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A COMPARATIVE LIFE-CYCLE ASSESSMENT MODEL TO INVESTIGATE E-GROCERY ENVIRONMENTAL SUSTAINABILITY

Graduation thesis of:
Luca Manicardi ID
928336

Supervisor:
Prof. Riccardo Mangiaracina
Co-supervisors:
Prof. Angela Tumino
Dott.ssa Chiara Siragusa

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Abstract

In 2020, Food & grocery e-commerce grew by 55% in Italy, reaching a value of 2.5 billion euros, boosted by the impact of COVID-19 as well. For this reason, it is fundamental for e-tailers to understand what is the most sustainable way to fulfil customer orders, not only economically, but also from an environmental perspective. The present work investigates the carbon footprint of various fulfilment methods currently used in the Italian online grocery industry, as well as the variables influencing those environmental performance, with the aim to provide useful insights and indications for online players. The analysis is conducted through the development of a comparative life-cycle assessment model following the Monte Carlo methodology. Results indicates that home delivery from dedicated warehouse directly replenished by suppliers is the most sustainable solution in environmental terms, with a median total emission of 0,033 $KgCO_2eq$ per item. The majority of the variability in the results is coming from product volume, last mile distance and product weight, while the only input parameter which is negatively correlated with the total Greenhouse gas emissions is the basket size. In conclusion, even supposing that for brick&mortar retailing a percentage of customers is reaching the store without using the car, e-grocery, both with home delivery and collection-point-based services, shows high potentials to be more sustainable.

Abstract

Nel 2020 l' e-commerce in ambito Food & Grocery è cresciuto del 55% in Italia, raggiungendo un valore di 2,5 miliardi di euro, spinto anche dall'impatto di COVID-19. Per questo motivo è fondamentale per gli operatori del settore capire qual è il modo più sostenibile per evadere gli ordini dei clienti, non solo economicamente, ma anche dal punto di vista ambientale. Il presente lavoro analizza l'impatto ambientale dei vari canali di distribuzione attualmente utilizzati per la vendita online nell'industria alimentare italiana, nonché le variabili che influenzano tali prestazioni ambientali, con l'obiettivo di fornire utili spunti e indicazioni per gli operatori. L'analisi è condotta attraverso lo sviluppo di un modello di valutazione comparativa del ciclo di vita secondo la metodologia Monte Carlo. I risultati indicano che la consegna a domicilio dal magazzino dedicato rifornito direttamente dai fornitori è la soluzione più sostenibile in termini ambientali, con un'emissione totale mediana di 0,033 $KgCO_2eq$ per articolo. La maggior parte della variabilità nei risultati dipende dal volume del prodotto, dalla distanza dell'ultimo miglio e dal peso del prodotto, mentre l'unico parametro di input correlato negativamente alle emissioni totali di gas serra è la dimensione dell'ordine. In conclusione, anche supponendo che per la tradizionale spesa in negozio una percentuale di clienti raggiunga il punto vendita senza l'utilizzo della macchina, la vendita online di prodotti in ambito Food & grocery, sia con consegna a domicilio che con servizi basati su punti di ritiro, mostra elevate potenzialità in termini di sostenibilità ambientale.

EXECUTIVE SUMMARY

Purpose of the study

Nowadays, e-commerce represents a global phenomenon which is rapidly re-design the majority of industries, with a total value of more than two trillion US dollar worldwide. E-grocery is one of the industries which is growing faster in the recent years, especially in Italy, where Food & grocery e-commerce grew by 55% in 2020, reaching a value of 2.5 billion euros. In this sense, the impact of SARS-COV-2, also known as COVID-19, and the subsequent change in customer behavior is contributing to boost this growth, reducing adoption barriers and forcing online players to invest to widen the geographical coverage and to increase the service level. For this reason, it is fundamental for e-tailers to understand what is the most sustainable way to fulfil customer orders, not only economically, but also from an environmental perspective. The scope of this master thesis is first of all to provide a complete overview on the link between B2C e-commerce and sustainability, highlighting the most important trade-offs that has to be faced by all the actors involved in this process, being online players, logistics operators, final customers and public authorities. Secondly, the present work investigates the carbon footprint of various fulfilment methods currently used in the Italian online grocery industry, as well as the variables influencing those environmental performance, with the aim to provide useful insights and indications for e-tailers. This analysis is conducted through the development of a comparative life-cycle assessment model following the Monte Carlo methodology.

Brief note on exant knowledge

Several studies discussed the relation between B2C e-commerce and environmental sustainability. According to the current literature, the majority of those studies claims that e-commerce is more sustainable than traditional retailing, even though this statement must be detailed with relative assumptions. The impact of last mile delivery is the primary reason behind the superiority of e-commerce (cairns et al., 2005), and it strongly depends on the penetration rate and on the degree of consolidation of customer orders, which is linked with demand density. On the other hand, Mangiaracina et al. (2015) underlines as B2C e-commerce contributes to the growth of van-related traffic, as well as the importance of single-item orders, failed deliveries and returns on sustainability. Moreover, the volume of packaging is significantly higher for online home deliveries, especially if cardboard packaging is present. As pointed out by several articles (Bertram et al., 2018, Rai et al., 2019, Belavina et al., 2017, Gee et al., 2019, Guo et al., 2019) the influence that e-commerce has on customers shopping behaviour is of fundamental importance when discussing this environmental comparison. Different fulfilment methods exist to reach the final customer, as presented by Van Loon et al. (2015), among which the main ones are home delivery, click&collect and pick-up point. On the basis of the choices that the e-tailer and the customer take, the distribution network will have a different design and a different carbon footprint. The industries which have been discussed the most in the current literature concerning e-commerce sustainability are apparel, consumer electronics, grocery and books, with the majority of the studies focused on the analysis of transportation-related activities.

After having selected and analysed 48 articles belonging to this area of research, a set of 28 variables influencing the carbon footprint of e-commerce has been identified, and a conceptual model has been developed, which aims is twofold: first of all, finding the connection between the variables and the source of polluting; secondly, the analysis of the relation between each variable and the main actors involved in the e-commerce fulfilment process.

VARIABLE	PRODUCT/MARKET	E-TAILER	CUSTOMER	EXTERNAL	PRESENCE IN THE PAPER SET
buildings energy efficiency		X			19%
Country's policy and investments				X	6%
customer behaviour			X		15%
customer trip			X		23%
delivery frequency		X			4%
delivery method		X			33%
delivery speed		X			4%
delivery time window		X			13%
demand density			X		23%
distance				X	44%
failed deliveries rate				X	8%
impact of ICT				X	10%
inventory management		X			13%
location of pick-up points		X			4%
location of supply points		X			2%
number of supply points		X			2%
number of vehicles used for LMD		X			2%
order size			X		10%
packaging	X	X			35%
picking strategy		X			8%
product shelf life	X				6%
product temperature	X				8%
product type	X				6%
return rate			X		27%
revenue model		X			2%
transportation mode		X			19%
vehicle capacity		X			4%
vehicle utilization		X			2%

Set of variables analyzed in the selected papers

This was done to emphasize the possible impact that customers, merchants or decision makers might have on the overall environmental impact of the entire process and, on the basis of the evidence provided in the literature, to understand which are the priority areas of intervention. First of all, e-tailers and logistics providers must be aware of the environmental impact of their distribution network design choices, and they should combine efficiency, effectiveness and sustainability-oriented decisions in a holistic view. This model shows the main levers through which they are able to manage those critical trade-offs. Secondly, the final customer is becoming more and more interested into sustainability issues, and this model underlines how important is customer behavior in determining the carbon footprint of B2C e-commerce, especially for what concerns the last mile. Finally, this model might be useful for regulators as well, in order to understand how public incentives, investments and legislations may impact on e-commerce sustainability.

Methodology

The main Research Question to which this study is willing to answer is the following:

RQ: **What is the differential impact that e-grocery fulfilment methods have on environmental sustainability, and which are the main variables responsible for those environmental performances?**

In order to answer to the research question, a comparative Life Cycle Assessment model (comparative LCA model) has been developed. This methodology of analysis is based on four main phases:

- Goal and scope definition
- Inventory analysis
- Impact assessment

- results interpretation

Since the environmental footprint of B2C e-grocery is affected by several parameters, many of which presents high levels of variability, the model has been developed through a stochastic simulation which follows the Monte Carlo methodology. The simulation was developed on RStudio, a free software environment for statistical computing and graphics, due to its data manipulation capabilities and open source nature. The model considers as source of emissions the following activities:

- Store and warehouse replenishment

  This activity includes the GHG emissions from upstream transportations of goods from the central warehouse to local stores and to the e-commerce warehouse. In addition, emissions from truck production are considered.

- Storage

  This activity considers all the storage, handling and refrigeration emissions related to warehouses and stores, expressed as electricity and natural gas consumption. Moreover, the electricity consumption of refrigerated lockers is included.

- Last mile transportation

  This activity includes the GHG emissions related to van trips of home delivery services or car trips of customers reaching the collection point. In addition, emissions from car and van production are considered.

- Packaging

  This activity refers to 100y $KgCO_2eq$ emissions of secondary packaging, namely plastic bags, used in the different channels.

The model considers 7 different scenarios based on the analysis of the state-of-the-art e-grocery operations and fulfilment methods adopted nowadays in Italy by Esselunga, which is the largest players in the market. Those scenarios are evaluated on the basis of the Global Warming Potential, namely GHG emissions, by measuring the $KgCO_2eq$, which are calculated following the methodology described by the fifth assessment report of the Intergovernmental Panel on Climate Change (IPCC). The functional unit chosen for this study is the single item purchased by the final customer, and the allocation of CO_2eq emissions in the various processes considered is the following:

- Replenishment emissions are allocated on the basis of the product weight.
- Store and warehouse consumptions emissions are allocated on the basis of the throughput flow.
- Secondary packaging emissions are allocated on the single item on the basis of the volume of the items and the saturation of the plastic bag.
- Last mile delivery emissions are allocated on the single item through the basket size, which is initially considered the same for all the fulfilment methods.

The 7 scenarios considered are the following:

- **Scenario 1 - Home Delivery from store (HDS)** The first scenario considered in this study refers to home delivery services performed from local stores. The structure of this fulfilment method is the following: replenishment orders from local stores are picked in the central warehouse and delivered through refrigerated articulated trucks. When the online order is received, in-store picking is performed by store employees, and the request is fulfilled by means of refrigerated vans following urban routes. In case of failed delivery, re-delivery is performed in another delivery tour always through refrigerated vans.
- **Scenario 2 - Home Delivery from dedicated warehouse (HDW1)**

  The second scenario considered represents home delivery services performed from a warehouse entirely dedicated to the online channel. The dedicated warehouse is directly replenished from suppliers; When the online order is received, warehouse picking is performed, and the request is fulfilled by means of refrigerated vans following urban and extra urban routes. In case of failed delivery, re-delivery is performed in another delivery tour always through refrigerated vans.

- **Scenario 3 - Home Delivery from dedicated warehouse replenished by central warehouse (HDW2)**

  The third scenario considered represents home delivery services performed from a warehouse entirely dedicated to the online channel, which is replenished from the central warehouse, as for the stores.

- **Scenario 4 - Brick&mortar (BM1)** The fourth scenario considered is based on traditional retailing. replenishment orders from local stores are picked in the central warehouse and delivered through refrigerated articulated trucks. In-store picking is performed directly by the final customer, who is responsible for last mile transportation as well.

- **Scenario 5 - Click&Collect at Locker (C&C)**

  The fifth scenario described by this model represents Click&Collect services by means of refrigerated lockers. As for store home delivery and Traditional retailing, store replenishment is performed from the central warehouse through refrigerated trucks. When the order is received, in-store picking is performed by store employees, and the packaged items are transferred to the locker.

- **Scenario 6 - Click&Drive at drive through station (C&D)**

  The sixth scenario modelled represents the so-called "Click&drive" approach, which is based on a click&collect service performed in specific drive through stations. The structure of this fulfilment method is similar to the previous one: stores are replenished from the central warehouse and in-store picking is performed by store employees. However, the withdrawal of the order is performed in specific stations where the final customer is not required to exit from the car but is directly served by the store staff.

- **Scenario 7 - Brick&mortar by foot (BM2)**

  The last scenario considered in this study is Brick&Mortar by foot, which is similar to Brick&Mortar scenario, but considering that the customer trip is performed by foot, hence without incurring in further emissions due to last mile.

The Monte Carlo simulation was developed by identifying the relevant parameters affecting the environmental performance of the different scenarios and by assigning to each parameter a statistical distribution. The statistical distribution can be divided in two main clusters: in case of variables whose uncertainty depends mainly on its variability (e.g. GHG emissions of vehicles), a lognormal distribution was used; on the contrary, in case of variables whose behavior is difficult to describe due to lack of data, different statistical distributions were adopted:

- **Beta PERT**: this distribution is a variation of the Triangular distribution which is based on the identification of a minimum, a more probable and maximum value for the parameter.

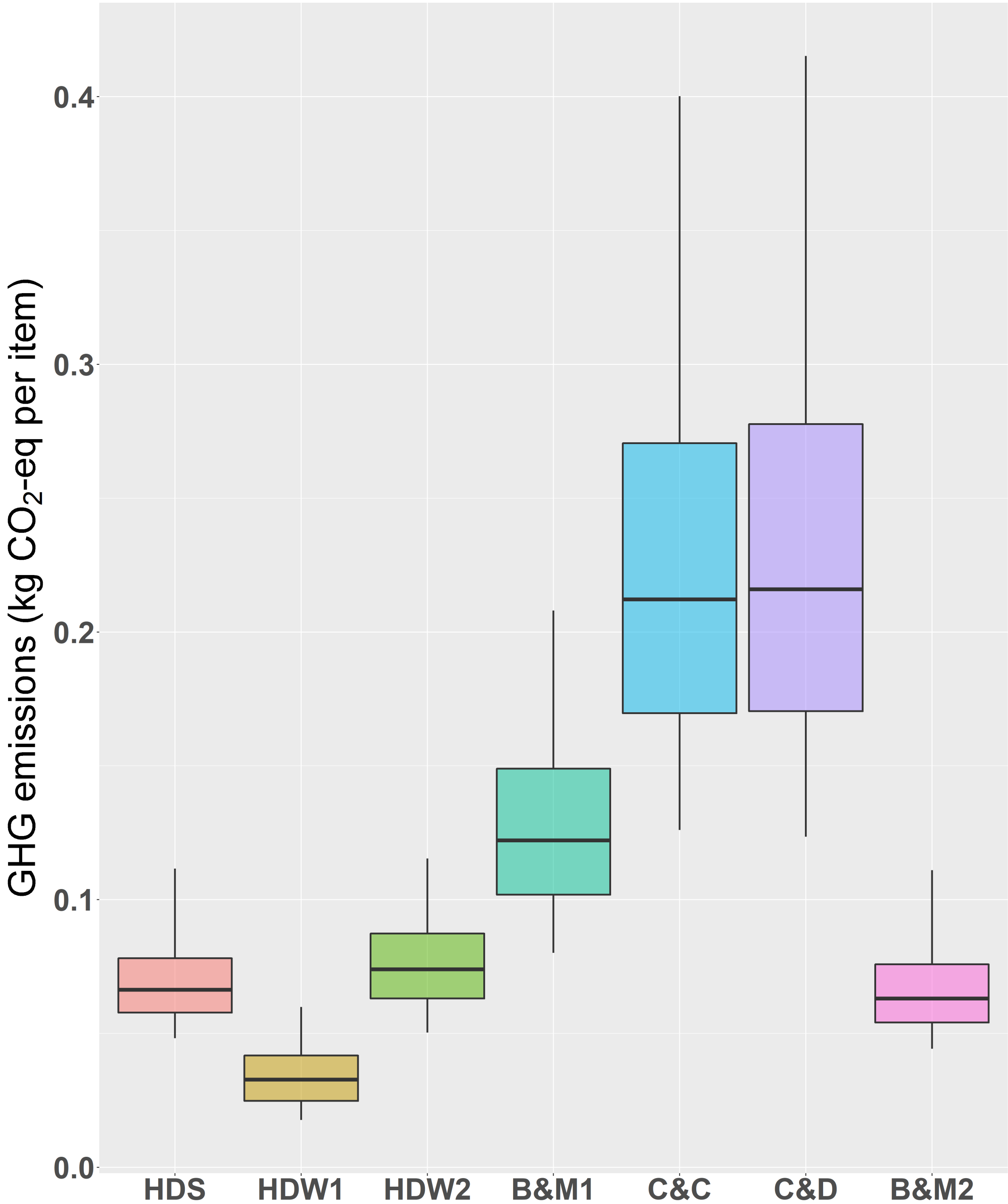
- **Uniform distribution**: this distribution assigns the same probability of occurrence to the entire range of values selected, and it was used only when a minimum and a maximum value were available, but the most probable outcome was not possible to accurately identify.

- **Deterministic parameter**: a single value was assigned in case only one data was available or in case of conversion factors provided by local entities.

Being this study focused on Italy, data collection was conducted taking as reference Italian data when available. Unfortunately, for the majority of the parameters none or very limited reliable local data were available. To cope with this issue, a twofold approach was used: in case of a parameter which is not depending on the country of analysis, a reliable universal source supported by the literature has been used; on the contrary, if the specific data strictly depends on the region considered, such as store energy consumption, a secondary source validated by the literature was accurately selected and compared with the limited or single data available for Italy, to assure compatibility.

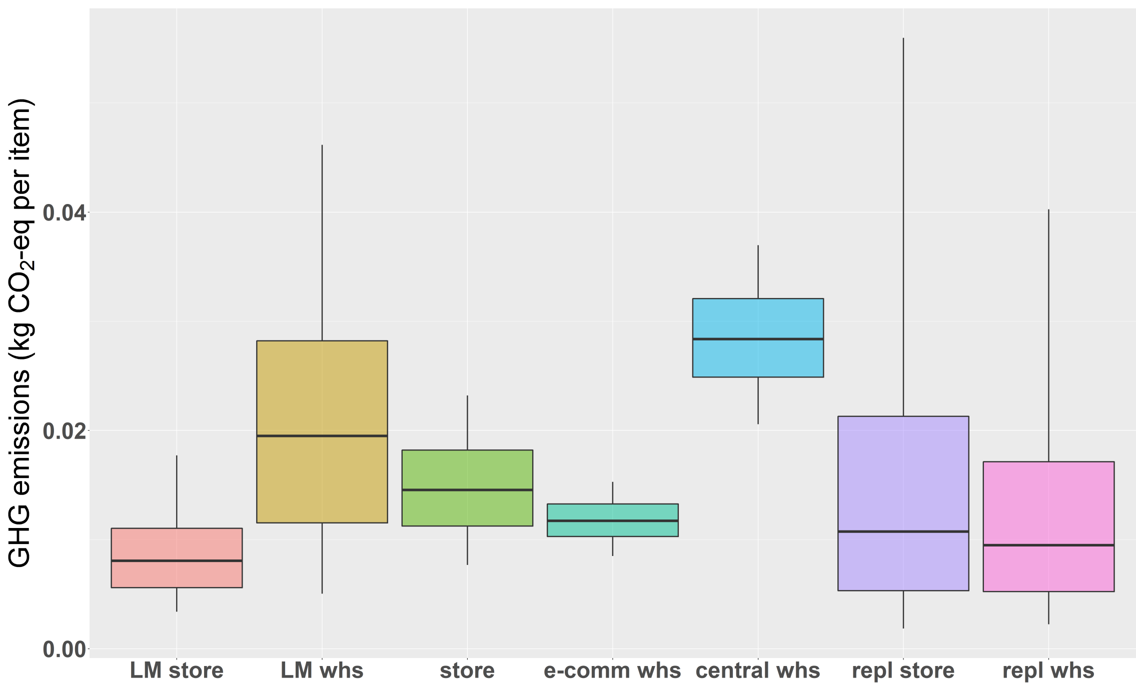
Main findings

Home delivery from dedicated warehouse directly replenished by suppliers is the most sustainable solution in environmental terms, with a median total emission of 0,033 $KgCO_2eq$ per item. Store home delivery and brick&mortar with last mile performed by foot present very similar behavior, both in terms of values and dispersion, resulting in a median total emission of approximately 0.06 $KgCO_2eq$ per item. On the other hand, if we consider the case of home delivery performed from a dedicated warehouse replenished by the central warehouse, the emissions increase even further, ranging between 0,05 and 0,115 $KgCO_2eq$. In the 65% of the cases, this fulfilment method is less sustainable than home delivery from store. Moreover, if we suppose that the last mile of brick&mortar retailing is performed by the customer by car (scenario 4), GHG emissions reached a median total emission of 0.122 $KgCO_2eq$ per item, resulting in the 97% of the cases worse that home delivery, both from store and warehouse. Under the assumption that the collection point is reached by car, click&collect and click&drive are by far the worst scenario in environmental terms, reaching a value of the 95th percentiles of respectively 0,400 and 0,415 $KgCO_2eq$ per item. However, if the collection of the order is performed by foot, or if we consider trip chaining and we assume that the customer would have performed this trip anyway, the environmental impact of click&collect and click&drive services is the same of brick&mortar retailing under the same assumption (B&M2), hence similar to store home delivery. Nonetheless, home delivery from dedicated warehouse (HDW1) remains the scenario with the lowest environmental impact in the 97% of the simulation runs.

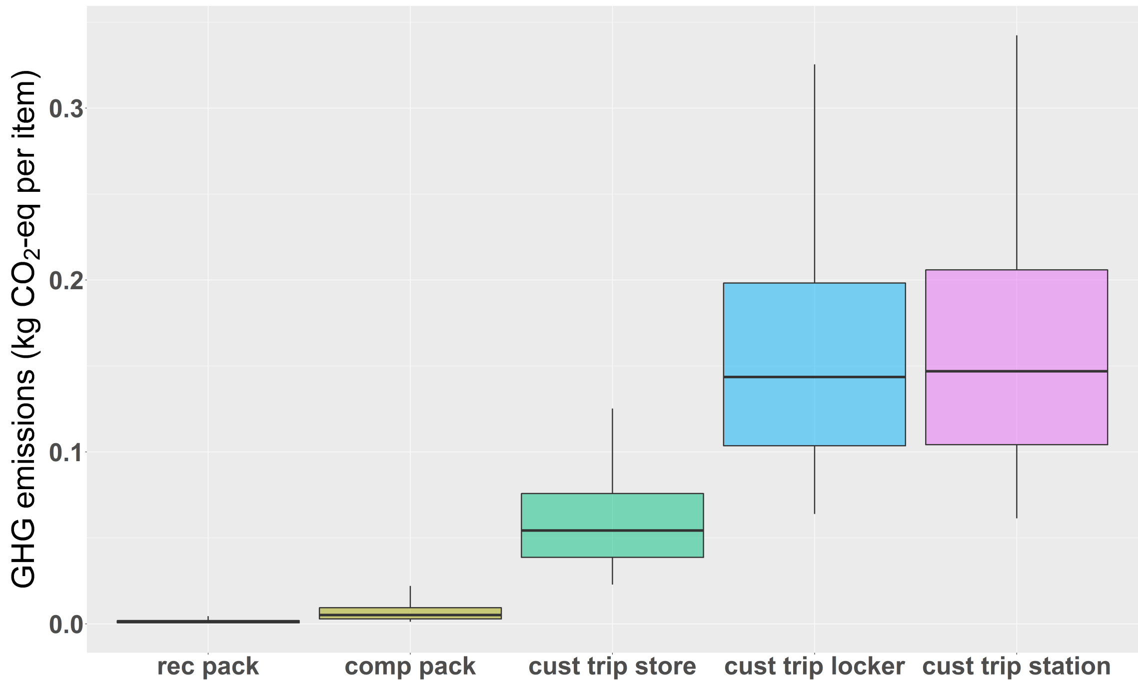


GHG emissions per item for each fulfilment method

Customer trip, in particular to reach collection points, is by far the most polluting phase, due to the travel distance and the GHG emissions of cars. On the contrary, emissions due to packaging are definitely the lowest, with recyclable packaging reaching a value of the 95th percentile of only 0,0045 $KgCO_2eq$ per item. Among the others, emissions due to Central warehouse are significant as well, with a median total emission of 0,028 $KgCO_2eq$. This value is twice as high as the one related to the e-commerce warehouse since the ratio between the dimensions (hence the consumptions) and the throughput flow of products is much higher for the central warehouse. In addition, store is more impacting than e-commerce warehouse in the 70% of the cases, but less than central warehouse in the 98% of the simulation runs. As expected, transportation phases present an high degree of variability, especially store replenishment, whose values range from 0,002 to 0,056 $KgCO_2eq$ per item. Last mile delivery from warehouse is less sustainable than last mile from store in the 86% of the runs, given the higher distance per parcel.



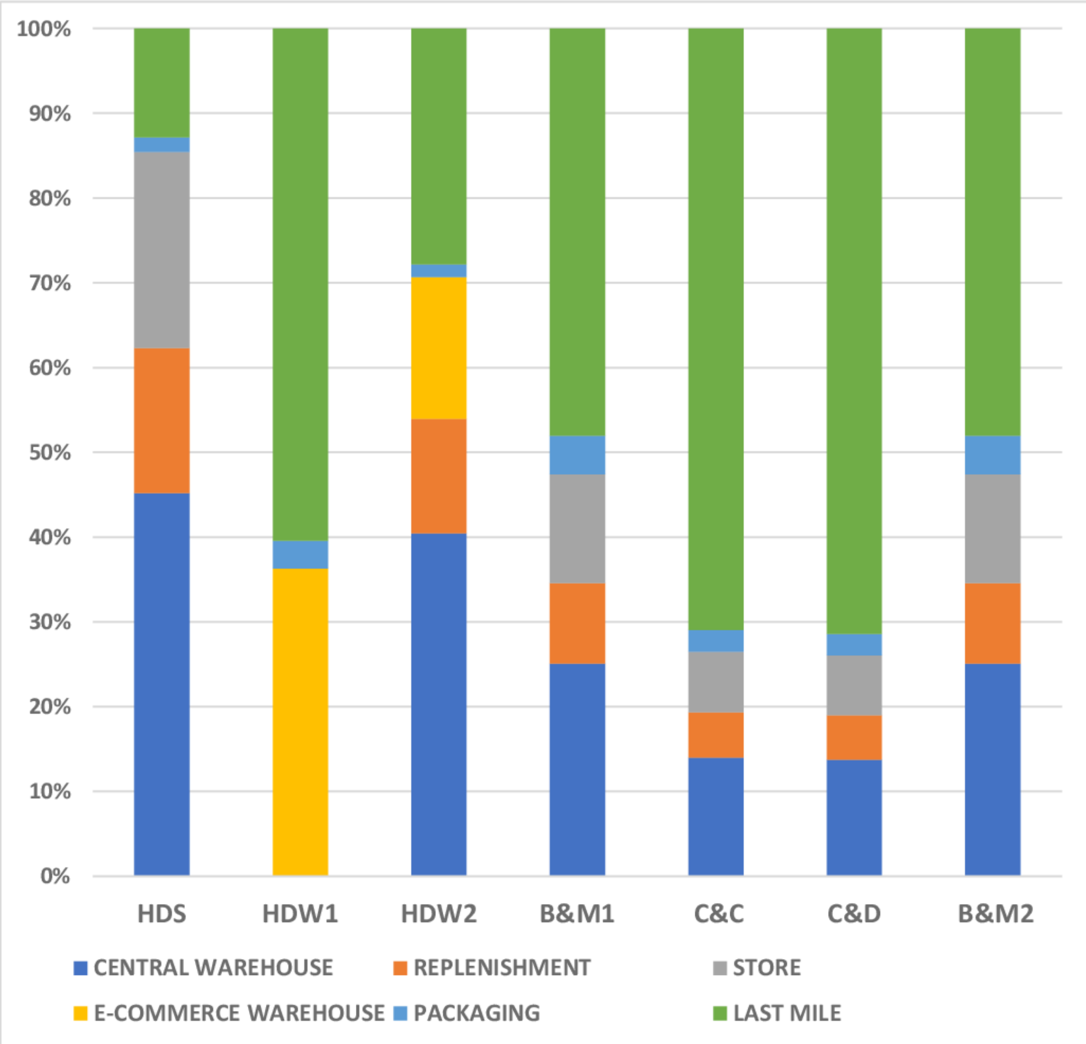
GHG emissions per item of each phase of the fulfilment process



GHG emissions per item of each phase of the fulfilment process

The results have been evaluated comparing the emissions of an order as well; as expected, emissions per order are very similar to emissions per item in terms of difference among scenarios.

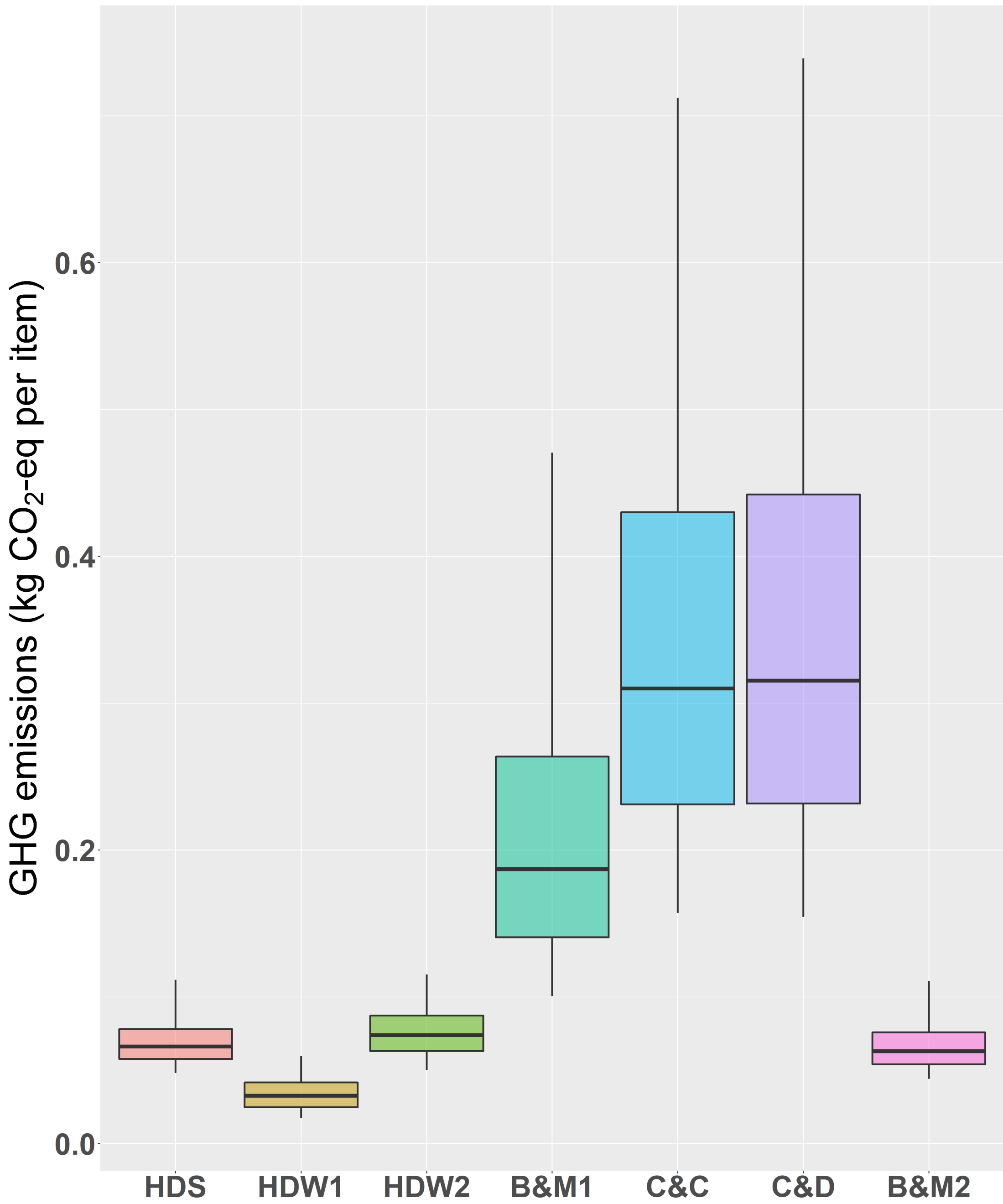
Looking at the contribution of the different phases to the median total emission of the fulfilment methods, it is possible to notice that last mile is the most polluting phase in 5 scenarios over 7. The importance of replenishment is higher in the first and in the third scenario, while in the last four is overcome by customer trip, which in case of click&collect and click&drive represent the 71% of the GHG emissions. Emissions related to store range from only 7% for C&C and C&D to over 20% for HDS, while e-commerce warehouse contribution in HDW1 is almost the double of the one in HDW2, since in this last scenario replenished and central warehouse are not included. Considering the whole 7 scenarios, KgCO_2eq due to packaging do not exceed the 5% of the total median emission.



Percentage of contribution of each phase to the carbon footprint of each fulfilment methods

In conclusion, even supposing that for brick&mortar retailing a percentage of customers is reaching the store without using the car, e-grocery, both with home delivery and collection-point-based services, shows high potentials to be more sustainable.

Considering the difference between the basket size of the different channels, the carbon emissions of traditional retailing and collection-point-based channels increase even further. Indeed, by consolidating more items per order, home delivery becomes even more environmentally efficient compared to the other fulfilment methods.



GHG emissions per item for each fulfilment method considering actual basket sizes

In order to evaluate the contribution of the input variables to the variance of the output values, a global sensitivity analysis has been performed for each scenario analyzed. Global sensitivity analysis is the study of how the uncertainty in the output of a model can be apportioned to different sources of uncertainty in the model input (Saltelli, 2004). Following the indications of Groen et al. (2017), the Spearman method has been adopted.

The majority of the variability of the various scenarios is coming from product volume, last mile distance and product weight, while the only input parameter which is negatively correlated with the total GHG emissions is the basket size, since if basket size increases, the emissions related to last mile delivery will be allocated to a larger base, thus decreasing $KgCO_2eq$ per item.

Research implications and limitations

This study provides meaningful insights on the various trade-offs e-tailers have to face when deciding which services to focus on, and aims to be the base for a structural analysis which relies almost exclusively on primary data, with the final purpose to guide future investments towards a more sustainable path. In fact, Italian e-grocery market is experiencing a fast growth, also due to recent events linked to COVID-19. For this reason, the analysis and understanding of environmental consequences of the choice undertaken by the online grocery players, as well as by the final customer, is fundamental to assure that this growth will be not only economically, but also environmentally sustainable.

The potential limitations of the present study are the following:

- the system boundaries of the study exclude the environmental impact of ICT-related tools, as well as the presence of alternative vehicles.
- Due to data limitations, no validation of statistical distribution was performed.
- For the sake of simplicity, complete trip substitution is assumed to calculate the carbon footprint of e-grocery home deliveries compared to traditional retailing.
- This study compares the different fulfilment methods assuming that the type of products sold between channels is the same.
- The presented model does not consider food losses along the supply chain, as well as possible product damage.
- The study presents geographical limitations, as it is based on Italian data regarding energy conversion factors and distribution networks.

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Chapter 1

INTRODUCTION

E-commerce and sustainability nowadays are everyday language. Those two global phenomena are continuously redesigning the reality we live in, deeply influencing the vast majority of industries. Despite many studies have been conducted to discuss the links among those two terms, still some undefined aspects remain. The area of uncertainty widens when looking for correlation among e-grocery and sustainability, especially in countries like Italy, where grocery e-commerce penetration rate is far behind European level. The aim of this thesis is to understand the link between e-grocery and sustainability by looking at the current Italian scenario, in order to provide general indication both for online grocery players and final customers. Being Italian online grocery market still immature, huge structural investments have not been made yet, except from Esselunga. However, the impact of SARS-COV-2 (also known as COVID-19) is boosting the growth of this market, making expansive investments more necessary than ever. For this reason, assessing the actual impact that e-grocery and its various fulfilment methods have on sustainability is of primary importance. This introductory section is organized as follow: first, a definition of e-commerce and e-grocery is provided (section 1.1). Secondly, a brief description of online grocery market in Italy is given (section 1.2), also considering the impact of COVID-19 (section1.3). Finally, sustainability implications of e-grocery are presented (section 1.4).

1.1 E-commerce

E-commerce (electronic commerce) is the activity of electronically buying or selling of products through the Internet. This phenomenon was born in the early 1970s and has thrived thanks to technological developments, such as mobile commerce, electronic funds transfer, supply chain management, electronic data interchange (EDI) and automated data collection systems, combined with the technological advances of the semiconductor industry and the advent of the World Wide Web. The base for the exponential growth of e-commerce during the last fifty years has been the development of Information technology (IT), which is, as reported by Wigand (1997) "vital for a modern firm' s optimal performance today, as it augments the firm' s capability to coordinate business transactions within the firm, but also among firms such as between buyers and suppliers". The author collected from previous studies four main effects that IT has on transactions and coordination costs:

- The communication effect: Advances in information technology allow for more information to be communicated in the same unit of time, thus reducing transaction costs.
- The electronic integration effect: A tighter electronic linkage between buyer and seller is enabled.
- The electronic brokerage effect: An electronic marketplace where buyers and sellers come together to compare offerings.
- The electronic strategic networking effect: Information technology (including networks) enables the design and deliberate strategic deployment of linkages and networks among cooperating firms intended to achieve joint, strategic goals to gain competitive advantage.

All those aspects contributed to boost the raise of this global phenomenon, which in 2020 have crossed the global value of more than two trillion US dollar. China is currently the number one Country with US$ 862.2 billion in 2019, mainly because of sales related to the fashion industry, followed by US (US$ 356.4 billion) and Europe (US$ 355.26 billion)

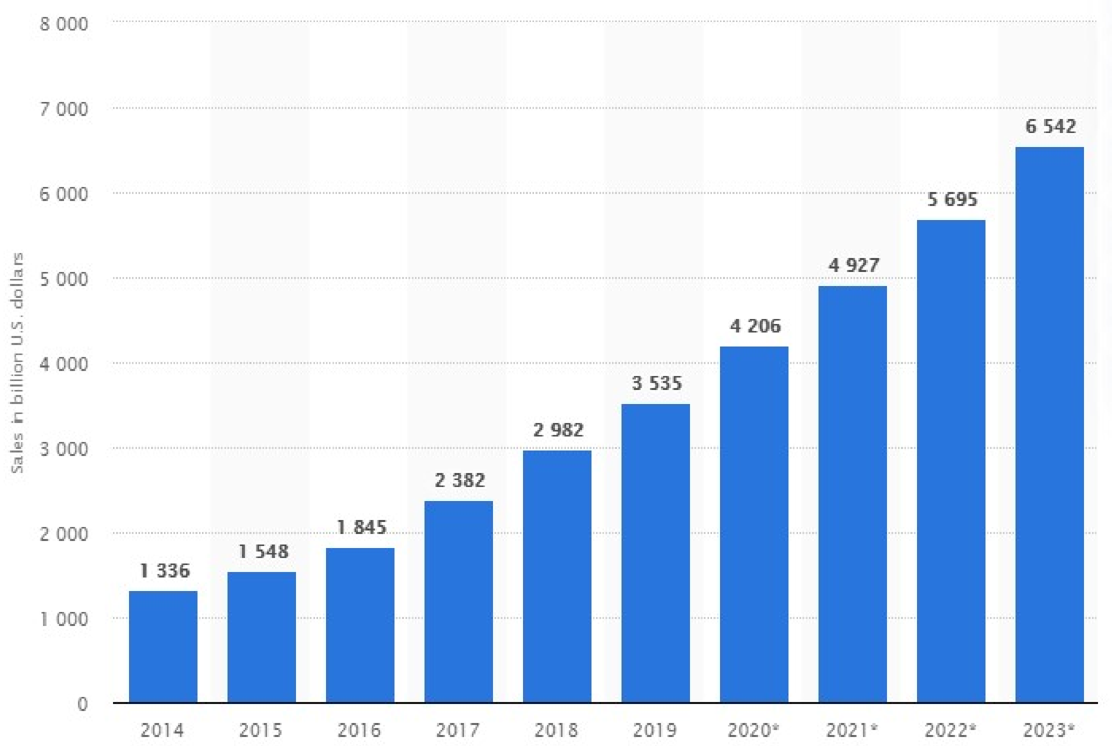


Figure 1.1: Retail e-commerce sales worldwide from 2014 to 2023, source: Statista, 2020

A specific subset of e-commerce is Business-to-Consumer e-commerce (B2C e-commerce), which is defined as the activity of selling product through Internet to the final customer (i.e. the user). B2C e-commerce presents several differences from B2B e-commerce, which instead involves online transactions between two companies: first of all, the items sold are usually mass-market products, which implies a lower value of a single transaction; secondly, the purchasing process is usually shorter since it is not based on a stable and strategic relationship between business partners, but rather on the decision of a single person; third, the decision-making process is based on emotional factors and service level requirements rather than on price and features of the product itself (Reynolds, 2004).

