Modelling the environmental impact of omni-channel purchasing in the apparel industry: the role of logistics

Abstract

This paper addresses an identified need of quantitative models in the rising field of omni-channel (OC) purchasing sustainability. It contributes with a detailed assessment of the environmental impact of two processes, Click and Collect (C&C) and Mobile Shopping in Store (MSiS), highlighting the weight of logistics activities. An activity-based model is developed and applied to a base case, that best represents the average purchasing process in the apparel industry, considering both the retailer's and the customer's perspectives. Sensitivity analyses are performed as well. Results show that MSiS is less sustainable than C&C, mainly due to the heavier impact of transport. For both configurations, the most critical parameter is the distance between the customer house and the store, whereas the customer profile and the location of the customer house (urban vs extra-urban area) are additional significant factors for MSiS. The results of this study are also compared to previous research in the field of e-commerce environmental sustainability.

Keywords: omni-channel; environmental sustainability; logistics; click and collect; mobile shopping in store;

1. Introduction

Business to Consumer (B2C) e-commerce has dramatically transformed the way companies conduct their business. Since its dawn, this phenomenon has indeed reshaped traditional business dynamics and, consequently, supply chain configurations. Over time, B2C e-commerce has gained increasing success due to a variety of factors including the widening of available products (Park *et al.*, 2012), the general price reduction consequent to fiercer competition (Bruce and Daly, 2010), the attention to the maximisation of customer experience (Brugnoli *et al.*, 2009) and the implementation of effective logistics processes (Ghezzi *et al.*, 2012). Additionally, some systemic factors, such as a proper customer protection legal framework (Rodiguez-Ardura *et al.*, 2008) and the availability of multiple payment systems (Mangiaracina and Perego, 2009), are commonly deemed as main enablers of B2C e-commerce diffusion (Mangiaracina *et al.*, 2012; Mangiaracina *et al.,* 2016). Over the past decade, the use of online selling channels has experienced a significant growth in all the main western countries, and predictions about future trends anticipate persistence on this path (eMarketer, 2016). The value of using e-commerce however is not only related to its adoption as a stand-alone channel.

Not long ago, solutions combining the online channel and traditional stores have emerged, thus paving the way to a multi-channel (MC) approach. MC has initially referred to the simple decision to add new channels, either online or offline, to the existing mix (Stone *et al.,* 2002; Choi and Park, 2006). This definition does not consider the way multiple channels are managed, neither their level of integration. More recently, the increasing diffusion of mobile channels, tablets and social media is however multiplying the touchpoints customers move through. In this regard, recent literature highlights a shift in MC retailing, suggesting we are moving to an omni-channel (OC) model (Rigby, 2011; Verhoef *et al.,* 2015). According to this view, the rising diffusion of new technologies is making customers more connected and willing to move across channels within single transactions, while asking for a seamless experience (Piotrowicz and Cuthbertson, 2014; Melacini *et al.,* 2017). From the retailers' point of view, the main challenge is to integrate offline and online channels and manage them synergistically, while following customers' requirements (Bernon *et al.,* 2016; Melacini *et al.,* 2018). Embracing OC means that customer, pricing and inventory data are shared across channels and fully integrated (Beck and Rygl, 2015). The rising number of integrated channels adds complexity to the logistics processes as retailers need to simultaneously satisfy and anticipate demand, manage inventory and minimise costs for each channel (Handfield *et al.* 2013).

OC strategies do not only affect internal company dynamics (Metters and Walton, 2007), but also the external environment. From this latter perspective, previous researchers have generally confirmed the importance of sustainability and its key role in building and maintaining a company's competitive advantage (e.g. Beske *et al.*, 2014; Samarrokhi *et al.*, 2014). Furthermore, environmental issues are a priority also for institutions as they are often at the top of the agenda of politicians in several countries, and much research is conducted to face the challenges of climate change and sustainability. In this setting, the environmental impact of retailing on greenhouse gases emissions (GHG) should not be underestimated (Carling *et al.,* 2015). In particular, logistics is commonly considered as one of the most polluting processes, and the question whether the adoption of digital technologies can help reduce the environmental impact of logistics does not seem to have a clear answer yet. In the e-commerce field, the extant literature shows that various authors have provided some measures of sustainability from a qualitative perspective (e.g. Abukhader and Jönson, 2008; Fulton and Lee, 2013), whereas others have tried to assess the environmental impacts through the calculation of delta carbon footprint between online and traditional shopping (Weber *et al.*, 2010, Edwards *et al.*, 2011, Wiese *et al.*, 2012b). However, these latter are mainly based on case studies, and few researches present quantitative estimation models. Moreover, a limited number of studies have been specifically developed to assess the environmental consequences of adopting an OC model, and even fewer have looked over logistics processes.

This paper aims to fill the identified research gap, i.e. the lack of quantitative models to assess the environmental impact of OC purchasing processes. As acknowledged by Wiese *et al.* (2012a), sustainability has recently received increasing attention in many business areas, but its role has not properly been investigated in the retailing industry. However, retailers have a central position in the supply chain, by linking producers and consumers. Therefore, they are responsible of many activities and can act on multiple levers to improve sustainability.

There are currently many processes that combine online and offline activities, among which "Click and Collect" (C&C) and the "Mobile Shopping in Store" (MSiS) appear as particularly interesting. C&C consists in the online order of a product which is then collected at the store by the consumer. It is adopted by those consumers defined by Swaid and Wigand (2012) as "online-focussed shoppers". Conversely, in the MSiS process − which is generally identified by the use of wireless devices, i.e. smartphones and tablets (Hung *et al.*, 2012; Groß, 2015) − the consumer orders an item via mobile by scanning its Quick Response (QR) code in the retailer's showroom, and the product is then delivered at home. The interest in C&C and MSiS derives from the fact that they are gaining increasing attention in the retailing industry. C&C is prevalent in Europe, especially in UK where 67% of consumers have used it at least once to pick up goods (The Guardian, 2014). Moreover, other regions, e.g. Canada, Thailand or South Africa are starting to deploy it (Deloitte, 2015). Mobile is also widely adopted, with an average of 25% of U.S. shoppers purchasing via mobile while in the store (InReality, 2015) and approximately 57% of Chinese retail shopping transactions being concluded over a mobile phone (China Internet Watch, 2016). Given the increasing diffusion of mobile in support of purchasing processes, it is interesting to investigate OC models based on the use of this tool.

