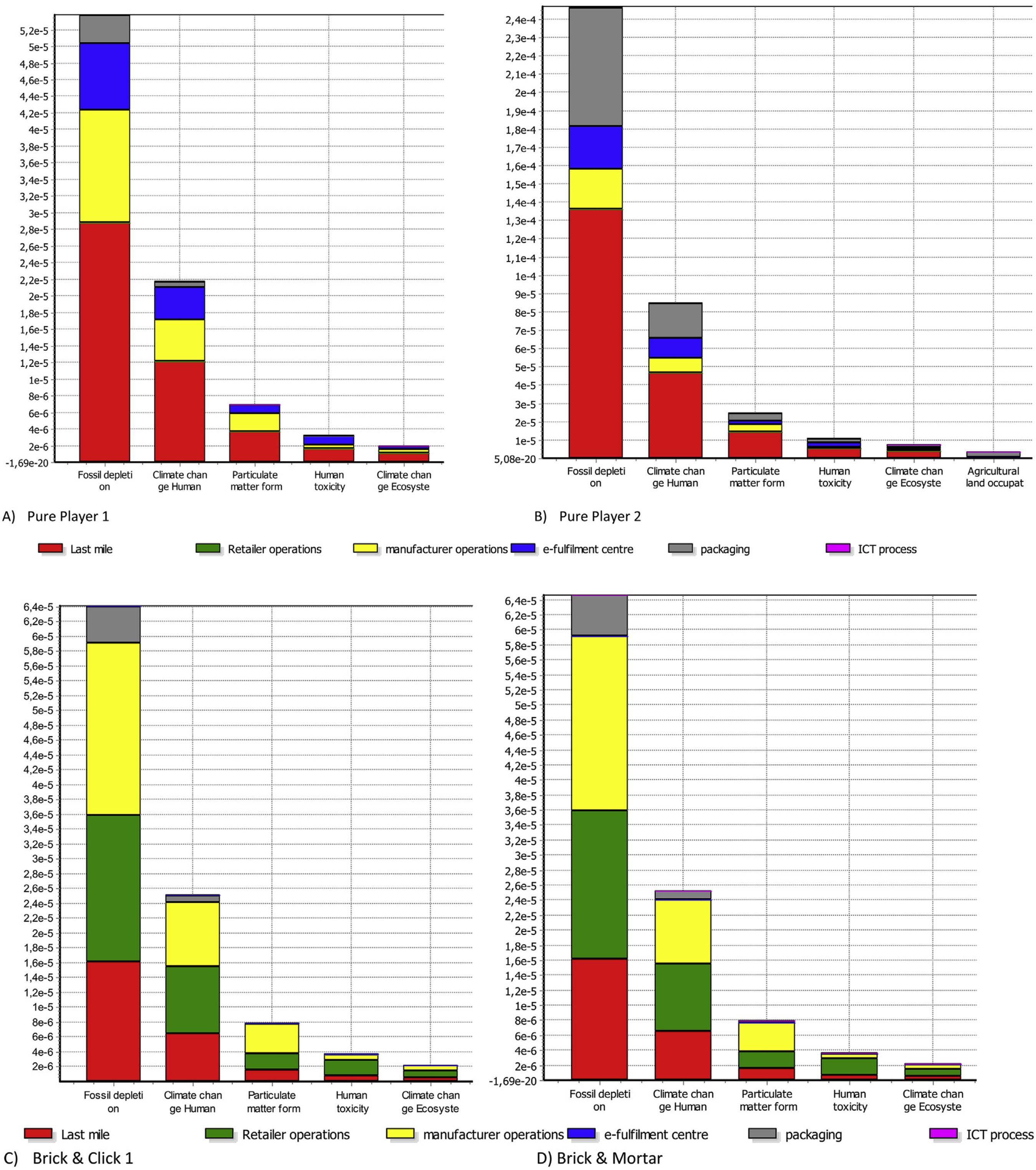

Fig. 6. Normalisation results for a) PP1, b) PP2, c) B&C1, d) B&M.

Appendix B. E-fulfilment channels

Table 4
Shopping basket size and consumer trips for retail channels (Source: Forrester, 2001 cited by Foley et al., 2003; Ocado, 2011; Internal reports and Authors estimations).

Model	PP1	PP2	PP3	B&C1	B&C2	D2C1	B&M
Explanation	Centralised pure player with van delivery	Centralised pure player through parcel delivery network	Drop-shipping from supplier through parcel delivery network	Van delivery from local shops	Click & collect in local stores	Bypass retailer and use parcel delivery network	Conventional retailing in local supermarkets
Number of items in order	55	2	1.4	45	45	6	30
Percentage trips to the local store[a]	75%	90%	90%	75%	100%	90%	100%
Percentage returns	0.1%	5%	5%	0.2%	0.2%	0.1%	0.01%
Percentage failed deliveries	1%	40%	40%	1%	0%	40%	0%

[a] The parameter 'percentage trips to the local store' is not included in the base scenario where complete trip substitution is assumed.

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