As previously stated, the impact that e-commerce had and has on our society is deep and spread, involving social, economic and environmental aspects. For what concerns logistics, B2C e-commerce represents a real challenge under several aspects: the basket size, often represented by a single product, the enormous offer available in online catalogues and customers' expectations on service level pulled by Amazon delivery performances contribute to make logistics one of the most important aspects to consider when developing an online-based business model.

B2C e-commerce in Italy is not as pervasive as for other European countries. Indeed, reporting the data collected by Osservatorio e-commerce B2C for 2019, e-commerce in UK, France and Germany had reached a penetration of two to four times higher. Several causes are behind those values, but probably the main one is the lack of supply in the Italian market, especially for Food and Grocery. However, even the Italian market is constantly growing. The main e-commerce industries in Italy are tourism, which accounts for the 34% of the overall value, consumer electronics, clothing, publishing and Food & Grocery (Osservatorio B2C e-commerce, 2020).

1.2 E-grocery in Italy

The present thesis will focus on the current Italian scenario regarding B2C e-commerce, more specifically on B2C e-grocery. E-grocery represents the activity of selling product belonging to the grocery industry through the online channel. In 2019 the online Food & Grocery market worth almost 1.6 billion euros, about 5% of the entire Italian e-commerce demand. However, this value is still significantly lower compared to more developed international markets such as France, Germany, UK and USA.

In this competitive scenario, two main clusters of players are present: the first one is composed of traditional retailers, such as Esselunga, Coop and Carrefour, who, especially the first one, have understood the importance of a multi-channel strategy and are investing to expand the online channel; the second one is represented by Dot Com pure players, such as Amazon Prime Now and Supermercato24, who are asset-free online players specialized in home delivery services whose business model is based on the creation of a platform to meet demand and supply. A third and more recent cluster includes all players involved in food delivery, such as traditional restaurants or platforms like Deliveroo or Just Eat, even though this segment is still restricted to more populated areas.

As previously stated, e-grocery in Italy is increasing its penetration rate year after year. Yet, the current developments allow only to 2 Italians out of 3 to benefit from e-grocery services, and not all of them have reached a satisfactory service level. Moreover, the regional coverage is highly disproportionate, with most of the served province being close to big urban areas such as Milan, Rome and Naples.

1.3 2020 and the advent of COVID-19

The previously presented number has changed radically in 2020, mainly due to the devastating impact of COVID-19. In only one year, Food & grocery e-commerce in Italy grew by 55%, reaching a value of 2.5 billion euros. Grocery products are the leading actor with the 87% of the total, followed by food delivery, whose growth was of 19%. Today, e-grocery services from traditional retailers are available for the 73% of the Italian population (+6.6% in respect to 2019). "At the end of 2019, Food & Grocery was the most dynamic online sector, i.e. with the most sustained growth rate (+ 40% approximately), but the least mature, i.e. the one with the lowest penetration rate (1.1% of the value total of retail purchases of Italian consumers)" declares Riccardo Mangiaracina, Scientific Director of Osservatorio e-commerce B2C of Politecnico di Milano. “With the outbreak of the Covid-19 emergency, the online demand for food products has in some cases increased tenfold, putting stronger pressure on e-commerce actors: the lockdown, the new needs (and fears) of consumers have brought down the barriers to the use of the e-Commerce channel (and digital payments) and have convinced even the most reluctant retailers to change the need to strengthen the online offer, not adequate today ".

The effects of this virus on customer behaviors has not been equal in all European countries. According to Nielsen, e-grocery spiked massively in Italy and France, while Germany mostly maintained traditional in-store shopping due to the diffusion of discounts with almost no online presence and the decision of the local government not to resort to a complete lockdown. Figure 1.2 shows the growth rate of e-commerce in Italy in respect to the previous year during the first three months of 2020 compared to the one of traditional retailers. With the beginning of the quarantine, the rate passed from +40% to more than +160% at the end of march. With the end of the lockdown, those values are predicted to fall, but still the trend is impressive.

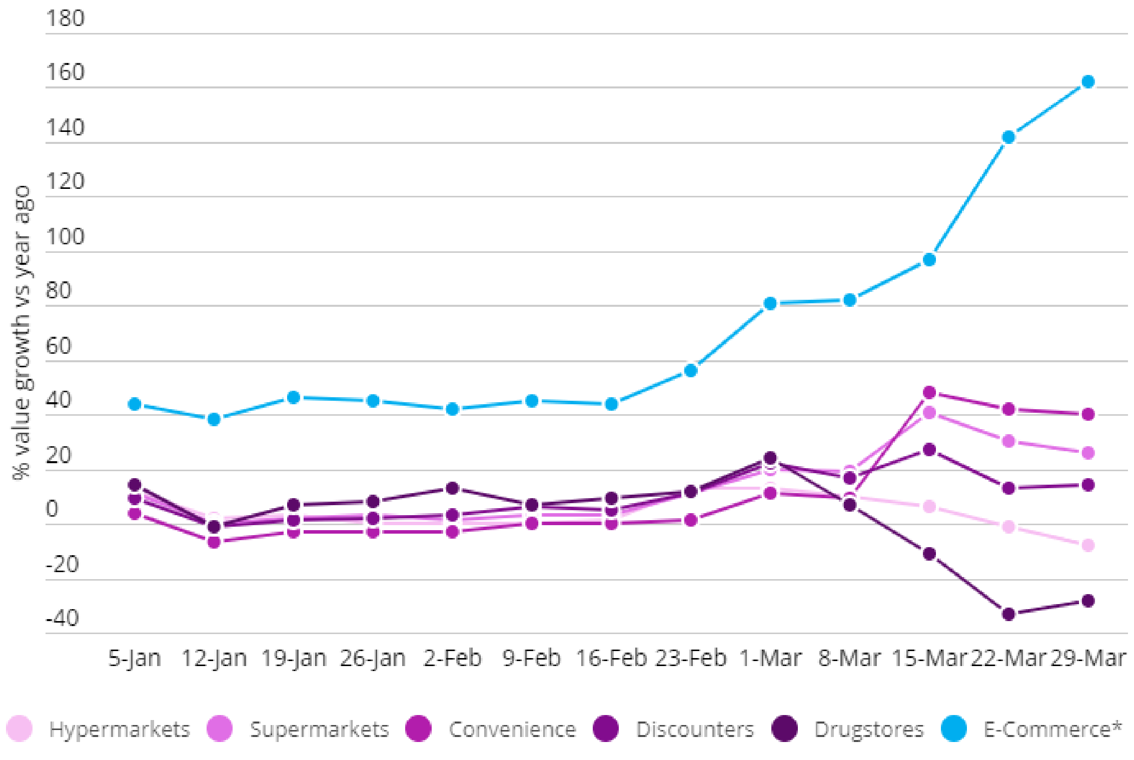


Figure 1.2: Growth of e-grocery in Italy during Covid-19 Quarantine, source: Nielsen

In this moment it is impossible to state precisely when this pandemic will end, neither if the effects on customer behavior will remain. However, the significant growth that online grocery market in Italy is showing might be a fundamental step to cover the distance with the most developed European markets. In this sense, huge investments are needed to guarantee the a sustainable service level.

1.4 E-commerce and sustainability

Thanks to its peculiarities, e-commerce has been often associated to environmental sustainability, defined as "meeting the resource and services needs of current and future generations without compromising the health of the ecosystems that provide them" (Morelli, 2011). This emerging trend which is reshaping the competitive scenario of several markets is asking to companies and institutions to be more aware of the effects that our choices have on the environment and, at the same time, to be more transparent about their environmental policies.

In this sense, many studies analyzed the environmental sustainability of B2C e-commerce, most of which claim e-commerce is "greener" than traditional retailing. However, many variables, most of which linked to logistics aspects, may affect this comparison and the final effect that e-commerce has on the environment. For this reason, the aim of this thesis is first of all to provide a complete overview on the state-of-the-art of B2C e-commerce sustainability studies, highlighting the most important variables involved. Secondly, Italian online grocery environmental impact will be assessed, focusing on the different services offered to the final customers and their impact on e-grocery carbon footprint.

Chapter 2

LITERATURE REVIEW

2.1 Introduction

This chapter aims at discussing the systematic analysis of the literature regarding the B2C e-commerce environmental sustainability, focusing on the variables and processes affecting the environmental performance of online sales in different industries. In this literature review, a particular emphasis on e-grocery environmental sustainability is present.

2.2 Methodology

2.2.1 Scope of the analysis

The primal scope of this section is to present and comment the up-to-date environmental performance of e-commerce, in order to identify the main variables and actors involved. Initially, the focus was restricted to e-grocery sustainability, since this research field is gaining momentum also in Italy. However, the number of articles which have been found dealing with this particular topic were not sufficient to assure completeness and exhaustiveness. Thus, a wider focus on e-commerce sustainability has been taken, analysing the current situation in different industries. Moreover, a comparison with traditional retailing has been performed, with the aim of highlight the most important differences and possible advantages of e-tailing in terms of environmental impact.

2.2.2 Articles selection process

The academic articles analysed have been collected by means of two main research databases: Scopus and ResearchGate. To identify the papers, strings and keywords have been used, such as “e-tailing”, “sustainability”, “e-commerce sustainability”, “e-grocery sustainability”, “environmental impact”, “carbon footprint” etc. which were present in the paper title, abstract or main body. In addition, further articles were identified through references and citations from the previous papers. After the collection, a selection was performed, based on the year of publication and on the relevance of sustainability in the content. The result was a collection of 48 academic articles, conference papers and reviews published between 2001 and 2019. To assure completeness, both quantitative and qualitative publications have been taken into consideration, even though the latter are the great minority.

2.2.3 Review method

All the papers have been analysed separately first, in order to identify and classify the main process and variables that affect the environmental performance of e-commerce. The processes cited in the paper set refer to the main phases of the fulfilment process:

- Production
- Warehousing
- Packaging
- Transportation
- Reverse logistics
- Disposal

On the other hand, the variables analysed in the papers were identified on the basis of the impact on the environmental performance: in this sense, also external variables affecting e-commerce in general and not a precise actor or process (e.g. traffic) have been included. Moreover, a variable is considered analysed in an article if it is cited and its effect on sustainability is explained, even though there are not numerical analysis or deep consideration regarding possible solutions. Once the structure of the analysis was established, all the papers were re-analysed multiple times, in order to highlight the previous variables and processes and to assure consistency in the terminology. Finally, the variables have been collected into conceptual frameworks, in order to enhance the level of clarity and to point out the actors influencing their final effect on environmental sustainability of e-commerce. Another aspect that have been taken into consideration to classify the articles is the environmental parameter highlighted in the main body, being CO_2 emissions (or CO_2-equivalent emissions), GHG emissions or other negative externalities related to e-commerce. Furthermore, a comparison between e-tailing and traditional retailing have been performed, in order to analyse the differences in terms of environmental impact and to understand if e-commerce is superior in these terms. For what concerns last-mile delivery, the delivery method and the presence or absence of vehicle routing problem (VRP) have been analysed. At last, innovative solutions proposed by the articles have been assessed, in order to understand their possible effect on variables and processes previously defined.

2.3 Synthesis of review and discussion

The present table summarizes the information related to the 48 articles selected for this systematic literature review.

Figure 2.1: List of articles analyzed

	TITLE	AUTHORS	JOURNAL	YEAR	COUNTRY	RESEARCH METHOD
1	**E-commerce and the environment: A gateway to the renewal of greening supply chains**	Abukhader, S.M., Jönson, G.	International Journal of Technology Management	2004	Sweden	survey
2	**The environmental implications of electronic commerce: A critical review and framework for future investigation**	Abukhader, S.M., Jönson, G.	Management of Environmental Quality: An International Journal	2003	Sweden	literature review
3	**Simulation of B2C e-commerce distribution in Antwerp using cargo bikes and delivery points**	Arnold, F., Cardenas, I., Sörensen, K., Dewulf, W.	European Transport Research Review	2018	Belgium	simulation, case study
4	**Online Grocery Retail: Revenue Models and Environmental impact**	Belavina, E., Girotra, K., Kabra, A.	management science	2017	US	analytical model
5	**A study of companies' business responses to fashion e-commerce's environmental impact**	Bertram, R.F., Chi, T.	International Journal of Fashion Design, Technology and Education	2018	France	literature review
6	**Carbon emissions comparison of last mile delivery versus customer pickup**	Brown J.R., Giuffrida A.L.	International Journal of Logistics: Research and applications	2014	US	analytical model
7	**Delivering supermarket shopping: More or less traffic?**	Cairns, S.	Transport Reviews	2005	UK	literature review
8	**E-commerce last-mile in Belgium: Developing an external cost delivery index**	Cárdenas, I., Beckers, J., Vanelslander, T.	Research in Transportation Business and Management	2017	Colombia	case study

	TITLE	AUTHORS	JOURNAL	YEAR	COUNTRY	RESEARCH METHOD
9	**Measuring transport related CO2 emissions induced by online and brick-and-mortar retailing**	Carling, K., Han, M., Håkansson, J., Meng, X., Rudholm, N.	Transportation Research Part D: Transport and Environment	2015	Sweden	empirical analysis
10	**Comparison of various urban distribution systems supporting e-commerce. Point-to-point vs collection-point-based deliveries**	Carotenuto, P., Gastaldi, M., Giordani, S., (...), Rabachin, A., Salvatore, A.	Transportation Research Procedia	2018	Italy	analytical model, case study
11	**Environmental implications for online retailing**	Carrillo, J.E., Vakharia, A.J., Wang, R.	European Journal of Operational Research	2014	US	analytical model
12	**Electric vehicles in the last mile of urban freight transportation: A sustainability assessment of postal deliveries in Rio de Janeiro-Brazil**	de Mello Bandeira, R.A., Goes, G.V., Schmitz Gonçalves, D.N., D'Agosto, M.D.A., Oliveira, C.M.D.	Transportation Research Part D: Transport and Environment	2019	Brazil	case study
13	**Impacts of Proximity Deliveries on e-Grocery Trips**	Durand, B., Gonzalez-Feliu, J.	supply chain forum: An international journal	2013	France	simulation
14	**Comparative carbon auditing of conventional and online retail supply chains: A review of methodological issues**	Edwards, J., McKinnon, A., Cullinane, S.	Supply Chain Management	2011	UK	conceptual analysis
15	**A decision support system to investigate food losses in e-grocery deliveries**	Fikar, C.	computers and industrial engineering	2018	Austria	simulation
16	**Public transport-based crowdshipping for sustainable city logistics: Assessing economic and environmental impacts**	Gatta, V., Marcucci, E., Nigro, M., Patella, S.M., Serafini, S.	Sustainability (Switzerland)	2018	Italy	analytical model

	TITLE	AUTHORS	JOURNAL	YEAR	COUNTRY	RESEARCH METHOD
17	**Deliver Me from food waste: Model framework for comparing the energy use of meal-kit delivery and groceries**	Gee, I.M., Davidson, F.T., Speetles, B.L., Webber, M.E.	Journal of Cleaner Production	2019	US	simulation
18	**Home delivery vs parcel lockers: An economic and environmental assessment**	Giuffrida, M., Mangiaracina, R., Perego, A., Tumino, A	Proceedings of the Summer School Francesco Turco	2016	Italy	analytical model
19	**Forecasting accuracy influence on logistics clusters activities: The case of the food industry**	Gružauskas, V., Gimžauskienė, E., Navickas, V.	Journal of Cleaner Production	2019	Lithuania	analytical model
20	**Forward and reverse logistics network and route planning under the environment of low-carbon emissions: A case study of Shanghai fresh food E-commerce enterprises**	Guo, J., Wang, X., Fan, S., Gen, M.	Computers and Industrial Engineering	2017	China	case study, simulation
21	**On integrating crowdsourced delivery in last-mile logistics: A simulation study to quantify its feasibility**	Guo, X., Lujan Jaramillo, Y.J., Bloemhof-Ruwaard, J., Claassen, G.D.H.	Journal of Cleaner Production	2019	China	conceptual analysis, simulation
22	**Comparison of life cycle environmental impacts from meal kits and grocery store meals**	Heard, B.R., Bandekar, M., Vassar, B., Miller, S.A.	resocurce, conservation and recycling	2019	US	analytical model
23	**Model conceptualization on e-commerce growth impact to emissions generated from urban logistics transportation: A case study of Jakarta**	Hidayatno, A., Destyanto, A.R., Fadhil, M.	Energy Procedia	2019	Indonesia	conceptual analysis, case study
24	**application of e-commerce in local home shopping and its consequences on energy consumption and air pollution reduction**	Karbassi, A.R.	Iranian Journal of Environmental Health Science & Engineering	2005	Iran	survey

	TITLE	AUTHORS	JOURNAL	YEAR	COUNTRY	RESEARCH METHOD
25	**Designing and assessing a sustainable networked delivery (SND) system: Hybrid business-to-consumer book delivery case study**	Kim, J., Xu, M., Kahhat, R., Allenby, B., Williams, E.	Environmental Science and Technology	2009	South Korea	case study
26	**Assessing traffic and environmental impacts of smart lockers logistics measure in a medium-sized municipality of Athens**	Kiousis, V., Nathanail, E., Karakikes, I.	Advances in Intelligent Systems and Computing	2019	Greece	simulation, case study
27	**Decision support for urban e-grocery operations**	Leyerer, M., Sonneberg, M.-O., Breitner, M.H.	Americas Conference on Information Systems 2018: Digital Disruption	2018	Germany	simulation
28	**Is on-demand same day package delivery service green?**	Lin, J., Zhou, W., Du, L.	Transportation Research Part D: Transport and Environment	2018	China	simulation, case study
29	**A comparative study of environment impact in distribution via E-Commerce and traditional business model**	Liyi, Z., Chun, L.	Proceedings - 5th International Conference on New Trends in Information Science and Service Science	2018	China	analytical model, case study
30	**Attended Home Delivery: reducing last-mile environmental impact by changing customer habits**	Manerba, D., Mansini, R., Zanotti, R.	IFAC-PapersOnLine	2018	Italy	simulation
31	**A review of the environmental implications of B2C e-commerce: a logistics perspective**	Mangiaracina, R., Marchet, G., Perotti, S., Tumino, A.	International Journal of Physical Distribution and Logistics Management	2015	Italy	literature review
32	**Assessing the environmental impact of logistics in online and offline B2C purchasing processes in the apparel industry**	Mangiaracina, R., Perego, A., Perotti, S., Tumino, A.	International Journal of Logistics Systems and Management	2016	Italy	analytical model, case study

	TITLE	AUTHORS	JOURNAL	YEAR	COUNTRY	RESEARCH METHOD
33	**Environmental and economic effects of e-commerce: A case study of book publishing and retail logistics**	Matthews, H.S., Hendrickson, C.T., Soh, D.L.	Transportation Research Record	2001	US	case study
34	**Achieving sustainable e-commerce in environmental, social and economic dimensions by taking possible trade-offs**	Oláh, J., Kitukutha, N., Haddad, H., (...), Máté, D., Popp, J.	Sustainability	2018	Hungary	literature review, case study
35	**A crowdsourcing solution to collect e-commerce reverse flows in metropolitan areas**	Pan, S., Chen, C., Zhong, R.Y.	IFAC-PapersOnLine	2015	China	simulation
36	**How does consumers' omnichannel shopping behaviour translate into travel and transport impacts? Case-study of a footwear retailer in Belgium**	Rai, H.B., Mommens, K., Verlinde, S., Macharis, C.	Sustainability	2019	Belgium	case study
37	**A new paradigm for packaging design in web-based commerce**	Regattieri, A., Santarelli, G., Gamberi, M., Mora, C.	International Journal of Engineering Business Management	2014	Italy	analytical model, case study
38	**GHG emissions of supply chains from different retail systems in Europe**	Rizet, C., Cornélis, E., Browne, M., Léonardi, J.	Procedia - Social and Behavioral Sciences	2010	France	survey
39	**Effects of e-commerce on greenhouse gas emissions: A case study of grocery home delivery in Finland**	Siikavirta, H., Punakivi, M., Kärkkäinen, M., Linnanen, L.	Journal of industrial ecology	2002	Finland	case study, simulation
40	**Potential last-mile impacts of crowdshipping services: a simulation-based evaluation**	Simoni, M.D., Marcucci, E., Gatta, V., Claudel, C.G.	Transportation	2019	Italy	simulation, case study

	TITLE	AUTHORS	JOURNAL	YEAR	COUNTRY	RESEARCH METHOD
41	**A comparative analysis of carbon emissions from online retailing of fast moving consumer goods**	Van Loon, P., Deketele, L., Dewaele, J., McKinnon, A., Rutherford, C.	journal of cleaner production	2015	UK	analytical model
42	**The growth of online retailing: A review of its carbon impacts**	Van Loon, P., McKinnon, A.C., Deketele, L., Dewaele, J.	Carbon Management	2014	UK	literature review
43	**State-of-the-art in E-Commerce Carbon Footprinting**	Velásquez, M., Ahmad, A.-R., Michael, B.	Journal of Internet Banking and Commerce	2009	Chile	literature review
44	**The energy and climate change implications of different music delivery methods**	Weber, C.L., Koomey, J.G., Matthews, H.S.	Journal of Industrial Ecology	2010	US	simulation
45	**Transport-related CO2 effects of online and brick-and-mortar shopping: A comparison and sensitivity analysis of clothing retailing**	Wiese, A., Toporowski, W., Zielke, S.	Transportation Research Part D: Transport and Environment	2012	Germany	survey
46	**A Comparative Study of Environmental Impacts of Two Delivery Systems in the Business-to-Customer Book Retail Sector**	Zhang, L., Zhang, Y.	Journal of Industrial Ecology	2013	China	analytical model
47	**Environmental benefits of electronic commerce over the conventional retail trade? A case study in Shenzhen, China**	Zhao, Y.-B., Wu, G.-Z., Gong, Y.-X., Yang, M.-Z., Ni, H.-G.	Science of the Total Environment	2019	China	case study
48	**Collaboration in urban distribution of online grocery orders**	Zissis, D., Aktas, E., Bourlakis, M.	International Journal of Logistics Management	2018	Greece	analytical model, simulation

2.3.1 Research methods

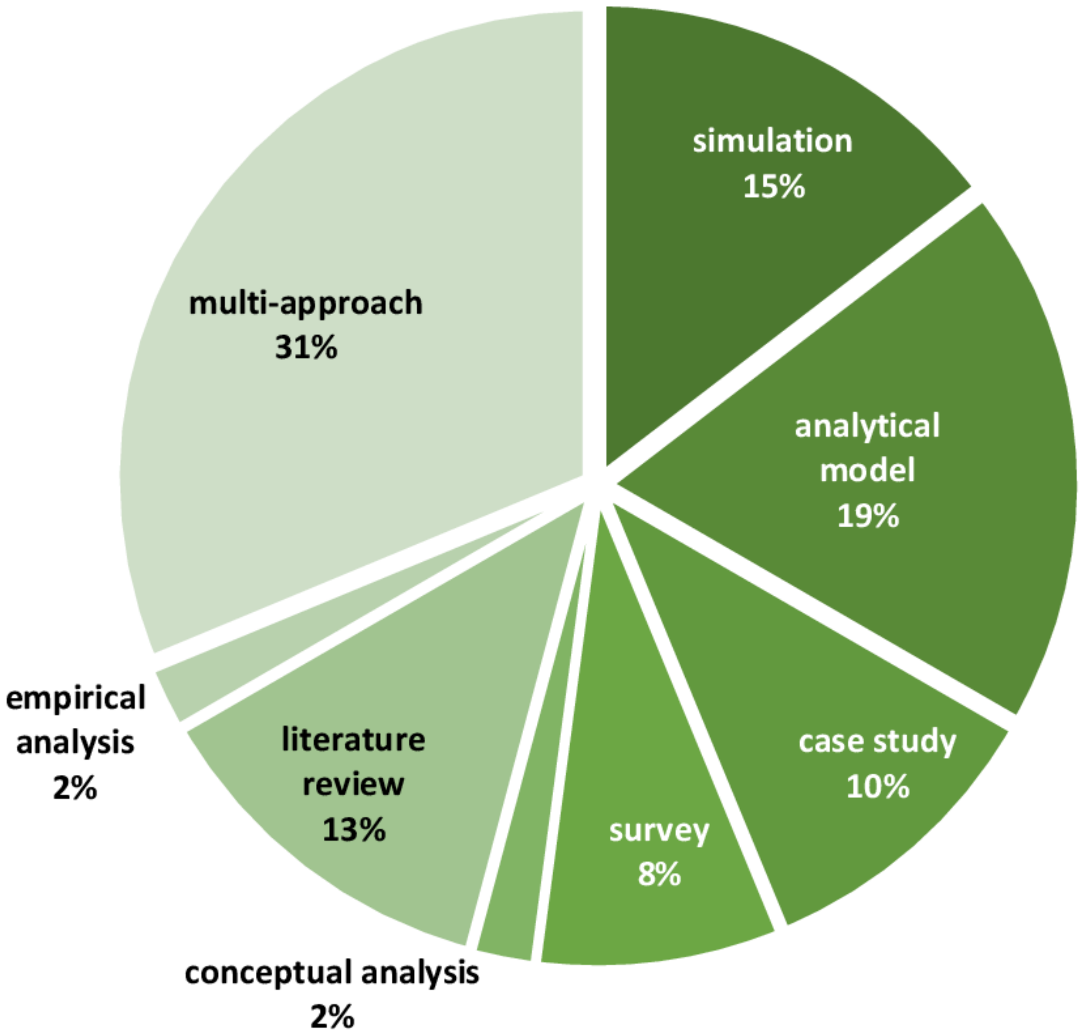


Figure 2.2: Research methods used in the analyzed papers

The majority of articles analysed presents an analytical approach (simulation or mathematical model) to the sustainability issue, by means of optimization algorithms, sensitivity analysis or, just in few cases, a life-cycle assessment (Van Loon et al., 2015; Heard et al., 2019). This is in accordance with the fact that the 77% of the papers provides numerical evidence as a result of the analyses carried on in the main body, making the identification of variables easier and their effect on environmental impact more visible.

However, conceptual articles like literature reviews and conceptual frameworks are necessary as well, to have a more complete and broad view on the issue and on the linkages that are presents between actors involved, processes and environmental impact. It is relevant to say that more than the 30% of the compositions are developed through a multi-approach: indeed, 15 articles present a case study to validate the analytical model or to find in real-word examples concepts elaborated in the literature review or in the conceptual framework.

2.3.2 Country of origin

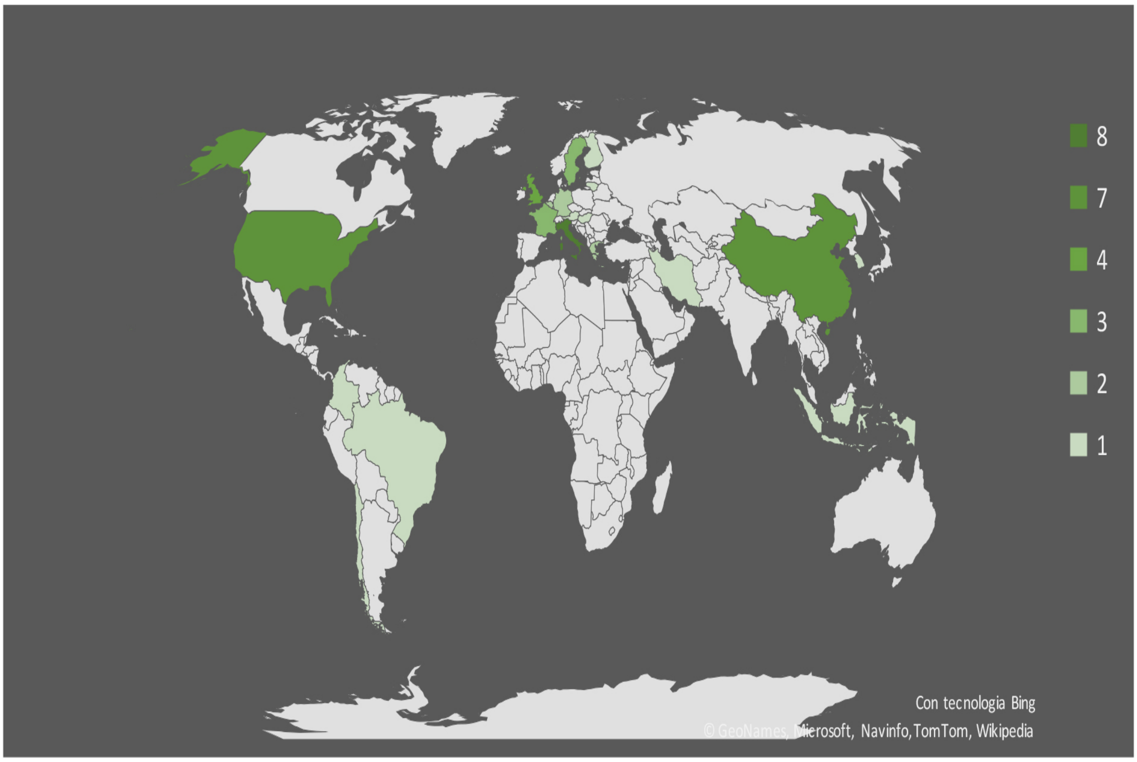


Figure 2.3: Country of origin of the first author

The authors of the selected articles come from 19 different Countries. This diversity shows the worldwide relevance that the topic is taking on. Italy, United States and China are the most represented Countries, respectively with 8, 7 and 7 papers. Together, they represent almost the half of the studies collected for this literature review. An important contribution is given by France and United Kingdom as well. Europe represents exactly the 50% of the paper works, with studies coming from most developed Countries, but also from east-Europe (Lithuania and Hungary) and north-Europe (Sweden and Finland). In addition, in the review is present a contribution from Colombia, Chile, Iran, Indonesia, South Korea and Brazil.

2.3.3 Process analyzed

As mentioned in section 2.2.3, the processes analysed in the articles are the following:

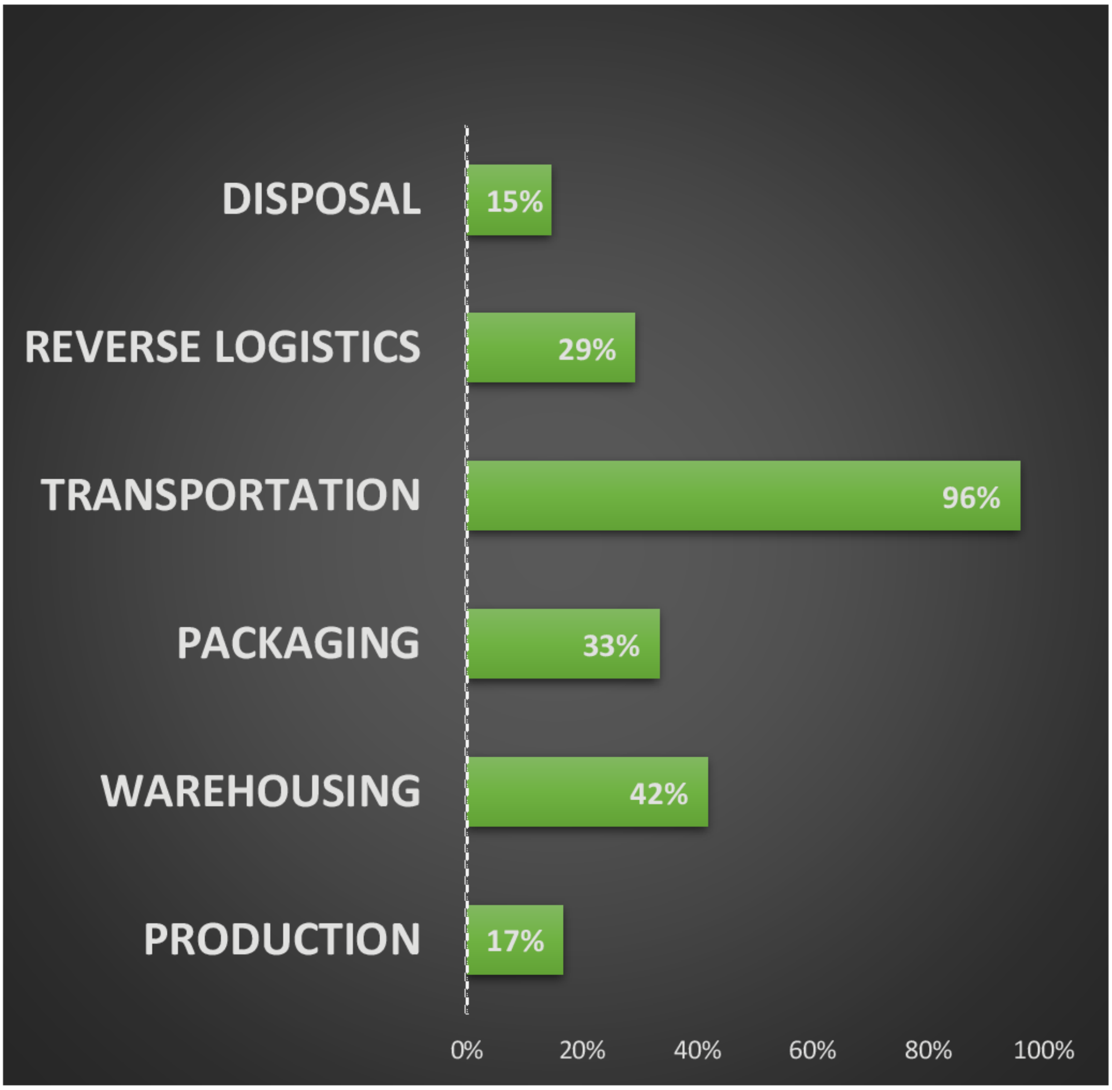


Figure 2.4: Processes analyzed in the set of papers

Production

Production refers to all the emissions related to the upstream part of the supply chain of the industry of analysis, including transportation to merchant's central warehouse. In the production phase, Heard et al. (2019) considers the GHG emissions related to the production of food, comparing meal kits and grocery store meals though a LCA. Meal kits are pre-portioned ingredients, packaged and delivered at customer house in refrigerated boxes that are becoming more and more popular especially in the United States, with a high potential to change the food industry. The potential of this revolutionary product lies in the lower food waste and emissions related to store refrigeration, even though the amount of packaging involved is higher. Overall, according to Heard, the meal kit is able to guarantee 33% less of GHG emissions in respect to traditional grocery shops, depending also on the type of food considered. Guo et al. (2017) analyses the role of food processing plants in re-processing returned food into canned or semi-finished products, to promote the concept of circular economy also in the fresh food industry.

Moving away from e-grocery, Van Loon et al (2014) argues that "The direct energy consumption and the indirect production, repair and disposal of ICT equipment should be included in environmental assessments of online shopping", even though its weight on total emissions is would be difficult to compute. However, e-commerce is not the only factor influencing production and usage of ICT equipment, nor the most important. Hence, this viewpoint is questionable.

Warehousing

Warehousing includes all the activities performed in merchant's central or regional warehouse, such as picking, sorting and handling. Moreover, the same activities performed in the courier's warehouse are considered too, as well as energy consumptions of all related buildings or machinery (e.g. trans pallet or automatic handling machine). For what concerns warehousing, the picking process, together with the inventory management and building energy efficiency, are the main topic discussed. , Fikar et al. (2018) in his study regarding food losses in e-grocery deliveries analyses six different order picking strategies, divided in two macro groups: global picking strategies, which considers the consolidated inventories of all stores, and local picking strategies, which on the contrary considers the inventory of each store separately. For each macro group, three inventory strategies are evaluated: FEFO (first-expired-first-out), which delivers first the product that is closer to the expiration date, LEFO (last-expired-first-out) and random picking. In this study, the author claims that by shipping products closer to expiration date, the spoilages would be reduced, although there is a reduction of customer satisfaction since the resulting average food quality is lower. Moreover, a global picking strategy results in lower product waste and higher quality, while the distance travelled increases. Hence, to decide what is the best response to this problem, a trade-off firm-specific must be performed.

Another perspective about how warehouse operations contribute to environmental impact can be found in Mangiaracina et al. (2016). In this paper, the authors developed an activity-based model to compare e-commerce and traditional retailing on the basis of the different phases of the purchasing process identified for the two channels. Regarding online sales, the phase "ORDER PICKING AND ASSEMBLY", which includes all the activities related to the preparation of the order performed in the merchant's warehouse, accounts for the 42% of the total CO_2 emissions, due to the fact that the order is often composed by a single piece.

Packaging

Another fundamental aspect to consider regarding e-commerce sustainability is the packaging. Packaging includes all the emissions related to the production and the disposal of primary or secondary packaging along the entire supply chain. Even though in some works it is included in the analysis of warehousing processes, the relevance of its impact on the carbon footprint justifies a deepening into this issue. An interesting contribution to this matter comes from Zhao et al

(2019), which used an Average Package Difference Model to assess the CO_2 emissions related to the two different distribution channels in Shenzhen, China. This method is based on the calculation of the CO_2 emission level of an average package (with equivalent weight and value from the same retail category) via the two trade channels, avoiding stages such as production and disposal, which are considered equal in the life cycle of the average package. The results of this analysis highlight the superiority of online sales in respect to traditional in-store shopping, even though packaging has by far the largest contribution to the carbon footprint of e-commerce.

Gee et al (2019) reopened the discussion about meal kits through a Monte Carlo simulation based on consumers data from Texas, saying that the single-use packaging contributes to double the energy usage related to e-grocery packaging, possibly offsetting the lower food waste and transportation distance. For this reason, recyclable packaging should be implemented, to allow meal kits to be environmental competitive once again. Reusable packaging could be another solution, even though it requires more energy in the production phase and a reverse logistics system.

Transportation

Since it accounts for the majority of the emissions related to e-commerce, it is not a surprise that Transportation is the most discussed process, with only two papers not directly dealing with it (Regattieri et al., 2016, Gružauskas et al., 2019). Transportation includes all the forward travels performed during the fulfilment process from merchant's central warehouse to the final customer. Even though some of them consider also the transportation of goods from regional warehouses to distribution centres or depots, most of the articles are focused on the last-mile issue, assessing the impact on environmental sustainability of different delivery methods, different characteristics of vehicle fleets and delivery frequencies or time windows. Moreover, as pointed out by Fikar (2018) and Heard et a. (2019), when talking about food last mile delivery we have also to take into consideration the perishability of the product, which often requires specific temperature ranges, thus impacting the fuel consumption of delivery vehicles. As a result, a large portion of possible innovative solutions proposed by the authors is focused on this stage of the fulfilment process, as explained in the related section, at the end of the analysis.

Reverse Logistics

Even though transportation is fully considered in the paper set, Reverse Logistics is not equally discussed. Indeed, only the 29% of the articles analysed includes this theme in the main body. Reverse Logistics considers all the reverse travel performed by the courier or by the customer itself due to a missed delivery or return. In addition, the extra activities that the courier and in some cases the merchant has to sustain after a missed delivery or a product return are analysed in this process as well. Those activities include sorting, storing, re-picking and re-packaging of returned products.

Edwars et al (2011) for example, points out that the reverse supply chain depends mainly on product characteristics, which also affects the return rate. In this paperwork, the forward and reverse flow of books, consumer electronics, garment and food are considered: while return rate for books is about 3%, this number can grow up to 40% in the apparel industry, where the management of reverse flow becomes crucial. Moreover, the customer may decide to return the product itself to the nearest store or through standard postal service, rather than asking the courier to collecting it back. In the case the parcel carrier was already on its trip, this last solution would be more efficient and environmentally friendly. According to Guo et al. (2017), forward and reverse logistics networks should be integrated in order to achieve economic and environmental efficiency, avoiding sub-optimal solutions. disposal

Disposal

The less mentioned, but still important process is Disposal. It considers all the CO_2 emissions coming from product disposal, including all wastes generated along the entire supply chain. This last stage is often excluded from the analysis due to its intrinsic difficulty in computation, yet it accounts for a large portion of GHG emissions, especially in the food industry. The 86% of paper works analysing this process, indeed, belongs to the e-grocery area, focusing the attention on the effect of food waste. Siikavirta et al. (2002), for example, claims that e-grocery home delivery reduces food waste if compared with traditional retailing, as mentioned before. However, other industries must face this issue as well.

In the apparel industry, Bertram et al. (2018) highlights the negative effect that fast fashion has on product disposal, reducing more and more the product life cycle. According to this study, speedy production and delivery, together with planned obsolescence of products, contribute to increase the carbon footprint of the fast-fashion industry, which accounts for the 20% of apparel production. "In 2013, Americans created 254 million pounds of municipal solid waste and recycled or composted roughly 34.3% of this total amount. Rubber, leather, and textiles, which the Environmental Protection Agency put into one category, account for 9% of America's waste (Carbon Dioxide Emissions, 2016)". Thus, a sensibilization towards reuse and donation is needed, even because "almost 100% of textile can be recycled or repurposed in some way", Bertram says.