Our purpose is to analyse in depth the C&C and MSiS processes, in order to provide OC retailers with a valuable tool to compare these two processes and support their decisions, taking into account the environmental perspective. More specifically, the paper illustrates a quantitative model to assess the GHG footprint (expressed in terms of kilos of CO_2 equivalent - $kgCO_2e$) of the two OC processes. Assessing environmental impacts of processes and activities by measuring $kgCO_2e$ is a common practice in both the conventional and online retailing sector (e.g. Edwards *et al.,* 2010; Mangiaracina *et al.,* 2016; van Loon *et al.,* 2015; Wiese *et al.,* 2012b). More specifically, the kgCO_2e are calculated as the weighted average of the Global Warming Potential (GWP) of CO_2, CH_4 and NO_2 (DEFRA, 2015). The analysis is developed with reference to the apparel industry. This is because of the high complexity characterising this sector, e.g. specific warehousing and handling needs, high return rates (Ghezzi *et al.* 2012; Mangiaracina *et al*., 2016), that usually affects logistics processes and their environmental sustainability. The whole process from pre-sale to delivery and potential post-sale activities (returns management included) is considered. A particular attention is devoted to logistics activities (i.e. transport, packaging and warehousing), as these are typically considered dominant in the production of emissions to the environment (Hjort *et al.*, 2013; Mangiaracina *et al.*, 2016).

The paper is organised as follows: section 2 presents an overview of current literature in the field of OC logistics and its environmental impact. Section 3 clarifies the Research Questions (RQs) derived from the theoretical background while section 4 describes the adopted methodology. Section 5 goes further into the description of the model design. Section 6 discusses the results, while in section 7 conclusions are drawn and streams for future research are identified.

2. Theoretical background

Logistics supporting omni-channel retailing

The past few years have been characterised by a change in the purchasing behaviour of consumers who have started using the online channel very extensively, to the detriment of traditional shops (Benini, 2011). This trend has implicitly challenged worldwide retailers to approach B2C e-commerce and integrate their online and offline channels to be competitive, and turn the initial threat into an opportunity (Agatz *et al.*, 2008). The presence of multiple commercial channels has thus become a critical and strategic issue for retailers (Lewis *et al.,* 2014).

Therefore, we have very often observed both traditional retailers open an online shop and digital native businesses enter the offline channel through direct investment or collaboration with traditional retailers (Agatz *et al.*, 2008). On the retailers' side, this is an opportunity to exploit synergies between the channels, thus enhancing financial performance (Geyskens *et al.,* 2002) and increasing customer satisfaction and loyalty, since each channel could overcome the deficiencies of the others (Zhang *et al.,* 2010). At the same time, a model of this type is highly challenging as it introduces additional fulfilment complexity (Savelsbergh, and Van Woensel, 2016).

Current literature seems to have used the terms multi-channel, cross-channel and omni-channel without a clear distinction for a long time to generally describe retailers operating both physical and e-commerce stores (Hübner *et al.,* 2016). More recently, however, Beck and Rygl (2015) and Verhoef *et al.* (2015) have explicitly distinguished OC retailing as the case when operations and physical flows are integrated in order to provide a seamless shopping experience. Managing OC retailing adds a further complexity to the business model. Retailers have to deal with differentiated stock-keeping, packing and shipping processes (e.g. click and collect, home delivery, drive-ins) (Colla and Lapoule, 2012), while facing more demanding consumers with different behaviours when switching from one channel to the other. The appropriateness of infrastructures and logistics management, commonly considered crucial for e-commerce (Ramanathan *et al.*, 2014), become even more important in an OC context. More specifically, Hübner *et al.* (2015) have pointed out that retailers operating multiple channels have to make a very important decision, i.e. whether to manage warehouses in a separated or integrated way across channels. An integrated approach can bring advantages for inventory pooling (Chiang and Monahan, 2005; Schneider and Klabjan, 2013; Bhatnagar and Syam, 2014; Hübner *et al.*, 2015), and generally enables the offering of larger assortment (Zhang *et al.*, 2010). However, it requires aligned picking processes for both store and home deliveries (Lang and Bressolles, 2013) and solutions for capacity management (Xie *et al.,* 2014). In addition, opting for an OC approach can have an impact also on city logistics. Indeed, home deliveries in e-commerce transactions tend to increase the number of freight movements. However, if online customers' orders are fulfilled from retail stores rather than from a distribution centre – as it can be the case in an OC context – the freight movements should be reduced, and this generally has an impact on lead times, costs and environmental sustainability (Savelsbergh and Van Woensel, 2016).

Given all these considerations, the authors conclude that OC logistics management is increasingly being considered an important issue although it is still recent as a specific research area. Hübner *et al.* (2015) are among the first to identify and describe the different logistics system configurations supporting OC retailing, while more recently Marchet et al. (2018) provide an empirical investigation of the main business logistics models currently adopted by companies, in an OC setting. These are the main investigated areas in the field. What is still missing, limited to the authors' knowledge, is an in-depth investigation of the transition from a MC to an OC context, i.e. an understanding of (i) how retailers should manage the path towards channels integration and (ii) what could be the effect produced by such a change on the logistics process, not only in terms of economic performances, but also from an environmental perspective.

Assessment of the environmental impact of omni-channel logistics

Logistics is a critical process not only because it is complex to manage, but also because of its recognised polluting effects. Since sustainability has become an urgent issue, many studies have been developed around the themes of green and sustainable supply chains. The topic has been tackled from multiple perspectives (e.g. Bask *et al.*, 2013) and contributions differ in terms of research methods, ranging from case studies (e.g. Smith, 2012) to interpretative models mapping the contribution of numerous variables to the effectiveness of green supply chain practices (e.g. Mangla *et al.*, 2014). Furthermore, some authors have developed broad literature reviews on the themes of supply chain sustainability, distribution network design, e-commerce and their intersections (e.g. Winter and Knemeyer, 2013; Mangiaracina *et al.,* 2015). Others have considered customers' perspective on sustainability to derive suggestions for retailers' green strategies (e.g. Goworek *et al.,* 2012). However, only a few studies based on quantitative modelling are retrieved (e.g. Edwards *et al.*, 2011; Mangiaracina *et al.*, 2016; Mckinnon *et al.,* 2015). An example is represented by van Loon *et al.* (2015), where a holistic assessment of all the factors contributing to the carbon footprint (including basket size, transport mode, trip length and trip frequency) is provided with reference to online retailing in the fast moving consumer goods (FMCG) industry in UK. Nonetheless, except these recent cases, the theme of sustainability in relation to the e-commerce activity has not been sufficiently studied by means of quantitative methodologies, neither has logistics been explored in depth. Also, a common approach is focussing on the analysis of last-mile activities (e.g. Brown and Guiffrida, 2014; Edwards *et al.,* 2010), without providing a complete overview of the entire purchasing process.

Even greater scarcity of quantitative contributions characterises OC literature. Given the novelty of the OC model, existing studies tend to focus on building conceptual frameworks (e.g. Saghiri *et al*., 2017). From a logistics perspective, some authors have recently addressed service quality issues (Murfield *et al.,* 2017) in the OC field, while environmental issues still seem disregarded. The lack of contributions on OC sustainability pushes us to investigate e-commerce sustainability more, in search of possible insights that could be useful also in an OC perspective.