2.3.4 Industries analyzed

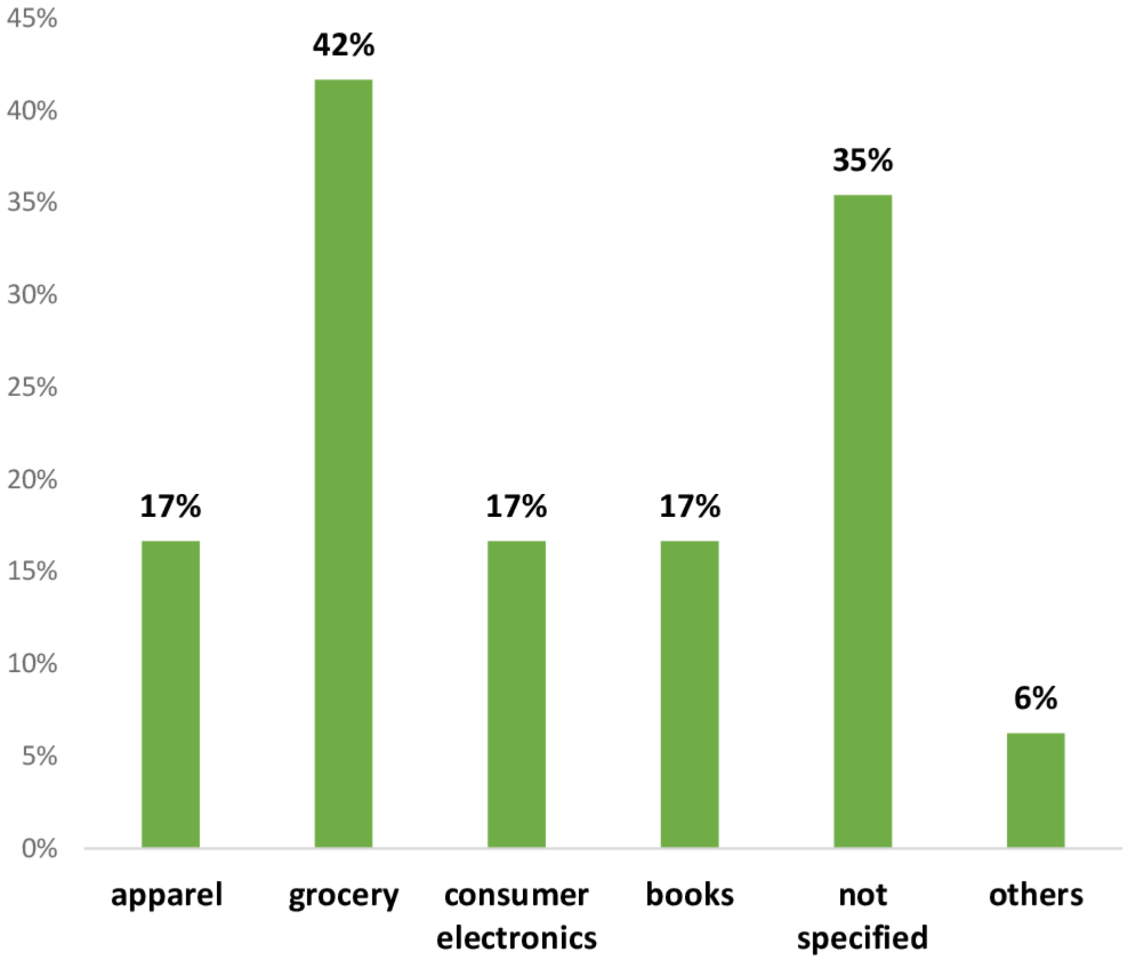


Figure 2.5: Industries analyzed in the set of papers

As explained before, an in-depth analysis on online commerce in the food industry was performed. In this sense, the 42% of the articles are fully or partially linked to this topic. Other industries discussed are the apparel industry, consumer electronics and books, since they are the ones were e-commerce has experienced the highest penetration rate.

It is interesting to notice the differences among those supply chains in terms of activities performed during the fulfilment process, as well as variables that affects the carbon footprint: for instance, product temperature and product perishability are influencing exclusively the food supply chain, where emissions related to product disposal are more relevant and the picking process becomes critical also in environmental terms. High return rate, instead, are typical of the apparel and the consumer electronics market, increasing considerably CO_2 emissions related to transportation. Therefore, order conformity and return process optimization may have a huge impact both on costs and carbon footprint.

Furthermore, the 35% of the studies does not specify the industry of analysis, thus we can assume that most of the conclusions coming from those works can be generalized to all the above-mentioned markets. For example, articles concerning the last-mile delivery problem, several of which including routing optimization, range from different industries and are common for all B2C e-commerce fulfilment processes. In conclusion, newspaper, footwear and postal delivery are cited as well.

2.3.5 Environmental parameter

In this section, the environmental parameter used in the analysed articles are discussed. Those parameters are CO_2 emissions (including CO_2-equivalent emissions), GHG emissions and other negative externalities, which includes among others food waste, energy consumption and traffic. As expected, polluting emissions are the most diffuse parameter used to express the environmental impact of e-commerce operations, both because the relation is direct and often easily calculated. In fact, if we join together CO_2 and GHG emissions, which include more in general all those polluting emissions that contribute to worsen the green-house effect, such as CO_2, CH_4 (methane) and N_20 (Nitrous oxide), we obtain the 73% of the papers.

It is relevant to mention the study from Lin et al. (2018), which is the only one focused on particulate matter emissions. Particulate matter is usually associated with car-based transportation and is significantly dangerous for human health, as it increases the probability to contract lung cancer, stroke or respiratory infections. 20 articles over 48 define the environmental impact of e-commerce through the effect on general negative externalities. In this cluster also energy consumption is included, even though it is not usually named as a negative externality. The most diffuse parameter in this sense is traffic. The influence that e-commerce may have on urban traffic is controversial: in fact, although e-commerce would theoretically reduce the number of vehicles circulating for shopping reasons, the complete substitution assumption is abandoned by almost all the authors. Moreover, the reduction in traffic congestions due to delivery optimization and vehicles minimization could be offset by failed deliveries, if customer self-collection is required, or product returns. In this sense, an interesting contribution comes from the use of pick-up points, if their location allows the customer to avoid the use of the car to reach it.

Another relevant parameter mentioned in the subset of articles concerning e-grocery is the level of food waste. This value, which includes all the food which is discarded along the supply chain, is becoming more and more important, as online grocery is penetrating the market.

2.3.6 Comparison with traditional retailing

Half of the articles analysed present a comparison between the carbon footprint of e-commerce and traditional retailing. Of these 24 papers, the 58% concludes the analysis by stating the environmental superiority of e-commerce, while for the 38% of them the results are controversial. Only one article, by Liyi et al. (2011), claims that, under certain specific assumptions, brick and mortar retailing is more sustainable. The proposed study is quite simplified, as it does not consider vehicle saturation, returns and frequency as variables, referring mainly on government and third-party data.

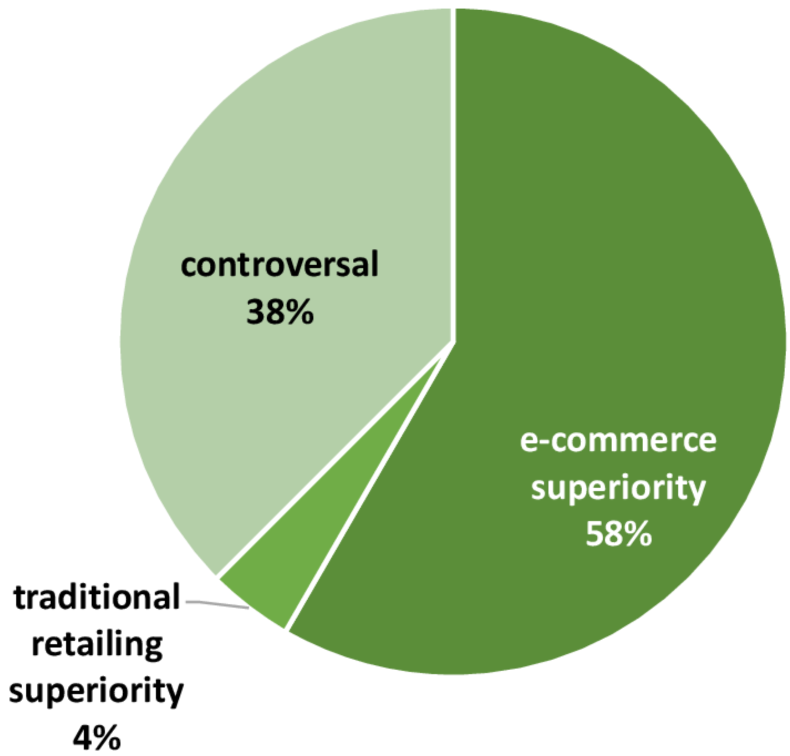


Figure 2.6: Comparison with traditional retailing

The significant difference among the two fulfilment processes can be found in the travel between regional warehouses and distribution centres, which represents the 98% of the emissions of the online channel. However, the author recognizes some limitations of the study, such as the source of emissions considered, population density and consumer trip. The demand density, indeed, is really high in China and this, combined with the fact that most of the population prefers to walk or to use the bike to reach the desired shop, contributes to make brick and mortar retailing environmentally efficient.

Apart from this paper, the majority of the studies are focused on last-mile delivery, assuming that the anterior part of the fulfilment process could be considered as similar from an environmental perspective. Hence, the dispute is mainly between traditional shopping and home delivery, as in the case presented by Cairns (2005). This literature review is full of significance since it summarizes several models regarding the challenge between e-commerce and traditional retailing, emphasizing their differences and the boundary conditions that might favour one solution in respect to the other. This particular study is focused on the grocery industry, but the majority of the statements might be generalized to other markets. The main conclusion of the article is that grocery home delivery, by substituting car trips with van trips, could be able to reduce kilometres travelled by 70%, decreasing carbon emissions and traffic congestion. This result, however, is strongly dependent on the penetration rate of e-grocery and on the degree of consolidation of customer orders.

On the other hand, another literature review, developed by Mangiaracina et al. (2015), analyses the inefficiencies linked to home delivery in environmental terms. The paper underlines as B2C e-commerce contributes to the growth of van-related traffic, which are more polluting than larger trucks usually used in traditional retailing, as well as the importance of single-item orders, failed deliveries and returns on sustainability. Finally, the volume of packaging is significantly higher for online home deliveries, especially if cardboard packaging is present. As pointed out by several articles, the influence that e-commerce has on customers shopping behaviour is of primary importance when discussing this environmental comparison.

To sum up, the two fulfilment processes present substantial differences in the distribution network design, which result in different carbon footprint. The environmental superiority of one process respect to the other is directly linked to several parameters, as return rate, failed deliveries rate, order size, and delivery method chosen for online purchases. Even though results and evidences are diverse depending on the industry of reference, if efficiently and effectively managed, B2C e-commerce as the potential not only to provide the customer superior service level, but also to reduce the impact that traditional retailing has on the environment.

2.3.7 Delivery method

This section presents the different delivery methods analysed and compared in the set of papers selected, along with their pros and cons. Although the set of papers introduces several delivery methods for online purchase, this review is based on three clusters of methods:

- 1. home delivery, which groups all fulfilment strategies based on in-store or warehouse picking performed by the e-tailer and courier's delivery at customers home, being attended, when the customer or a family member collects the order, or unattended by means of reception boxes;

- 2. pick-up point, where the item is picked by the e-tailer, delivered by the courier and collected by the final customer in a parcel locker or in any structure which is not the store.

- 3. click&collect, which includes e-tailer in-store picking and the customer collecting the item in the same place.

The first delivery method is the most analysed and common in B2C e-commerce, with the 83% of the articles dealing with it. At the same time, home delivery may be performed though different transportation modes (traditional vans, bicycles, electric vehicles..), different distribution networks (direct delivery from store, through a logistics service providers, from a regional warehouse or from a depot..) and different reception mode (attended home delivery versus reception boxes). On the basis of the choices that the e-tailer and the customer take, the distribution network will have a different design and a different carbon footprint. For instance, Siikavirta et al. (2002) claims that by using refrigerated reception boxes for unattended e-grocery home deliveries, the level of food waste and failed deliveries would drop, allowing moreover a better optimization of vehicle capacity and routing.

Routing scheduling is fundamental for home deliveries. In fact, almost the half of the studies concerning home deliveries solve a Vehicle Routing Problem

(VRP) for the optimization of the trip. The vehicle routing problem is a combinatorial optimization and integer programming problem which generalizes the travelling salesman problem (TSP). It appeared for the first time in the latest 1950's (Dantizi- Ramser, 1959). The objective of the VRP is to minimize the total route cost, which in this case coincides with the minimization of carbon emissions. As reported in the literature, determining the optimal solution to VRP is NP-hard (non-polynomial hard), thus the complexity of problems that can be optimally solved using mathematical programming or combinatorial optimization may be limited. For this reason, the authors of the analyzed articles tend to use heuristic methods due to the size and frequency of real world VRPs they need to solve. Anyway, if well implemented and supported by effective data, the sub-optimal solution obtained might have an important impact on kilometers travelled and CO_2 emissions.

To provide a broad and comprehensive view on the different delivery method described, reference has been made to Van Loon et al. (2015), who analyses the different carbon footprint of different fulfilment methods for fast-moving consumer goods. The author compares five different methods of home deliveries: the first method proposed is composed by retailers without physical stores (here called "centralized pure players"), which fulfil the order thanks to the combination of long haul truck and local vans performing the last-mile delivery; alternatively, the pure player might use a parcel delivery network; the third option is called "drop-ship", and consists of direct shipment from the supplier to the final customer, bypassing the retailer who actually sold the item; the retailer may also deliver the order from a local shop, again through a local van network; eventually, the producer may ship directly use a parcel delivery network to reach the final customer, without any involvement of the e-tailer, even though this final alternative is not diffused yet. Along with those alternatives, the article analyses click&collect in local stores and traditional retailing as well. Referring to the above-mentioned clusters, pick-up point is the only delivery method not mentioned in the paper. The study takes as a base-case scenario the following configuration, based on UK-specific data, such as average basket size composed by two items for parcel delivery and forty-five items for store deliveries, and supposing complete substitution of consumer trips.

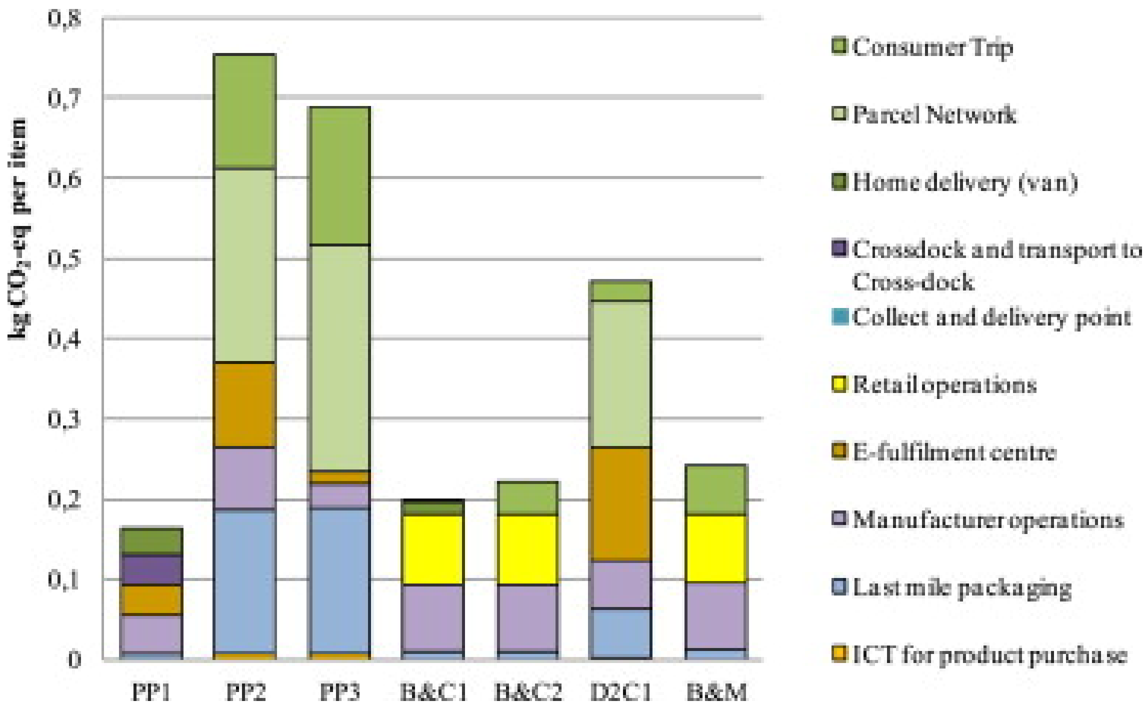


Figure 2.7: Base case scenario, from Van Loon et al., (2015)

Figure 2.7 shows that, under the mentioned assumptions, the first home delivery method proposed, pure player and van deliveries, is the most environmental efficient. Similar results are obtained by store deliveries and click&collect. On the contrary, the parcel network presents a significantly higher environmental impact. The article analyses the effect of a variation in order size and consumer trips as well. Consumer trips may arise due to product returns (a 3.5% of returns is supposed) or failed deliveries (40% of total deliveries), which may imply customer collecting the item at a local distribution point.

This introduction leads to the second proposed scenario (figure 2.8), where the situation is similar to the previous one.

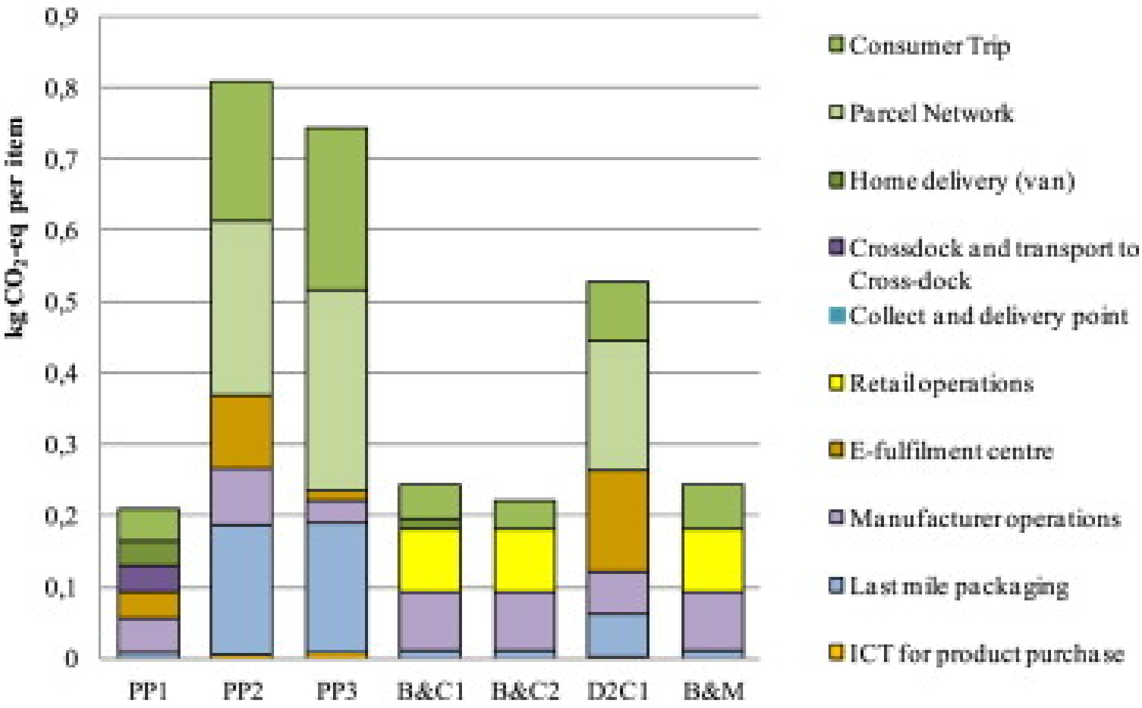


Figure 2.8: Scenario 2, from Van Loon et al., (2015)

The author claims that "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". Moreover, "when failed deliveries occur, the consumer can pick up items at a local shop, leading to a shorter distance than when the consumer has to pick up items at a carrier depot as is the case with failed parcel deliveries." Another important aspect is that click&collect in this scenario is almost as performing as pure player van deliveries. Of course, the impact of customers picking up the order in the store depends also on the transportation mode used. However, a significant change arises due to the variation of the basket size. Indeed, if only one item per order is considered, the parcel network becomes definitely more sustainable. This result is a consequence of the fact that pure players tent to split large orders into several packages, since they might come from different supply points, increasing the carbon impact of the fulfilment process. The author concludes that 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 (figure 2.9).

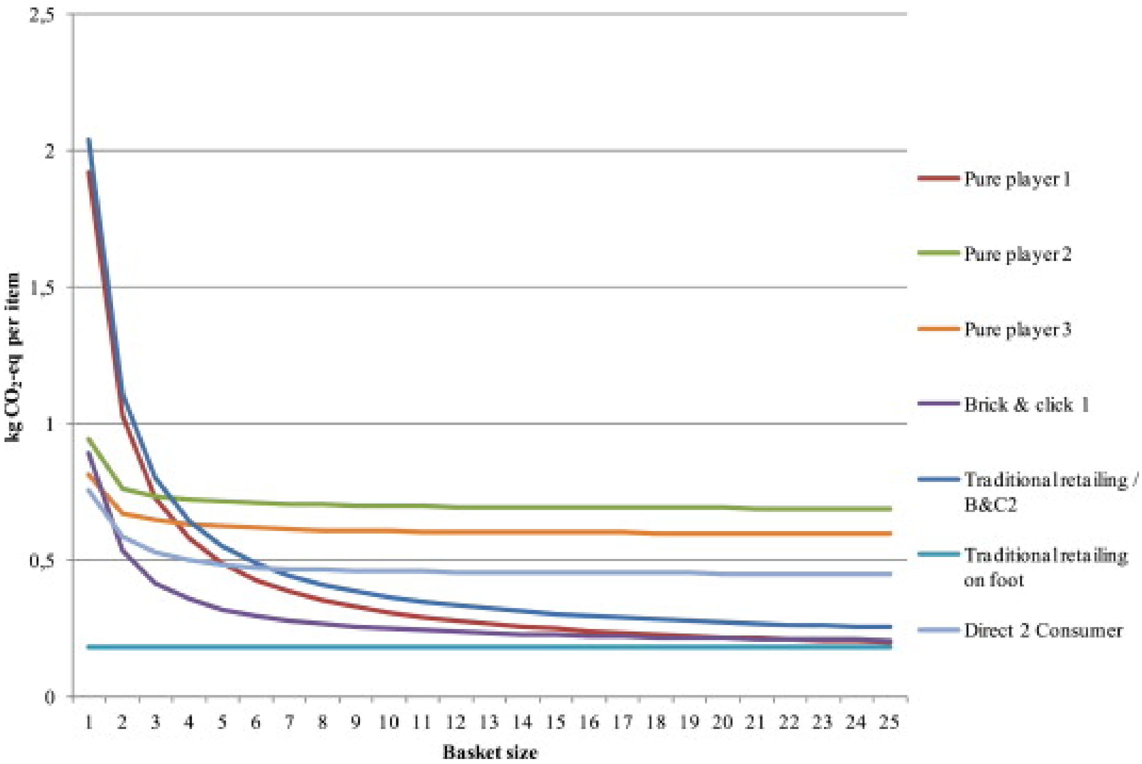


Figure 2.9: Emissions of various fulfiment methods in respect to the basket size, from Van Loon et al., (2015)

In conclusion, the carbon footprint of the different delivery methods depends on several parameters which are case-specific, thus a general and definitive judgement cannot be given. In order to perform an environmental comparison between home delivery and customer pick-up at an external structure which is not the store, the analysis will refer to Brown et al. (2014), who provides a decision framework to identify the optimal solution to fulfil customer order. The results of the mathematical model implemented in the article show that environmental efficiency is linked to the number of customers to serve. In fact, the paper identifies the break-even number of customers, after which home delivery is more sustainable than customers pick-up.

The break-even point depends on the value of a parameter "p", which represents "the proportion of distance that a customer travels that is devoted to the depot". Therefore, if we assume a sufficient customer base, last mile delivery performed by the minimum number of trucks required is more environmentally friendly. However, the paper assumes that all customer trips to collect the item are performed by car, which is likely, but not always true. To conclude, as pointed out by several studies, the potential of pick-up points strongly depends on the avoidance of additional customer trips, or the limitation of polluting transports. Still, home delivery is the most diffuse and easily optimizable delivery method since it implies a lower customer involvement.

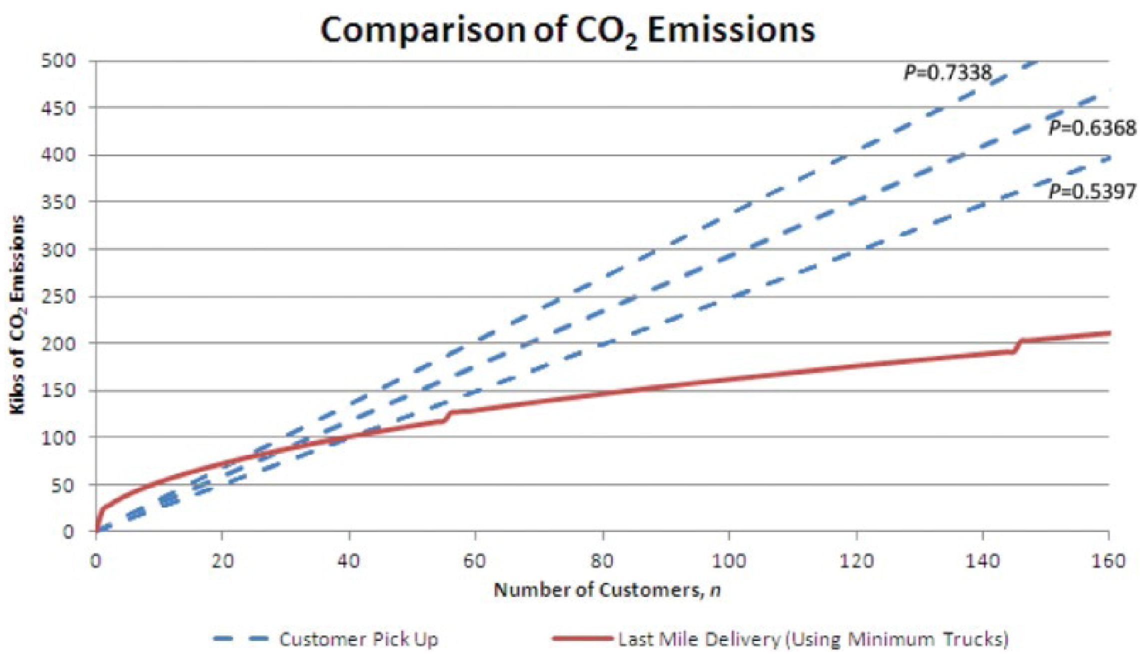


Figure 2.10: Relation between the number of customers to serve and the CO_2 emissioms, from Brown et al., (2014)

2.4 Variables analyzed

As explained in the review method section, each article has been analysed deeply with the aim of identify the main variables affecting e-commerce environmental sustainability. The aforesaid variables are included in the list only if the relation with emissions is clear and explained, as well as the main actors influencing them. After several reviews of the selected paper works, a final set composed of 28 variables has been created. These are the identified variables:

VARIABLE	PRODUCT/MARKET	E-TAILER	CUSTOMER	EXTERNAL	PRESENCE IN THE PAPER SET
buildings energy efficiency		X			19%
Country's policy and investments				X	6%
customer behaviour			X		15%
customer trip			X		23%
delivery frequency		X			4%
delivery method		X			33%
delivery speed		X			4%
delivery time window		X			13%
demand density			X		23%
distance				X	44%
failed deliveries rate				X	8%
impact of ICT				X	10%
inventory management		X			13%
location of pick-up points		X			4%
location of supply points		X			2%
number of supply points		X			2%
number of vehicles used for LMD		X			2%
order size			X		10%
packaging	X	X			35%
picking strategy		X			8%
product shelf life	X				6%
product temperature	X				8%
product type	X				6%
return rate			X		27%
revenue model		X			2%
transportation mode		X			19%
vehicle capacity		X			4%
vehicle utilization		X			2%

Figure 2.11: Set of variables analyzed in the selected papers

This section will go through the description of all the variables, explaining the way they have been defined during the analysis and their link with e-commerce carbon footprint. To clarify this last aspect, a conceptual model has been developed, which aim is twofold: first of all, finding the connection between the variables and the source of polluting emissions. In this sense, the main sources of emissions considered were:

- Retailer store
- Warehouses, which may include merchant central or regional warehouse, manufacturer warehouse or logistics provider depot
- ICT
- Truck transportation
- Van transportation
- Car transportation
- Product disposal
- Packaging production or disposal

Secondly, the analysis of the relation between each variable and the main actors involved in the e-commerce fulfilment process. Those actors are the merchant, which is the producer or the e-seller of the final product, the logistics operator, who in some cases deals with last-mile delivery, and the final customer. In case none of the previous mentioned actors is directly influencing the variable, the model groups all other external factors into one single cluster. Those external factors might be linked to product or market-specific aspects, as in the case of product shelf life, or other external actors, such as local government.

Moreover, the model acknowledges the presence of correlation effects among variables, which consequently impacts their final contribution to carbon footprint. In fact, there might be a variable whose primary effect on e-commerce sustainability is positive but, worsening the impact of another variable, it results harmful for the environment. Indeed, some variables included in the set are subject to a trade-off. For example, by increasing the temperature of a grocery product in order to save on refrigeration expenses you are reducing the product shelf life, thus having an impact on food-waste-related emissions. On the contrary, there might be also a variable whose positive effect on sustainability is enforced by a positive correlation with another variable, resulting in a higher beneficial effect. For instance, by reducing the delivery time window in home deliveries, you are also reducing delivery frequency, since the courier is now able to consolidate more orders and increase the saturation of delivery vans. For these reasons, during the analysis of the impact of the single variable, a focus on the big picture should be maintained. It is important to underline that the model depicts the connection between the identified variable, the actor and the source of emissions only if supported by the selected articles, even though other connections might be found referring to studies not considered in this review.

In addition, the conceptual model identifies the phase of the e-commerce purchasing process that is influenced by the considered variable, on the basis of the five phases defined by Mangiaracina et al. in the paper "Assessing the environmental impact of logistics in online and offline B2C purchasing processes in the apparel industry" (2016). Those phases are: PRE-SALE&SALE, ORDER PICKING AND ASSEMBLY, DELIVERY AND POST-SALE. More precisely, PRE-SALE&SALE "begins when the consumer accesses the internet and ends with the payment, including the search for an item using search-engines, browsing on the retailer website, item selection, the main actions conducted when the item is in the cart (e.g., filling out a form with personal data, choosing a delivery method, payment), and the possible interactions between the retailer and the consumer via e-mail and/or phone. Some of these activities may be carried out only once or multiple times, according to the purchasing behaviour of the customer"; ORDER PICKING AND ASSEMBLY "begins upon receipt of the order at the retailer warehouse and ends with cartons ready to be picked up by the courier in the shipping area. It includes activities such as picking and packing of the item";

DELIVERY "This phase begins when the cartons are picked up by couriers at the retailer warehouse and ends with delivery at the consumer house. It includes all of the main activities performed by the courier (i.e., transport from the retailer warehouse to the courier receiving hub and handling at the hub, transport to the shipping hub and handling at the hub) and the possible interactions between the courier and the consumer to provide/acquire information about the order tracking"; to conclude, POST-SALE considers a set of activities that may or may not take place, on the basis of many factors: "The trigger for post-sales activities is the consumer intention to return the item and it is assumed that the objective is the replacement of the purchased item. Given this premise, this phase starts out with a request for a return and ends with the delivery of the new item to the consumer house. It 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". In this analysis, it is included also the REPLENISHMENT phase, which considers all the activities performed by the merchant to replenish the store (or the regional warehouse) from the central warehouse, even if in the mentioned article this phase is considered only for the offline purchasing process.

Figure 2.12: Conceptual model showing the connection between the identified variables, emissions sources and the phases of e-commerce purchasing process

ACTORS				
EXTERNAL	P	R,O,D	P	O,D,P
MERCHANT				O,P
CUSTOMER				O,P
LOG OPERATOR				D,P
VARIABLES	PRODUCT SHELF LIFE	PRODUCT TEMPERATURE	PRODUCT TYPE	PACKAGING
MACRO VARIABLES	PRODUCT/ MARKET CHARACTERISTICS			PACKAGING

ACTORS				
EXTERNAL				
MERCHANT	O,D	R,O,P	O	D
CUSTOMER				D
LOG OPERATOR	O,D	O,D,P	D	D
VARIABLES	PICKING STRATEGY	INVENTORY MANAGEMENT	BUILDINGS ENERGY EFFICIENCY	DELIVERY FREQUENCY
MACRO VARIABLES	E-TAILER / LOG OPERATOR			

PRE-SALE & SALE	REPLENISHMENT	ORDER PICKING & ASSEMBLY
S	R	O
DELIVERY	POST-SALE	
D	P	

MACRO VARIABLES	E-TAILER / LOG OPERATOR			
VARIABLES	DELIVERY TIME WINDOW	DELIVERY SPEED	TRANSPORTATION MODE	VEHICLE CAPACITY
ACTORS				
EXTERNAL				
MERCHANT	D,P	D		
CUSTOMER	D,P	D		
LOG OPERATOR	D,P	D	D	D

MACRO VARIABLES	E-TAILER / LOG OPERATOR			
VARIABLES	N OF VEHICLES USED FOR LMD	VEHICLES UTILIZATION	DELIVERY METHOD	N OF SUPPLY POINTS
ACTORS				
EXTERNAL				
MERCHANT			O,D	D
CUSTOMER			O	
LOG OPERATOR	D	D		D

MACRO VARIABLES	E-TAILER / LOG OPERATOR			CUSTOMER
VARIABLES	LOCATION OF SUPPLY POINTS	LOCATION OF PICK UP POINTS	REVENUE MODEL	DEMAND DENSITY
ACTORS				
EXTERNAL				
MERCHANT	D	D	D,P	
CUSTOMER				D
LOG OPERATOR	D	D		

MACRO VARIABLES	CUSTOMER			
VARIABLES	CUSTOMER BEHAVIOUR	ORDER SIZE	CUSTOMER TRIP	RETURN RATE
ACTORS				
EXTERNAL				P
MERCHANT				P
CUSTOMER	D,P,O	O,P,D	D,P	P
LOG OPERATOR				P

ACTORS				
EXTERNAL	D,P	P		D
MERCHANT			R,O,P	
CUSTOMER		P	S	
LOG OPERATOR		P	O,P	
VARIABLES	DISTANCE	FAILED DELIVERY RATE	IMPACT OF ICT	COUNTRY'S POLICY AND INVESTMENTS
MACRO VARIABLES	EXTERNAL VARIABLES			

Figure 2.13: Conceptual model showing the connection between the variables, the actors involved and the phases of e-commerce purchasing process

CO2 EMISSION SOURCES				
STORE		O		
WHS/DEPOTS		O	P	
ICT				
TRUCK		R		D
VAN		D	P	D
CAR			P	
PRODUCT DISPOSAL	P		P	P
PACKAGING PRODUCTION/DISPOSAL			P	P
VARIABLES	PRODUCT SHELF LIFE	PRODUCT TEMPERATURE	PRODUCT TYPE	PACKAGING
MACRO VARIABLES	PRODUCT/ MARKET CHARACTERISTICS			PACKAGING

CO2 EMISSION SOURCES				
STORE	O		O	
WHS/DEPOTS	O	O	O,D	
ICT				
TRUCK		R		
VAN		D		D
CAR				
PRODUCT DISPOSAL	P	P		P
PACKAGING PRODUCTION/DISPOSAL				
VARIABLES	PICKING STRATEGY	INVENTORY MANAGEMENT	BUILDINGS ENERGY EFFICIENCY	DELIVERY FREQUENCY
MACRO VARIABLES	E-TAILER / LOG OPERATOR			

CO2 EMISSION SOURCES				
STORE				
WHS/DEPOTS	P			
ICT				
TRUCK				
VAN	D,P	D	D	D
CAR	P			
PRODUCT DISPOSAL				
PACKAGING PRODUCTION/DISPOSAL				
VARIABLES	DELIVERY TIME WINDOW	DELIVERY SPEED	TRANSPORTATION MODE	VEHICLE CAPACITY
MACRO VARIABLES	E-TAILER/LOG OPERATOR			

CO2 EMISSION SOURCES				
STORE			O	
WHS/DEPOTS			O	
ICT				
TRUCK				
VAN	D	D	D	D
CAR			D	
PRODUCT DISPOSAL				P
PACKAGING PRODUCTION/DISPOSAL				
VARIABLES	N OF VEHICLES USED FOR LMD	VEHICLES UTILIZATION	DELIVERY METHOD	N OF SUPPLY POINTS
MACRO VARIABLES	E-TAILER / LOG OPERATOR			

CO2 EMISSION SOURCES				
STORE				
WHS/DEPOTS				
ICT				
TRUCK				
VAN	D	D	D	D
CAR		D		
PRODUCT DISPOSAL			P	
PACKAGING PRODUCTION/DISPOSAL				
VARIABLES	LOCATION OF SUPPLY POINTS	LOCATION OF PICK UP POINTS	REVENUE MODEL	DEMAND DENSITY
MACRO VARIABLES	E-TAILER / LOGISTICS OPERATOR			CUSTOMER

CO2 EMISSION SOURCES				
STORE				
WHS/DEPOTS		O		P
ICT				
TRUCK				
VAN	D	D		P
CAR			D,P	
PRODUCT DISPOSAL	P	P		P
PACKAGING PRODUCTION/DISPOSAL		P		P
VARIABLES	CUSTOMER BEHAVIOUR	ORDER SIZE	CUSTOMER TRIP	RETURN RATE
MACRO VARIABLES	CUSTOMER			

MACRO VARIABLES		EXTERNAL VARIABLES		
VARIABLES	DISTANCE	FAILED DELIVERY RATE	IMPACT OF ICT	COUNTRY'S POLICY AND INVESTMENTS
CO2 EMISSION SOURCES				
STORE				
WHS/DEPOTS		P		
ICT			S	
TRUCK				
VAN	D,P	P		D
CAR	D,P	P		D
PRODUCT DISPOSAL				
PACKAGING PRODUCTION/DISPOSAL				

2.4.1 Product/market characteristics

The first set of variables refers to all those aspects of the fulfilment process that depends primary on product or market characteristics, such as product shelf life, product temperature and product type. In the list it is included also the variable "packaging", even though many actors may influence this parameter.

Product shelf life

Product shelf life is defined as "the length of time that a product may be stored without becoming unfit for use, consumption, or sale." In this review, this variable refers uniquely to food perishability, which has an impact on e-grocery sustainability. Perishability, indeed, is the primary cause of food waste, that, has already mentioned, has a huge negative effect on the carbon footprint of e-grocery. Moreover, perishability leads to high return rate in case of low-quality-product delivery, as explained by Guo et al. (2017). This implies that several additional activities must be performed to assure a correct re-delivery (e.g. re-picking and re-shipping) and that an additional amount of packaging must be used, leading to an overall unfavourable effect on environmental sustainability. Product shelf life depends mainly on product type (a can of tuna, for instance, has a higher shelf life than an apple or a milk derivative), thus it can be defined as an external variable.

However, referring to Belavina et al. (2017), merchant's managerial policies in terms of picking strategy and inventory management, as well as courier's delivery management, can affect the final quality of the product that reaches the customer. Moreover, the customer itself might have an influence on food waste in this sense on the basis of the order size. If the order size is higher, order frequency is lower, but at the same time the risk of food spoilage is increasing, resulting in a controversial effect on emissions. Since the primary effect of product perishability is food waste, the only phase of the e-commerce purchasing process affected by this variable is the POST-SALE. To sum up, even if this variable is considered only in 3 articles, due to the correlation with many other variables, its final effect on e-grocery carbon footprint might be substantial, thus specific attention regarding this product-specific parameter is recommended.

Product temperature

Product temperature is another variable which depends on product characteristics and e-grocery-specific. In this analysis, product temperature is the correct or sufficient temperature at which the product must be maintained during the fulfilment process from the producer to the final customer, in order to avoid food waste and related emissions. To assure the adequate temperature, both the merchant and the courier must sustain refrigeration costs during the journey of the product, impacting warehouses energy efficiency during ORDER PICKING AND ASSEMBLY as well as fuel consumption during DELIVERY and REPLENISHMENT. Moreover, also the store energy efficiency is influenced, in case of in-store picking. The specific temperature is considered independent from any decision of the actors involved, even though different refrigeration mode exists that might assure the same result with different levels of energy consumptions and emissions.

Regarding this aspect, Heart et al. (2019) reports that with the introduction of meal kit refrigeration packs, the average emissions related to product temperature maintenance would be reduced by 0.37 $KgCO_2eq$ per meal. Those refrigeration packs are composed mainly by water, even though the study underlines that this solution is not suitable for all kind of meal kits, and that different chemical-based refrigerants would increase emissions. On the other hand, Carrillo et al. (2014) claims that the refrigeration capabilities needed for e-grocery delivery vans and trucks is one of the reasons that might offset the environmental advantages of e-commerce in the food sector.

Product type

As explained before, the product type has a strong influence on the CO_2 emissions related to e-commerce, since it influences many aspects of the related supply chain. For instance, according to Heard et al. (2019), the product type influences on one hand the emissions related to food waste and on the other hand the amount of packaging necessary during the fulfilment process. Moreover, Edwards et al. (2011) claims that the characteristics of the product affect also the return rate: in this study, grocery, apparel, book and consumer electronics industry are compared on the basis of the percentage of returned products, which is higher for clothes, between 20-40%, and lower for books, about 3%. As a result, carbon emissions related to all the activities that must be performed in case of product return are significantly higher in the apparel industry, due to the huge quantity of returned items. Of course, this variable cannot be controlled in any way by any actor.

However, it is relevant to understand which are the relative strengths or weaknesses of the product in environmental terms, in order to be able to exploit the strengths and limit the weaknesses. In the case of the apparel industry, since the rate of returns is relevant, a particular attention must be put on optimizing all the related activities such as collection of returned items, re-packing and re-shipping, resulting in a considerable reduction of CO_2 emissions.

Packaging

This variable refers to the amount of packaging used during the entire life cycle of the product, including both primary (e.g. the package in direct control with the product) and secondary (e.g. the case containing the primary package) package. In particular, the emissions related to packaging disposal are considered, which directly depends on the volume of packaging utilized. Moreover, in the post-sale phase of e-grocery purchasing process, the type and amount of packaging might also affect the perishability of the product, hence food waste emissions. Indeed, according to the study conducted by Gee et al. (2019), a reduction of the packaging weight or a change towards more eco-friendly packages, which leads to lower packaging-related emissions, might affect product shelf-life. However, this relation is difficult to assess, and the author suggests that alternative packaging or recyclable packaging could be convenient even so.

Another source of environmental impact linked with this variable are transportation-related emissions. The amount and shape of packaging can have an impact on truck and van saturation, affecting the overall distance travelled to deliver the product. Moreover, Olah et al. (2018) argues that the right kind of packaging leads to lower returned items. In this sense, packaging is a variable under the direct control of the merchant during the preparation of the order and, for what concerns the secondary packaging and final delivery, of the logistic operator. Regattieri et al. (2014) conducted a study to develop a framework for the design of the packaging which aims at optimizing e-operations and related costs and reduce the environmental impact. The framework includes considerations regarding protection of the product, handleability, security and respect for the environment. In particular, for what concerns sustainability, the author suggests the use of reusable packaging together with air pillows as filling solution, which are composed by 99% of air. However, as mentioned before, packaging is also product-dependent, and in some cases, it might be influenced by customer decisions as well, considering that a greater order size means often greater packaging required. As a consequence, the overall effect of this particular variable on e-commerce sustainability is as relevant as complicated to assess, as it requires several trade-offs.

2.4.2 E-tailer/logistics operator decisions

The second set of variables includes all those parameters that the merchant or the logistics operator are able to directly influence, impacting its carbon footprint.

Picking strategy

As anticipated in the analysis of the processes, the picking strategy adopted by the merchant or by the logistic operator has a strong impact on e-commerce sustainability. In particular, it can affect the energy efficiency of the warehouse or the store in which is performed and the level of food waste, by impacting the quality of the product delivered. Thus, an important aspect to consider is the picking location, as pointed out by Van Loon et al. (2014). In this paper, it is reported that performing the order picking in a warehouse could be more energy efficient than store picking, especially if the warehouse is designed specifically for e-commerce orders. However, the picking strategy adopted is strongly correlated with the delivery method chosen, thus a more comprehensive approach should be maintained.

A study focused on this aspect is the one conducted by Durand et al. (2012), which compares regional warehouse picking combined with home delivery, depot self-pick-up and in-store picking combined with both home delivery and click&collect. Depot is defined as "infrastructures, exclusively dedicated to storage and to order-picking", located close to the consumption point. Moreover, the study provides real-life examples of the strategies adopted by French players such as Auchan and Carrefour. According to this study, depot self-picking is the most attractive solution in environmental terms, even though it is the costliest and requires longer times to be developed.

Inventory management

Another aspect linked with picking strategy is the inventory management. This connection is accurately described by fikar (2018), as reported in the analysis of the WAREHOUSING process. From this study, it is possible to understand that inventory allocation may impact on one hand the quality of the final product delivered and the level of food waste (in case of e-grocery supply chain) in the POST-SALE phase, and on the other hand the total distance travelled by the courier during the DELIVERY phase and by the merchant during the REPLENISHMENT process. As underlined in the paper, those two aspects are in a firm-specific trade-off, thus they might be carefully analyzed.

As for picking strategies, also inventory managerial policies influence the energy efficiency of the warehouse, even though many articles focus their attention on the inventory level along the supply chain. Velasquez et. Al (2009) and Van Loon et al. (2014) suggests that centralized management of inventories could reduce energy and resources usage, as well as environmental impact, thanks to a reduction in the inventory level, exploiting the "square root law". "This "law" dictates that, other things being equal, the more centralized the inventory, the smaller are the amounts of inventory needed to maintain a given level of product availability". Siikavirta et al. (2002) considers as one of the potential benefits of e-commerce against traditional retailing the reduction of inventory levels, which leads to fewer warehouses needed and to lower energy consumption. Abukhader et al. (2004) evaluates the possible environmental effects of the application of just-in-time (e. g. JIT) practices. According to the author, JIT lead to overall lower inventory level, which implies less pollution coming from production, but it might increase wastes, since the small batches typical of this particular philosophy require more frequent changeovers. Moreover, the inventory level has a strong positive correlation with food waste, thus forecasting accuracy in the grocery industry, as highlighted by Gružauskas et al. (2019), is of primary importance.

Buildings energy efficiency

With buildings energy efficiency is intended the contribution of warehouses, depots and stores energy consumption to e-commerce carbon footprint. This variable has an impact on the ORDER PICKING AND ASSEMBLY phase for what concerns stores and merchant's warehouse, while it influences the DELIVERY phase in case we are considering logistics operator's warehouse or depot. The energy efficiency depends primary on merchant's and courier's managerial policies, such as picking and inventory policies, but it has also a correlation with product type and temperature. If we consider fresh food, indeed, the necessity of maintaining the product at a specific temperature strongly increase energy consumption of warehouses and stores.

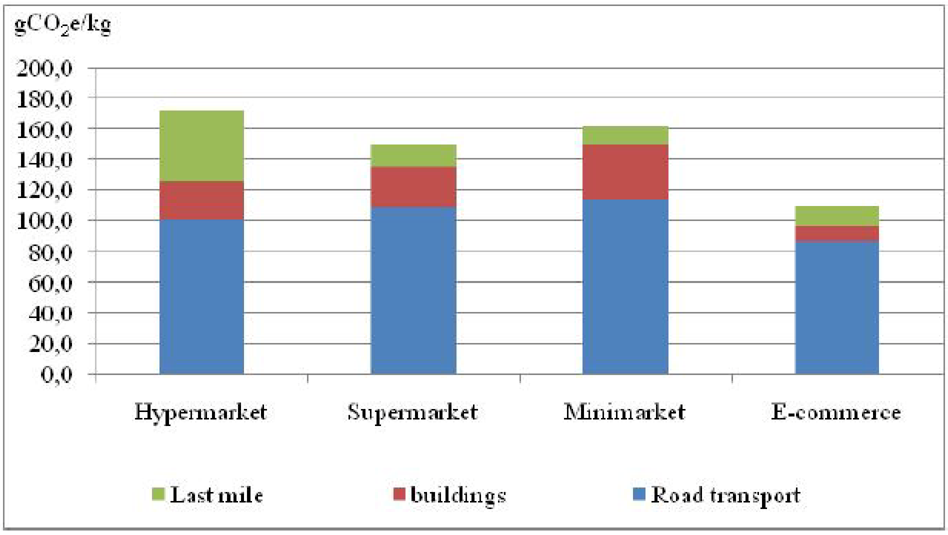


Figure 2.14: GHG emission of different yogurt supply chains in the Paris region, from Rizet et al., (2010)

Moreover, on the basis of the market the e-tailer is operating in, the warehouse will have specific characteristics, such as dimensions and level of automation, that will have an impact on the amount of energy needed to make it operational. This specific variable is crucial in the environmental comparison between e-commerce and traditional retailing, since it is one of the main sources of CO_2 emissions of the latter, as described by Zhao et al. (2019). This great difference is due to the energy consumptions of stores, which often are absent in the case of e-tailing strategies. Moreover, "A warehouse holds far more merchandise than a shop, yet uses considerably less energy;" Edwards et al. (2011) claims. In this sense, Zhao et al. (2019) suggests that "More integrated shopping centers and energy-saving measures in lighting and air conditioning are needed". Rizet et al. (2010) reports that, for what concerns the grocery industry, e-commerce fulfilment centers are more environmentally efficient than shops, since they avoid air conditioning, high lighting consumptions and other electrical equipment.

This variable includes considerations concerning the store size and location as well. For instance, Mangiaracina et al. (2016) claims that the size of the store has a "significant effect on the environmental impact of all of the in-store activities (e.g., interactions between the consumer and the salesperson, finding and trying on product, etc.)". Even though nine articles, the 19% of the total, analyze the relation between buildings energy consumption and environmental sustainability of e-commerce, very little indications about how to reduce the impact are provided.

Delivery frequency

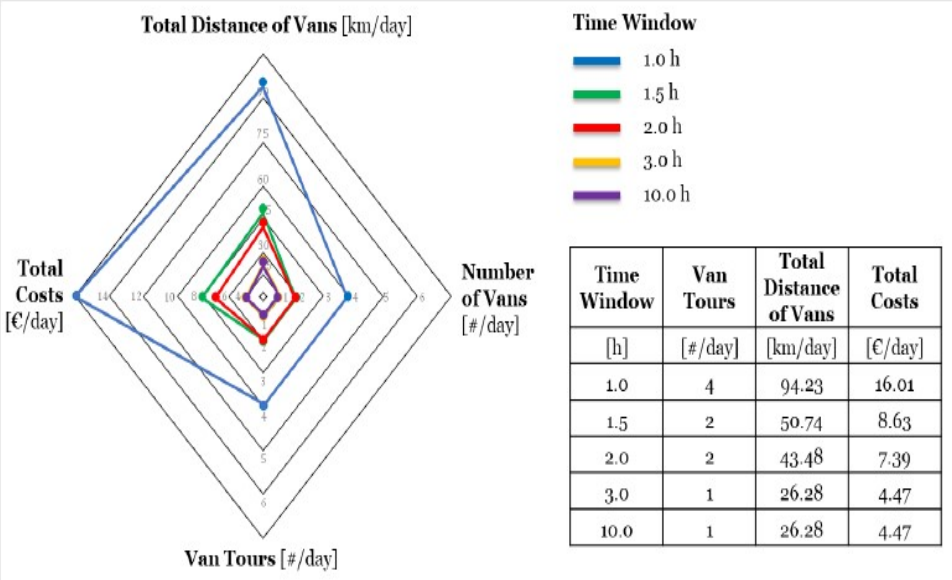
Delivery frequency is defined as the number of deliveries performed by the courier within a given amount of time. This variable is influenced on one hand by the order frequency coming from the final customer, on the other hand by the consolidation and routing policies of the courier. Furthermore, the e-tailer itself may affect the delivery frequency, by offering to the customer different options concerning delivery speed and delivery time window. In fact, delivery frequency is strictly connected to delivery time window and speed. As for all variables belonging to this subset, delivery frequency impacts e-commerce sustainability by influencing total distance travelled by the logistics operator, thus CO_2 emissions. In this sense, frequency is directly proportional to kilometers travelled and emissions.

However, this is not the only environmental effect of this parameter. Belavina et al. (2017) discusses the relation between delivery frequency and the level of food waste for e-grocery home deliveries. In this paper, it is stated that by increasing the delivery frequency, it is possible to extend the life of the product, consequently reducing the amount of food discarded. Moreover, the results of the simulation run by the author indicate that the positive effect on food-waste emissions overcomes the negative impact on distance travelled, thus reducing overall carbon footprint. This aspect is also connected to the decision of the merchant about what business model to pursue, which will be analyzed in the relative section.

Delivery time window

Delivery time window is defined as the interval of time within which the delivery will be performed by the courier. This interval is often the result of the match between e-tailer's and logistics operator's technical needs and customer preferences, even though the first two have greater decision-making power. In fact, not all couriers are willing to provide this service to the customer since it implies a reduction in delivery flexibility. However, the presence of time windows may have multiple positive effects on e-commerce sustainability. First of all, it reduces failed delivery rate, as pointed out by Van Loon et al. (2014), in case of attended deliveries. If the customer knows in advance when the order will be delivered, indeed, it is likely to be prepared to collect it, avoiding in this way all those activities related to POST-SALE phase that would doubtless impact sustainability. Secondly, time windows might be useful from the courier perspective as well, in order to better schedule the activities needed to perform a delivery tour. In this sense, the size of the time interval is crucial.

Leyerer et al. (2018) analyses following an optimization approach a 2-echelon grocery distribution network in which the customer can choose between home delivery, performed by electric cargo bikes, and self-pick-up at refrigerated grocery lockers. The objective of the paper is to "determining optimal grocery locker locations, optimized routes for direct locker-to-customer deliveries, and optimized routes for the locker-supply from a central depot", in order to minimize total costs of delivery and the related environmental impact. In analyzing the tour performed by the courier, the author shows as shorter delivery time windows implies low saturation of vans and consequently a higher number of vans needed, since the delivery frequency is growing. All this brings to higher delivery costs and CO_2 emissions.



Time Window	Van Tours	Total Distance of Vans	Total Costs
[h]	[#/day]	[km/day]	[€/day]
1.0	4	94.23	16.01
1.5	2	50.74	8.63
2.0	2	43.48	7.39
3.0	1	26.28	4.47
10.0	1	26.28	4.47

Figure 2.15: Benchmark results for different grocery locker-to-customer distances, from Leyerer et al., (2018)

Those results are confirmed also by Van Loon et al. (2014):"Widening the delivery time window also improves the delivery efficiency and cuts emissions per order. Nockold analyzed the relationship between the width of home delivery windows and transport costs in London. Expanding the window from 180 minutes to 225 minutes and 360 minutes cut transport costs by, respectively, 6–12 and 17–24%. Giving the home delivery company freedom to deliver at any time yielded cost savings of up to a third". (...) "Basically, the larger the time interval, the more the flexibility of the retailer in organizing the vehicle routing, and the better the environmental sustainability of the FD service. This is also evident in the number of vehicles used for the service".

Delivery speed

Another important parameter related to the DELIVERY phase is the speed of the delivery. As for the delivery time window, the delivery speed depends on both the merchant and the courier, but also on customer preferences and product type. Customer expectations about delivery speed depends also on the type of product the customer is ordering: for grocery and consumer electronics market, same-day delivery is reality in the main cities, while in the apparel industry, especially if the item considered comes from abroad, the customer is willing to wait even a week to receive the order. Since Amazon raised customer expectations with same-day or even one-hour-deliveries, all e-commerce players had to struggle in order to be compliant with the new standard. This necessity often results in the use of more polluting solutions for transportations, such as airfreights, as pointed out by Siikavirta et al. (2002), or in less efficient consolidation process for the logistics operator.

Regarding this topic, Lin et al. (2018) analyses same-day package delivery transportation time costs, fuel costs and environmental costs, here defined as particulate matter with particle size lower than 2.5 μm (PM 2.5), since commercial vehicles are one of the major sources of those polluting emissions. As explained in the article, the PM 2.5 emission rate is negatively correlated with vehicle speed and directly correlated with vehicle weight. For this reason, if we only look at the average speed of the van, higher delivery speed might be associated with lower PM 2.5 emissions, assuming constant the weight. On the other hand, increasing the speed means increasing fuel consumptions and CO_2 emissions, so the overall result in environmental terms is probably negative.

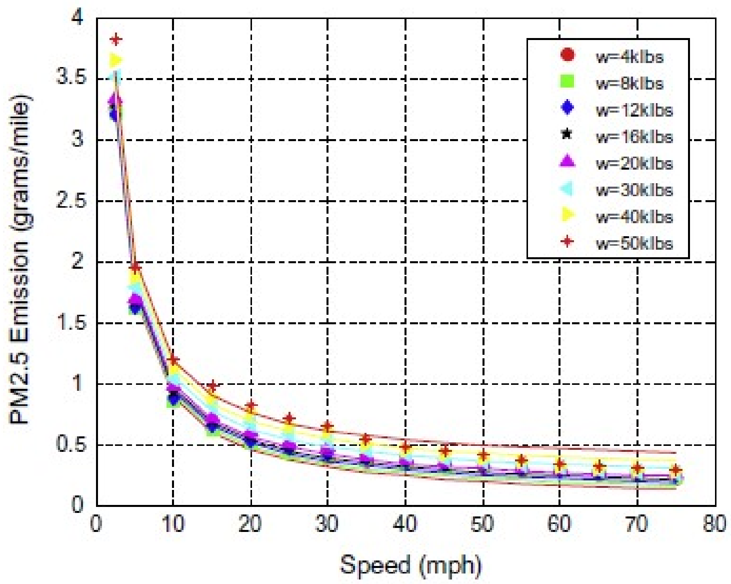


Figure 2.16: $PM_{2.5}$ emission factor curve, from Lin et al., (2018)

Manerba et al. (2018) compares different options offered to the customer in terms of delivery speed and time window, on the basis of van-kilometers travelled. The author states that “If the retailer adopts a fast delivery service, the environmental impact in terms of kilometers grows at a rate of almost 400%, when reducing the time interval width from the whole day down to 2 hours”.

To conclude, delivery speed, delivery time window and delivery frequency are strictly connected, and the influence of customer preferences and expectations on those variables is becoming more and more important. Therefore, it is important to make the customer more sensitive and aware about environmental costs generated by the order.

Transportation mode

The variable “transportation mode” describes the means of transport chosen by the logistics operator to perform last-mile delivery. On the basis of the vehicle type used, last-mile delivery will have different levels of emissions, thus different environmental performances. Vans are largely the most diffused vehicle type for e-commerce home deliveries, due to the flexibility and the accessibility in terms of costs. Recently, hybrid vehicles and electric vehicles are gaining momentum, along with cargo bi- and tricycles, as Leyerer et al. (2018) reports. This new trend is the result on one hand of the will of the logistics operator to become more sustainable, on the other hand of public incentives offered by local government for the purchasing of vehicles considered "greener". Despite the fact that a LCA could question the real sustainability of electric vehicles, this is definitely a way to reduce polluting emissions in urban areas, which is one of the most important concerns of green city logistics. Furthermore, the use of cargo bikes would also reduce other negative externalities, like road traffic and noise, even though it is limited in terms of capacity and speed.

Arnold et al. (2018) reports the outcomes of a study performed in London, which supported the potential also in terms of costs of a combination of urban distribution and bike deliveries. However, the necessity of public intervention to support this solution, for example with investments in new depots to perform cross-docking, is highlighted in the article. The author concludes that "a delivery system based on cargo bikes can be beneficial for all the stakeholders, if it is correctly implemented and incentivized. It requires a sufficient density of DPs in the city, and a possibility for customers to pick up parcels themselves." Transportation mode depends on several product characteristics, like product size, weight or perishability. In this sense, electric cargo bikes, if equipped with refrigerated systems, are suitable for e-grocery deliveries, while other industries such as medium-large size consumer electronics might require the use of vans. Another interesting solution which is growing in terms of popularity is crowd shipping, that will be properly described in the section dedicated to innovative solutions.

Vehicle capacity

Vehicle capacity is a fundamental parameter when considering e-commerce last-mile deliveries. In fact, the greater the capacity of the single vehicle, the smaller is the number of vehicles needed to perform the same amount of orders in the same zone, and thus the lower the emissions. Obviously, a vehicle having larger volumes costs more and has also a higher weight, but if we compare two vehicles that have to deliver a fixed number of orders, the larger one will be more efficient. The study developed by Zissis et al. (2018) goes in this direction. In the article, the author suggests resource sharing between e-tailers, in order to optimize transportation costs and reduce CO_2 emissions through orders consolidation and by avoiding overlapping deliveries. The figure below shows the results of the simulation, with greater savings in terms of distance travelled increasing the vehicle capacity. Moreover, the capacity utilization increases as well.

	Picking Location 1 (North)				Picking Location 2 (West)			
Capacity	C10	C15	C20	C25	C10	C15	C20	C25
Distance (↓)	6.4%	8.6%	10.1%	11.5%	5.5%	5.7%	9.4%	11.7%
Distance/route (↓)	4.0%	5.8%	6.5%	8.8%	4.6%	6.9%	8.4%	10.6%
Distance/order (↓)	6.4%	8.6%	10.1%	11.5%	5.5%	5.7%	9.4%	11.7%
Routes (max) (↓)	3.8%	5.0%	2.9%	7.1%	6.2%	3.4%	0.0%	3.0%
Stops/route (↓)	30.6%	38.7%	41.2%	42.5%	32.7%	42.2%	42.5%	42.6%
Driving Time (↓)	6.4%	8.6%	10.1%	11.5%	5.5%	5.7%	9.4%	11.7%
Driving Time/route (↓)	4.0%	5.8%	6.5%	8.8%	4.6%	6.9%	8.4%	10.6%
Drop-off Time (↓)	16.9%	20.5%	21.8%	22.1%	17.9%	21.6%	22.4%	22.5%
Drop-off Time/route (↓)	14.8%	18.0%	18.6%	19.8%	17.1%	22.6%	21.6%	21.5%
Total Time (↓)	9.5%	12.8%	14.9%	16.2%	9.5%	12.0%	15.3%	17.0%
Total Time/route (↓)	7.1%	9.9%	11.4%	13.5%	8.5%	12.6%	13.9%	15.5%
Vehicle Capacity Utilisation (↑)	2.4%	3.0%	3.8%	2.7%	0.8%	-1.1%	1.1%	1.2%

Figure 2.17: Benefits when two retailers collaborate with shared vehicles for the stem distance, from Zissis et al., (2018)

Therefore, capacity and utilization are strictly correlated. Indeed, increasing the capacity without a consequent growth of the saturation has the opposite effect on environmental sustainability.

Cairns et al. (2005) analyses several aspects related to home deliveries through a literature review, which underlines the positive effect on sustainability of a growth in vehicle capacity. Furthermore, vehicle capacity is also connected with delivery frequency and time window. According to Cairns, "the effects of introducing tight time windows can be assumed to be equivalent to a lower level of customer demand or vans with less capacity".

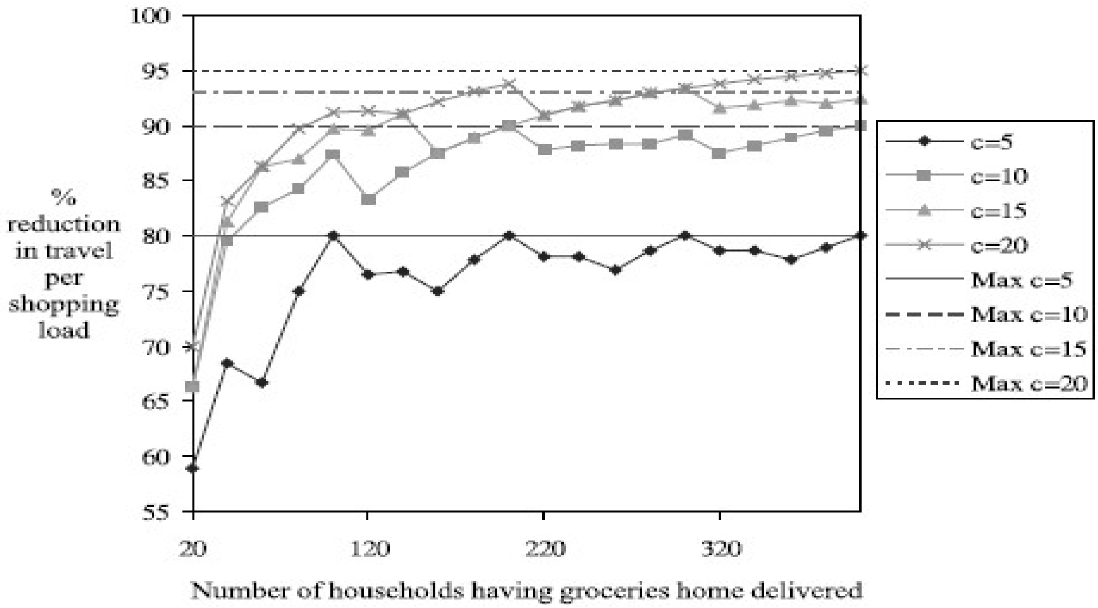


Figure 2.18: Reduction in travel from substituting individual car trips with home shopping trips as delivery vehicle capacity varies, from Cairns et al., (2005)

Vehicle utilization

As mentioned while discussing the vehicle capacity, vehicle utilization is positively correlated with a reduction in the carbon footprint of home deliveries. Hidayatno et al. (2019) develops a conceptual model that analyses the relation between capacity, frequency and utilization. He claims that e-commerce, since it implies a growth in the frequency of urban freights, results in the shipment of smaller quantities per delivery, inherently reducing transport saturation.

Number of vehicles used for last mile delivery

The number of vehicles used by the logistics operator for last-mile delivery has an impact on the total kilometres travelled and, as a consequence, on CO_2 emissions. This parameter is directly proportional to the total demand of the considered area, the size of the area and the order frequency, while it is inversely correlated with the capacity of the single vehicle. Brown et al. (2014) studies more in depth the relation between the number of vehicles and the customer demand, computing the minimum (and optimal) number of delivery trucks to serve a specific area on the basis of a variable demand.

In this way, the author identifies also the break-even point related to the demand, which, if optimized accordingly, grants to e-commerce an environmental advantage over traditional retailing. The intuition behind is that "as the number of trucks increases, the break-even number of customers rises because fewer trucks will always cover less distance to service the same number of customers". Several articles underscore the importance of reducing the number of vehicles optimizing the delivery routing. Lin et al. (2018), after solving a VRP, reduces the number of vehicles needed to fulfil customer orders from 138 to 77, significantly reducing the carbon footprint.

Number of supply points

Supply point identifies any point of origin, namely courier's warehouse, depots or merchant's store, used for the accomplishment of home delivery. This number can have an impact on emissions by influencing both the distance travelled and the level of food waste, in case of e-grocery home deliveries. This aspect is described accurately bi Fikar (2018), who claims that, from the e-tailer perspective, having a reduced number of stores from which performing the delivery can be cost-effective and sustainable at the same time. In this way, indeed, the e-tailer can exploit economies of scale and benefit from the reduced costs of inventory centralization. Moreover, the total distance travelled to fulfil the delivery is lower, since there is no store-to-store travel, and the overall degree of food waste is reduced, if we suppose that the item closest to the expiration date will be the first to be shipped (FEFO picking policy).

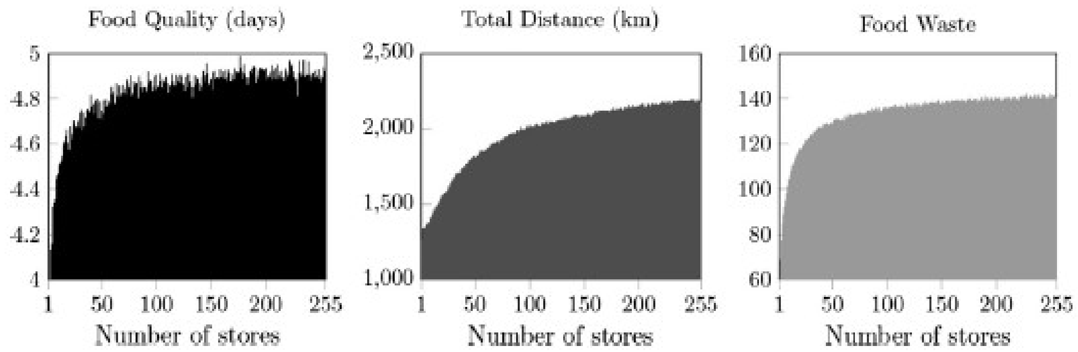


Figure 2.19: Impact of the number of operated stores in the problem setting considering a local FEFO strategy and the optimization objective to reduce travel distances, from Fikar, (2018)

However, we have to consider that such a reduction is in contrast with the aim of the e-tailer to maintain the required service level, as the average food quality (measured in days before expiration date) and the delivery speed would definitely drop.

To sum up, "fulfilling e-groceries from a large number of stores improves food quality at delivery, while a smaller number enables one to reduce travel distance and food waste substantially". A further beneficial impact that the choice of decreasing the number of stores could have on environmental sustainability concerns store size and utilization. In fact, being fixed the final demand, reducing the number of stores used to fulfil customer orders results in bigger stores with high utilization rates, which are often more energy efficient.

Location of supply points

As for the number, the location of supply points influences the carbon footprint of e-commerce, since it impacts the distance to the final customer, hence total kilometres travelled. As a consequence, the location choice is strongly dependent, among others, on customer location. Several articles are focused on the optimization of the supply point position, especially for what concerns depots and warehouses. Zissis et al. underlines the importance of warehouse and depot location to reduce total distance travelled, which in the context described in the paper is even more relevant, since it suggests resource sharing among e-tailers to exploit economies of scale in distribution. If the hypothesis proposed by the author were realized, there would not be travel overlapping, and the total distance travelled by the entire fleet would be minimized.

The same concept is analysed by Carling et al. (2005), who analyses the difference in terms of emissions between e-commerce and traditional retailing, and claims that "The suboptimal location of retailers generated on average 22% more CO_2 emissions than did a case in which they were optimally located". For this reason, the author uses the p-median model to find the more sustainable location of stores. The model was developed by Hakimi in 1965, and aims at reduce the average individual distance by locating the centres on the basis of the distance from the demand point and of the mass of the demand point, assuming to assign the single demand point to the closest centre. Even though in the paper it is considered only the location of traditional retail store, this approach could be easily extended to all aforesaid types of supply point with similar results. However, the decision about the location depends on several other factors that might not relate to sustainability, such as land cost and presence of infrastructures. In addition, also Fikar (2018), after discussing the optimal number of stores to fulfil customer orders, underlines the importance of store location in the decision-making process.

Location of pick-up points

The same reasoning explained for the location of supply point could be followed to analyse the positioning of pick-up points, in case of customer self-pick-up. Even in this case, indeed, the parameter that will be affected is the total distance travelled in the DELIVERY phase, thus CO_2 emissions. Carotenuto et al. (2018), for instance, develops a simulation to solve a capacitated-vehicle-routing-problem considering the position of pick-up points as a variable. For what concerns pick-up points, the decision for the e-tailer is someway easier, since it is usually a place already visited by the customer, which does not need to be built for the sole purpose of self-pick-up, as for depots. In the study, which is focused particularly on lockers, the author reports that "Locker location is a determinant factor in allowing these systems to be exploited to a greater extent. The idea is to combine home-to-work travel with travel to reach the locker. Therefore, the best places are supermarkets, shopping malls, service stations, pedestrian zones, etc., i.e. all areas where consumers expect to find them". Moreover, Giuffrida et al. (2012) underlines the importance of pick-up point location both for van travel and car travel reduction. The author claims that the location is more important for the environmental perspective than the number of pick-up points.

Revenue model

Another variable under the direct control of the merchant is the business model adopted. This decision, indeed, may have a huge impact on the carbon footprint of the fulfilment process. Belavina et al. (2017) compares from an environmental perspective two different business model: subscription business model, which implies for the customer the payment of a yearly fee and unlimited deliveries, and per-order business model, which requires a payment for each order issued. The study concludes that the subscription model results on one hand in a higher average food quality delivered, thus lower food-waste-related emissions, on the other hand, since it increases the delivery frequency, the emissions related to transportation grow. On the contrary, in the per-order model the delivery frequency drops as the customer has to pay for each order, but at the same time the average food quality is reduced, because the order size increases, increasing the probability that a single item expires. As a consequence, the e-tailer has to solve this trade-off, also considering the difference in terms of profitability between the two models. The overall environmental result will depend on several parameters, such as the size of the city and the characteristics of the products. At the end of the analysis, the author claims that subscription model is almost always the more sustainable solution, especially "in small cities, where the driving disadvantage is small; for low margins, high delivery costs, and high store visit costs (all of which increase waste because of lower adoption rates); and for low mean demand and product life, which increase waste in the per-order model".

2.4.3 Customer related

This subset groups all those variables related directly to the final customer, both in terms of location and behavior. The customer location is analyzed in the variable "demand density", while the customer behavior is divided following four different aspects: the order size, the customer trip, the return rate and customer behavior more in general, which includes all those aspects related to the customer not mentioned in the other three variables.

Demand density

As explained in the previous paragraph, with demand density is intended the location of customers inside the considered area. More specifically, the variable considers the impact on e-commerce sustainability of the average distance between two subsequent customers who have to be served by the logistics operator in the same delivery tour. Following this definition, if the area of interest has a higher demand density, the distance between two orders will be reduced and the delivery will result as more efficient and sustainable at the same time, as supported by Arnold et al. (2018).

Furthermore, this aspect is underlined also by Van Loon et al. (2015), which defines the variable as "drop density" and claims that "an average rural delivery round results in five times higher $CO2$ emissions per item than deliveries in a typical city center".

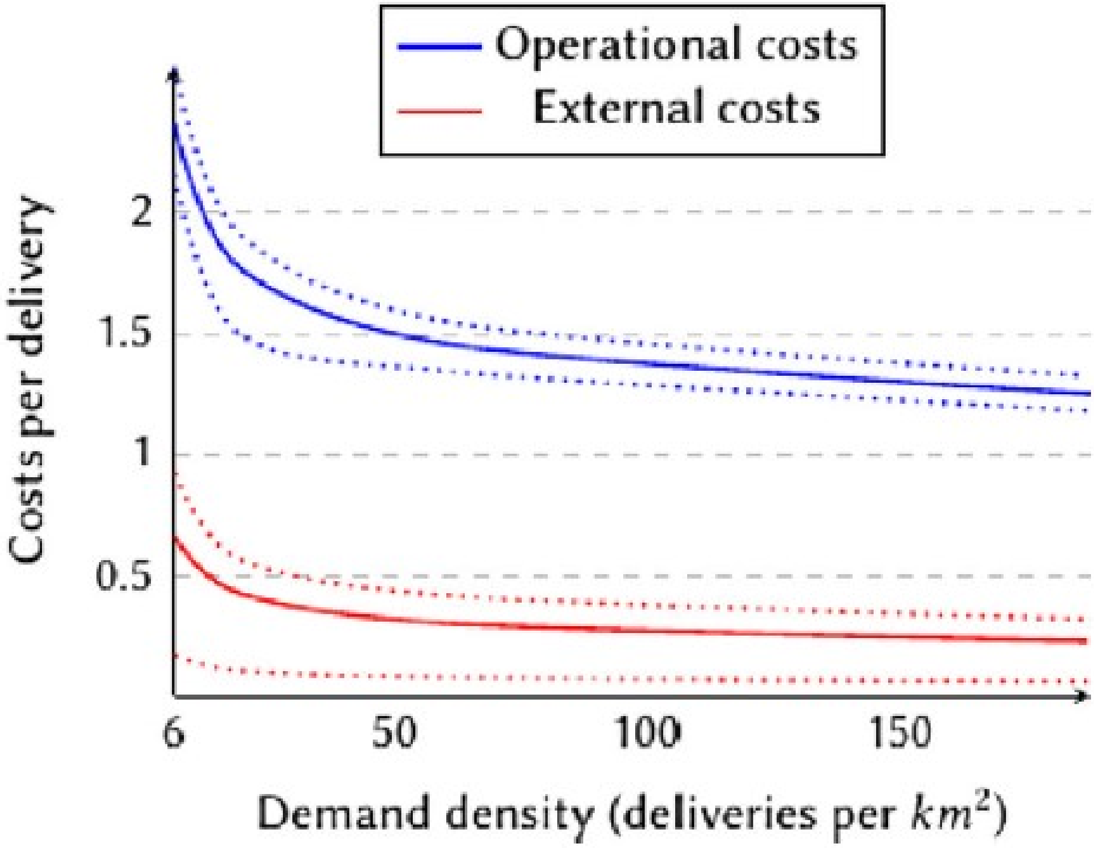


Figure 2.20: Costs per delivery as a function of demand, from Arnold et al., (2018)

Even though several articles underline its importance within the analyzed scope, this variable is difficult to control or influence for all the involved actors. What e-tailers and couriers can do is to acknowledge the importance of this parameter and act consequently. For example, the e-tailer or the courier may choose to locate a warehouse or depot near to a high-density area, in order to reduce transportation-related costs and emissions. For this reason, demand density is correlated to the distance between the supply point and the final customer, as reported by Wiese et al. (2012). In fact, high demand density is associated to shorter distance to stores, warehouses or depots. As a consequence, this variable has a fundamental role in the comparison between traditional brick and mortar retail and e-commerce in terms of sustainability. Zhang et al. (2013) reports a study from Williams and Tagami (2002), who selected three different Japanese cities and compares the environmental impact of online and conventional book retailing considering the difference in population density. "Their results indicate that in dense urban areas, each book traded through e-commerce consumed more energy because of the additional packaging used (5.6 MJ/book) compared with conventional retail (5.2 MJ/book)."

Customer behavior

The variable "customer behavior" describes all those aspects related to customer decisions and habits which are not connected to order size, customer trip and return rate. The effect on e-commerce sustainability, even if it is often difficult to quantify, is significant and includes almost all the sources of polluting emissions. As reported in the matrix, this aspect influences the environmental performance in three different phases: "ORDER PICKING", "DELIVERY" and "POST-SALE". For instance, Gee et al. underlines as the consume pattern plays an important role in the definition of the overall energy consumed, especially for what concerns "typical food waste habits from groceries and shopping habits (e.g. store-of-choice or fulfillment center proximity and frequency of grocery shopping trips), on per-week relative embedded energy".

Another aspect to consider, which is well described by Van Loon et al. (2015), is the effect that consumer preferences have on several parameters belonging to last-mile delivery, such as speed, frequency and time window of the delivery. In fact, if the customer demands frequently for one-day deliveries with a tight time window, not only the cost to sustain will be higher, but also the environmental impact. In this sense, Bertram et al. (2018) discuss the impact of e-commerce on fast-fashion sustainability, and claims that customers' expectations are putting more and more pressure on all the players involved in the fashion supply chain, who are required to reduce the lead time and increase the inventory level. As a result, the fast fashion industry is far to be sustainable. This aspect is reinforced by the study of Rai et al. (2019), which summarize the results of a survey by classifying the customer shopping behavior in six main categories: the traditional shopper, who choose exclusively brick and mortar retailing, the online shopper, the research shopper, who search the item online and the purchases it in store, the showroomer, who acts in the opposite way, the click&collect shopper and the ship-from-store shopper.