However, even when moving from an OC context to a pure e-commerce setting, finding a shared view on whether e-commerce is more environmentally friendly than traditional commerce is rather difficult. The answer would indeed depend on contextual factors (McKinnon *et al.*, 2015). Some contributions state that online purchases do produce beneficial effects for the environment, such as the reduction of travelling (e.g. from house to shops and back) or the avoidance of the unsold items problem, which might require additional travels from shops to warehouses (Matthews *et al.*, 2001). However, possible negative environmental effects counterbalance these benefits. Examples include the increase in the information technology (IT) adoption with consequent higher energy consumption levels, the need for additional packaging or the emissions derived from the logistics and distribution process, e.g. transport and stocking (McKinnon *et al*, 2015). Allen and Browne (2010) have noted that online purchasing, paired with home delivery, contribute to an increase in van traffic thus leading to the consumption of higher quantities of fuel and the release of more emissions. Missed deliveries (McLeod *et al.*, 2006) and frequent item returns (e.g. Park and Regan, 2004) might negatively contribute to GHG emissions, as well. Also, the entity of the environmental effects surely depends on the specific business sector. For instance, the apparel industry is characterised by highly complex logistics dynamics, mainly related to warehousing and return management (Ghezzi *et al.*, 2012) and, consequently, logistics activities are expected to impact considerably on the sustainability of the purchasing process.

According to Wiese *et al.* (2015) retailers should focus on trying to shift consumer behaviours towards more sustainable transport means to reach stores, as customer journeys generally contribute more than other transports along the supply chain to CO_2 emissions. Whether this consideration holds true in an OC purchasing processes is yet to be discovered. Indeed, the majority of studies in the extant literature simply focus on comparing pure online with brick and mortar purchases. The question as whether an integrated logistics management across online and offline channels can help optimise the environmental consequences with respect to single channel purchasing is still to be answered.

3. Research questions

Based on the gaps identified in the extant literature, the objective of this paper is to present a model for quantifying the environmental impact, measured in terms of $kgCO_2e$, of two OC purchasing processes, i.e. C&C and MSiS, and perform comparative analyses in the apparel industry.

The choice of focussing on a single industry is a consequence of the fact that products of different industries have their own specific weight-volume characteristics, and the order features can significantly vary from one sector to the other (e.g. the average number of items per order in the apparel industry is generally lower than in grocery). Such differences have an impact on all the main logistics activities (e.g. picking and transport). Consumers' behaviour can easily change across sectors as well, thus influencing many aspects of the purchasing process (e.g. interactions with salespeople and return management).

Among all the industries, apparel was selected for three main reasons. First, it is one of the most important industries in the B2C e-commerce scenario in terms of both market value and growth rate in the last 5 years (Osservatorio eCommerce B2C, 2016; eMarketer, 2016). Indeed, in the more advanced markets it accounts for 15÷25% of the overall e-commerce value, and registers impressive growth rates, up to 20÷30% on a yearly basis (Osservatorio eCommerce B2C, 2016). Second, apparel is one of the industries contributing the most to the mobile commerce market. This is due also to the diffusion of the "flash sales" phenomenon, i.e. short online campaigns, only available for a limited time, where the moment of the purchase counts: mobile devices represent a valuable option as they allow purchases at one's convenience. In addition, the high probability of stock-out may push consumers to order through their smartphones those products no more available in the store. Third, the high variety (e.g. colours, sizes, fabrics), seasonality and incidence of returns make the apparel logistics management considerably complex (e.g. Liu *et al.*, 2014).

This being the premise, the following research questions are identified:

RQ1. How can the environmental impact of the C&C and MSiS processes – split by both phase and type of activity – be modelled and quantified?

RQ2. What is the impact of logistics activities on the environmental performance of the two purchasing processes examined? How do results differ with respect to the ones related to single channel purchases?

RQ3. What are the main parameters affecting the environmental impact of the logistics activities and what outcomes can be observed varying these parameters?

4. Methodology

For the purposes of the present paper, a three-stage methodology was adopted:

- stage I − Definition of the purchasing processes;
- stage II − Modelling of the environmental impact (expressed in terms of kgCO_2e) for each phase and type of activity;
- stage III − Model application.

First (stage I), the two examined OC purchasing processes (i.e. C&C and MSiS) were analysed in-depth and modelled, starting from the information collected from both interviews with logistics service providers and case studies of companies implementing an OC strategy. In total, 25 interviews were conducted, out of which 20 with manufacturers or retailers adopting at least one of the examined OC strategies in the apparel industry. The remaining five where addressed to expert logistics operators. Each process was divided into phases, and phases were then split into individual activities following an activity-based approach, similarly to McKinnon *et al.*, 2015; Mangiaracina *et al.,* 2016; Marchet et al., 2017. To overcome one of the limitations emerged from the literature review (i.e. in previous contributions the analysis mainly referred to the last-mile logistics process), it was decided to widen the perspective and include all those downstream supply chain phases that directly enable the purchasing process. As such, the analysis includes all the activities performed from the retailer's warehouse to the post-sale service to the consumer.

Second (stage II), the environmental impact − measured in terms of kgCO_2e – was assessed for each individual activity of the examined purchasing processes.

Three main sources were adopted in stage II:

- review of the scientific literature to investigate how the environmental impact of a variety of processes is typically computed;
- interviews with five logistics service providers operating in the apparel industry, to both obtain useful information for building the model and receive feedbacks on its robustness;
- secondary sources, such as logistics practitioners' journals, case studies, and web reports presenting either analyses on the environmental impact of single activities (e.g. FEFCO, 2015) or information related to the computation of the GHG footprint for different activity types (e.g. DEFRA, 2015). These latter were mainly used to derive the contextual factors adopted in the model.

Finally (stage III), the model was applied. First, a base case was considered, built with average data collected from 20 interviews with senior supply chain and/or e-commerce managers in the apparel industry and triangulated with secondary sources (e.g. reports, company websites). Then, different scenarios were examined, and sensitivity analyses were performed.

5. Model design

Description of the examined purchasing processes

The two examined purchasing processes (i.e. C&C and MSiS) were broken down into their main phases starting from the information collected from both interviews with supply chain experts in the apparel industry and case studies of companies implementing an OC strategy (Figure 1).

[Take in Figure 1]

As far as the C&C purchasing process is concerned, a store offers the consumer the possibility to order and pay online the required product, and then pick it up at the store. In particular, the following phases were considered:

- store replenishment: this phase begins with the replenishment order made by the store manager (or with an online order made by the consumer) and ends with the shipment of the products to the store ;
- pre-sale and sale: this phase includes all the activities carried out during the item selection process and involves both the retailer and the consumer. It begins when the consumer accesses the Internet and ends with the payment;
- product pick-up: this phase starts with the consumers' trip to the store by car. It includes the interaction with a salesman and ends with the consumers going back home with the ordered item;
- post-sale: this phase is not mandatory and is usually triggered by the consumer's intention to replace the product. It includes the trip to the store, the return trip home, new interactions with the salesperson, and it could involve an additional visit to the fitting room.