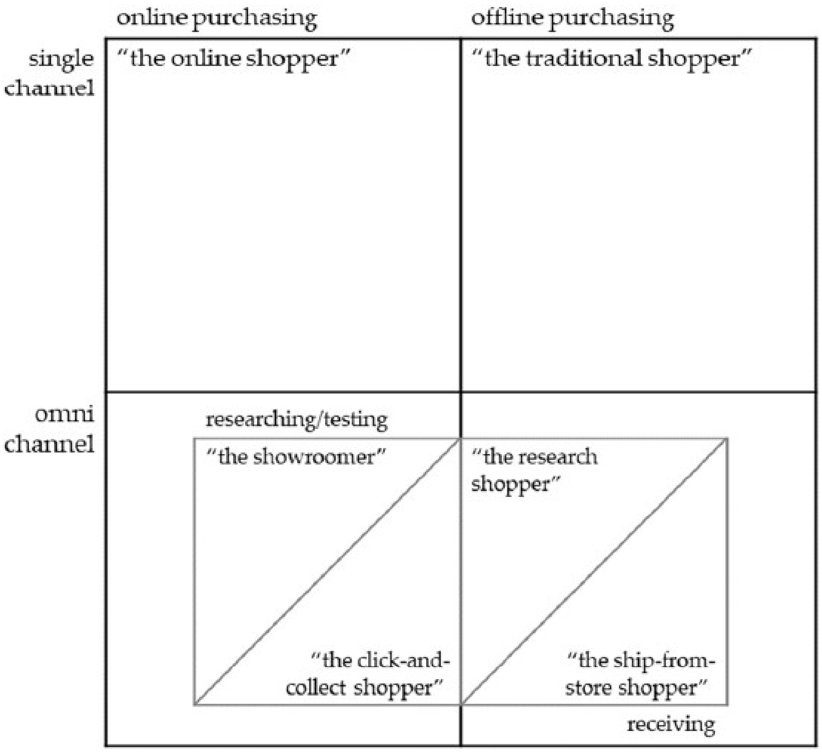


Figure 2.21: Six omnichannel shopping behaviour profiles, from Rai et al., (2019)

Even though the author recognizes the fact that omnichannel behavior depends on product type as well, customers purchasing path is unquestionably impacting the environmental efficiency of the fashion industry and of e-commerce in particular.

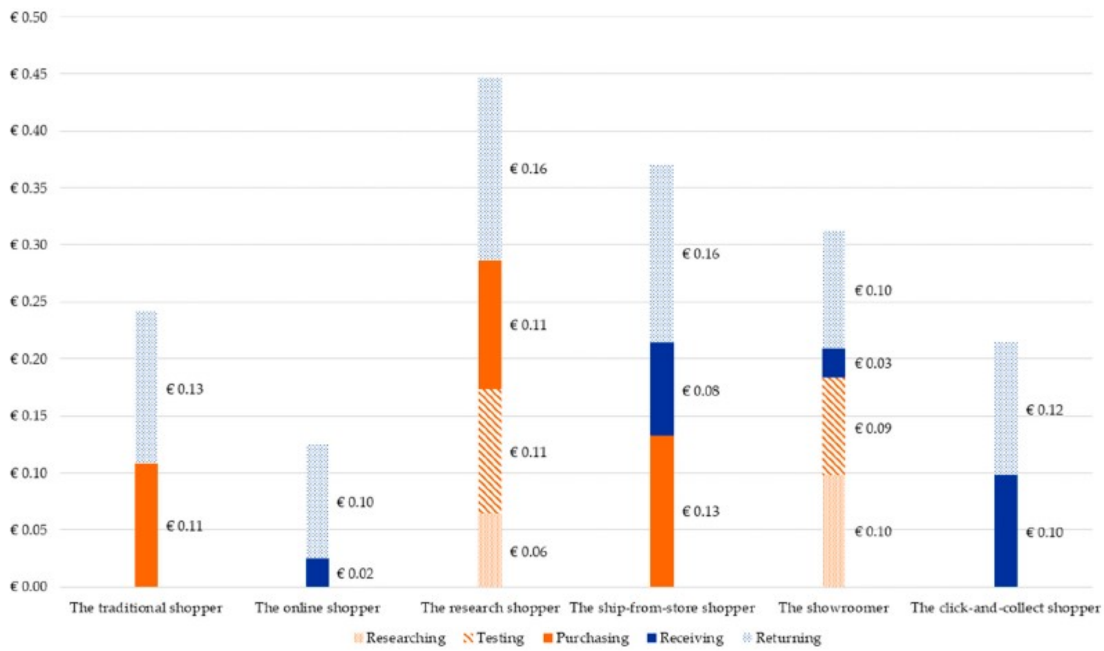


Figure 2.22: Total external transport cost for CO_2 emissions per omnichannel shopping behaviour profile, from Rai et al., (2019)

Order size

Another parameter through which the final customer may influence the environmental performance of e-commerce is the order size. The previous sections describe as this value has a strong effect on the fulfilment process. For instance, order size is inversely correlated to order frequency, upon which depends the level of food waste generated and the emissions related to the delivery tour. At the same time, the size of the order is connected to the amount of packaging delivered. Mangiaracina et al. (2016) compares the impact of different phases of purchasing process e-commerce and traditional retailing sustainability and highlights, among the others, the importance of single-item orders typical of online purchasing. The results of the study indicate that both handling activities and packaging suffer for the reduced order size in the online channel, which represent respectively the 38% and the 11% of total emissions. Furthermore, the author conducted a sensitivity analysis to analyze the impact of the number of items per order on the environmental efficiency of each activity performed to fulfil the customer demand. "The results highlighted that all of the activities – with the exception of warehousing – generate an environmental impact that is less than proportional to the number of items in both the online and offline purchasing processes".

Customer trip

Customer trip is defined as the transportation mode and the route that the final customer adopts to reach a store, a pick-up point or to return an item. This variable involved in the DELIVERY PHASE impacts the emissions deriving from customers car, if used, and depends primary on the mode of transport, the distance to travel, product type and the order size. Van Loon et al. (2015) compares different delivery models underlying this aspect as well and claims that the incidence of customer trip is much lower for van-based deliveries, when delivery windows are present, since the rate of failed deliveries is reduced. For what concerns the transportation mode, Van Loon et al. (2014) reports the results of a survey conducted in the UK, which states that "87% of people use their car to pick up a missed delivery at the carrier's depot, 6% walk, 2% cycle and 5% take the bus, but when the package can be picked up at a local CDP, 48% would walk, 43% take the car, 5% cycle and 4% take the bus.

Moreover, the article supports the strict relation between the distance to travel and the likelihood that the customer will use the car, as it was expected. Another point to make in this regard concerns the level of trip substitution. In fact, one of the most important environmental advantages of e-commerce lies in the capacity of reducing or avoiding consumers car trips. In this sense, Edwards et al. (2011) reports a study which identifies three possible scenarios regarding trip substitution: substitution thesis, which implies the complete elimination of customer trips, complementary thesis, which considers no significant change in the level of customer trips due to online purchases, and finally induction thesis, which hypnotizes even the increase of customer trips to shops, as a result of online-based information, and to other location thanks to the time saved through online purchasing. Since all three scenarios are realistic, on the basis of the percentage of occurrence of each scenario, the customer trip will have different effects on e-commerce sustainability.

Return rate

The return rate is defined as the percentage of orders delivered to the final customer that are returned to the courier or directly to the e-tailer through different ways. The choice to return the item delivered depends on the propensity of the customer, the accuracy of the delivery process and the product type. Accuracy of the delivery includes exactly the right item or items ordered, in the expected conditions and with the appropriate packaging. The importance of packaging is underlined by Van Loon et al. (2014), who states that the attractiveness of packaging may transmit the value of the purchased product, discouraging returns. As a matter of fact, returns are typical of the apparel industry (about 20-40%) or consumer electronics, while in the grocery, as many articles claim, are uncommon.

On the contrary, Guo et al. (2017) reports that, since e-grocery is becoming more and more popular in China and fresh good may be easily spoilt, the return rate is significant in this industry as well. Intuitively, returns increase the amount of packaging and food waste, but this is not the only effect. Edwards et al. (2011) highlights the importance of return method on the carbon footprint of e-commerce. If the item is collected by a parcel carrier during a delivery tour, indeed, the emissions might be minimal, even though both the logistics operator and the e-tailer would still have to manage the returned item in the warehouse or in the depot, to prepare re-delivery or dispose it.

Despite, if the customer is performing the return, the difference stands in the place the customer has to reach. If we consider return to a depot or warehouse of the courier, the customer will probably use the car, and those emissions are already mentioned under "customer trip". However, if the return has to be performed in a nearby store, the customer might consider reaching it by foot, by bicycle or through public transportation, not impacting the carbon footprint. Mangiaracina et al. (2016) analyses the link between customer behaviour and return rate by clustering the customer base of the apparel industry in three categories: the "fashion addicted" consumer, with high propensity for returns disregarding the characteristics of the item; the "moderate" consumer, who returns the item only when the size or the colour is not coherent with what purchased; the "apathetic" consumer, who is focused on minimizing the time spent in the purchasing process and thus returns the item only if it is defective or there is a huge mistake in the size. To sum up, to reduce the environmental impact arising from product returns, three actions should take place: first, the e-tailer and the courier should work together to assure maximum delivery conformity; secondly, there should be a sensibilization of the final customer towards the reduction of avoidable product returns; third, in case of product return, there should be the possibility for the courier to collect it without incurring in an additional tour.

2.4.4 External variables

This subset of variables includes all those parameters which influence the environmental impact of e-commerce that are not under the direct control of the actors considered in this analysis and that do not depend on market or product characteristics, but are generalizable to all industries. In particular, the aforesaid variables are: Distance, Traffic, Failed delivery rate, Impact of ICT and Country's policy and investments.

Distance

The variable Distance indicates the distance between the supply point of the delivery, being a store, a depot, a warehouse or a pick-up point, and the final customer, as well as the distance between the customer and the return point. As a consequence, this parameter will impact van and car-based emissions. This variable is the most analysed among the ones defined in the set, being present in the 44% of the articles. The distance that the logistics operator has to cover in case of home delivery can be divided in two elements, following the terminology used by Zissis et al. (2018): "drop distance, which is the distance travelled once a drop or delivery zone is reached and stem distance, which is the distance to and from a delivery zone". The drop distance is strictly correlated to the customer density as it has been defined, while the stem distance depends on the number of supply points. To reduce this last value, the author proposes to share vehicles among grocery e-tailers for the stem distance, in order to avoid travel overlapping and exploit scale economies.

According to the study, the possible benefits coming from collaboration could be the reduction by more than 10% in the distance travelled and by 16% in the time of delivery. The impact of this variable is manifold: Gee et al. (2019) claims that, in case of long distance between the customer and the grocery store, the ability of e-commerce, in this particular case meal-kits delivery, to reduce the shopping frequency is even more significant. Furthermore, as pointed out by Leyerer et al. (2018), small distances to run encourage the customer to pick-up or to return the product by bicycle or by foot, thus reducing emissions and traffic. Therefore, the e-tailer and the courier are strongly incentivized to consider this variable when deciding the location of the supply points, especially for what concerns pick-up points, which are more flexible and easily movable.

Failed delivery rate

Failed delivery rate represents the percentage of unsuccessful deliveries, either because the customer was not at home or because the logistics operator was not able to perform the delivery. When this event occurs, the customer may ask for a second delivery or, if the logistics operator does not offer this service, has to collect the order to the warehouse, depot or eventually to a near store. In the first case, the impact on sustainability will depend on the possibility for the courier to perform the re-delivery without incurring in extra tours, while in the second scenario, the carbon footprint would be affected if the customer decides to retire the order by car. Anyway, failed delivery represents an inefficiency from the environmental perspective, also because the logistics operator would have to manage the returned order, increasing energy consumptions of the warehouse or depot.

As reported by many papers, another parameter that influences the impact of failed deliveries is the distance that the courier has to travel a second time, or the distance between the customer and the collection point. In the literature, there are controversial indications about the actual percentage of failed deliveries. For instance, Edwars et al. (2011) reports that the average value may vary around 11%, even though this source is not updated. Moreover, when a company requires personal reception and customer signature, this percentage might reach the 25%. In order to reduce this value, the author suggests the use of unattended reception boxes at home. Other solutions presented in the set of works are the use of delivery time window, in order to assure the presence of the customer, or customer self-pick-up. The sustainability of this last aspect, however, depends on the means of transport the customer uses to pick-up the order. If, as it happens frequently, the pick-up point is a place already visited by the customer, this solution is environmentally preferable.

Impact of ICT

This variable groups all the effects that the use of Information and Communication Technology (ICT) may have on e-commerce sustainability. The primary impact derives from the use of electricity, whose production is usually not carbon neutral. In this analysis, both the impact coming from customers PC's while issuing the order and from e-tailer and logistics operator's electronic devices is included. This second aspect is considered in the emissions of the warehouse or depot. Van Loon et al. (2014) considers in his literature review studies which, following a LCA approach, include the emissions deriving from the production and the disposal of devices as well, there denominated as "first-order effects". However, in the same review, it is reported that the production phase, in respect to the usage, has very little impact, and that the attribution of those emissions to the online order is questionable, thus it can be ignored. Furthermore, in his activity-based model, Mangiaracina et al. (2016) reports that computer-based activities involved in the PRE-SALE & SALE phases produce only 0.03 $KgCO_2eq$. Still, the relevance of ICT cannot be omitted, even due to the toxicity of the end-of-life equipment, as pointed out by Abukhader et al. (2003).

Several studies tried to allocate the emissions of ICT to the single order placed by the customer, in order to have an estimation of the impact on the overall carbon footprint. Resuming the article from Van Loon et al. (2014), it is said that a LCA study by Sivaraman et al. uses a burden factor to allocate the emissions of the production and disposal of electronic devices. This factor is the ratio between the time spent to place an order, which is supposed five minutes for a DVD, and the total number of hours the device is used during its entire life. Other research estimated a higher value for the online shopping time. In addition, the author suggests considering also "the construction, use and ultimate disposal of computer servers for data warehousing, hosting, back-up and system management functions". For instance, the paper reports that the average Google search (including both the Google servers and the consumer PC) emits 7 g of CO_2, even if Google claims that only 0,2 g per-search are its responsibility. Once again, it is remarked the difficulty to compute precisely the impact that ICT has on e-commerce environmental impact.

Country's policy and investments

This last variable includes all those public policies, incentives, investments and infrastructures that are under the control of the local or national government and that can change the structure of the fulfilment process, strongly impacting the carbon footprint of e-commerce. Some important investments, for example, require public intervention to couple environmental, social and economic sustainability, as the one reported by De Mello Bandeira et al. (2019), who suggests implementing a fleet of electric vehicles for last-mile postal delivery in Rio de Janeiro. This initiative would significantly reduce car and van-based emissions but requires public incentives for the economic feasibility. Further projects that would require public intervention are present in the studies from Gatta et al. (2018) and Simoni et al. (2019), who both proposed a crowd shipping-based model for urban deliveries in the city of Rome. The first paper introduces the use of the metro lines of the city for the creation of a network of crowd shippers, which in this case are regular passengers that use the metro for personal reasons, and pick-up points, in particular automated parcel lockers located inside the metro station or nearby. Simoni et al.,on the other hand, presents two alternative crowd shipping models: the first is car-based, the second one is public-transport-based, as the one suggested by Gatta et al. In both scenarios presented, the project requires a public intervention to be realized.

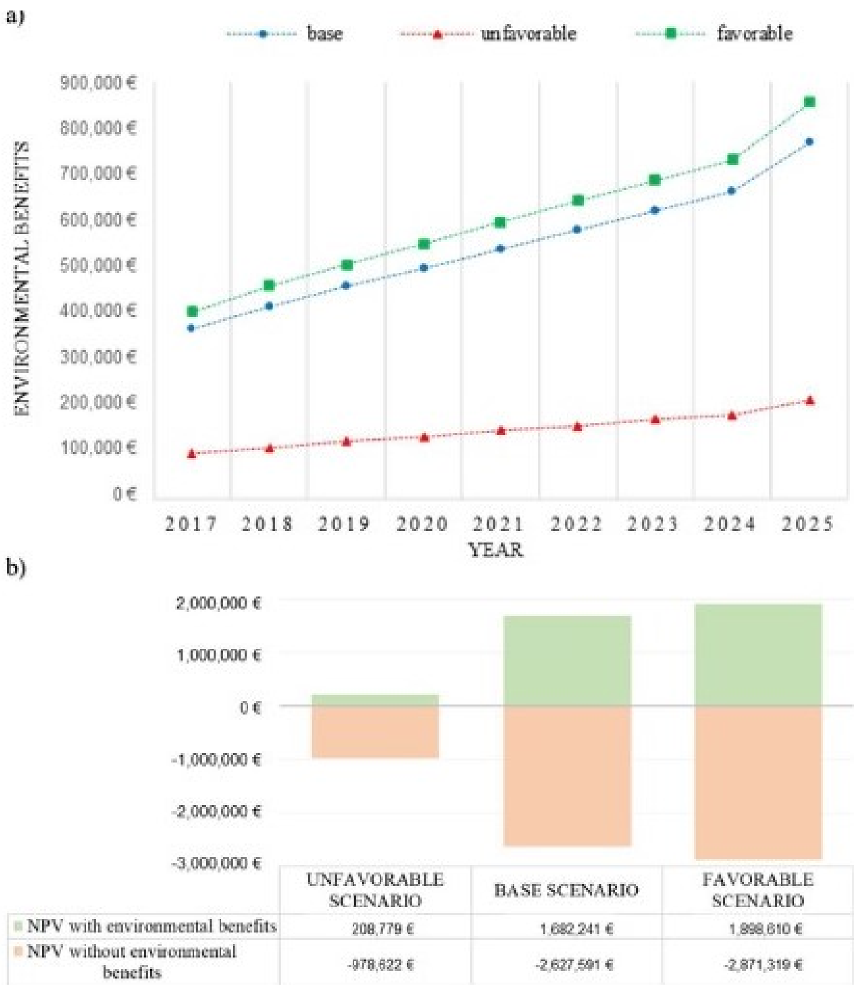


Figure 2.23: (a) Estimation of monetized collective benefits. (b) Net present value, from Gatta et al., (2018)

The economic evaluation performed by Gatta et al., indeed, presents a negative net present value if environmental benefits, which are converted in public incentives, are not considered. For this reason, the author suggests that policy makers provide the funds to cover platform costs by subsidizing the crowd shippers. However, to fully exploit the potential of the project, the 100% of the environmental benefits should be converted. The same conclusion is present in the paper from Simoni et al., who claims that "without any supporting policy in terms of incentives or regulations, it would be difficult to steer crowd shipping practices in the public transit-oriented direction".

2.5 Possible solutions

This section summarizes the possible solutions proposed by the selected articles which aim at reducing the environmental impact of B2C e-commerce. The solutions presented might be already widely implemented, as in the case of alternative vehicles for last-mile delivery, or following a more innovative approach, like crowd shipping-based models. In the first case, the effects on e-commerce carbon footprint are easily understandable: the use of alternative vehicles for urban deliveries, such as electric vehicles or bicycles, as suggested by De Mello Bandeira et al. (2019), will not only reduce the polluting emissions, but clearly contribute to decrease traffic congestions, depending on specific urban characteristics of the city of analysis. Crowd-based models, on the other hand, are scarcely implemented nowadays, mainly because the interaction between different actors, that may have different objectives, is difficult to manage and due to the lack of scale and learning economies, upon which big logistics operator base their competitive advantage.

Those innovative models, which are emerging together with other sharing economies, may offer a positive contribution to e-commerce sustainability, as claimed by Guo et al. (2019). This study proposes a crowdsourced delivery model along with a conceptual framework developed in five steps to guide its implementation, followed by an illustrative simulation to prove the consistency of the framework. The paper presents three different crowdsourced delivery models: peer-to-peer delivery, following a uber-like model where no external organisation is involved, Business-to-consumer shipping, where e-tailers like Amazon select a random carrier to perform the delivery and B2C neighbour receiving points, which exploit the neighbours to receive the package for the absent customer. The simulation implemented, however, proposes the use of traditional offline customers to fulfil online neighbours' orders in a dual-channel perspective. The feasibility and effectiveness of the model depends mainly on the level of matched demand between order request and carrier, delivery lead time offered (shorter lead time increases crowd shipping effectiveness, especially for perishable products) and the level of trust that the system transmit to the involved actors. This last point is fundamental to reach the necessary level of participation and to assure the required service level to be competitive with the traditional delivery system. As shown by the results of the study, this model could provide not only a reduction in carbon emissions deriving from customer trips, but also lower delivery costs.

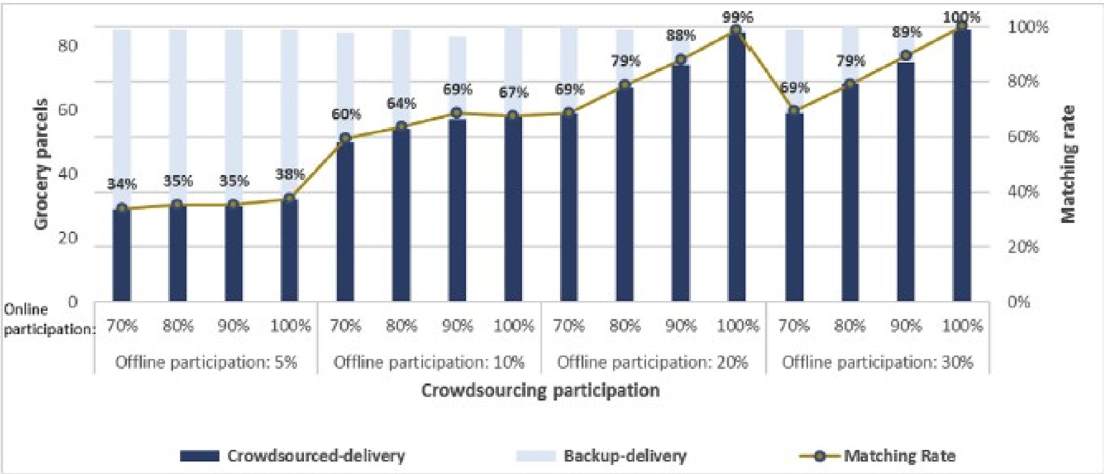


Figure 2.24: Matching rate performance per level of crowdsourcing participation, from Guo et al., (2019)

Another area where innovation can have a significant impact is packaging: as discussed in the homonymous section, difference in size, thickness, material and reusability influences the carbon footprint of the packaging type considered, especially if taking a life-cycle perspective. Finally, Gružauskas et al. (2019), suggests a process of customer integration through collaborative forecasting, which may reduce the Mean Absolute Percentage Error (MAPE), which is an indicator of the precision of the forecasts. This reduction would be particularly important in the grocery industry, since it would result in an overall lower level of inventories along the supply chain, as well as in a decreased level of food waste.

2.6 Final considerations

The aim of the presented model was to accurately describe the main variables affecting B2C e-commerce carbon footprint, as well as the leading actors involved. This was done to emphasize the possible impact that customers, merchants or decision makers might have on the overall environmental impact of the entire process and, on the basis of the evidence provided in the literature, to understand which are the priority areas of intervention. In fact, not all the variables have the same importance, neither a similar way to tackle them. Moreover, as stated in the introduction of this session, many variables present correlation effects among them. This means that players along the supply chain are put in front of several trade-off, among which the decision is not trivial at all, considering that their first interest is often economical. In this sense, the framework may be used by all agents described during their decision-making process.

First of all, e-tailers and logistics providers must be aware of the environmental impact of their distribution network design choices, and they should combine efficiency, effectiveness and sustainability-oriented decisions in a holistic view. This model shows the main levers through which they are able to manage those critical trade-offs. Secondly, the final customer is becoming more and more interested into sustainability issues, and this model underlines how important is customer behavior in determining the carbon footprint of B2C e-commerce, especially for what concerns the last mile. Finally, this model might be useful for regulators as well, in order to understand how public incentives, investments and legislations may impact on e-commerce sustainability.

2.7 Focus on e-grocery

As explained is section 2.1, the present work presents a specific focus on e-grocery sustainability. 20 articles out of 48 are mentioning the impact of B2C e-commerce in the grocery industry, even though only 15 of them are strictly focused on this topic. Despite several mentions of the topic were provided during the analysis, this section is aimed at summarizing the state-of-the-art of e-grocery sustainability. As the number of paper works found shows, this research area is far to be complete. Among the 20 articles, 9 were elaborated in Europe, while US and UK present respectively 4 and 3 studies. Almost the 50% of the paper was published in the last three years, to mean that the popularity of this topic is constantly growing. As for e-commerce sustainability, analytical papers are predominant, in particular mathematical models and simulations, and the most discussed process is TRANSPORTATION, with a specific focus on last-mile delivery. In fact, grocery home delivery is treated in almost all of the presented works, while other delivery methods like click&collect or external pick-up point are described only in 6 papers.

However, differently from other industries, the environmental parameter which is most used to describe the environmental performance of e-grocery is not CO_2 emissions, but rather negative externalities generated by urban traffic and food waste. This last topic in particular is becoming more and more important also from a social perspective, as well as the concept of meal kit, as presented in the previous sections. The 60% of the subset of papers presents a comparison between e-grocery and traditional retailing: unlike in other industries, the general opinion towards this comparison is not sided. Only 6 studies, indeed, state that e-grocery is more environmentally friendly than brick and mortar, while other 6 claim that the answer is controversial. However, none of the analyzed articles claims that traditional grocery retailing is greener than the online one.

2.8 Conclusions

The aim of this section is to summarize the main findings of the systematic literature review on the environmental impact of B2C e-commerce, with a particular focus on the grocery industry. 48 papers from 19 countries were analyzed, published between 2001 and 2019. After accurately describing the set of paper works, it is possible to conclude that the topic of B2C e-commerce sustainability is vastly discussed in the literature. Moreover, the 50% of the articles were published in the last three years. Even though this number partly depends on a precise choice of the author of the literature, whose aim was to focus the review on more recent studies and papers, it is possible to say that this topic is becoming more and more popular for researchers, companies and governments.

However, despite the effort of the author, only 15 papers specifically focused on e-grocery were found, none of which was elaborated in Italy. For this reason, an evident gap is present in the current literature.

Chapter 3

OBJECTIVE OF THE STUDY AND METHODOLOGY

3.1 Literature gaps and research goal

The present work aims at filling the significant gap in the current literature related to e-grocery environmental sustainability in Italy. In the literature review, indeed, despite the 17% of the articles analyzed was elaborated in Italy, none of them is focused on e-grocery sustainability. The primal reason behind this lack is the low penetration rate of online grocery in Italy in respect to other European countries, as reported in the previous sections.

Hence, the main Research Question to which this study is willing to answer is the following:

RQ: **What is the differential impact that e-grocery fulfilment methods have on environmental sustainability, and which are the main variables responsible for those environmental performances**

The comparison between e-commerce and traditional retailing has been discussed widely in the literature and it will be considered in this study as well, since brick&mortar is one of the scenarios analyzed. However, only 5 papers out of 20 are presenting a comparative environmental assessment of different fulfilment methods.

Another important point of discussion are the variables responsible for those differences in the environmental impact. In fact, as it is important to compare the different processes, is fundamental to understand why they present different values, which are the parameters most impacting and, at last, what can be done in this sense to improve the overall carbon footprint. In this sense, considering the set of articles analyzed, only the study conducted by Van Loon et al. (2015) compares different e-commerce fulfilment methods while providing insights about the variables involved. However, this study is not precisely focused on e-grocery, but rather on generic fast-moving consumer goods, including products belonging to industries substantially diverse such as consumer electronics, whose difference in terms of distribution network design, order size and product returns in respect to the food industry might affect the final results of the analysis.

Moreover, this particular work was not referred to the Italian market, which diverge under several points from other European countries. Indeed, geographic and demographic aspects heavily influences the road network, consequently impacting transportation, especially last mile delivery; energy source mix determines the level of emissions of production and consumption of electricity; finally, customer behaviors affects the average basket size, the mode of transport, and several other parameters directly impacting e-grocery carbon footprint. All the previous mentioned aspects contribute to the novelty of this study.

3.2 Choice of the model

In order to answer to the research question, a comparative Life Cycle Assessment model (comparative LCA model) has been developed.

As stated by the National Risk Management Research Laboratory of the US Environmental Protection Agency (EPA), "LCA is a technique to assess the environmental aspects and potential impacts associated with a product, process, or service, by:

- Compiling an inventory of relevant energy and material inputs and environmental releases
- Evaluating the potential environmental impacts associated with identified inputs and releases
- Interpreting the results to help you make a more informed decision".

This methodology of analysis is officially documented into ISO 14040 and, more specifically, into ISO 14044:2006, which was revised and confirmed in 2016.

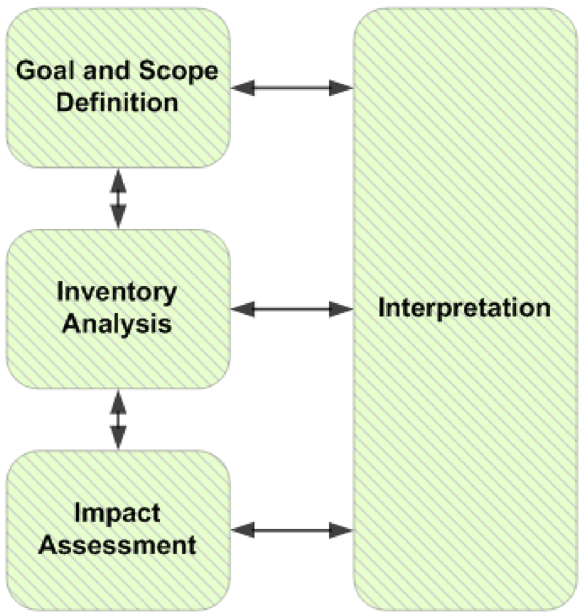


Figure 3.1: Phases of LCA study, source: ISO 14040:2006

According to this protocol, four main phases must be included in a LCA study:

- Goal and scope definition

  In the goal and scope definition phase, the purpose and method of including environmental information in decision making are defined. The goal usually includes a comparison between alternative products or processes, as well as opportunities for reduction in resource use and emissions, guiding the future improvement of the product or process considered. In addition, this first phase must specify the kinds of data that will be included and what restrictions (date range, completeness, county or region of study, etc.) will be applied (ISO 14044:2006).

  This is done by defining the system boundaries, namely the life cycle phases considered in the analysis. Depending on the goal, the LCA study may not include all life cycle phases in the scope of the research. This may be justified in cases where such phases are known to have negligible impact or where such phases are equal for all product or process alternatives considered. (Nieuwlaar Evert, 2013).

  LCA data and results will be expressed in terms of a functional unit, which provides a reference to which the inputs and outputs can be related and provides a basis for comparing alternative products or processes. (Rebitzer et al., 2004). Moreover, the environmental impact category or categories considered in the study must be defined, in order to translates the energy, resource, and emissions flows identified into their potential consequences for human health and the environment. The calculation of the magnitude of the associated impacts is performed in terms of a reference unit for each category, multiplying the related resource, material, or energy flows with their respective impact factors. Translating the environmental impacts to a reference unit provides a common basis for the generated impact so that different emissions and resources can be compared and aggregated using a common unit (Zaimes et al., 2015).

For instance, the global warming potential (GWP) for a generic Greenhouse gas (GHG) is measured in respect to its equivalent CO_2 emissions specified over a given time horizon, and it is calculated by multiplying the mass of the GHG released by its corresponding impact factor. In this sense, according to the classification provided by the EPA, 11 impact categories can be identified:

- Ozone depletion
- Global warming
- Acidification
- Eutrophication
- Tropospheric ozone (smog) formation
- Ecotoxicity
- Human health criteria-related effects
- Human health cancer effects
- Human health non cancer effects
- Fossil fuel depletion
- Land-use effects.

Finally, the allocation methods of the selected impact category to the functional unit and any assumptions or limitations must be explained in this introductory phase of the LCA study.

- Inventory analysis

  Life cycle inventory (LCI) analysis is defined by ISO as the "phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle". The inventory relates to the compilation of various environmental inputs and outputs involved in the life cycle of a product or process.

Inventory analysis translates in practice to data collection and analysis. Data collection involves the recording of the relevant inputs and outputs of the life cycle of a product or process.

The following are the four steps to be followed in a life cycle inventory analysis (Subramanian Senthilkannan Muthu, 2014):

  - Development of a flow diagram of the processes within the defined system boundary
  - Development of a data collection methodology
  - Collection of the relevant data
  - Evaluation and reporting of results

- Impact assessment The impact assessment phase (LCIA) is aimed at evaluating the significance of potential environmental impacts based on the life-cycle impact flow results. The procedure follows the selection of impact categories considered, after which the inventory parameters are sorted and assigned to the specific category. Finally, the categorized LCI flows are characterized into common equivalent units that are then summed to provide an overall impact category total.

- Interpretation

  The final phase of a LCA study is the interpretation of results. Life cycle interpretation is the procedure during which the results of the LCI and LCIA are identified, checked, and evaluated, and consists of the following steps:

  - Identify significant issues
  - Evaluate the completeness, sensitivity, and consistency of the data
  - Draw conclusions and make recommendations

Significant issues are the data elements that contribute the most to the results of the LCI and LCIA. These can be certain inventory parameters (e.g., energy use), impact categories (e.g., acidification), or certain life cycle stages (e.g., manufacturing). In the second step, checks are performed regarding completeness, sensitivity of the significant data elements, and consistency (with regard to the goal definition and scope of the study). Such checks are required to reach consistent and reliable conclusions. (Nieuwlaar Evert, 2013).

3.3 Literature on LCA for e-commerce environmental sustainability

LCA has been already applied in the literature for comparative environmental assessment regarding e-commerce sustainability. More specifically, restricting the research only to articles present on Scopus, eight articles analyzing the environmental impact of e-commerce in different industries have been identified and compared on the basis of the functional unit, system boundaries and environmental parameter selected for the LCA study. In the set of papers, it has been included the study performed by Shahmohammadi et al. (2020) even though it is not precisely following the LCA methodology. Still, the methodology used and the processes considered in this study makes it relevant to consider for this comparison.

3.3.1 Functional unit

For what concerns the functional unit, it can be seen that all the studies decided to use the single item, disregarding the industry of analysis. Sivaraman et al. (2007) set a quite particular functional unit, i.e. renting three DVDs at one time, but only because at the manufacturing facility, DVDs are packed in three. The choice of the single item, indeed, allows the reconstruction of the footprint on a bottom-up basis for higher-level entities, such as basket or parcel, as a summation of items. However, choosing one consumer item as the functional unit has its limitations. In fact, no distinction is made between the types of consumer item, the weight or volume of the product. Nevertheless, when appropriate caution is taken when interpreting findings, choosing the item as the functional unit is a suitable approach (Van Loon et al.,2015). This does not mean that only purchases of one item are considered. The item, indeed, can be part of a larger shopping basket containing several items; the environmental impact, in terms of carbon emissions, is then divided by the number of items in the shopping basket to report the emissions per item fulfilled.

3.3.2 Environmental parameter

Sivaraman et al. (2007) employs different parameters to assess the environmental emissions. They measure primary energy (MJ), carbon monoxide (CO), lead (Pb), sulfure dioxide (SO_2), nitrogen oxides (NO_x), hydrocarbons (HC), particles (PM_{10}) and carbon dioxide (CO_2). This is one of the few studies, among the sample, providing different metrics. Another example is the one by Williams and Tagami (2002): they indeed include in their analysis the global warming potential, the acidification potential, the eutrophication potential and the photochemical oxidation potential. The study developed by Borrgren et al. (2011) is even more complete under this aspect, evaluating cumulative energy demand, global warming potential, abiotic depletion, acidification potential, eutrophication potential, ozone depletion potential, freshwater aquatic ecotoxicity potential, human toxicity potential, marine aquatic ecotoxicity potential, terrestrial ecotoxicity potential and photochemical ozone creation potential. All the others show the results in terms of CO_2 equivalent, except for Norris et al. (2003), who chose primary energy consumption.

PAPER	INDUSTRY	FUNCTIONAL UNIT	PRODUCTION	UPSTREAM TRANSPORTATION	STORAGE	LAST MILE	PACKAGING	VEHICLES	PRODUCT DISPOSAL	ICT	RETURNS
Williams and Tagami (2002)	Book	Item			X	X	X				
Norris et al. (2002)	Electronics	Item	X	X	X						
Sivaraman et al. (2007)	DVD	Item	X	X	X	X	X		X	X	
Weber et al. (2010)	Music	Item	X	X	X	X	X			X	
Borrgren et al. (2011)	Book	Item	X	X		X			X	X	X
Van Loon et al. (2015)	FMCG	Item		X	X	X	X	X		X	X
Heard et al. (2019)	Food & Grocery	Item	X	X	X	X	X		X		
Shahmohammadi et al. (2020)	FMCG	Item		X	X	X	X	X			
Present study	Food & Grocery	Item		X	X	X	X	X			

Figure 3.2: Reviewed LCA paper on e-commerce environmental sustainability

3.3.3 System boundaries

As explained before, the definition of the system boundaries is particularly important for LCA studies, since it influences the source of emissions considered, hence the final result. In this sense, unlike for the functional unit, the industry of analysis plays an important role. Indeed, processes sources of emissions such as product returns might have a significant impact for FMCG or books, while the low return rate in the Food&Grocery industry makes this phase irrelevant and often not considered (Van Loon et al., 2015 and Borrgren et al., 2011 are the only exception). On the contrary, transportation, storage (in warehouses or retails stores) and secondary packaging are usually impacting all the industries, even though the contribution might not be the same. In fact, except Norris et al. (2002) and Borrgren et al. (2011), all the studies considered analyze both phases. In addition, comparative LCA are usually structured considering only those sources of emissions which are differential between two products or processes, as suggested by Edwards et al. (2011). For this reason, as explained by Van Loon et al. (2015), in the present study 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. Moreover, Primary packaging is considered as an indistinguishable part of the consumer item and is therefore also excluded from the environmental assessment.

This line of reasoning is not the one chosen by Heard et al. (2019) to compare traditional retailing and meal kits delivery; in this paper, indeed, the author considers the emissions coming from food production and food waste as well, especially because the second aspect is one of the most important difference, according to the paper, between brick&mortar retailing and pre-portioned meal kits delivery. Weber et al. (2010) considers the carbon footprint of the production phase as well, since the difference between plastic CDs and downloaded music in this sense is substantial. For what concerns secondary packaging, only Norris et al. (2003) and Borrgren et al. (2011) are excluding this aspect from the analysis, while none of the studies analyzed is considering primary packaging.

Following the approach of Shahmohammadi et al. (2020), in this study ICT-tools-related emissions have been excluded as well, since the estimated relevance on the final impact was low, as proved by other similar studies such as Van Loon et al. (2015). However, this study acknowledges that other papers claimed the environmental impact of ICT for B2C e-commerce must be considered. For instance, Van Loon- Mckinnon (2014) defined as Frist-order effects the impact that ICT had on e-commerce carbon footprint. The authors report that many of e-commerce negative externalities are caused by ICT-related sources, such as "the production, use, repair and disposal of ICT equipment used for e-commerce transactions, the associated use of hazardous substances, the related energy consumption and the generation of electronic waste". In order to consider this impact, Sivaraman et al. (2007) suggested to use a burden factor based on time to allocate all ICT-related emissions. In this study, the author chose the time required to perform an online order, in respect to the life span of a single device, to allocate the emissions of personal computers. The energy for the disposal of a computer was also determined and allocated using the burden factor, and, in addition to the use of the computer, usage of other ancillary equipment was also considered (i.e. lamps to light the room, heating/cooling the room). Nevertheless, the final impact on primary energy consumption was only 6%.

Similarly, Borrgren et al. (2011) considered the energy required to perform an online order, which is represented by the energy usage of the modem, hubs and routers for Internet access, production of cables and computers, always allocated on the basis of the time required to perform an order. Weber et al. (2010), who studied instead the environmental impact of different music delivery methods, claims that home computer usage and internet usage to download tracks is relatively unimportant, while he considers data center electricity usage to run e-commerce and online music sites, which results to be far more impacting in the music industry.

On the contrary, the present study considers also the emissions related to the production of delivery vehicles, namely trucks vans and cars. In fact, those emissions are allocated to the life span of the single vehicle and added to the one related to the trips, as indicated by Shahmohammadi et al. (2020). In this way they become differential among fulfilment methods, hence to be considered.

3.4 Stochastic model with Monte Carlo method

As presented in the literature review, the environmental footprint of B2C e-grocery is affected by several parameters, many of which presents high levels of variability. Distances, customer behavior, buildings energy efficiency are just a few examples. Moreover, nearly all analyses of environmental problems are confronted with uncertainty (Frey, 1992). It is sufficient to think about vehicles emission rates, which strongly depends on the fuel type, the weight of the vehicle, the speed and several other parameters. Describing this parameter with a single deterministic value would strongly affect the accuracy of the model.

The most common approach to manage those uncertainties is to use sensitivity analysis. In sensitivity analysis, the value of one or a few model input parameters are varied following a predetermine range, and the effect on a single model output parameter is observed. Meanwhile, all other model parameters are held at their "nominal "values. The main limitation of sensitivity analysis is that the combinatorial explosion of possible sensitivity scenarios (e.g., one variable "high", another "low," and so on), which is typical of practical problems with many input variables which may be uncertain, becomes unmanageable. Furthermore, sensitivity analysis provides no insight into the likelihood of obtaining any particular result. Indeed, even though it indicates a range of possible values, sensitivity analysis does not provide any explicit indication of how a decision-maker should weigh each possible outcome.

In order to overcome those limitations and to increase the accuracy and adherence to reality of the model, it was chosen to develop a stochastic simulation following the Monte Carlo methodology. A stochastic simulation is a simulation of a system that has variables that can change randomly with individual probabilities (Dlouhy, 2005). The random variables are generated through statistical distribution and then inserted into a model of the system to be described. After that, the outputs of the model are recorded and the process is repeated a sufficient amount of times to guarantee the required accuracy. Lastly, the distribution of outcomes is analyzed, in order to provide expectations regarding the probability of occurrence of each range of values.

On the other hand, Monte Carlo methods, or Monte Carlo experiments, are a broad class of computational algorithms that rely on repeated random sampling to obtain numerical results, which are mainly used for three problem classes: optimization, numerical integration and generating draws from a probability distribution (Kroese et al, 2014). In particular, the model developed in this thesis refers to the third class of problems.

Thanks to the possibility to simulate phenomena with significant uncertainty in inputs and to manage systems with many coupled degrees of freedom, the areas of application of Monte Carlo methods are various, among which physical science, engineering, finance and business. It is important to make a distinction, as reported by Sawilowsky (2003), between a simulation, Monte Carlo Method and a Monte Carlo simulation: a simulation is a fictitious representation of reality; a Monte Carlo method is a technique that can be used to solve a mathematical or statistical problem; and a Monte Carlo simulation uses repeated sampling to obtain the statistical properties of some phenomenon (or behavior). Hence, the model represented in this study will be realized through a stochastic model following the Monte Carlo methodology, that is Monte Carlo simulation.

The choice to use Monte Carlo simulation to assess the environmental impact of e-grocery was supported by several studies in the analyzed literature related to B2C e-commerce sustainability (Weber et al., 2010, Heard et al., 2019, Gee et al., 2019, Zhao et al., 2019, Zissis et al., 2018). Moreover, Monte Carlo has become the default procedure for propagating uncertainties in LCA studies (Heijungs, 2020).

As previously reported, the main idea behind Monte Carlo simulations is that output values are computed on the basis of repeated random sampling. In particular, a fundamental parameter to define regarding Monte Carlo simulations is the number of iterations (or runs), that is the number of times each sampling procedure and calculation is repeated. Usually this kind of simulations need a sufficient number of iterations to create a representative set of possible outcomes to be analyzed. As a consequence, most studies decided to have the maximum number of runs allowed by the amount of data analyzed and the computational capacity of the processor used, in order to reach the maximum confidence interval (which represents the grade of certainty with which I can state that one value is included in a specific range of values) and to take into consideration even the so-called "tales" of the distributions, or "rare events". Of course, this choice depends on the field of application of Monte Carlo simulations (Frey, 1992). Indeed, this methodology is often used for quantitative risk analysis and mitigation, where the necessity to know the probability of occurrence of those rare events is significant. On the contrary, if the study is aimed at obtaining only mean values of the relative distribution of outcomes, the number of iterations only needs to be sufficiently high to make the mean value converge and stabilize.

Being this study based on a model, hence subjects to several simplifications, even rare events might be interesting to analyze. Moreover, the overall complexity of the model is not that high to limit the number of runs from a computational point of view. For these reasons, it was chosen to run 100000 iterations, also following the indications of Shahmohammadi et al (2020). However, even though increasing the number of runs contribute to increase the precision of outcome values, this does not mean that the final output will be more correct. In fact, the correctness of the result does not depend on the number of runs of the simulation, but rather on the correctness of input data and model structure. (Heijungs, 2020).

Unfortunately, Monte Carlo simulations are typically characterized by many unknown parameters, many of which are difficult to obtain experimentally (Shojaeefard, 2017). Indeed, the standard approach in probability theory requires that the choice of the statistical distribution should pass a Goodness-of-fit test, such as the Pearson Chi-squared test (Pearson, 1900). Although this approach is of course to be preferred when possible, in many practical cases the available data may not be sufficient to conduct such tests and analysis. Therefore, some degree of judgment about the available data may be required. In this sense, an alternative approach is the so-called "Bayesian" view, which is based on the assessment of the probability of an outcome through an evaluation of all the relevant information an analyst currently has about the system. Thus, the probability distribution may be based on empirical data and/or other considerations, such as technically informed judgments or predictions (Frey, 1992). Given the general lack of primary data to develop statistical tests of hypothesis to verify the statistical distributions, this last-mentioned approach was used.

3.5 Tools

Following the example of Shahmohammadi et al. (2020) and Heard et al. (2019), the simulation was developed on RStudio, a free software environment for statistical computing and graphics. This tool was chosen in respect to other tools which allow to run Monte Carlo simulations such as Excel also because of its data manipulation capabilities and the performance in terms of speed. The model, indeed, will be more accurate increasing the number of iteration and the dimension of the dataset used for the analysis. Moreover, in respect to several other studies who used more sophisticated tools such as SimaPro or GaBi software or OpenLCA to implement the simulation, R was preferred due to its open source nature.

	R	Excel	Matlab	Minitab
Data manipulation	Large	Small	Large	No
Automation	Easy	Hard	Easy	No
Performance	Very fast	Slow	Very fast	Fast
Dataset dimension	Big Data	<500 MB	Big Data	Large Data
Interface	Complex[1]	Easy	Medium	Easy
Knowledge	High	Low	High	Medium
Open Source	Yes	No	No	No
Cost	Free	From 149 €	From 2000 €	From 1250 €

[1] With Rstudio the interface becomes similar to Matlab

Figure 3.3: Comparison between possible tools for data manipulation, Source ASCP laboratory 2020

In addition, thanks to its modular structure, RStudio presents several advantages. In fact, it is easily updated, and it offers the possibility to expand the boundaries of the analysis or to perform ulterior calculations and functions by just downloading new packages completely free from the Web. The present study acknowledges that other free Building Life Cycle Assessment tools indeed exists. However, several drawbacks of these tools can be highlighted, described by Chamindika and Moncaster (2014) as the "free software syndrome":

- lack of flexibility
- lack of time and resources to keep the software updated and running
- the complexity of calculations
- the need to provide reliable results

To sum up, even though the interface is not immediate and it requires some basic programming skills, RStudio seems to be a more than adequate tool for Monte Carlo simulations.

Despite the software, the main difference between this study and a standard product LCA lies in input data: as previously mentioned, LCA studies generally need a huge amount of accurate and updated information to gain significance, especially for what concerns inventory analysis. Nowadays, one of the most updated and comprehensive sources to be used for life cycle inventory analysis is the public on-premise database EcoInvent, which was born in the early 2000's with an initiative of the Swiss Federal Research Institutions and Administration. The initial project (Ecoinvent 2000) involved a few dozen products distributed into five groups: energy supply, materials and wastes, transport services, basic chemicals, and agricultural products and processes, while more recent versions include over 11,500 inventory datasets on products or services such as: energy supply, chemicals, plastics and plastics production, production and processing of metals, transport and mobility, disposal, construction, agriculture, information and communication technology, electronics, biofuels and materials, engineering, paper industry, recycling processes, and water data (Gnansounou, 2017).

However, unlike product LCAs, the present study is not aimed at precisely identify and calculate the emissions coming from the entire life cycle of an item, including extremely specific data such as raw materials extractions emissions, but rather to compare different choices that online players could make on the basis of their main differences in terms of environmental sustainability. As a consequence, the use of such specific databases is not needed for the purpose of this study.

3.6 Goal and scope definition

3.6.1 Goal of the study

As declared in section 3.1, the goal of this study is to perform a comparative environmental assessment of different fulfilment methods in the Italian B2C online grocery industry through the development of a stochastic life-cycle assessment model following the Monte Carlo methodology. The different scenarios considered will be evaluated on the basis of the Global Warming Potential (GWP), namely GHG emissions. The LCA model is based on the analysis of the state-of-the-art e-grocery operations and fulfilment methods adopted nowadays in Italy by the largest players in the market. As explained in the introduction, the dominant player in grocery e-commerce belonging to the traditional retailers cluster is Esselunga, which will be taken as main reference for the creation of the model structure.

Esselunga S.p.A. is an Italian company operating in the grocery retail industry in northern and central Italy, which controls approximately 8.9% of sales in Italian supermarkets and hypermarkets (Nielsen, 2019), with over 159 sales outlets mostly concentrated in Lombardy, Tuscany, Piedmont and Emilia-Romagna. Since its foundation, Esselunga has always been a pioneer for innovation in the grocery industry, opening the online channel in 2001, much earlier than other competitors. Nowadays, "Esselunga a casa" is the first Italian site for online sales of products, and the company is always introducing new services, such as click&drive services, and expanding the presence on the territory.

Of course, given the complexity of the distribution network of e-grocery services, the model development will be based on several assumptions and simplifications. Indeed, the aim of this model is not to accurately describe the real distribution network of online retailers, but rather to define and assess the main sources of polluting emissions present in each of the fulfilment method currently adopted.

3.6.2 System boundaries

Following the approach proposed by Edwards et al. (2011), the environmental impacts of the different fulfilment methods is compared from the point of divergence to the point of consumption, considering only the differential parameters. Hence, the boundaries of the present LCA study are from product storage in the central warehouse to the final delivery to the customer, excluding all manufacturing processes, as well as replenishment from suppliers and product disposal. Product returns can be considered negligible in the grocery industry since this option is often unavailable due to the perishability of several grocery items. Moreover, primary packaging, here defined as all packaging directly used to pack products, is not considered, following the explanation of subsection 3.3.3.

The model considers as source of emissions the following activities:

- Replenishment of store and warehouse

  This activity includes the GHG emissions from upstream transportations of goods from the central warehouse to local stores and to the e-commerce warehouse. In addition, emissions from truck production are considered.

- Storage

  This activity considers all the storage, handling and refrigeration emissions related to warehouses and stores, expressed as electricity and natural gas consumption, since they are the predominant energy sources currently used in Italy for storage activities (rapporto annuale energia elettrica, 2018). Moreover, the electricity consumption of refrigerated lockers is included.

- Last mile transportation

This activity includes the GHG emissions related to van trips of home delivery services or car trips of customers reaching the collection point. In addition, emissions from car and van production are considered.

- Packaging

  This activity refers to $KgCO_2eq$ emissions of secondary packaging, namely plastic bags, used in the different channels.

3.6.3 CO_2-equivalents allocation and functional unit

The functional unit of this study is the single product purchased by the final customer, in line with the approach presented in the literature (subsection 3.3.1). The allocation of CO_2eq emissions in the various processes considered is the following:

- Replenishment emissions are allocated on the basis of the product weight, as suggested by Shahmohammadi et al. (2020) and Heard et al. (2019).

- Store and warehouse consumptions emissions are allocated on the basis of the throughput flow, following the indications of Edwards et al. (2011), Van Loon et al. (2015) and Weber et al. (2010). However, the literature reports also studies which allocation choice was different. Shahmohammadi et al. (2020) allocated the emissions related to storage on the basis of the volume of the single item by using a storage factor computed both for store and warehouse, while Edwards et al. (2011) claims that the time spent in the warehouse or store could be another allocation base.

- Secondary packaging emissions are allocated on the single item as suggested by Heard et al. (2019), on the basis of the volume of the items and the saturation of the plastic bag.

- Last mile delivery emissions are allocated on the single item through the basket size, as reported by all the studies analyzed. Indeed, "vehicle fuel use and emissions can simply be averaged across packages/parcels on a delivery without reference to their specific size and weight." (Edwars et al., 2011).

3.6.4 Environmental parameter

The parameter used to describe the environmental impact of B2C e-grocery in Italy are Greenhouse gas (GHG) emissions, here described using $KgCO_2eq$, coherently with the choice of the impact category. The methodology described by the fifth assessment report of the Intergovernmental Panel on Climate Change (IPCC) is still the most widely recognized impact method for measuring climate change impact potentials over 100 years. Hence, all the calculations will follow the fifth assessment report of the IPCC (Mhyre et al., 2014), which recognizes the following GWP values for 100-year time horizon:

- 1 for Carbon dioxide emissions
- 28 for Methane emissions
- 265 for Nitrous oxide emissions

Even though the report recognizes several other sources of GHG emissions, such as chlorofluorocarbons (CFC) or hydrofluorocarbons (HFC), only the previous emissions will be included, being the most relevant for the processes considered in this study.

3.7 Inventory analysis

3.7.1 Model structure

The presented model is structured in 7 different scenarios, developed following the current fulfilment methods adopted by Esselunga and the various alternatives that Italian B2C e-grocery players have to reach the final customer:

Scenario 1 - Home Delivery from store (HDS)

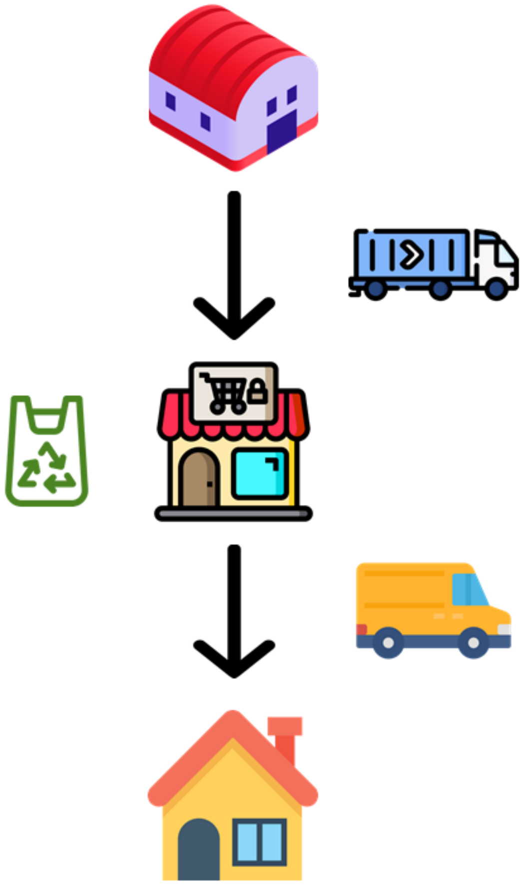


Figure 3.4: Scenario 1 - Home Delivery from store (HDS)

The first scenario considered in this study refers to home delivery services performed from local stores. The structure of this fulfilment method is the following: replenishment orders from local stores are picked in the central warehouse and delivered through refrigerated articulated trucks. When the online order is received, in-store picking is performed by store employees, and the request is fulfilled by means of refrigerated vans following urban routes. In case of failed delivery, re-delivery is performed in another delivery tour always through refrigerated vans. This scenario includes emissions from central warehouse storage, store replenishment, store storage, secondary packaging and last mile transportation.

Scenario 2 - Home Delivery from dedicated warehouse (HDW1)

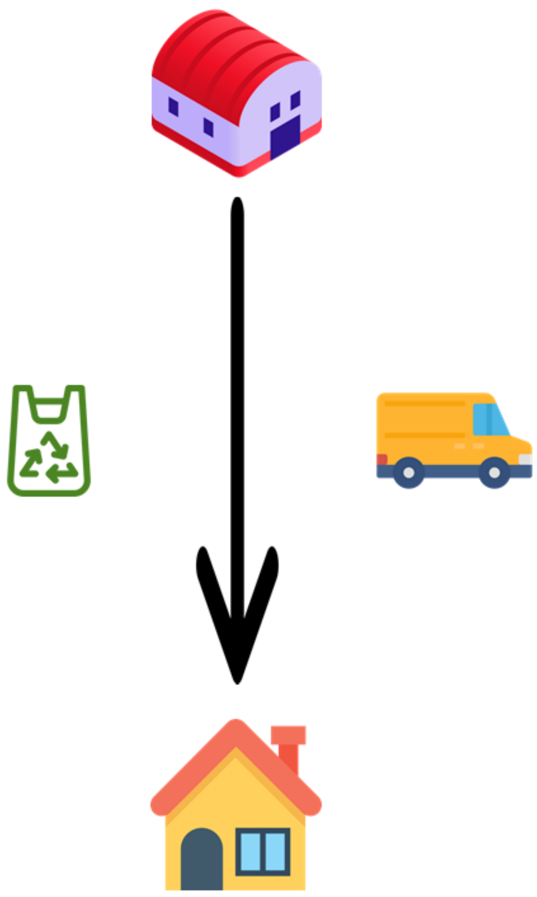


Figure 3.5: Scenario 2 - Home Delivery from dedicated warehouse (HDW1)

The second scenario considered represents home delivery services performed from a warehouse entirely dedicated to the online channel. The dedicated warehouse is directly replenished from suppliers; When the online order is received, warehouse picking is performed, and the request is fulfilled by means of refrigerated vans following urban and extra urban routes. In case of failed delivery, re-delivery is performed in another delivery tour always through refrigerated vans. This scenario includes emissions from warehouse storage, secondary packaging and last mile transportation.

Scenario 3 - Home Delivery from dedicated warehouse replenished by central warehouse (HDW2)

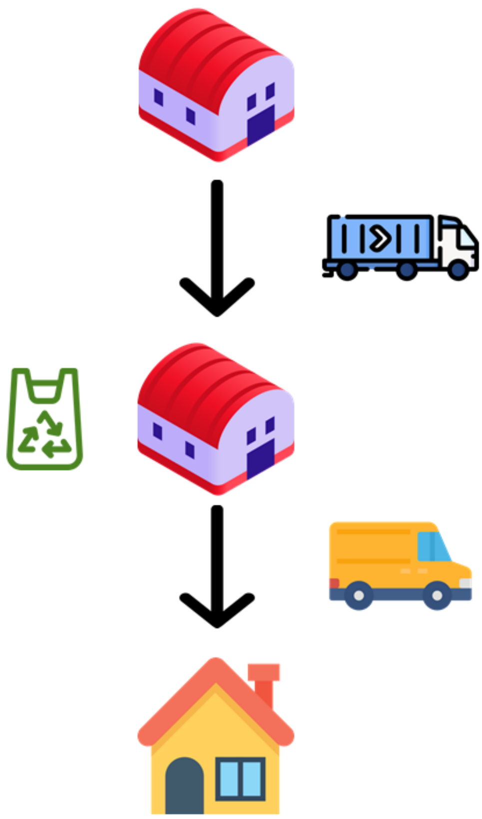


Figure 3.6: Scenario 3 - Home Delivery from dedicated warehouse replenished by central warehouse (HDW2)

The third scenario considered represents home delivery services performed from a warehouse entirely dedicated to the online channel, which is replenished from the central warehouse, as for the stores. This scenario includes emissions from central warehouse storage, e-commerce warehouse replenishment and storage, secondary packaging and last mile transportation.

Scenario 4 - Brick&mortar (BM1)

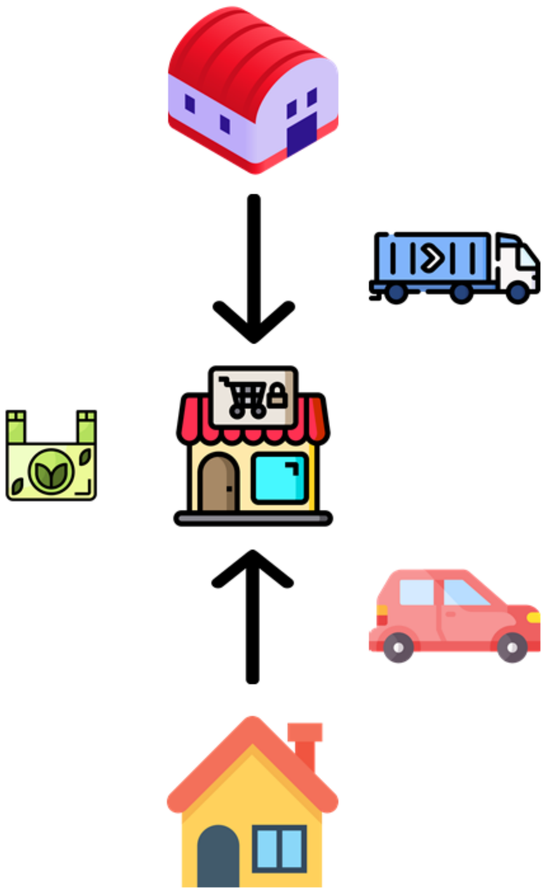


Figure 3.7: Scenario 4 - Brick&mortar (BM1)

The fourth scenario considered is based on traditional retailing. replenishment orders from local stores are picked in the central warehouse and delivered through refrigerated articulated trucks. In-store picking is performed directly by the final customer, who is responsible for last mile transportation as well. This scenario includes emissions from central warehouse storage, store replenishment, store storage, secondary packaging and customer trip to store. This scenario presents the same emissions sources of the one involving Click&Collect in store; the only difference between the two cases is that in the latter in-store picking is performed by store employees. However, this difference does not impact polluting emissions, hence only one scenario was considered.

Scenario 5 - Click&Collect at Locker (C&C)

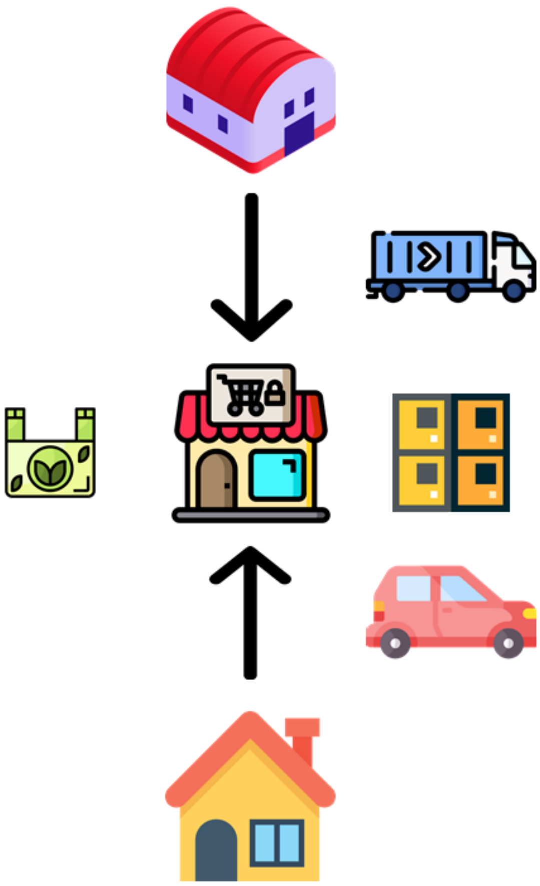


Figure 3.8: Scenario 5 - Click&Collect at Locker (C&C)

The fifth scenario described by this model represents Click&Collect services by means of refrigerated lockers. As for store home delivery and Traditional retailing, store replenishment is performed from the central warehouse through refrigerated trucks. When the order is received, in-store picking is performed by store employees, and the packaged items are transferred to the locker. The model assumes that lockers are located only in a limited number of stores and replenished only from store manually, which is quite realistic considering the current distribution network of Esselunga. Finally, the customer reaches the locker and withdraw the order in a specific time slot. This scenario includes emissions from central warehouse storage, store replenishment, store storage, locker electricity consumptions, secondary packaging and customer trip to locker.

Scenario 6 - Click&Drive at drive through station (C&D)

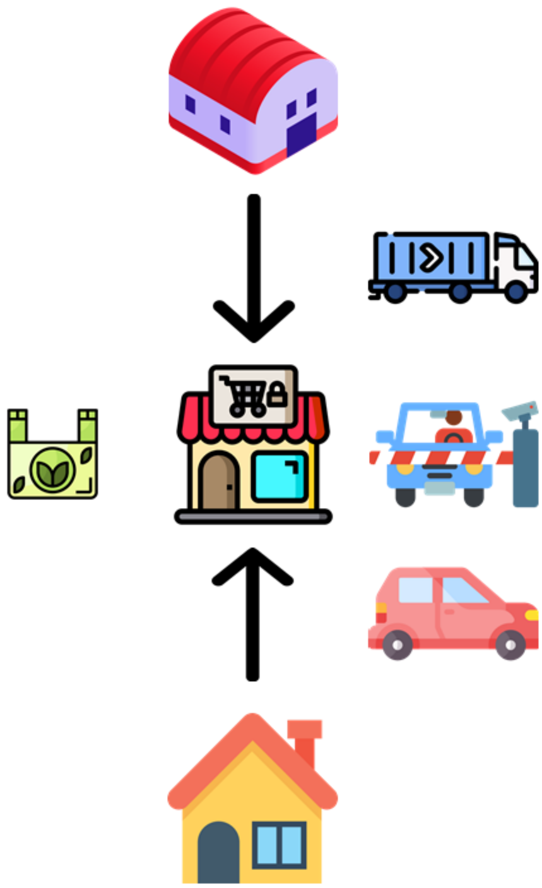


Figure 3.9: Scenario 6 - Click&Drive at drive through station (C&D)

The sixth scenario modelled represents the so-called "Click&drive" approach, which is based on a click&collect service performed in specific drive through stations. This fulfilment method is quite recent, and it is currently adopted by Esselunga alone. The structure of this fulfilment method is similar to the previous one: stores are replenished from the central warehouse and in-store picking is performed by store employees. However, the withdrawal of the order is performed in specific stations where the final customer is not required to exit from the car but is directly served by the store staff. The model assumes that drive through stations are located in a limited number of stores and replenished only from stores manually. This assumption is based on actual scenario and real practices. Click&drive at dedicated warehouse is currently not performed by any player in Italy, so it was not considered. This scenario includes emissions from central warehouse storage, store replenishment from the central warehouse, store storage, secondary packaging and customer trip to drive through stations. Drive through stations emissions are excluded, since they are considered not significant and dependent mostly on ICT tools, such as barcode scanners.

Scenario 7 - Brick&mortar by foot (BM2)

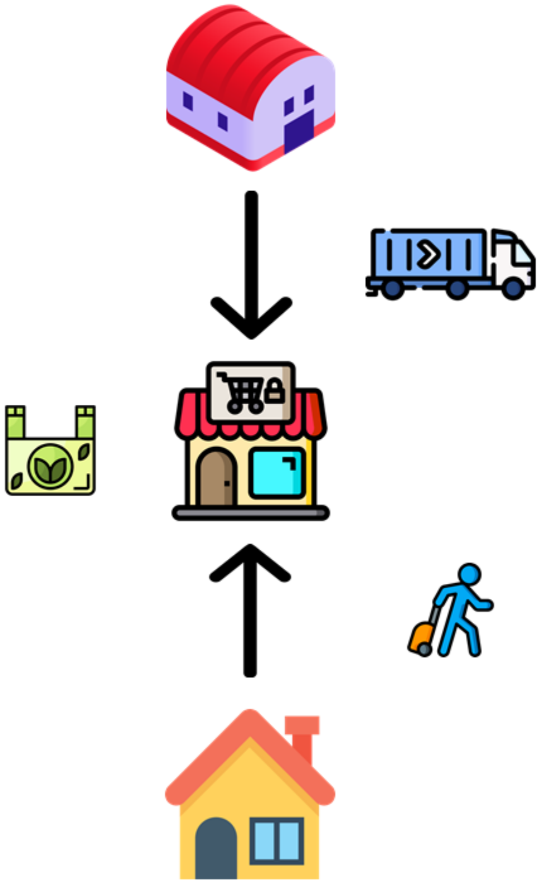


Figure 3.10: Scenario 7 - Brick&mortar by foot (BM2)

The last scenario considered in this study is Brick&Mortar by foot, which is similar to Brick&Mortar scenario, but considering that the customer trip is performed by foot, hence without incurring in further emissions due to last mile. As a consequence, this scenario includes emissions from central warehouse storage, store replenishment, store storage and secondary packaging. All other scenarios which include customer trip assume that no public transport or alternative vehicles are used.

3.7.2 Statistical distribution

As suggested by the literature, the Monte Carlo simulation was developed by identifying the relevant parameters affecting the environmental performance of the different scenarios and by assigning to each parameter a statistical distribution. The evaluation of the statistical distribution used to describe the behavior of the selected variables was performed following a systematic approach based on the upstream separation of two sources of uncertainty: The epistemic Uncertainty is defined as the modelers' lack of knowledge concerning the parameters that characterizes the modeling system (defined as the level of ignorance). On the other hand, Variability uncertainty depends on the fact that many empirical quantities (measurable properties of the real-world systems being modelled) vary over space or time in a manner that is beyond control, simply due to the nature of the phenomena involved (Salling et al, 2007).

One of the main advantages of separating the uncertainty and variability is that the total uncertainty of a model system does not show the actual source of the uncertainty. The information corresponding to the two sources implied in the total uncertainty is of great relevance towards the decision makers in a given situation. If a result shows that the level of uncertainty in a problem is huge this means that it is possible to collect further information and thereby reduce the level of uncertainty which enables us to improve our estimate. On the other hand, if the total uncertainty is nearly all due to variability it is proven to be a waste of time to collect further information and the only way to improve and hereby reduce the total uncertainty would be to change the whole modeling system.

Following this line of reasoning, the statistical distribution used for this study can be divided in two main clusters: in case of variables whose uncertainty depends mainly on its variability (e.g. GHG emissions of vehicles), when data availability allows it, a lognormal distribution was used, with the identification of a geometric mean and standard deviation. This distribution is based on a logarithmic parametrization of the standard normal distribution, which brings the advantage of eliminating the possibility to include negative values for the specific parameter. On the contrary, in case of variables whose behavior is difficult to describe due to lack of data (epistemic uncertainty), different statistical distributions were adopted. Following the approach of Shahmohammadi et al. (2020), those distributions are:

- Beta PERT

  this distribution is a variation of the Triangular distribution which is based on the identification of a minimum, a more probable and maximum value for the parameter. The expected value is the result of the following calculation:

$$\mathbf{EXP\ V} = \frac{\mathbf{MIN\,V} + \lambda * \mathbf{MOST\,PROB\ V} + \mathbf{MAX\ V}}{\mathbf{2} + \lambda}$$

  The default value for lambda is 4, which is also the one adopted in this study. In this way, in respect to the triangular distribution, a significant impact is attributed to the most probable value, and a behavior more similar to the normal distribution is obtained. This distribution is used in all cases where a minimum, a maximum and a most probable value were available.

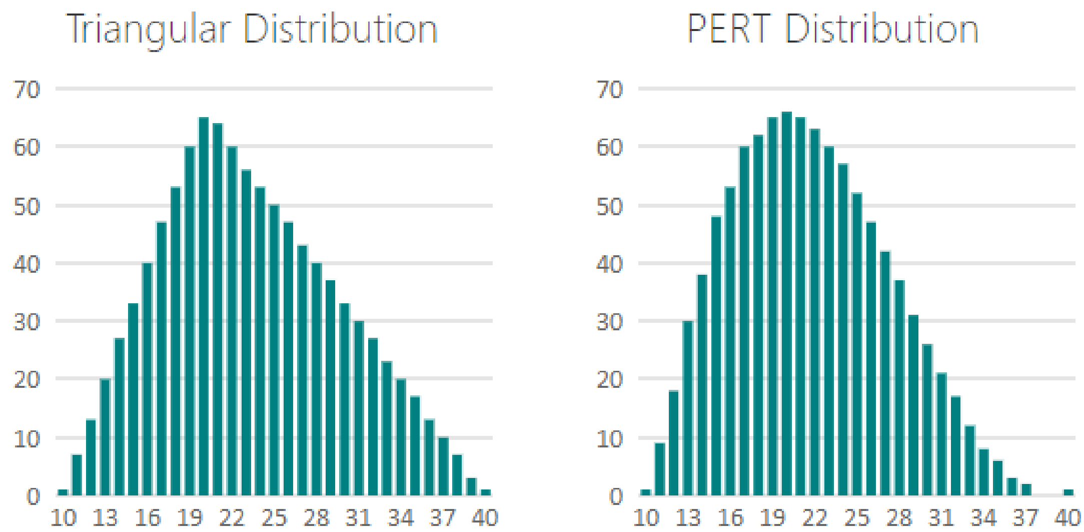


Figure 3.11: Probability density distribution funcitons of triangular and Beta PERT distributions, Source: RiskAMP

- Uniform distribution

  this distribution assigns the same probability of occurrence to the entire range of values selected, and it was used only when a minimum and a maximum value were available, but the most probable outcome was not possible to accurately identify.

- Deterministic parameter

  a single value was assigned in case only one data was available (e.g. from articles which referred to ECOINVENT data) or in case of conversion factors provided by local entities (e.g. kgco_2eq/kwh).

3.7.3 Data collection

Methodology

Being this study focused on Italy, data collection was conducted taking as reference Italian data when available. In fact, as described in the section related to the research goal, several input variables are country dependent. Unfortunately, for the majority of the parameters none or very limited reliable local data were available. To cope with this issue, a twofold approach was used: in case of a parameter which is not depending on the country of analysis, a reliable universal source supported by the literature has been used; on the contrary, if the specific data strictly depends on the region considered, such as store energy consumption, a secondary source validated by the literature was accurately selected and compared with the limited or single data available for Italy, to assure compatibility. The following section will explain in detail the assumptions as well as the data sources for each module which compose the simulation, being Central warehouse, Replenishment, Store, E-commerce warehouse, Secondary packaging, Last mile delivery and Customer trip. First, general parameters common to all the considered fulfilment methods are explained.

3.7.4 General parameters

General data includes the variables basket size, product volume and product weight. The basket size is initally considered the same for all the fulfilment methods, to assure comparability between scenarios. This variable is described through a beta-PERT distribution, whose values are obtained in the following way: the minimum value was calculated considering that some channels, usually home delivery, request a minimum expense to fulfill the order; the average value comes from Osservatorio e-commerce and it is related to Italy; the maximum value is adapted from Shahmohammadi et al (2020). Product volume and product weight are obtained from primary data, considering both fresh, dry and frozen items.

PHASE	VARIABLE		VALUE	SOURCE
GENERAL PARAMETERS	BASKET SIZE	BS	Bpert(10-65-100)	Shahmohammadi et al. (2020), Osservatorio e-commerce
	PRODUCT VOLUME [dm3]	V_P	lognormal(0,69;2,39)	primary data
	PRODUCT WEIGHT [kg]	W_P	lognormal(0,41;2,39)	primary data

Figure 3.12: General parameters

3.7.5 Last mile delivery

Figure 3.13 summarizes the variables concerning last mile delivery. Parameters related to distance per order both for store and warehouse home delivery have been obtained by combining primary data provided by industry operators regarding total travel distance and total orders fulfilled in a tour. Failed delivery rate is designed as a single parameter, provided by Osservatorio e-commerce. GHG emissions related to refrigerated vans are taken from the most updated data provided by ISPRA (Istituto Superiore per la Protezione e la Ricerca Ambientale). The database provided data related to emissions of different polluting matter of light commercial vehicles. Starting from those data, GHG emissions have been calculated following the indications reported into subsection 3.6.3 and considering only vehicles categorized as EURO 4, EURO 5 or EURO 6. For what concerns store home delivery, being the tour restricted to urban areas, emissions related to urban travels have been used. On the contrary, for warehouse home delivery a total average parameter of emission is adopted, being tours both urban and extra urban. In addition, emissions related to refrigeration of items during the tour have been taken into account by multiplying emissions with a refrigeration factor provided by the report from EcoInvent. LCA data for van life span was

PHASE	VARIABLE		VALUE	SOURCE
LAST MILE	DISTANCE PER ORDER HOME DELIVERY FROM STORE [km]	$d\ HD_S$	uniform(1-4)	primary data
	DISTANCE PER TOUR HOME DELIVERY FROM WHS [km]	$d\ HD_W$	uniform(1,25-12,5)	primary data
	FAILED DELIVERY RATE [%]	FDR	0,01	osservatorio e-commerce
	GHG EMISSIONS PER KM VAN TOTAL AVERAGE [kgCO2eq/km]	GHG_V	lognormal(0,36;1,18)	ISPRA 2018
	GHG EMISSIONS PER KM VAN URBAN AREAS [kgCO2eq/km]	GHG_{VU}	lognormal(0,24;1,13)	ISPRA 2018
	REFRIGERATION PARAMETER	REF	uniform(0,15-0,25)	EcoInvent
	VAN LIFE SPAN [km]	$GHG\ P_V$	240000	Shahmohammadi et al. (2020)
	VAN PRODUCTION [kgCO2eq/kg]	LS_V	8	Yang et al. (2018)
	VAN WEIGHT [kg]	$GHG\ M_V$	uniform(3500-4000)	US department of Energy

Figure 3.13: variables related to last mile delivery

taken from Shahmohammadi et al (2020), while van production emission factor refers to Yang et al (2018). For what concerns van weight, a uniform distribution has been created following the data provided by the US department of Energy.

3.7.6 Packaging

PHASE	VARIABLE		VALUE	SOURCE
PACKAGING	GHG EMISSION FACTOR COMPOSTABLE PLASTIC BAG [kgCO2eq/dm3]	GHG_{CP}	0.004965	Chaffe et al. (2007)
	GHG EMISSION FACTOR RECYCLABLE PLASTIC BAG [kgCO2eq/dm3]	GHG_{RP}	0,0009425	Chaffe et al. (2007)
	SATURATION COEFFICIENT COMPOSTABLE PLASTIC BAG	SAT_{CP}	uniform(0,33-0,85)	primary data
	SATURATION COEFFICIENT RECYCLABLE PLASTIC BAG	SAT_{RP}	uniform(0,2-0,75)	primary data

Figure 3.14: Variables related to packaging

In table 3.14 are reported the parameters and the relative sources regarding secondary packaging, namely plastic bags. As previously explained, primary packaging is excluded since it is considered as part of the product itself. Analyzing current practices in the Italian e-grocery industry, a distinction was made between secondary packaging related to home delivery services and secondary packaging related to customer pick-up. Indeed, in the first case large recyclable plastic bags are used, with relatively low saturation coefficient, while the second one presents small compostable plastic bags, with higher saturation coefficient. In this study, it is assumed that the customer does not use reusable bags for grocery shopping, hence the number of grocery bags assigned to each order will depend solely on products volume and saturation coefficient. GHG emissions factors for both types of grocery bags are taken from the LCA study of Chaffe et al. (2007), adapting the values obtained to the real size of compostable and recyclable plastic bags used by Esselunga.

3.7.7 Store

Store-related input data are presented in table 3.15. Unfortunately, very limited data regarding store electricity and natural gas consumptions in Italy were found. In fact, despite several studies presents data related to other European countries, a specific study providing local data was not identified. For this reason, it was chosen to adopt a secondary source already used by other studies in the literature (Weber et al. (2010), Shahmohammadi et al. (2020), Sivaraman et al. (2007)) and then to check those data with the limited Italian data available. This source is the commercial buildings energy consumption survey (CBECS), a large survey conducted in the United States by the Energy Information Administration (EIA) in 2012. As reported by EIA, 2018-related data always provided by CBECS will be available soon, so future studies could benefit from more recent values. For what regards GHG conversion factors, it was preferred to use local data provided by ISPRA for electricity since this value is highly country dependent. However, such data was not available for natural gas, so it was chosen to adapt a largely recognized and authoritative source such as the Department for Environment Food and Rural Affairs (DEFRA). To parametrize the dimension of stores, data from Osservatorio Nazionale del Commercio allowed to calculate the average dimension related to the sale area, while minimum and maximum values follows the ISTAT definition of Supermarket in Italy. On the contrary, the yearly throughput rate of the store is defined with a single parameter taken from local primary data. Refrigerated Lockers energy consumption was taken from Inpost, an English company who produce and delivers lockers for the grocery industry also in Italy. Moreover, for the time that an order pass inside the locker, which is the base through which electricity consumptions are allocated, Esselunga indications regarding click&collect services has been followed.

PHASE	VARIABLE		VALUE	SOURCE
STORE	ELECTRICITY CONSUMPTION STORE [kwh/m2y]	E_S	βpert(378-469-594)	commercial buildings energy consumption survey 2012
	NATURAL GAS CONSUMPTION STORE[kwh/m2y]	G_S	βpert(69-161-237)	commercial buildings energy consumption survey 2012
	GHG EMISSION FACTOR ELECTRICITY [kgCO2eq/kwh]	GHG_E	0,301	ISPRA ITALIA 2017
	GHG EMISSION FACTOR NATURAL GAS [kgCO2eq/kwh]	GHG_G	0,184	DEFRA 2020
	THROUGHPUT FLOW STORE [prod/y]	TF_S	14645000	primary data
	DIMENSION STORE [m2]	D_S	βpert(400-1175-2500)	Osservatorio Nazionale del Commercio 2018
	ELECTRICITY CONSUMPTION LOCKER [kw]	E_L	0,55	InPost
	TIME ORDER IN LOCKER[h]	T_L	uniform(0,5-7,5)	primary data

Figure 3.15: Variables related to store

3.7.8 E-commerce warehouse

PHASE	VARIABLE		VALUE	SOURCE
E-COMMERCE WAREHOUSE	GHG EMISSION FACTOR ELECTRICITY [kgCO2eq/kwh]	E_S	0,301	ISPRA ITALIA 2017
	GHG EMISSION FACTOR NATURAL GAS [kgCO2eq/kwh]	G_S	0,184	DEFRA 2020
	ELECTRICITY CONSUMPTION REFRIGERATED WAREHOUSE [kwh/m2y]	E_{Wref}	βpert(15-38-72)	commercial buildings energy consumption survey 2012
	ELECTRICITY CONSUMPTION WAREHOUSE [kwh/m2y]	E_W	βpert(113-271-496)	commercial buildings energy consumption survey 2012
	NATURAL GAS CONSUMPTION WAREHOUSE [kwh/m2y]	G_W	βpert(17- 43-93)	commercial buildings energy consumption survey 2012
	THROUGHPUT FLOW E-COMMERCE WAREHOUSE [prod/y]	TF_{EW}	25430000	primary data
	DIMENSION E-COMMERCE WAREHOUSE [m2]	D_{EW}	7600	primary data
	PERCENTAGE OF DRY PRODUCTS [%]	$\%_{DRY}$	0,71	primary data

Figure 3.16: Variables related to e-commerce warehouse

The approach followed to describe input data related to e-commerce warehouse were similar to the one adopted for the store. Hence, data from ISPRA and DEFRA for emissions factor and from CBECS for consumptions have been used. Since the CBECS provided significantly different values for refrigerated and non-refrigerated warehouses, the yearly throughput flow of products has been divided considering the percentage of dry and fresh or frozen products. This percentage, along with the annual throughput rate and the total area of the dedicated warehouse are taken from local primary data. Moreover, following the indication of CBECS, natural gas consumptions of refrigerated warehouse is considered null.