As far as the MSiS purchasing process is concerned, it involves the presence of a retailer-owned showroom, which offers an exposition of a single product (available in different sizes and colours) for each type of item available within its selection. The consumers can test the item in order to understand which one fits them best. Once chosen the desired item, the consumers scan its QR code via their mobile devices and complete the online payment procedure. The required item is subsequently delivered directly to the consumer's house. The entire purchasing process can be synthesised into the following phases:

- pre-sale and sale: the consumers reach the showroom by car, possibly interact with the salesperson, and test one or more products depending on their attitude towards shopping. Once the item has been selected, they scan its QR code, issue the order, pay and, after receiving the order confirmation via e-mail, go back home;

- order picking and assembly: this phase includes picking and packaging. It starts with the order receipt at the retailer's warehouse and ends with pick-up of the cartons by the courier;
- delivery: this phase starts with the pick-up of the cartons by the courier and ends with delivery at the consumer's house. It includes both the main activities performed by the courier (i.e. transport from the retailer's warehouse to the courier receiving hub, transport to the shipping hub, handling at both the courier and the shipping hubs) and the possible interactions between the courier and the consumer;
- post-sale: similarly to the previous case, this phase is possibly originated by the consumer's will to return the item and includes all of the activities undertaken by the consumer in order to prepare the return (i.e. packaging and labelling), those carried out by the retailer to store the returned item (i.e. item receiving and reconditioning, storing) and to fulfil the new order (i.e. additional order picking and packing activity), as well as the new delivery carried out by the express courier.

Please note that for the MSiS purchasing process the showroom replenishment activity was not taken into account, as the only purpose of the showroom is to display the whole selection of products offered by the retailer, and not to have products in stock.

Model architecture

The model architecture includes four building blocks, i.e. the user interface displaying the inputs required to run the model, the contextual data, the engine for the computation of the environmental impact of each activity, and the final interface that shows the results. In particular, the user interface includes the input data related to:

- consumer's features, i.e. consumer's profile (consumer's attitude towards shopping), location of the consumer's house (urban vs. extra-urban area);
- distance between consumer's house and store;
- retailer's features, i.e. retailer's profile (retailer's size − i.e. number of employees − and store size), retailer's warehouse (e.g. size, storage capacity, building energy rating), store and showroom characteristics.

In OC contexts, many factors may influence the consumers, such as their personal attitude towards shopping, the perceived risk of transaction, the trust towards the retailer, and the confidence with mobile in store payments (Hahn and Kim, 2009, Kuan and Bock, 2007, Bock *et al.*, 2012). For all these reasons, according to the literature, three consumer's profiles were identified (Cardoso *et al.*, 2010), namely:

- fashion addicted consumers, i.e. particularly interested in fashion, willing to spend much time in searching the desired item and not reluctant to return the item in case of deluded expectations;

- moderate consumers, i.e. more rational and cautious, they generally visit fewer websites/stores, test a limited number of products, interact with the retailer/salesperson only if needed. Item returns generally happen only in case of wrong size or colour;
- apathetic consumers, i.e. very pragmatic and with little fashion involvement. They normally enter very few websites/stores with no interaction with the salesperson. Item return is rare.

As far as the location of the consumer's house is concerned, the model considers either urban or extra-urban settings, since the impact of the last-mile delivery differs significantly in the two cases. The number of deliveries per tour considered in the urban area (i.e. 40) is expected in fact to be higher than that in the extra-urban area (i.e. 20), due to longer distances between two consecutive delivery points, as confirmed by the express couriers interviewed.

With regard to the distance between the consumer's house and the store, it is assumed to range between a minimum of 1 km to a maximum of 15 km.

Looking at the retailer's profile, different variables were considered. For each variable three numerical values were set in order to provide the users with three possible choices (high, medium, low), therefore improving the model usability. Table 1 reports the possible values of the input data.

[Take in Table 1]

The information used to insert input data were primarily derived through the analysis of literature and the interviews with practitioners. The following Table 2 clarifies the main sources for each type of input.

[Take in Table 2]

As far as the contextual data are concerned, they were clustered into four main categories:

- energy consumption [kWh], related to both machinery and buildings;
- CO_2e emissions [kgCO_2e/km] or [kgCO_2e/kWh], used to obtain the environmental impact for each individual activity;
- times [s or %], such as the elementary time required to conduct each activity, or the percentage of time spent for conducting a specific activity;
- logistics and transport features*,* related to all the warehousing and transport activities;

The information used to define context data were derived through interviews with logistics service providers and retailers, as well as through secondary sources (i.e. specialised reports issued by public or private institutions). Table 3 specifies the main sources used for the contextual factors.

[Take in Table 3]

The section containing the computation algorithms is the core of the model. It allows the calculation of the CO_2e per order delivered [(kgCO_2e)/order] for each activity of the examined processes. The CO_2e are calculated as the weighted average of the Global Warming Potential (GWP) of CO_2, CH_4 and NO_2.

Finally, the model outputs are listed into a spreadsheet. They can be selected by the user and visualised through tables and graphs showing different views and aggregation levels of the examined processes. A synthetic representation of the model design is proposed in Figure 2.

[Take in Figure 2]

6. Application of the model

Application of the model to the base case

The model was first applied to a base case. To this extent, all variables were set to values that best represent the average C&C and MSiS purchasing processes in the apparel industry, taking into account both the retailer's and the customer's perspectives.

The main characteristics and assumptions embedded in the base case are:

- the retailer's variables are set to "medium" values;
- the consumer is set to the "moderate" profile;
- the consumer's house is located in the urban area;
- the average distance between the consumer house and the store is fixed at 7 km. This value was derived as the average distance found in literature (Edwards *et al.*, 2010; Mangiaracina et al., 2016; Matthews *et al.*, 2001; Matthews *et al.*, 2002; Sivaraman *et al.*, 2007; Weber *et al.*, 2010; Wiese *et al.*, 2012b).

The application of the model to the C&C and the MSiS purchasing processes in the base case allows answering our RQ1, as it quantifies the impact of both processes and reveals a lower environmental impact of C&C (- 26%), as shown in Figure 3A and 3B.

[Take in Figure 3]

In order to detect the reasons behind the differences between C&C and MSiS, it is appropriate to investigate the specific phases constituting each process. With reference to those common to both processes (see Figure 3A), we can note the following:

- pre-sale and sale: this phase has a negligible environmental impact on the C&C purchasing process, whereas it accounts for almost 70% of the kgCO_2e emissions in MSiS. This is mainly due to the trip from the consumer's house to the showroom and backward that happens in MSiS and not in C&C, in which the purchasing is performed online;
- delivery (or product pick-up): despite being significant for both purchasing processes, the environmental impact of this phase is higher in C&C. This is due to the car travel of the single

customer to the store, which is less efficient than a multi-drop delivery of an express courier (40 deliveries per tour in the urban area);

- post-sale: the emissions are mainly caused by the travels required to return the product. Then, the environmental consequences of this phase highly depend on the return rate for each specific channel, which is significantly lower in MSiS (1%) than in C&C (10%) because with MSiS customers can see and try the product before ordering.

Coming to the phases that belong to only one of the two processes, the following considerations can be made:

- order picking and assembly is specific of the MSiS channel. When working on single products, high emissions per piece are produced as a consequence of higher consumption of packing material, and multiplication of picking travel time, which often requires the use of man-on-board trucks;
- store replenishment only applies to the C&C purchasing process. Emissions for this activity derive from the picking of products in the warehouse and their shipment to the store.