3.7.9 Central warehouse

In order to be coherent, the same approach adopted for store and e-commerce warehouse has been used to parametrize the variables related to the central warehouse. The only difference in respect to the e-commerce warehouse is represented by the dimension and, consequently, by the daily throughput rate. Both values are coming from primary sources. Even in this case, the lack of reliable local data did not allow to vary this parameter.

PHASE	VARIABLE		VALUE	SOURCE
CENTRAL WAREHOUSE	ELECTRICITY CONSUMPTION REFRIGERATED WAREHOUSE [kwh/m2y]	E_{Wref}	βpert(15-38-72)	commercial buildings energy consumption survey 2012
	ELECTRICITY CONSUMPTION WAREHOUSE [kwh/m2y]	E_W	βpert(113-271-496)	commercial buildings energy consumption survey 2012
	NATURAL GAS CONSUMPTION WAREHOUSE [kwh/m2y]	G_W	βpert(17- 43-93)	commercial buildings energy consumption survey 2012
	PERCENTAGE OF DRY PRODUCTS [%]	$\%_{DRY}$	0,71	primary data
	THROUGHPUT FLOW CENTRAL WHS [prod/y]	TF_{CW}	65000000	primary data
	DIMENSION CENTRAL WAREHOUSE [m2]	D_{CW}	47000	primary data

Figure 3.17: Variables related to central warehouse

3.7.10 Customer trip

Table 3.18 collects the variables used to describe the customer trip, either for click&collect, brick&mortar or click&drive channel. For what concerns car GHG emissions, the same approach adopted for vans was maintained. Hence, data from ISPRA has been used for the emissions related to urban or extra urban travels of vehicles categorized at least EURO 4, while data reported by Shahmohammadi et al (2020) has been taken has reference for LCA data regarding production. In addition, the values used to describe car weight and life span has been taken from US department of Energy.

PHASE	VARIABLE		VALUE	SOURCE
CUSTOMER TRIP	GHG PER KM CAR [kgCO2eq/km]	GHG_C	lognormal(0,16 ; 1,35)	ISPRA 2018
	CUSTOMER TRIP TO STORE [km]	CT_S	βpert(1-6-11)	national travel survey 2018
	CAR PRODUCTION [kgCO2eq/kg]	GHG P_C	7	Shahmohammadi et al. (2020)
	CAR WEIGHT[kg]	W_C	uniform(1100-2850)	US department of Energy
	CAR LIFE SPAN[km]	LS_C	120000	US department of Energy
	NUMBER OF DRIVE THROUGH STATIONS	N_D	uniform(5-8)	primary data
	NUMBER OF STORES	N_S	47	primary data
	NUMBER OF LOCKER STATIONS	N_L	uniform(6-10)	primary data

Figure 3.18: Variables related to customer trip

The travel distance related to customer shopping trips has been difficult to parametrize. In order to collect reliable data related to Italian consumers, a wide survey would be needed. For reason of time, such a survey was not possible to conduct. As a consequence, also in this case an authoritative secondary source was taken as a reference, followed by a validation of the values from the literature (in particular, Van Loon et al, 2015). The secondary source used is the National Travel Survey of 2018, a wide survey conducted by the English government to analyze the movements of peoples in the country. The model acknowledges that the urban structure of Italy is significantly different from the one of other European countries, and so might be customer behaviors. Hence, Italian data should be used in future studies. Moreover, for reasons of simplicity, trip chaining has not been considered for this study, hence all shopping trips performed by the customer are dedicated.

To assess the distance travelled by the customer to reach lockers or drive through stations, a distance factor based on the ratio between the number of locker stations or drive through stations and the number of stores present in the same area has been multiplied by the customer trip to reach the store. In this way, the variable considers the fact that, on average, the customer will have to travel higher distances to reach lockers or drive through stations, being them less present in respect to store. The number of stores refers to the actual number of Esselunga stores present in the Milano area, while the number of locker stations and drive through stations is varied from the current value to a realistic value which can be obtained in the short term. Indeed, by increasing the presence of lockers and stations, the distance factor will be reduced, along with the environmental impact.

3.7.11 Replenishment

PHASE	VARIABLE		VALUE	SOURCE
REPLENISHMENT	GHG EMISSIONS TRUCK [kgCO2 eq/tkm]	GHG_T	βpert(0,08-0,14-0,16)	DEFRA 2020
	TRUCK WEIGHT[t]	W_T	uniform(5,2-6,6)	US department of Energy
	TRUCK LIFE SPAN[km]	LS_T	1000000	US department of Energy
	TRUCK AVERAGE LOAD [t]	L_T	15,8	Eurostat
	TRUCK PRODUCTION [kgCO2eq/t]	$GHG\ P_T$	0,008	Yang et al. (2018)
	DISTANCE REPLENISHMENT STORE [km]	$d\ R_S$	βpert(10,87,300)	Google Maps
	DISTANCE REPLENISHMENT E-COMMERCE WAREHOUSE [km]	$d\ R_W$	86,3	Google Maps

Figure 3.19: Variables related to replenishment

The last phase described in the model is replenishment, whose variables are summarized in figure 3.19. As explained in subsection 3.6.3, replenishment emissions have been allocated through product volume, following the indications of the literature, without considering packaging weight. For this reason, the conversion factor had to consider the load of the refrigerated truck. Since such factor was not provided by ISPRA, it has been decided to rely on data coming from DEFRA. However, the database provided only a limited number of values, so it was not possible to build a lognormal distribution. The weight of the single product, as for the volume, has been taken from primary data considering dry, fresh and frozen products, together with primary packaging, while the replenishment distance both for store and for the dedicated warehouse has been calculated through Google Maps, considering Esselunga actual distribution network. In order to add the emissions coming from truck production, reported by Yang et al. (2018), the average load in tons provided by Eurostat has been considered, along with the average life span of the truck and the weight, always taken from the US department of Energy, as for the other means of transport.

3.8 Impact assessment

This section will explain how the core of the stochastic LCA model is structured. The core of the model is the way through which input variables are combined in order to obtain the output values, which will be then analyzed to provide insights about the carbon footprint of the various fulfilment methods described. The structure of the core will follow the same subdivision in phases or modules used for the description of the input variables. As previously stated, in this study the only impact category analyzed is the Global Warming Potential, hence the aim of the calculation is to express the final results in terms of $KgCO_2eq$.

3.8.1 Last mile delivery

To obtain the total GHG emissions of refrigerated vans, both for urban and extra urban tours, first the refrigeration factor was added to the initial value provided by ISPRA; after that, the emissions related to production have been calculated on the basis of the weight of the van and have been allocated on the entire life span of the van, in order to obtain a value per Km to sum to the emissions related to travelling, which represent the only difference between urban and extra urban tours.

$$\mathbf{TOT\,GHG_{VU}} = \mathbf{GHG_{\,VU}} * \mathbf{REF} + \frac{\mathbf{GHG\,P_V} * \mathbf{W_V}}{\mathbf{LS_V}}$$

$$\mathbf{TOT\,GHG_{V}} = \mathbf{GHG_{\,V}} * \mathbf{REF} + \frac{\mathbf{GHG\,P_V} * \mathbf{W_V}}{\mathbf{LS_V}}$$

Following the indications of the literature, last mile delivery emissions have been allocated on the single item through the basket size. The total GHG emissions for each order have been obtained by multiplying the total emissions factor by the distance travelled per each order, both from store and from warehouse. Then, the value obtained has been increased through the failed delivery rate, to include emissions related to re-deliveries.

$$\mathbf{GHG_{HD_S}} = \frac{\mathbf{TOT\,GHG_{VU} * d\,HD_S}}{\mathbf{BS}} * (\mathbf{1} + \mathbf{FDR})$$

$$\mathbf{GHG_{HD_W}} = \frac{\mathbf{TOT\,GHG_{V} * d\,HD_W}}{\mathbf{BS}} * (\mathbf{1} + \mathbf{FDR})$$

3.8.2 Packaging

To allocate the polluting emissions related to secondary packaging to the single item, the CO_2-equivalent per unit of volume related to either compostable or recyclable plastic bags has been multiplied by the item of the single item. Since plastic bags capacity cannot be 100% saturated, a saturation coefficient is used to consider the fact that in each bag less products will be present. For the sake of simplicity, this model assumes that the number of items contained in each bag does not depend on items weight.

$$\mathbf{GHG_{PACK_{RP}}} = \frac{\mathbf{GHG_{RP} * V_P}}{\mathbf{SAT_{RP}}}$$

$$\mathbf{GHG_{PACK_{CP}}} = \frac{\mathbf{GHG_{CP} * V_P}}{\mathbf{SAT_{CP}}}$$

3.8.3 Store

The environmental impact of the supermarket has been calculated by multiplying the annual consumption per square meter related to both electricity and natural gas by the relative GHG emissions factor; then, the two values obtained have been summed, and the total has been multiplied by the sales area, to calculate the total emissions of the building. At last, emissions have been allocated to the single item by using the annual flow of products which passes through the store.

$$\mathbf{GHG_S} = \frac{(\mathbf{E_S} * \mathbf{GHG_E} + \mathbf{G_S} * \mathbf{GHG_S}) * \mathbf{D_S}}{\mathbf{TF_S}}$$

To calculate lockers-related emissions, the hourly consumption has been multiplied by the time passed inside the locker and by the electricity emission factor. The value obtained has been then divided by the basket size.

$$\mathbf{GHG_L = \frac{GHG_E * E_L * T_L}{BS}}$$

3.8.4 E-commerce warehouse

The procedure followed to assess the carbon footprint of the e-commerce warehouse is the same adopted for the grocery store. The only difference is represented by the allocation of the annual throughput flow of items on the basis of the need of refrigeration. To consider this aspect, the total area of the warehouse has been divided in two parts, one refrigerated and one non-refrigerated, on the basis of the percentage of dry items stored.

$$\mathbf{GHG_{EW} = \frac{D_{EW} * \%_{DRY} * (GHG_E * E_W + GHG_G * G_W)}{TF_{EW}} + \frac{D_{EW} * (1 - \%_{DRY}) * GHG_E * E_{Wref}}{TF_{EW}}}$$

3.8.5 Central warehouse

The formula used to calculate total GHG emissions per item for the central warehouse is exactly the same used for the e-commerce warehouse. Hence, the assumption is that the percentage of space allocation to dry and fresh items is the same for both buildings.

$$\mathbf{GHG_{CW}} = \frac{\mathbf{D_{CW} * \%_{DRY} * (GHG_E * E_W + GHG_G * G_W)}}{\mathbf{TF_{CW}}} + \frac{\mathbf{D_{CW} * (1 - \%_{DRY}) * GHG_E * E_{Wref}}}{\mathbf{TF_{CW}}}$$

3.8.6 Customer trip

As for last mile delivery emissions, the carbon footprint of customer trip has been allocated on the single item through the basket size. The procedure to calculate total GHG emissions of passenger car is the same used for vans: to the value obtained from ISPRA has been added the emissions related to production of cars, spread on the life span. Since the customer trip can be related both to urban and extra urban travels, depending on customer location, the general value for emissions related to travel has been used.

$$\mathbf{TOT\,GHG_C} = \mathbf{GHG_C} + \frac{\mathbf{GHG\,P_C * W_C + GHG\,M_C}}{\mathbf{LS_C}}$$

The value obtained through the previous calculation is hence multiplied by the double of the distance covered by the customer to reach the store and finally the total emissions are divided by the basket size, in order to get the final value to be used for Brick&mortar channel.

$$\mathbf{GHG_{CT_S}} = \frac{\mathbf{GHG_C * CT_S * 2}}{\mathbf{BS}}$$

As explained in subsection 3.7.3, for what concerns the customer trips to reach lockers and drive through stations, a distance factor has been calculated. This factor is calculated as the square root of the ratio between the number of store and the number of locker stations or drive through stations related to the Milano area. The reasoning behind this calculation is that the distance to be covered by the customer depends on the number of possible points to reach, being store, lockers or drive through stations, under the assumption that each customer will choose the nearest point. Indeed, if we represent the area of Milan as a circumference, it is possible to subdivide this area in smaller circles of equal radius, at which center there is a store. The more stores are present in the area, the smaller is the radius of each circle, which represents the average distance between a generic customer location and the nearest store. Consequently, the ratio between the customer trip to a store which present lockers or a drive through station and a generic store depends only on the square root of the ratio between the number of stores and the number of locker stations or drive through stations.

$$\mathbf{d_{factor_{CC}}} = \sqrt{\frac{\mathbf{N_S}}{\mathbf{N_L}}}$$

$$\mathbf{d_{factor_{CD}}} = \sqrt{\frac{\mathbf{N_S}}{\mathbf{N_D}}}$$

The value obtained through these calculations is then multiplied by two times the distance travelled by the customer to reach the store and by GHG emissions of passenger car. At last, the total obtained is allocated to single items using the basket size. This procedure is repeated for both customer trip to locker stations and customer trip to drive through stations.

$$\mathbf{GHG_{CT_L}} = \frac{\mathbf{GHG_C * CT_S * d_{factor_C C} * 2}}{\mathbf{BS}}$$

$$\mathbf{GHG_{CT_D}} = \frac{\mathbf{GHG_C * CT_S * d_{factor_C D} * 2}}{\mathbf{BS}}$$

3.8.7 Replenishment

The approach chosen to allocate the emissions of replenishment to single items is based on product weight, as reported in subsection 3.6.3. To do so, the total GHG emissions of refrigerated truck for each kilometer travelled and tons of load is multiplied by the replenishment distance and by product weight.

$$\mathbf{GHG_{R_S} = GHG_T * \ d_{R_S} * 2 * W_P}$$

$$\mathbf{GHG_{R_W} = GHG_T * \ d_{R_W} * 2 * W_P}$$

To obtain the total emissions of delivery trucks, the weight has been multiplied by the emissions related to production and divided by the life span and the average load. The resulting value has then been added to the emissions coming from the distance travelled. Those calculations are performed identically both for store and warehouse replenishment.

$$\mathbf{TOT\,GHG_T = GHG\,_T + \frac{GHG\,P_T * W_T}{LS_T * L_T}}$$

3.8.8 Total emissions

Once the emissions of the single phases have been calculated, those values are combined to obtain the total GHG emissions related to each fulfilment method, which are in turn composed by 100000 values.

$$\mathbf{TOT\,GHG_{HD_S} = GHG_{CW} + GHG_{R_S} + GHG_S + GHG_{PACK_{RP}} + GHG_{HD_S}}$$

$$\mathbf{TOT\,GHG_{HD_{W_1}} = GHG_{EW} + GHG_{PACK_{RP}} + GHG_{HD_W}}$$

$$\mathbf{TOT\,GHG_{HD_{W_2}} = GHG_{CW} + GHG_{R_W} + GHG_{EW} + GHG_{PACK_{RP}} + GHG_{HD_W}}$$

$$\mathbf{TOT\,GHG_{BM_1} = GHG_{CW} + GHG_{R_S} + GHG_S + GHG_{PACK_{CP}} + GHG_{CT_S}}$$

$$\mathbf{TOT\,GHG_{CC} = GHG_{CW} + GHG_{R_S} + GHG_S + GHG_{PACK_{CP}} + GHG_{CT_L}}$$

$$\mathbf{TOT\,GHG_{CD} = GHG_{CW} + GHG_{R_S} + GHG_S + GHG_{PACK_{CP}} + GHG_{CT_D}}$$

$$\mathbf{TOT\,GHG_{BM_2} = GHG_{CW} + GHG_{R_S} + GHG_S + GHG_{PACK_{CP}}}$$

Chapter 4

RESULTS INTERPRETATION

4.1 Results

In order to show the results of the simulation, the carbon footprint of each fulfilment method has been described through a boxplot, which represents the values from the 5th to the 95th percentiles, as suggested by Shahmohammadi et al. (2020). Heard et al. (2019), on the contrary, chose to show only the values within the 25th and the 75th percentiles, considering the remaining values as outliers. However, as explained in section 3.4, given the high variability of input data, it might be beneficial for the comparison to include almost all the values obtained through the simulation, excluding only the "small tails".

As showed by figure 4.1, the second scenario, namely home delivery from dedicated warehouse directly replenished by suppliers, is the most sustainable in environmental terms, with a median total emission of 0,033 KgCO_2eq per item (table 4.2). Store home delivery and brick&mortar with last mile performed by foot (scenario 1 and 7, respectively) present very similar behavior, both in terms of values and dispersion, resulting in a median total emission of approximately 0.06 KgCO_2eq per item, the double of scenario 2. On the other hand, if we consider the case of home delivery performed from a dedicated warehouse replenished by the central warehouse, the emissions increase even further, ranging between 0,05 and 0,115 KgCO_2eq. In the 65% of the cases, this fulfilment method is less sustainable than home delivery from store.

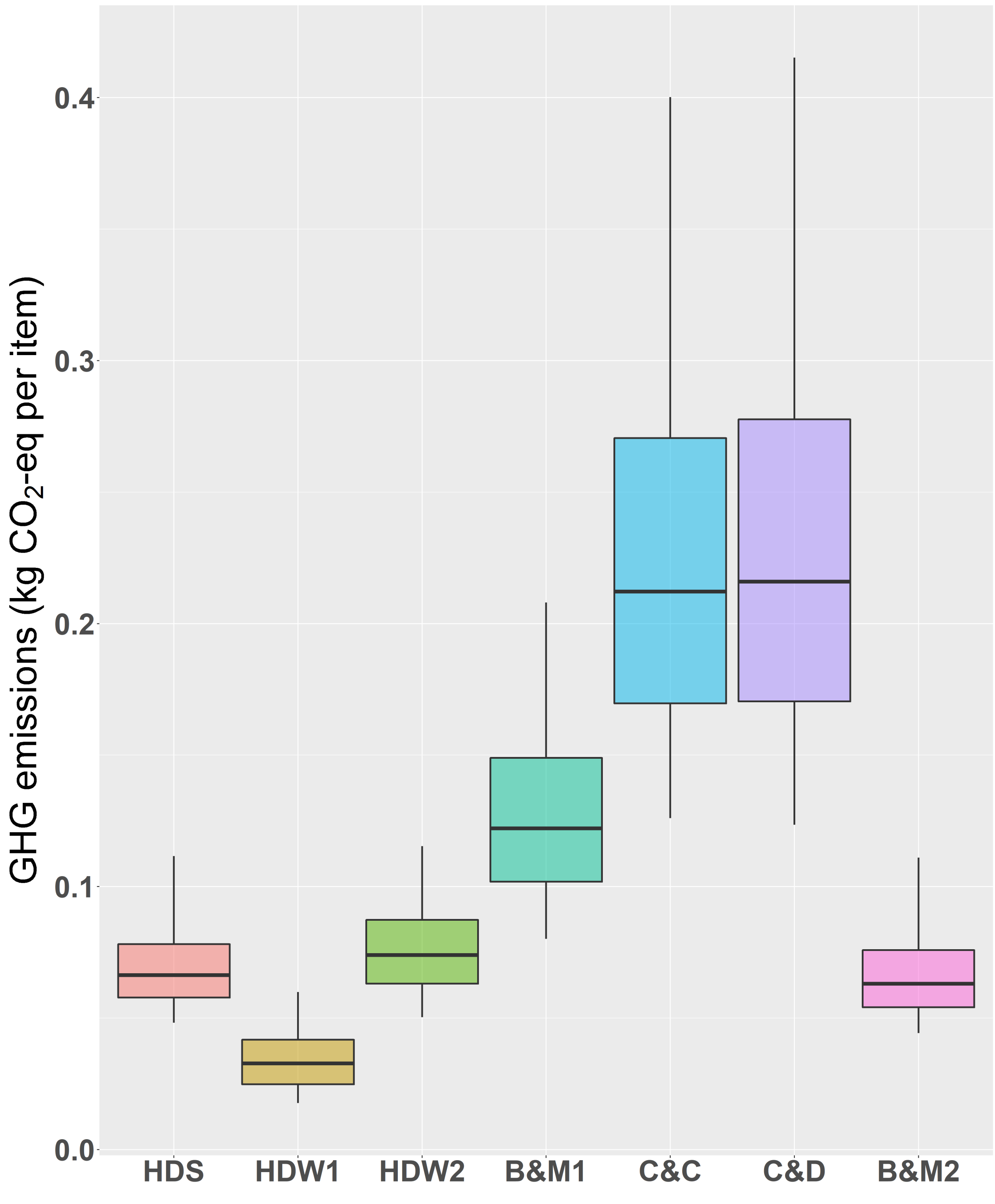


Figure 4.1: GHG emissions per item for each fulfilment method

quantiles	HDS	HDW1	HDW2	B&M1	C&C	C&D	B&M2
5%	0,0482	0,0177	0,0503	0,0801	0,1261	0,1235	0,0443
25%	0,0578	0,0249	0,0631	0,1019	0,1697	0,1704	0,0541
50%	0,0663	0,0328	0,0740	0,1222	0,2122	0,2159	0,0631
75%	0,0781	0,0418	0,0874	0,1490	0,2705	0,2777	0,0759
95%	0,1116	0,0599	0,1154	0,2081	0,4001	0,4152	0,1110

Figure 4.2: 5th, 25th, 50th, 75th and 95th percentiles of GHG emissions per item for each fulfilment method

Moreover, if we suppose that the last mile of brick&mortar retailing is performed by the customer by car (scenario 4), GHG emissions reached a median total emission of 0.122 KgCO_2eq per item, resulting in the 97% of the cases worse that home delivery, both from store and warehouse. Under the assumption that the collection point Is reached by car, click&collect and click&drive are by far the worst scenario in environmental terms, reaching a value of the 95th percentiles of respectively 0,400 and 0,415 KgCO_2eq per item. Click&collect is slightly greener that click&drive, since the number of locker station is higher, thus the distance to cover is higher and so it is the impact of last mile. However, if the collection of the order is performed by foot, or if we consider trip chaining and we assume that the customer would have performed this trip anyway, the environmental impact of click&collect and click&drive services is the same of brick&mortar retailing under the same assumption (B&M2), hence similar to store home delivery. Nonetheless, home delivery from dedicated warehouse (HDW1) remains the scenario with the lowest environmental impact in the 97% of the simulation runs.

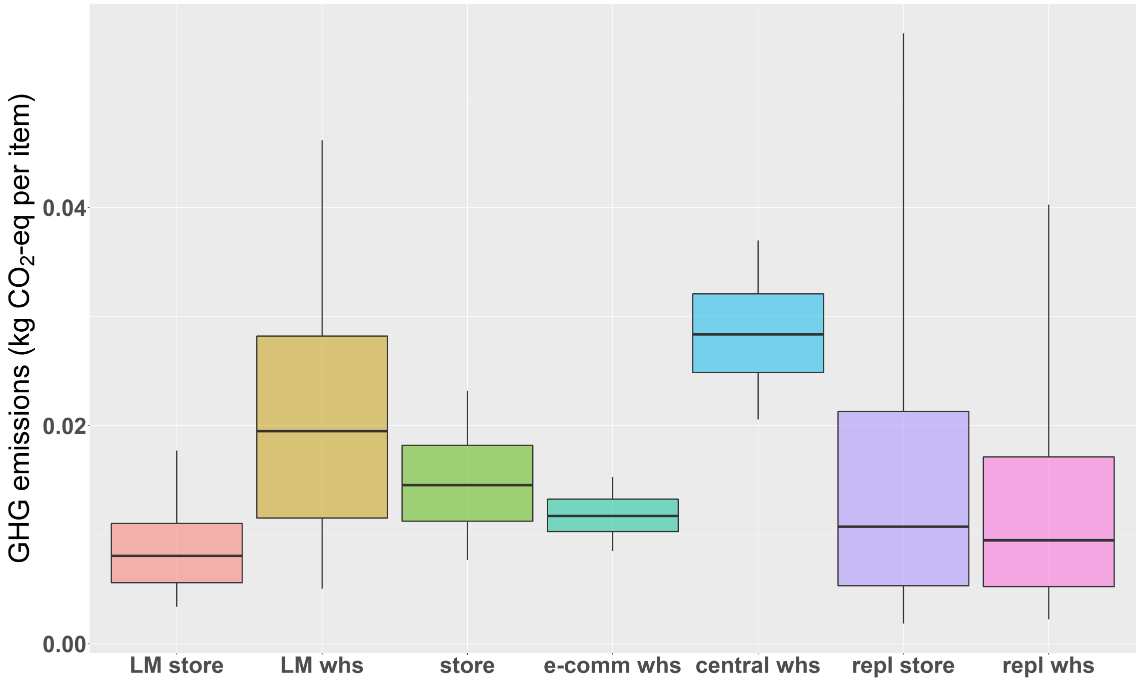


Figure 4.3: GHG emissions per item of each phase of the fulfilment process

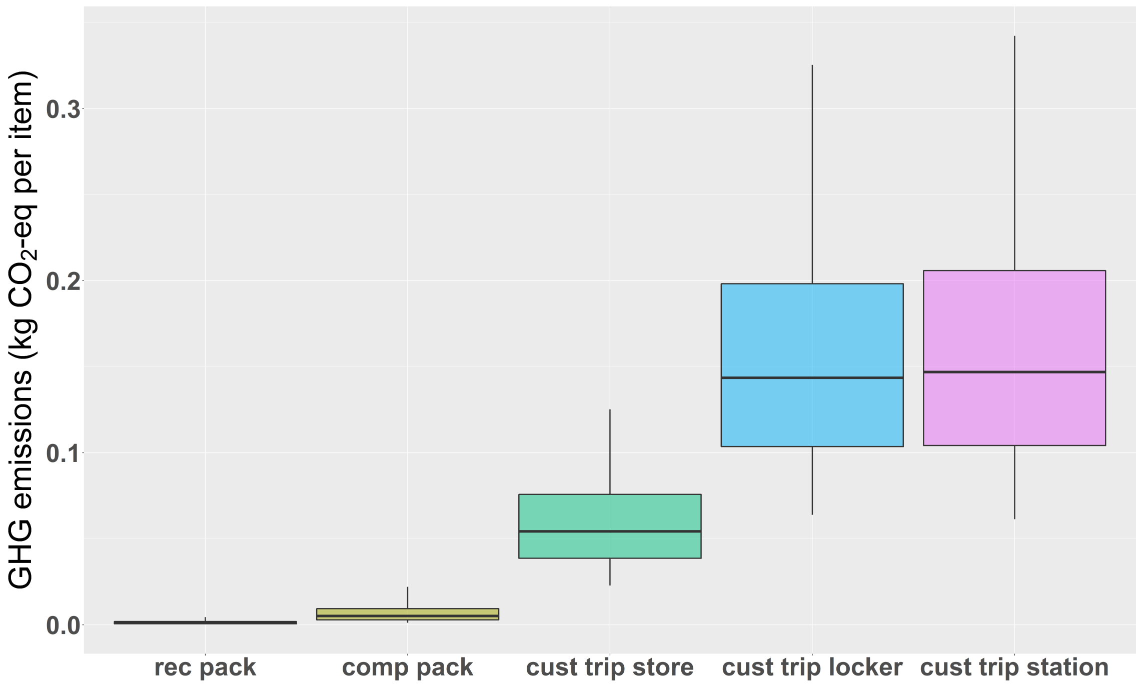


Figure 4.4: GHG emissions per item of each phase of the fulfilment process

Figures 4.3 and 4.4 report the carbon footprint of the different phases considered in this study. From the relative tables is possible to see that customer trip, in particular to reach collection points, is by far the most polluting phase, due to the travel distance and the GHG emissions of cars. On the contrary, emissions due to packaging are definitely the lowest, with recyclable packaging reaching a value of the 95th percentile of only 0,0045 $KgCO_2$eqper item. It is interesting to notice that the impact of compostable packaging is almost five times higher than the one related to recyclable packaging, even though the saturation coefficient is greater for the former. This is counterbalanced by the value of the GHG emissions per dm3 of plastic, 0,0049 vs 0,0001 $KgCO_2$eq/dm3.

quantiles	CENTRAL WAREHOUSE	STORE REPLENISHMENT	E-COMMERCE WAREHOUSE REPLENISHMENT	E-COMMERCE WAREHOUSE	STORE	COMPOSTABLE PACKAGING	RECYCLABLE PACKAGING
5%	0,0206	0,0019	0,0022	0,0085	0,0077	0,0012	0,0003
25%	0,0249	0,0053	0,0052	0,0103	0,0112	0,0029	0,0006
50%	0,0284	0,0107	0,0095	0,0117	0,0146	0,0052	0,0011
75%	0,0321	0,0213	0,0171	0,0133	0,0182	0,0094	0,0019
95%	0,0370	0,0560	0,0403	0,0153	0,0232	0,0221	0,0045

Figure 4.5: 5th, 25th, 50th, 75th and 95th percentiles of GHG emissions per item for each phases of the fulfilment process

Among the others, emissions due to Central warehouse are significant as well, with a median total emission of 0,028 KgCO_2eq. This value is twice as high as the one related to the e-commerce warehouse since the ratio between the dimensions (hence the consumptions) and the throughput flow of products is much higher for the central warehouse. In addition, store is more impacting than e-commerce warehouse in the 70% of the cases, but less than central warehouse in the 98% of the simulation runs. As expected, transportation phases present an high degree of variability, especially store replenishment, whose values range from 0,002 to 0,056 KgCO_2eq per item. Last mile delivery from warehouse is less sustainable than last mile from store in the 86% of the runs, given the higher distance per parcel.

quantiles	LAST MILE STORE	LAST MILE WAREHOUSE	CUSTOMER TRIP TO STORE	CUSTOMER TRIP TO LOCKER STATION	CUSTOMER TRIP TO DRIVE THROUGH STATION
5%	0,0034	0,0050	0,0228	0,0639	0,0613
25%	0,0056	0,0115	0,0387	0,1036	0,1042
50%	0,0081	0,0195	0,0543	0,1436	0,1469
75%	0,0110	0,0282	0,0758	0,1982	0,2058
95%	0,0177	0,0462	0,1252	0,3254	0,3423

Figure 4.6: 5th, 25th, 50th, 75th and 95th percentiles of GHG emissions per item for each phases of the fulfilment process

The results have been evaluated comparing the emissions of an order as well. As explained in subsection 3.3.1, indeed, by using the single item as functional unit, to calculate the emissions coming from the entire basket of products is sufficient to multiply the values related to the product by the average basket size.

$$\mathbf{TOT\,GHG_{ORDER}} = \mathbf{TOT\,GHG_{ITEM}} * \mathbf{BS}$$

quantiles	HDS	HDW1	HDW2	B&M1	C&C	C&D	B&M2
5%	2,22	1,02	2,54	4,50	7,78	7,59	1,90
25%	3,23	1,53	3,63	6,11	10,60	10,62	3,00
50%	4,07	2,03	4,50	7,41	12,96	13,18	3,92
75%	5,09	2,52	5,46	8,91	15,65	16,11	5,05
95%	7,40	3,07	7,21	11,71	20,26	21,11	7,55

Figure 4.7: 5th, 25th, 50th, 75th and 95th percentiles of GHG emissions per order of each fulfilment method

As expected, emissions per order (figure 4.8) are very similar to emissions per item in terms of difference among scenarios. The only peculiarity which can be highlighted is the increased variability in HDS, whose values ranges from 2,22 to 7,40 KgCO_2eq per order (figure 4.7) and are greater than those related to home delivery from warehouse replenished by the central warehouse (HDW2) in the 35% of the cases.

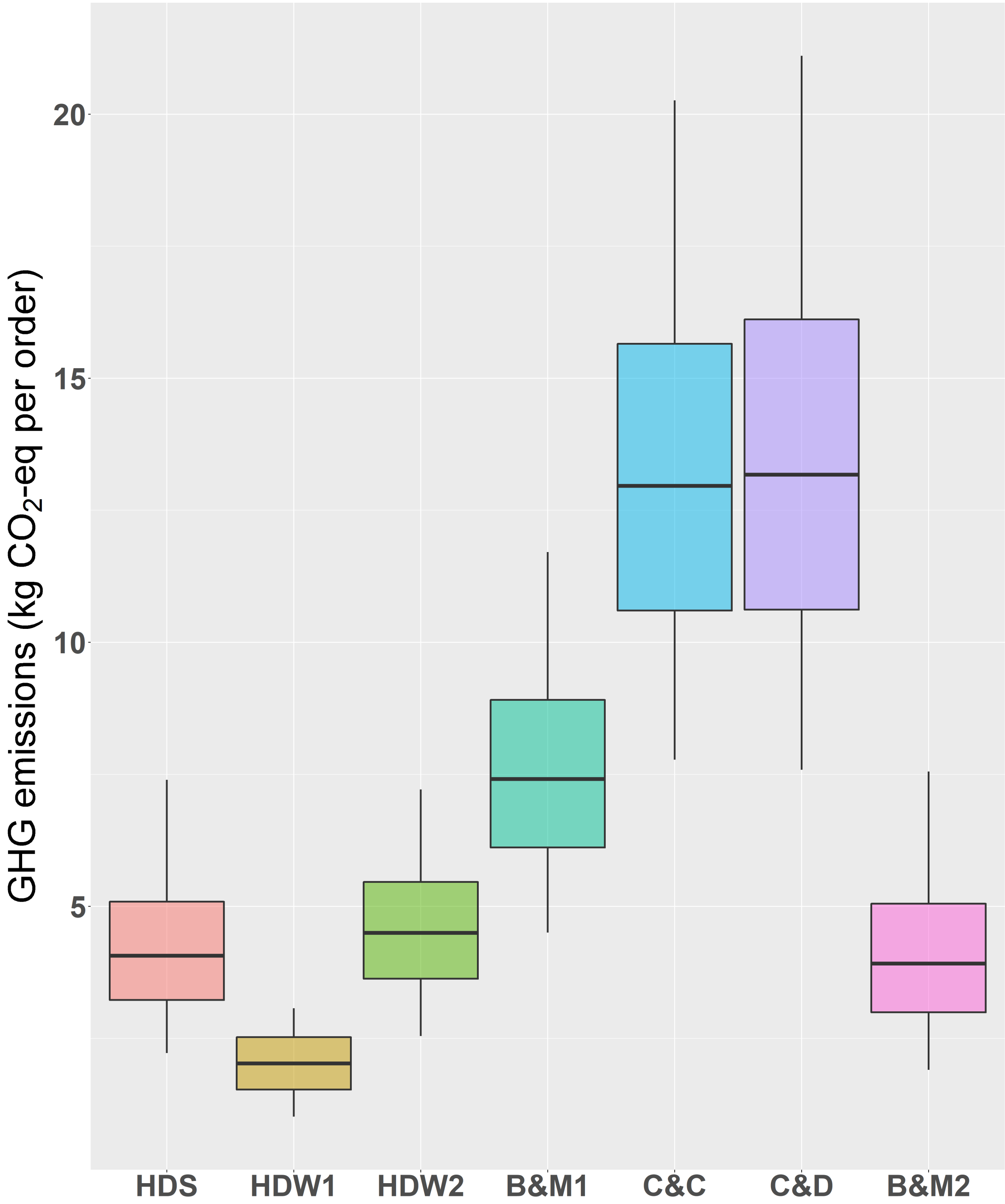


Figure 4.8: GHG emissions per order for each fulfilment method

Looking at the contribution of the different phases to the median total emission of the fulfilment methods, it is possible to notice that last mile is the most polluting phase in 5 scenarios over 7. Indeed, only for HDS and HDW2 this value is under the 45% of the median total emission, mostly due to the impact of central warehouse, which is 45% and 40% respectively. The importance of replenishment is higher in the first and in the third scenario, while in the last four is overcome by customer trip, which in case of click&collect and click&drive represent the 71% of the GHG emissions. Emissions related to store range from only 7% for C&C and C&D to over 20% for HDS, while e-commerce warehouse contribution in HDW1 is almost the double of the one in HDW2, since in this last scenario replenished and central warehouse are not included. Considering the whole 7 scenarios, $KgCO_2eq$ due to packaging do not exceed the 5% of the total median emission.