An alternative and insightful way to analyse the environmental impact of the two processes is to calculate total emissions grouped by type of activity. The two processes have been split up in the following categories: logistics activities (namely transport, handling, packing, warehousing) and non-logistics activities performed online (e.g. product search, requests for information, order issuing) or in the store (e.g. interaction with the salesperson, product test). Results in Figure 3 show that logistics plays a major role in driving the level of emissions. In both processes the impact of logistics activities largely exceeds 2/3 of total emissions (87% for C&C and 75% for MSiS).

With regard to transport, in both cases we can observe a significant impact mainly caused by car emissions along the way to the store or showroom and back. The heavier impact of this activity in the MSiS is due to the home delivery that has to be performed by the express courier in addition to the consumer's travel by car. Handling activities have a stronger impact in the MSiS channel than in the C&C case, due to the need of handling single pieces. Packaging has a limited importance in the two examined processes. The slight improvement in the C&C is mainly attributable to the fact that bulk packaging is generally used in place of single packaging.

The analysis performed in this paragraph, beyond answering our RQ1, also helps address part of RQ2. More specifically, the model here presented and applied to a base case highlights the strong impact of logistics activities on the environmental performance of both purchasing processes.

From a practical point of view, the main implications of these results are as follows:

- if retailers are only concerned about minimising the environmental impact of their operations, they should opt for a C&C model, as it produces lower emissions than MSiS;
- nonetheless, there can be other reasons why MSiS might be adopted, despite its higher environmental impact (e.g. improving customer experience in light of the increasing pervasiveness of mobile commerce);

- since logistics activities have a prominent impact on the sustainability of both processes, specific attention should be posed to logistics (and, especially, transport optimisation) in order to reduce the environmental impact of the analysed purchasing models.

Comparison with "pure" online and offline processes

Since OC purchasing processes can be essentially seen as a combination of the online and offline approaches, it may be interesting to perform a comparison between the two "pure" alternatives (i.e. totally online or offline), already investigated by some authors in literature, and the two "hybrid" OC ones (C&C and MSiS). This addresses the second part of RQ2, that aims to highlight the differences among the environmental impact of omni-channel and single channel purchases.

As shown in the works by Mangiaracina *et al.* (2015), McKinnon *et al.* (2012) and Sivaraman *et al.* (2007), the online purchasing process is more sustainable than the offline one, due to a lower environmental impact in the pre-sale and sale and in the delivery phases. More specifically, pure online purchases can cause from four to six times fewer CO_2e emissions than traditional retailing. By comparing these results with the outcomes of this paper, we can observe that the online process is not only more sustainable than the offline, but it also causes less emissions than the considered OC processes. Indeed, MSiS produces much higher emissions than the pure online, reaching values that are similar to the pure offline process. The C&C's overall impact lies in the middle.

Whatever the configuration of the process, however, it must be noted that logistics activities are significant in the determination of the carbon footprint.

Sensitivity analysis

In order to answer RQ3, a sensitivity analysis was conducted by changing the values of the main inputs of the model. Therefore, two alternative scenarios were identified and compared to the base case (see Table 4). The worst case is the one producing the highest environmental impact and the best case is the one minimising the quantity of kgCO_2e emitted.

[Take in Table 4]

For both C&C and MSiS, the overall environmental impact was computed in the three scenarios. In C&C, only the first three inputs displayed in table 3 were changed (i.e. retailer's profile, consumer's profile and distance house-store). In MSiS, also the location of consumer's house was considered, as this impacts a specific process of this OC model, i.e. home delivery.

[Take in Figure 4]

As shown in Figure 4, the environmental impact of C&C process ranges from a minimum of 1.94 kgCO_2e/order, when all the inputs are set at the best case values, to 9.2 kgCO_2e/order in the worst case (Figure 4A). In order to detect the main determinants of these variations, the individual contributions

of the considered inputs were computed for each scenario, i.e. a one-at-a-time sensitivity analysis was performed. Graphically, the results are represented in Figure 4B. More specifically, darker grey bars represent the change in the output (i.e. increase or decrease of $kgCO_2e$ emissions) obtained when each input is set at the worst scenario value and the others remain at the base case value. Similarly, light grey bars are used to indicate the shift from the base case to the best case. The longer the bars, the higher the individual contribution of each input to the overall change in the output.
As we can observe, the input influencing the most the environmental impact is the distance between the consumer's house and the store. The distance plays a major role due to the car trip the consumer makes from home to the store and backwards when collecting the order. This input is followed at due distance by the consumer's profile, where different return rates affect all the main logistics activities. The retailer's profile impacts the emissions very slightly, whereas the location of the consumer's house (urban vs extra-urban areas) does not affect the results since home delivery is not performed in the C&C.

[Take in Figure 5]

With regard to MSiS, the environmental impact varies from 2.7 $kgCO_2e$ in the best case to 13.8 $kgCO_2e$ in the worst one (Figure 5A). Again, in each scenario MSiS proves to produce higher emissions than C&C. By analysing the individual contributions of the inputs to the overall output change (Figure 5B), we can observe the distance between the consumer house and the showroom significantly affects the results in the MSiS as well. The fact that the distance between the house and the store is the main driver of carbon emissions provides useful hints for practitioners interested in measuring and influencing the environmental impact of OC purchasing. Indeed, if they aim at reducing the emissions, they should try to minimise the distance between houses and stores. This can either be done by increasing the capillarity of the store network (i.e. increasing the number of stores) or, most probably, by detecting the most effective and strategic positioning for the stores. Coming to the other inputs, the difference between the best and the base cases is mainly related to the consumer's profile, and more in detail to the number of stores visited and the amount of time spent inside the store. The increase of emissions observed in the worst case is mainly due not only to the consumer's profile, but also to the location of the consumer's house in an extra-urban area. This latter influences the efficiency achievable by the express courier in the delivery tour. The retailer's profile is again the least influential input.

Application of the model to a real case

In order to further test the model, it was eventually applied to a real case. The selected retailer operates in the fast-fashion industry with a network of several hundred stores all over Italy. The company has been offering, beside pure e-commerce, also C&C and MSiS since 2014. The main input data for this case are summarised in Table 5.

[Take in Table 5]

Results are in line with the average data above presented, as they reveal an overall impact of 3.6 kgCO_2e/order for C&C and 5.3 kgCO_2e/order for MSiS. Logistics activities play a major role on the emissions, as they account for 83% of total carbon footprint in the C&C case and for 68% in MSiS.

7. Conclusions

Given the purpose of this paper, a quantitative activity-based model was developed to assess the GHG footprint of two OC processes, i.e. C&C and MSiS.

Five main evidences stem from the study. First, when comparing the two OC processes, the results highlight that MSiS always causes more CO_2e emissions than C&C. Second, logistics activities have a prominent impact on both purchasing processes, accounting for 87% of total emissions in the C&C process and 75% in the MSiS one. Third, most of the environmental impact is related to transport (accounting for 69% in C&C and 53% in MSiS). In MSiS this is due to both the pre-sale phase – when the customer goes to the showroom and comes back home – and the delivery phase – when the product is home shipped by an express courier. In the C&C process, transport refers to the customer trip by car to pick-up the product in the store. Fourth, the sensitivity analysis shows that the most influencing parameter is the distance between the consumer's house and the store/showroom, as it significantly affects transport, which is in both cases the phase causing the highest emissions. Then, only in case home delivery is performed (i.e. for MSiS), the location of the consumer's house has a significant impact as well, affecting the routes of the express courier. Finally, by looking at previous literature, both OC purchasing processes prove to be less sustainable than the online one. However, C&C seems to be more sustainable than offline purchasing, while the environmental impact of MSiS is similar or even slightly higher than the one of the offline purchasing process.

The present paper has important academic and practical implications. It represents a starting point to bridge the gap found in the extant literature regarding the investigation of OC strategies, which is quite recent as a specific research area, and their impact on the environment. Another strength point is the quantitative nature of the model that calculates sustainability indicators that can be measured and compared over time, thus abandoning a mere qualitative perspective. Plus, the quantitative approach has allowed a comparison of the results with previous contributions in strictly related areas (i.e. the pure online and traditional purchasing process). The main practical implication of this study consists in the possibility to provide merchants and retailers with an effective tool to quantify the environmental footprint of their business. It is also useful to assess the impact deriving from each activity, with a specific reference to logistics (e.g. warehousing and transport), which happens to be particularly significant in the e-commerce scenario.

The model has been applied to a single industry in this paper. In the future, it would be interesting to investigate whether results change if different sectors are considered. For instance, consumer electronics, design, home furnishing are identified as promising sectors to analyse (Volpe and Spinelli, 2012). Another future research direction comes from a limitation of the model. Indeed, the obtained results are not appropriate to derive a comprehensive evaluation of the OC processes. The analysis is solely based on the assessment of the environmental impact of each purchasing process, while financial indicators, or metrics related to other factors that customers might deem important (e.g. on time deliveries) are not taken into account. Building a more comprehensive model, able to include some of these other metrics could be a valuable purpose for future research.

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Tables

Consumer's profile	Fashion addicted	Moderate	Apathetic
No. of websites visited before buying (C&C)	5	3	2
No. of showrooms visited before buying (MSiS)	3	2	1
No. of interactions with the retailer (C&C)	2	1	0
No. of interactions when returning an item (C&C)	3	2	1
No. of items tested when returning one (C&C)	3	2	1
No. of interactions in the showroom (MSiS)	5	2	0
No. of items tested in the showroom (MSiS)	8	5	2
Location of the consumer's house	**Urban area**	**Extra urban area**	
Distance between the consumer's house and the store	**From 1 km to 15 km**		
Retailer's features	**Large**	**Medium**	**Small**
Retailer size [no. of employees]	>1,000	500-1,000	<500
Warehouse size [m^2]	32,000	20,000	13,000
Store size [m^2]	500	350	125
Showroom size [m^2]	150	100	60
Fulfilled orders per day in the store (C&C)	50	35	13
Flow of people in the store per day (C&C)	50	35	13
Fulfilled orders per day in the warehouse (MSiS)	250	125	63
Flow of people per day in the showroom (MSiS)	210	140	84
C&C's return rate [%]	10%	10%	10%
All buildings' energetic class	E	E	E

Table 1 – *Main inputs*

Input	Source
Consumer profiles and features	Literature
Retailer features	Interviews with OC retailers
Distance between consumer house and store/showroom	Literature
Location of the consumer house	Literature

Table 2 – *References for input values*

Input	Source
Energy consumption	Secondary sources
CO_{2e} emissions	Secondary sources
Times	Interviews with OC retailers and logistics service providers
Logistics and transport features	Interviews with logistics service providers

Table 3 – *References for context data values*

Input	Worst Case	Base Case	Best Case
Retailer's profile	small	medium	large
Consumer's profile	fashion addicted	moderate	apathetic
Distance between consumer house and store/ showroom	15 km	7 km	1 km
Location of the consumer's house	extra-urban area	urban area	urban area

Table 4 – *Sensitivity analysis: features of the considered scenarios*

Consumer's profile	**Moderate**
Location of the consumer's house	**Urban area**
Distance between the consumer's house and the store	**4 Km**
Retailer's features	**Large**
Retailer size [no. of employees]	>1,000
Warehouse size [m^2]	32,000
Store size [m^2]	1500
Showroom size [m^2]	150
Fulfilled orders per day in the store (C&C)	150
Flow of people in the store per day (C&C)	150
Fulfilled orders per day in the warehouse (MSiS)	250
Flow of people per day in the showroom (MSiS)	210
C&C's return rate [%]	20%
All buildings' energetic class	E

Table 5 – Main input data for real case application

Figures

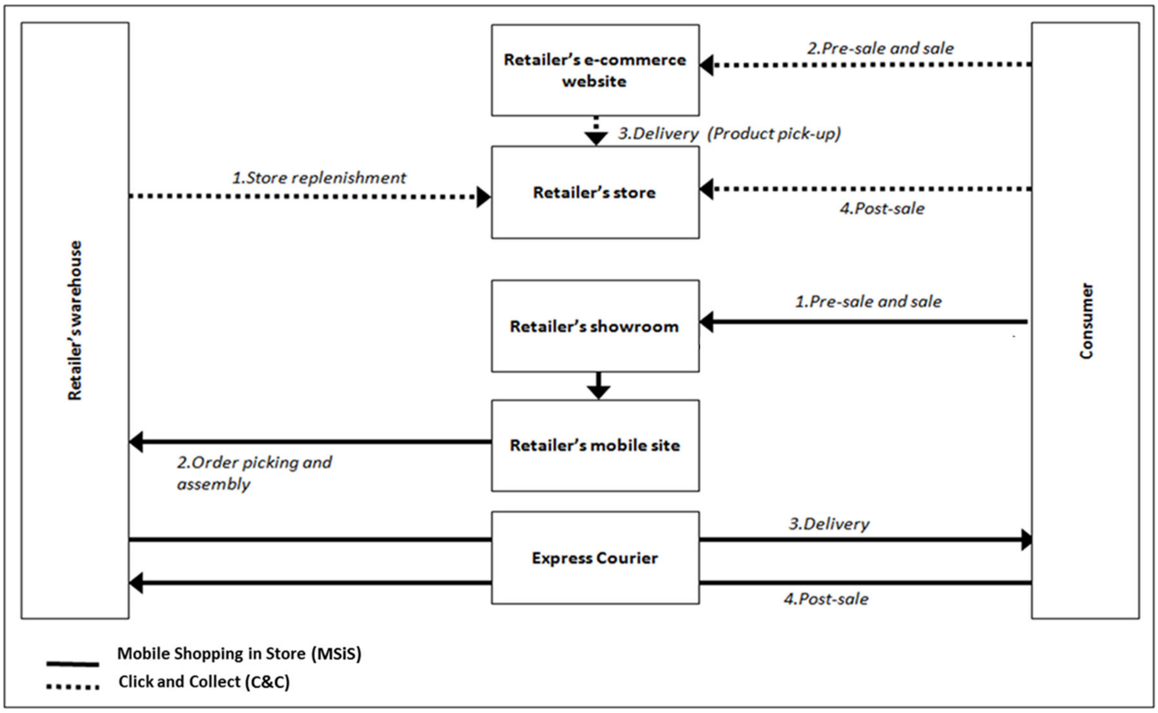

Figure 1 – *The examined purchasing processes (C&C and MSiS)*

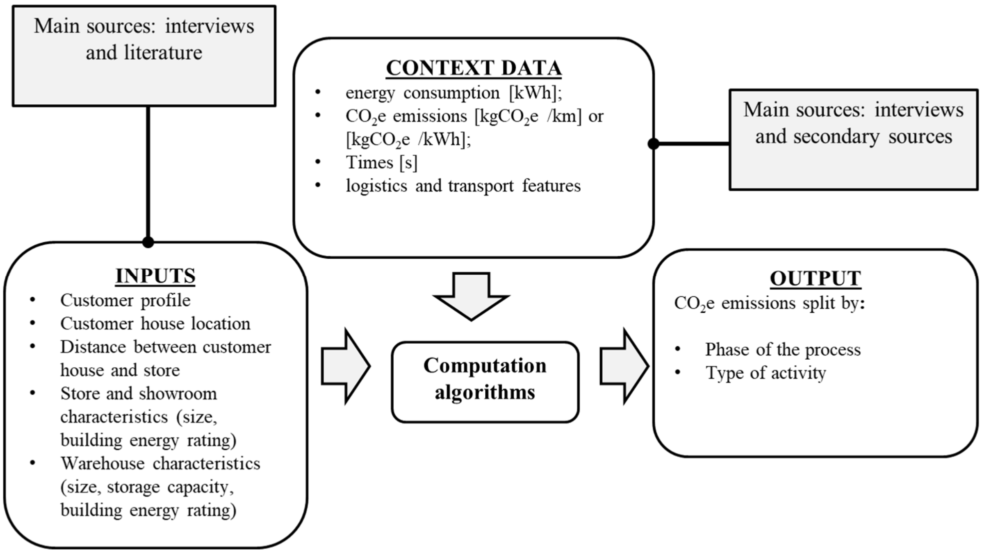

Figure 2 – *Model design*

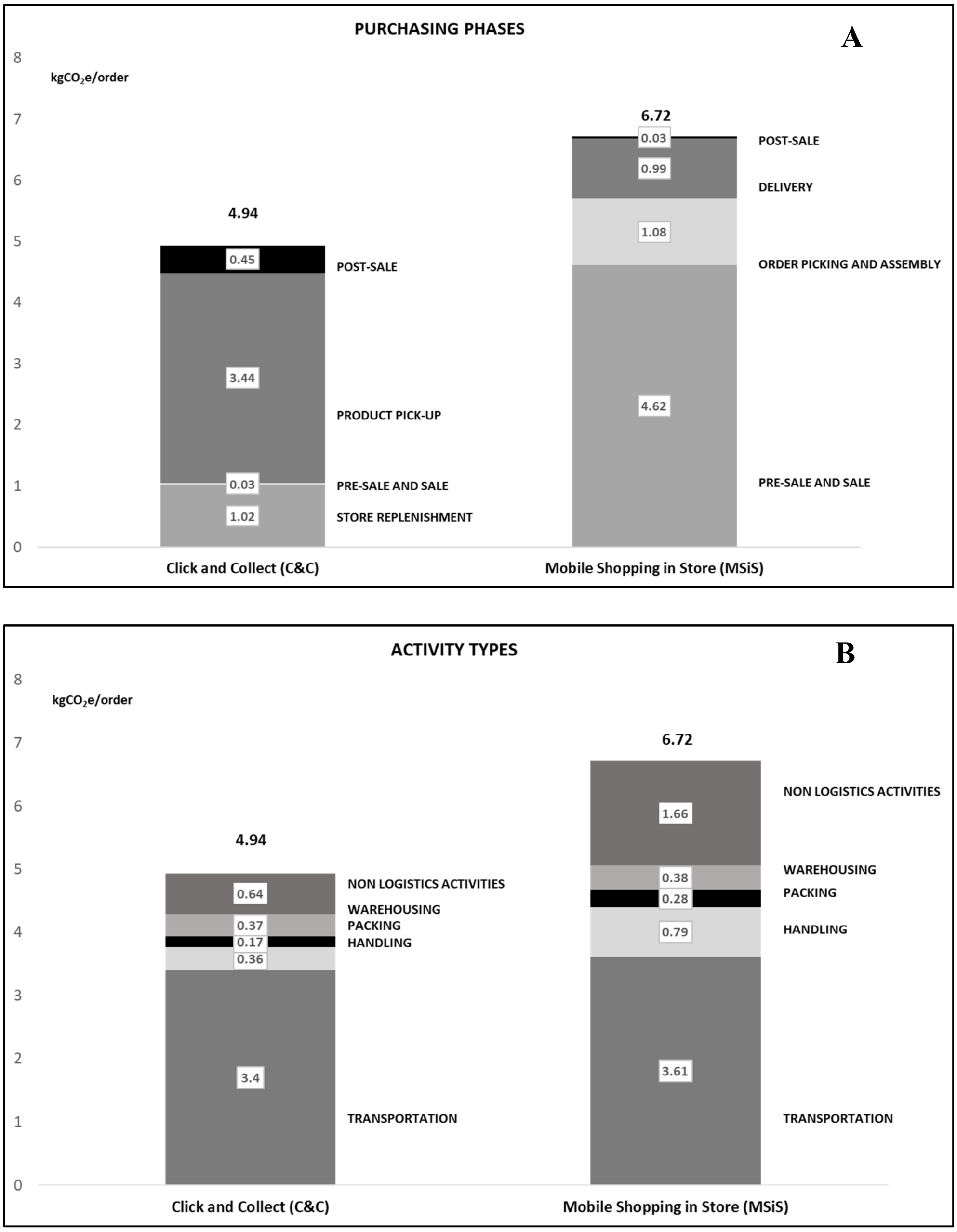

Figure 3 – *Environmental impact by activity type and purchasing phase*

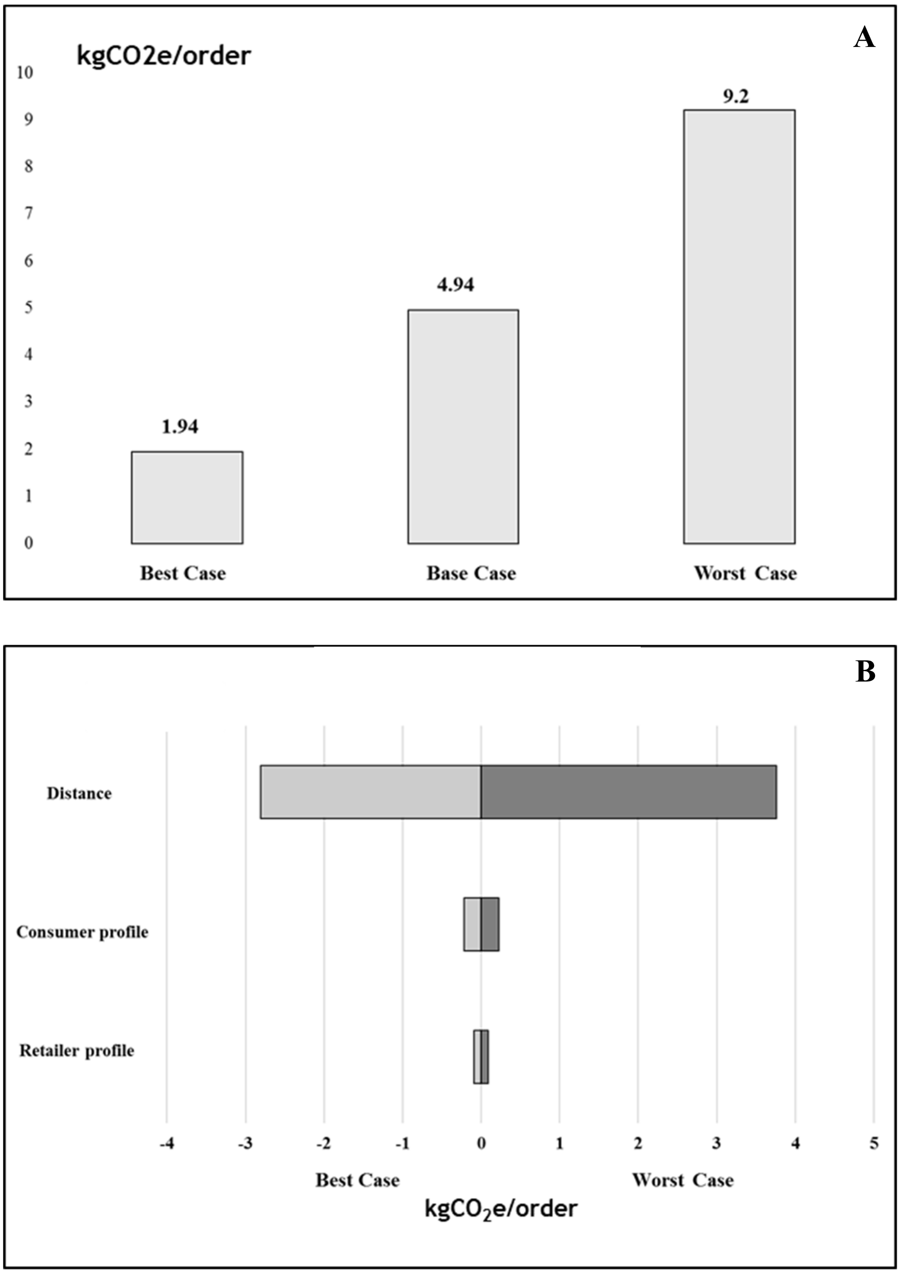

Figure 4 – *Sensitivity analysis − Click and Collect (C&C)*

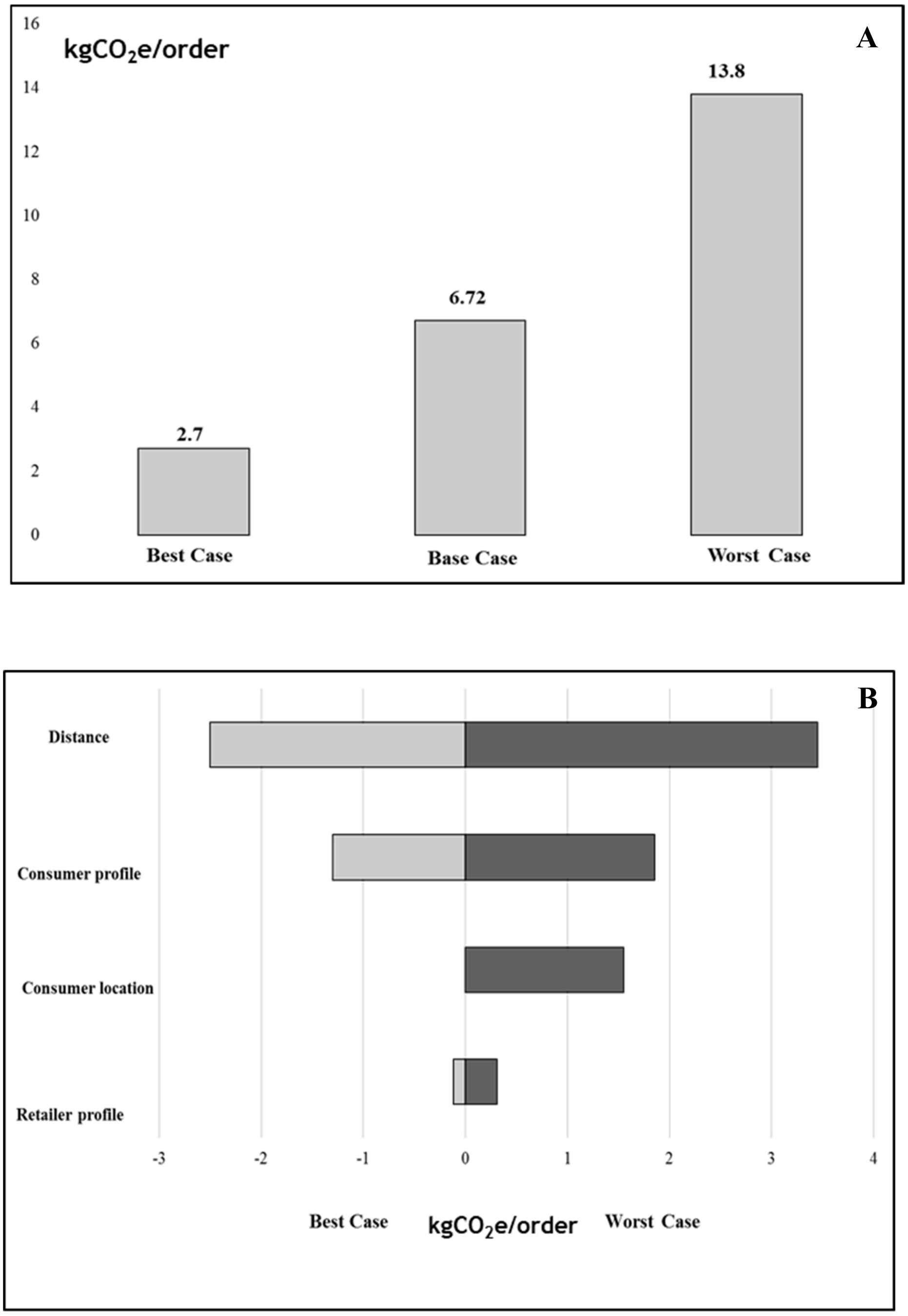

Figure 5 – *Sensitivity analysis −Mobile Shopping in Store (MSiS)*