	HDS	HDW1	HDW2	B&M1	C&C	C&D	B&M2
CENTRAL WAREHOUSE	45%	\	40%	25%	14%	14%	25%
REPLENISHMENT	17%	\	14%	9%	5%	5%	9%
STORE	23%	\	\	13%	7%	7%	13%
E-COMMERCE WAREHOUSE	\	36%	17%	\	\	\	\
PACKAGING	2%	3%	2%	5%	3%	3%	5%
LAST MILE	13%	60%	28%	48%	71%	71%	48%

Figure 4.9: Percentage of contribution of each phase to the carbon footprint of each fulfilment methods

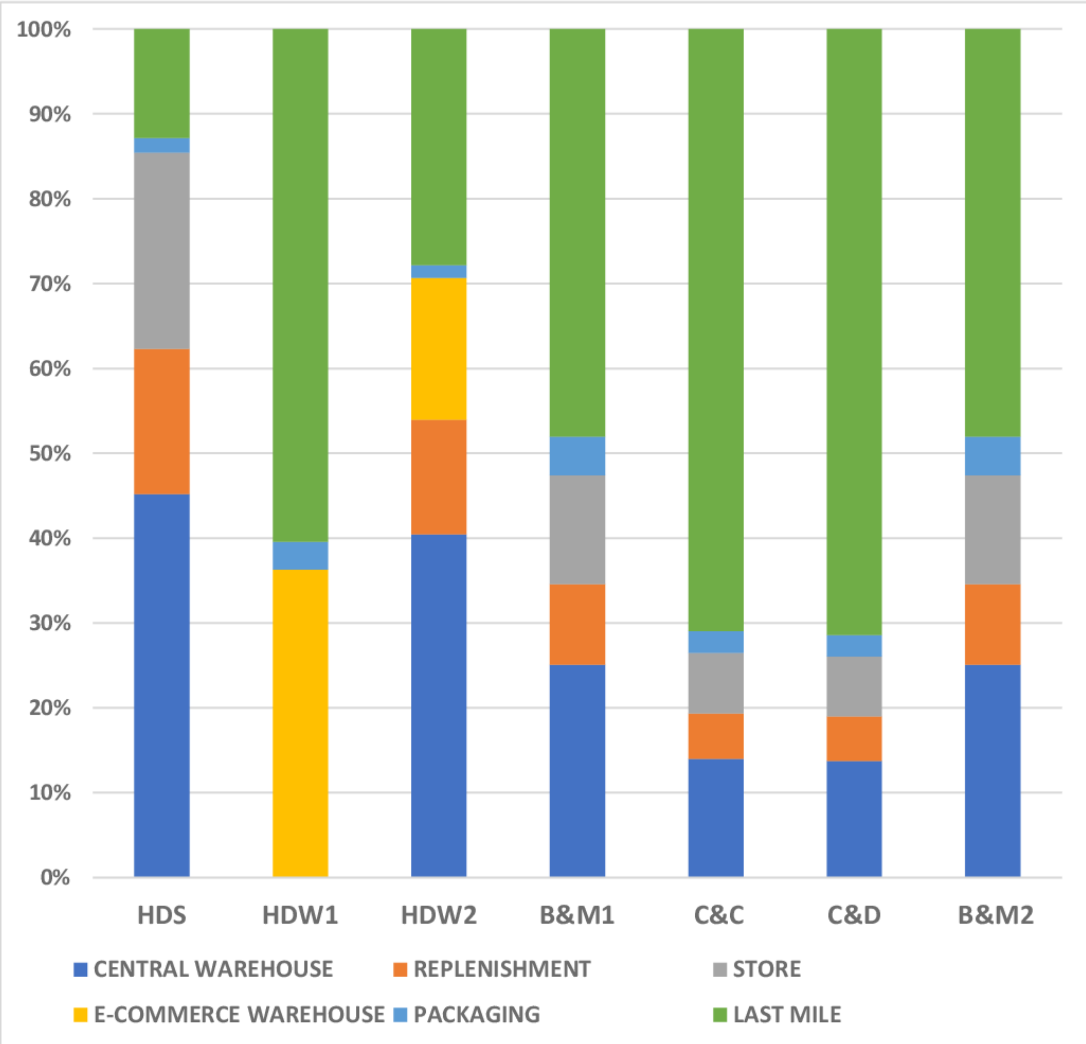


Figure 4.10: Percentage of contribution of each phase to the carbon footprint of each fulfilment methods

4.1.1 Emissions considering different basket sizes between channels

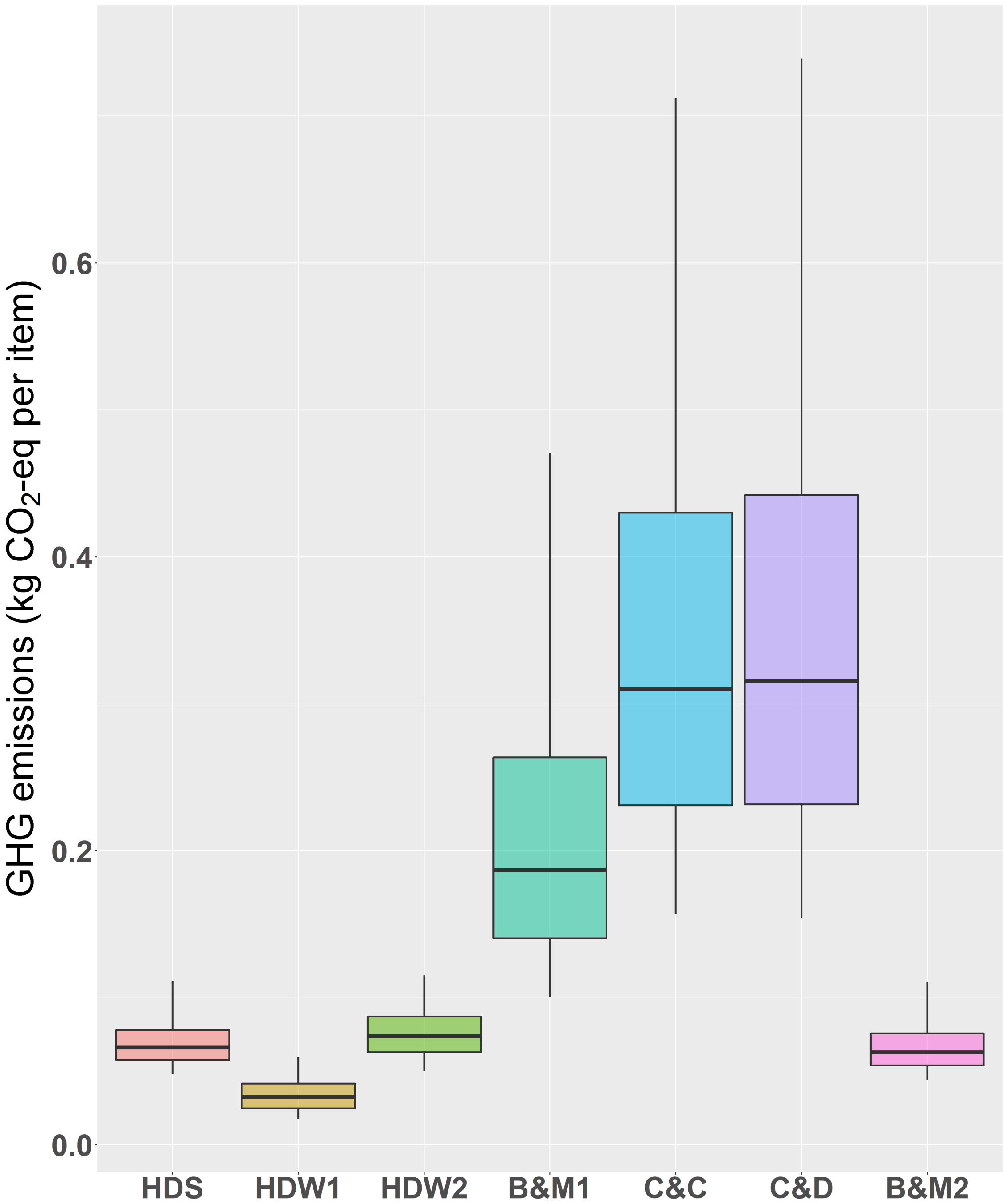


Figure 4.11: GHG emissions per item for each fulfilment method considering actual basket sizes

As reported in subsection 3.7.4, in the simulation the same basket size for all fulfilment methods has been used, in order to assure comparability and to highlight other differences. However, data from Osservatorio e-commerce of Politecnico di Milano reports that the average number of items included in a click&collect or click&drive order can be even half of the one measured for home delivery, while the average basket size of traditional retailing is even lower. As a consequence, in order to provide a complete view of the carbon footprint of the various scenario, a further simulation have been run, changing only the mean value of the basket size, respectively from 65 to 30 for click&collect and click&drive (scenarios 5 and 6) and from 65 to 20 items per order for brick&mortar (scenarios 4 and 7).

quantiles	HDS	HDW1	HDW2	B&M1	C&C	C&D	B&M2
5%	0,0482	0,0177	0,0503	0,1005	0,1572	0,1545	0,0443
25%	0,0578	0,0249	0,0631	0,1406	0,2310	0,2316	0,0541
50%	0,0663	0,0328	0,0740	0,1870	0,3101	0,3154	0,0631
75%	0,0781	0,0418	0,0874	0,2637	0,4302	0,4421	0,0759
95%	0,1116	0,0599	0,1154	0,4706	0,7123	0,7391	0,1110

Figure 4.12: 5th, 25th, 50th, 75th and 95th percentiles of GHG emissions per item considering actual basket sizes

As we can see from figure 4.12,considering the actual average basket size, the emissions related to scenarios 5 and 6 are even higher, reaching a median emission of 0,31 $KgCO_2eq$ per item sold. The same behavior is showed by traditional retailing with customer trip performed by car (B&M1), which becomes less sustainable than home delivery in the 99% of the simulation runs. On the contrary, emissions related to the last scenario (B&M2) do not change, since none of the emissions related to the activities considered in this fulfilment method are allocated on the basket size.

To sum up, if we consider real basket size of the different channels, we can see that by consolidating more items per order, home delivery becomes even more environmentally efficient compared to the other fulfilment methods.

4.2 Global sensitivity analysis

In order to evaluate the contribution of the input variables to the variance of the output values, a global sensitivity analysis has been performed for each scenario analyzed, following the indications of Shahmohammadi et al. (2019). Global sensitivity analysis is the study of how the uncertainty in the output of a model (numerical or otherwise) can be apportioned to different sources of uncertainty in the model input (Saltelli, 2004). This methodology of analysis is particularly useful for LCA studies, in order to gain more insight into output variance (Groen et al., 2017). To perform such kind of analysis, several methods exists and are documented in the literature. Following the indications of Groen et al. (2017), the Spearman method has been adopted. This method, indeed, performed best with large input uncertainties (Groen et al., 2017) and it is especially useful in case of nonlinear monotonic relationship between input and output variables (Iooss et al., 2014), as in the case of this study. The analysis has been conducted considering the same basket size for all scenarios.

The procedure to follow is explained in Shahmohammadi et al. (2019), and it is based on the ratio between the squared Spearman's rank correlation coefficient related to each input parameter and the sum of all squared rank correlation coefficients of the continuous input parameters. More specifically, the Spearman's rank correlation coefficient is a nonparametric measure of rank correlation, namely the statistical dependence between the rankings of two variables, and it assesses how well the relationship between two variables can be described using a monotonic function. The value of this coefficient can be expressed as the ratio between the covariance of the two variables (input and output) and the product of the standard deviation of the two variables (Dodge, 2008). This value may span from -1, which indicates a strong negative correlation, to +1, which conversely shows a positive correlation, and it is null when the correlation between the two variables is absent.

$$\mathbf{SPEARMAN\,COEFFICIENT}\,(\mathbf{x};\mathbf{y}) = \frac{\mathbf{Cov}(\mathbf{x};\mathbf{y})}{\sigma_{\mathbf{x}}\sigma_{\mathbf{y}}}$$

Figure 4.13 shows the percentage contribution to output variance of the main input variables used to elaborate the first scenario. More than the 70% of the variability is coming from product volume, while store replenishment distance contributed to the 14% of the total output variance. Store dimensions and electricity consumption of refrigerated warehouse are almost equally impacting, respectively 4,1% and 4,2%, whilst the only input parameter which is negatively correlated with the total GHG emissions is the basket size, even though the correlation is low (-1,8%). Indeed, if basket size increases, the emissions related to last mile delivery will be allocated to a larger base, thus decreasing $KgCO_2eq$ per item.

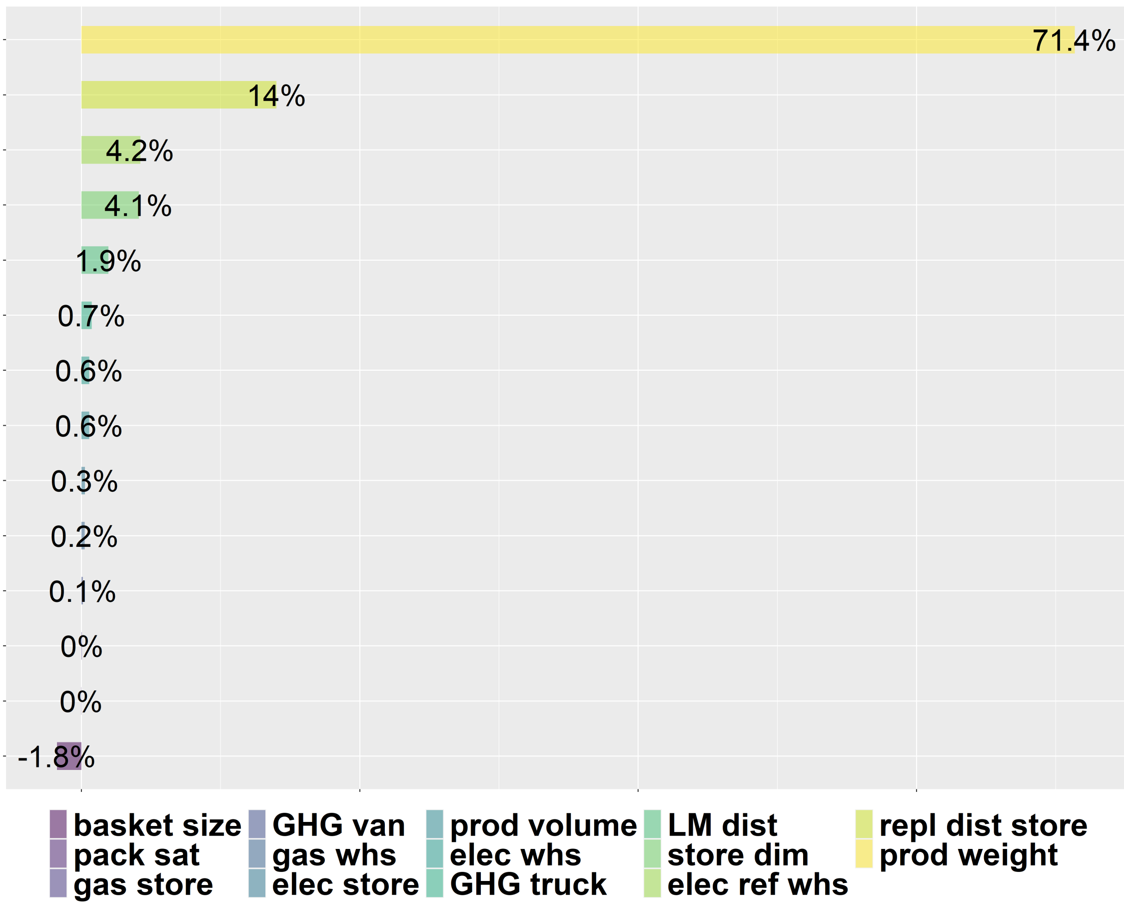


Figure 4.13: Global sensitivity analysis related to Scenario 1

For what concerns HDW1, the variables involved are significantly less. In fact, only 7 parameters contribute to the variability of the output values, among which last mile distance and basket size are the only two with a correlation coefficient higher than 3% (+63% and -31,8%, respectively).

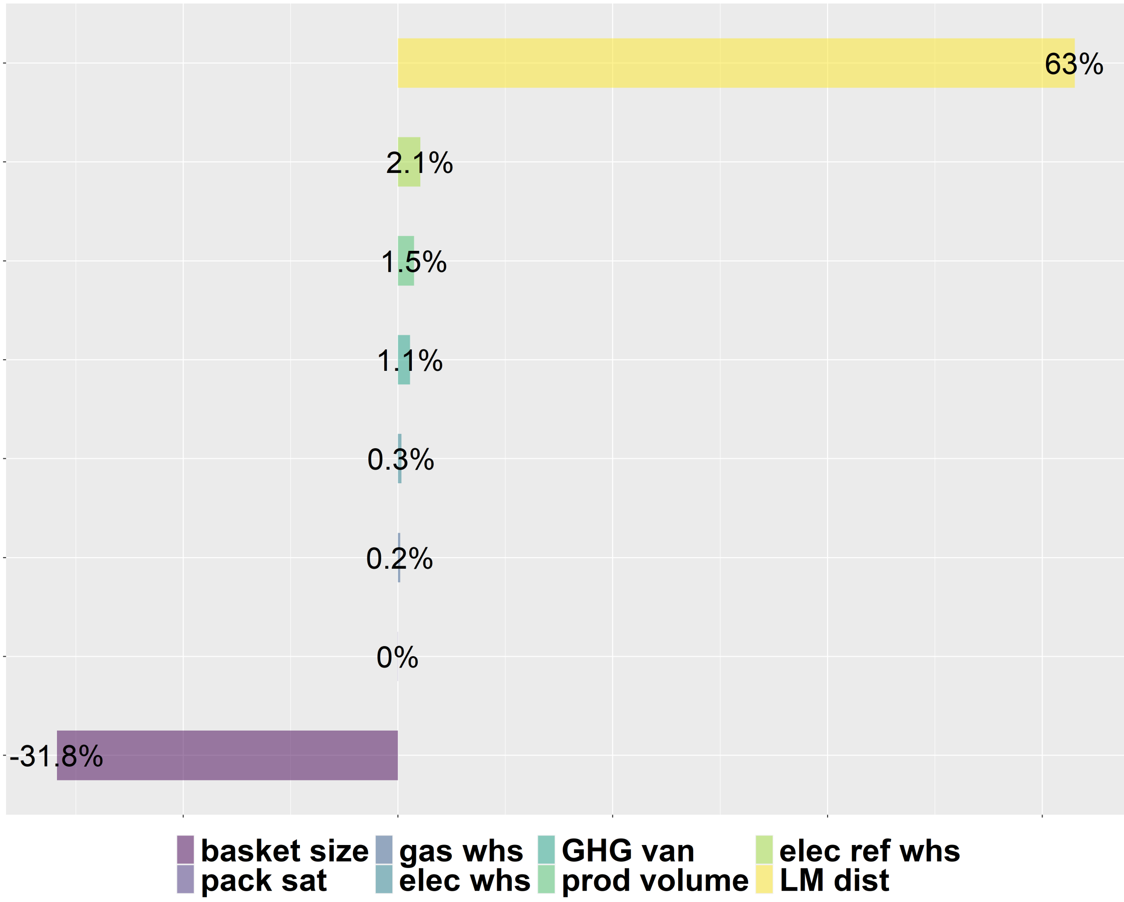


Figure 4.14: Global sensitivity analysis related to Scenario 2

On the contrary, in scenario 3, since replenished emissions are allocated on product weight, this variable is responsible for more than the 50% of the variability of the total GHG emissions. Last mile distance and refrigerated warehouse electricity consumptions contribute for the 24% and 9,5%, while also in this case basket size is the only parameter which is negatively correlated with the output values (-11,9%).

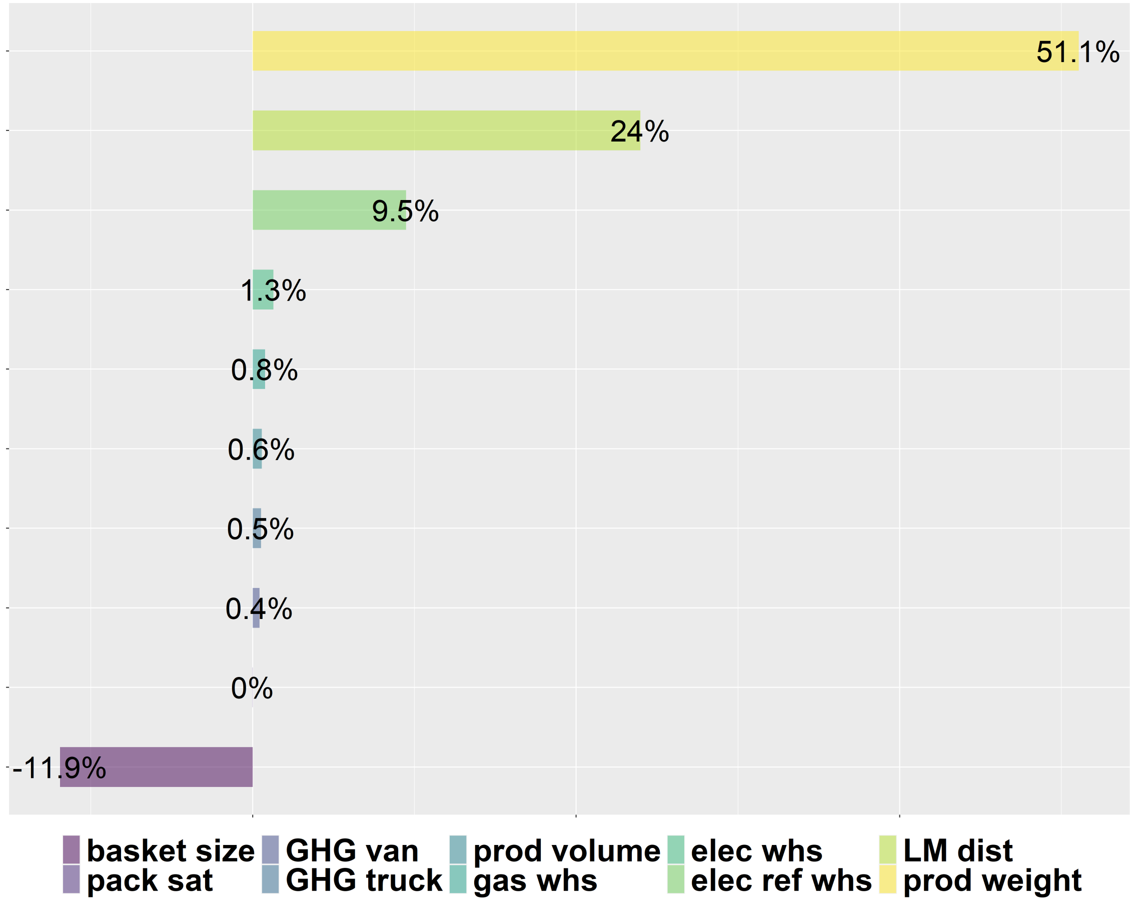


Figure 4.15: Global sensitivity analysis related to Scenario 3

The parameters influencing the variability of brick&mortar retailing (B&M1) are pretty similar to the one involved in the previous scenarios, but with different values: customer trip and product weight represent the 25% and the 23,2% of the variability, while GHG emissions of cars account for the 11,6%. Moreover, replenishment distance, product volume, electricity consumptions of refrigerated central warehouse and store dimensions are positively correlated with the final output as well, whilst basket size is again the only parameter presenting a negative correlation (-28,2%), thus reducing the final carbon footprint of the fulfilment method. It is possible to see how, as the impact of last mile delivery on the final emissions grows, the intensity of the correlation between the final value and the basket size gets more negative.

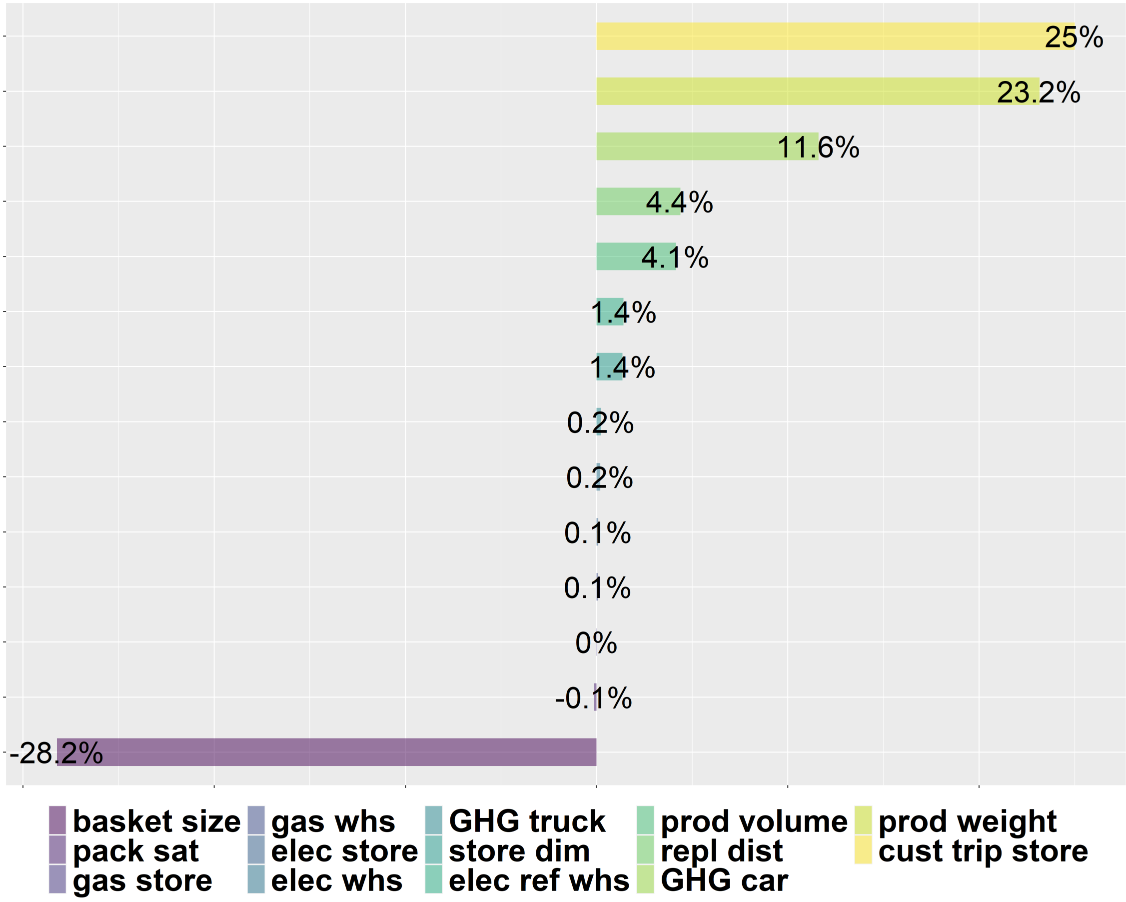


Figure 4.16: Global sensitivity analysis related to Scenario 4

The contribution to variance related to C&C and C&D is almost the same (figure 4.17 and 4.18). In fact, in both cases the customer trip is the parameter mostly positively correlated with the final output, while basket size is the only one which is negatively correlated.

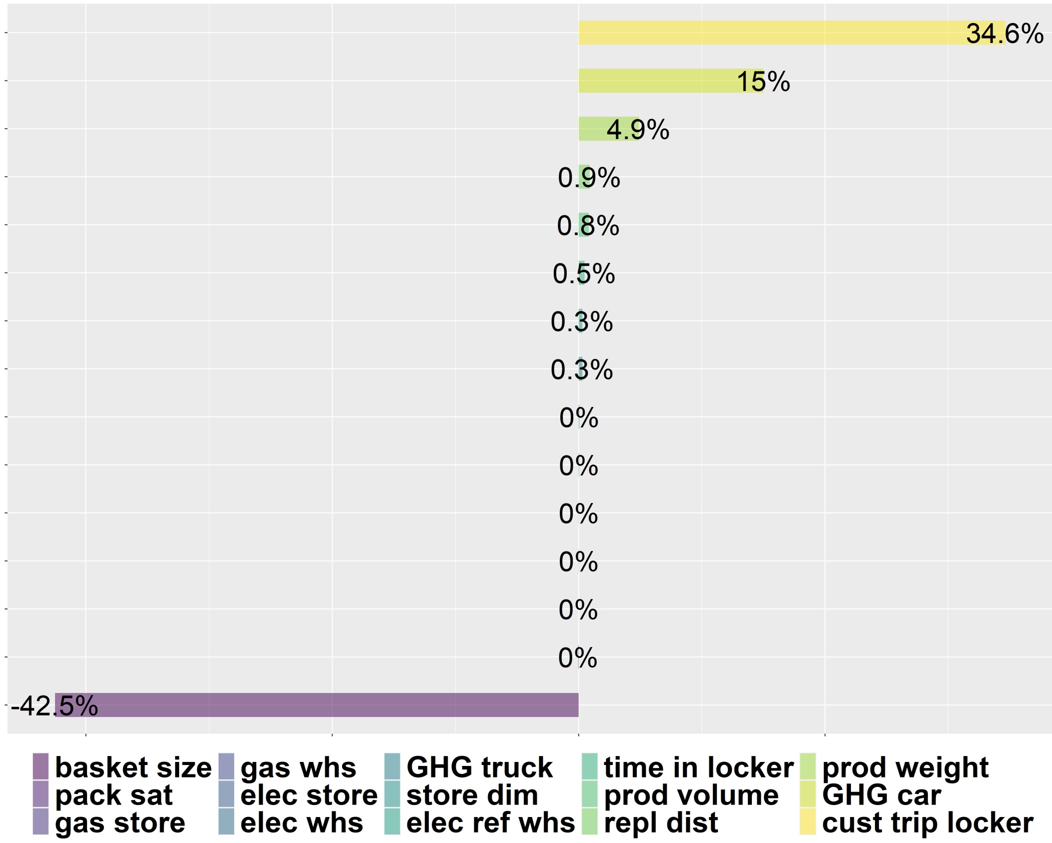


Figure 4.17: Global sensitivity analysis related to Scenario 5

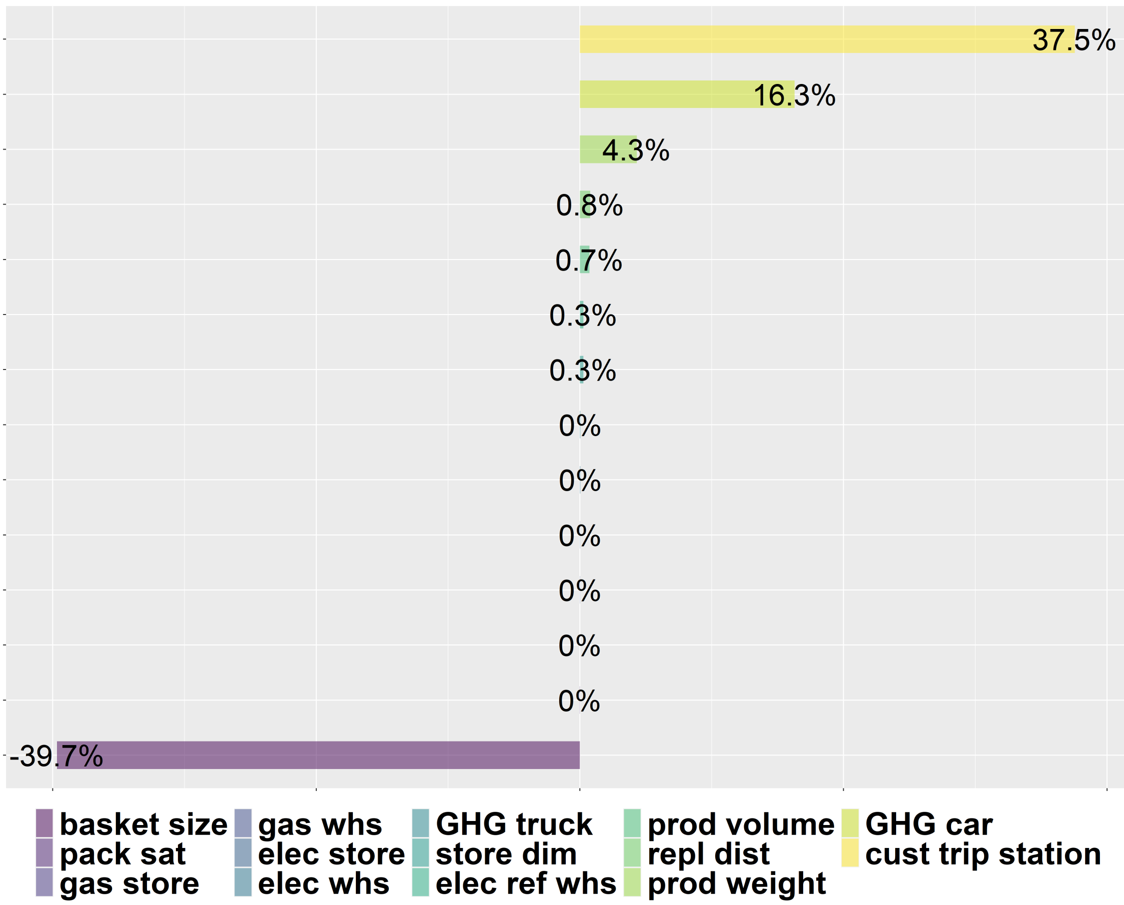


Figure 4.18: Global sensitivity analysis related to Scenario 6

On the other hand, in the last scenario (B&M2), since last mile is performed by foot, no emissions are accounted, thus the basket size becomes irrelevant for the determination of the final GHG emissions. In this case, the only parameter which is slightly negatively correlated with the output is packaging saturation (-0,3%), while the majority of the variability is caused by product weight (65,4%).

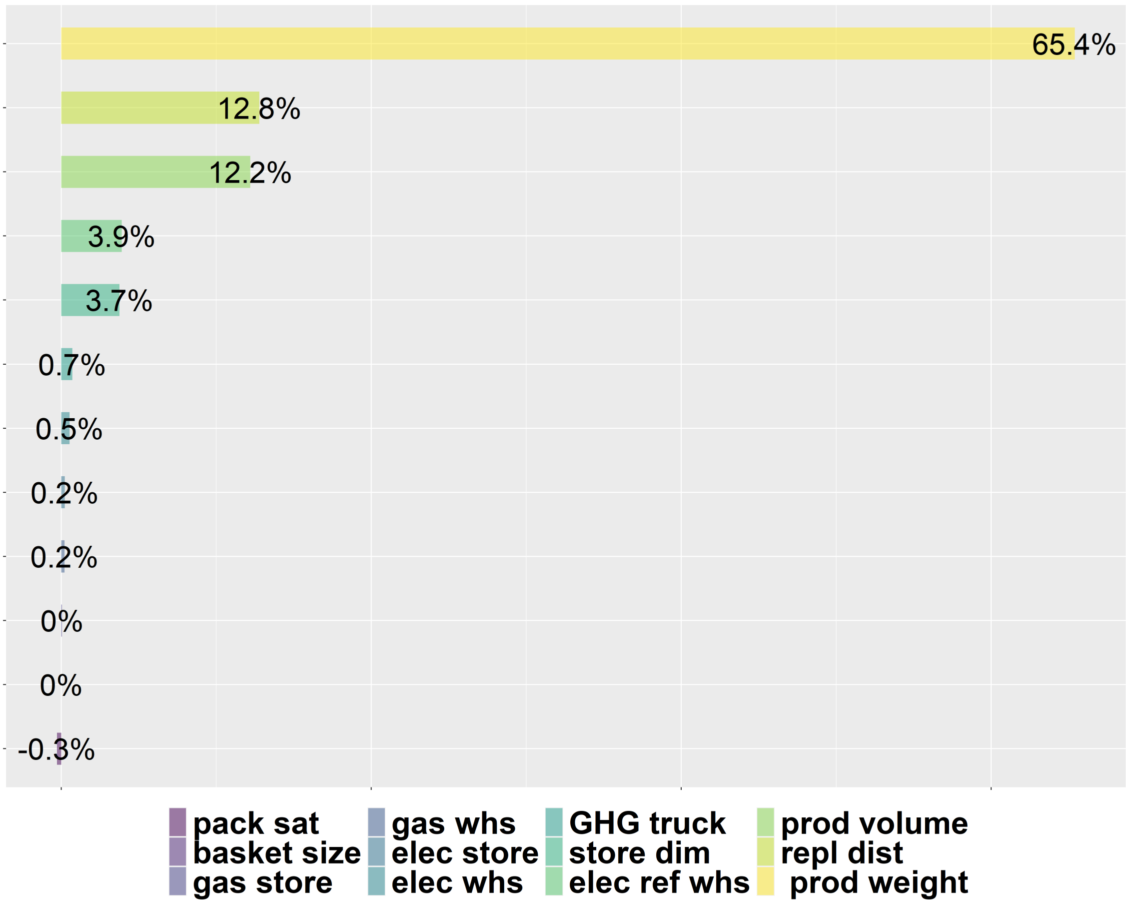


Figure 4.19: Global sensitivity analysis related to Scenario 7

4.3 Discussion and comparison with other studies

4.3.1 Discussion of results

The research question this thesis is focused on is the following:

RQ: **What is the differential impact that e-grocery fulfilment methods have on environmental sustainability, and which are the main variables responsible for those environmental performances?**

In order to answer to this question, a stochastic LCA model following the Monte Carlo methodology has been elaborated, whose results shows that, under the model assumptions, home delivery performed from a dedicated warehouse replenished directly by suppliers is the most sustainable fulfilment method in the 97% of the simulation runs, mainly thanks to a lower environmental impact related to product storage. However, if the distribution network of the e-tailer is composed by an ulterior tier, which means that products are passing through a central warehouse before being stored in the e-commerce dedicated building, GHG emissions raise significantly, from 0,03 to 0,07 $KgCO_2eq$ per item, and the scenario is no more the greener one.

Home delivery from local store, instead, presents lower emissions related to last mile delivery in respect to the previous scenario, thanks to a lower distance to cover by delivery vans, but higher energy consumptions per item related to stores. The environmental impact in terms of $KgCO_2eq$ per item of HDS is very similar to the one calculated for the last scenario analyzed in this study, namely traditional retailing with the customer trip performed by foot. This means that, even if the final customer is reaching the local store without using any polluting means of transport, store home delivery remains a competitive fulfilment methods in environmental terms, thanks to a very efficient last mile delivery (only 0,008 $KgCO_2eq$ per item of median emissions). Click&collect and click&drive scenarios are significantly worse in terms of carbon footprint in respect to other fulfilment methods, since emissions coming from customer trip are huge (0,144 and 0,147 KgCO_2eq per item, respectively). However, this value is based on the hypothesis that the customer is willing to travel more to reach those collection point than to reach the closest store and it is predicted to fall with the growth of locker and drive through stations. Moreover, the main advantage of those fulfilment methods is to support trip chaining, which means that the part of the customer trip attributable to grocery shopping might be drastically reduced. In short, this value has to be read carefully, as it is caused by the immaturity of the fulfilment method itself.

In conclusion, even supposing that for brick&mortar retailing a percentage of customers is reaching the store by foot or bike, e-grocery, both with home delivery and collection-point-based services, shows high potentials to be more sustainable. This result, even though it is based on several assumptions, is in accordance with the 58% of the studies regarding B2C e-commerce sustainability.

4.3.2 Comparison with similar studies and position in the literature

In this section, the results previously presented will be compared with those coming from similar studies, as well as with studies focused on different industries in the literature regarding B2C e-commerce sustainability. For this comparison, only the values obtained considering the same basket size for each scenario will be considered.

Frist of all, the findings of the present simulation will be confronted with two similar studies, namely the study from Van Loon et al. (2015), as it analyzes different fulfilment methods likewise, and the paper from Shahmohammadi et al. (2020), since it presents methodological aspects similar to the present study. Both studies present a similar structure and the same functional unit and environmental parameter used to express the carbon footprint, even though system boundaries might differ. However, since Van Loon et al. (2015) LCA model, unlike the other paper and the present work, is not obtained through Monte Carlo method, for this comparison, only the total median emission values will be considered.

As discussed in the literature (subsection 2.3.7), Van Loon et al. (2015) analyzed 7 different fulfilment methods as well. However, only four of them are comparable to the ones considered in this study, namely van home delivery from warehouse, van home delivery from local store, click&collect in store and traditional retailing. Moreover, only the "base-case scenario" described in Van Loon et al. (2015) will be taken as reference, thus excluding complementary shopping trips and product returns.

According to this study, van home delivery from warehouse is the most sustainable fulfilment method as well, with an emission of approximately 0,17 $KgCO_2$ equivalents, which is significantly higher than the one identified by the present simulation, due to the difference in the system boundaries. In fact, if we exclude from the analysis emissions coming from product manufacturing and cross-docking, which are accounting for the 30% and the 23,2% of the total, we obtain 0,08 $KgCO_2eq$ per item. This value is still more than the double of the median emissions of HDW1 reported in the present study; this difference is caused mainly by the different basket size considered (55 items in respect to an average of 65) and last mile distance, which in both cases is the most impacting parameter. The impact of packaging is similar, lower than 5%. Home delivery from store, on the other hand, is more polluting also in Van Loon et al. (2015), reaching a value of 0,2 $KgCO_2eq$ per item. As for the previous scenario, also in this case the system boundaries have to be redefined to assure comparability, hence production emissions are excluded. The value obtained is 0,115 $KgCO_2eq$per item, still more than twice the value resulting from the present work. This can be explained by looking again at the basket size, which for this scenario is composed by 45 items, but the substantial difference lies in the store emissions, which accounts for the 40% of the total emissions (0,08 against 0,015 $KgCO_2eq$ reported in this thesis). Since the allocation base for store emissions is the same, namely throughput flow of items, this value must be the principal responsible for the great distance between the two carbon footprints. Unfortunately, the article does not report the value used for this calculation, so a proper comparison is not possible.

Click&collect and traditional retailing present a similar carbon footprint, between 0,21 and 0,24 KgCO_2eq per item. While the value for Brick&mortar is significantly different from the one of the present work, click&collect emissions are almost equal. Nevertheless, the sub-processes contributing the most to those results are not the same. Indeed, while in Van Loon et al. (2015) is the store the most polluting part of the process, in the present study customer trip is definitely the less sustainable, since distances to cover are higher (the value used by Van Loon et al.,2015 is similar to the one used by the present study for the customer trip to store, without considering the distance factor explained in subsection 3.8.6) and alternative means of transport are not considered. In addition, all the previous mentioned scenarios included ICT emissions, but the impact is never above 0,4% of the total. Those results confirm the choice not to consider this source of emissions in the present model. To conclude, the results are similar in terms of ranking of the different fulfilment methods, while in terms of values, several difference can be highlighted. The main source of diversity among the two models are represented by the system boundaries, the country of reference (UK versus Italy) and the industry of analysis, FMCG in respect to food&grocery.

The study conducted by Shahmohammadi et al. (2020) is more similar to the present one in terms of system boundaries and, since it is based on Monte Carlo method, the variability of results can be compared as well. The paper considers only three different scenarios, namely brick&mortar, brick&clicks, which is the equivalent of HDS (scenario 1 of the present study) and pure player, which corresponds to HDW2 (scenario 3 of the present study). The present comparison will be based on results related to UK, even though the paper compares the emissions related to traditional retailing for UK, US, China and the Netherlands.

According to Shahmohammadi et al. (2020), the most sustainable fulfilment method is represented by van home delivery from local stores, while home delivery from dedicated fulfilment center is 2 to 5 times more polluting. Brick&mortar retailing presents intermediate values, ranging from 0,04 to 0,37 KgCO_2eq per item. Those values are higher than the ones related to brick&click and lower in respect to pure player in the 81% of simulation runs. For all the three scenarios, last mile delivery is definitely the part of the process which presents the highest GHG emissions, with median value of 0.04 KgCO_2eq/item for brick and mortar, 0.02 KgCO_2eq/item for bricks and clicks and 0.11 KgCO_2eq/item for the pure-play channel. Those values are pretty similar from the one obtained from the present simulation (see figure 4.1), except for HDW2, were last mile delivery presents an environmental impact of only 0,02 KgCO_2eq per item. This difference is due to the distance covered and number of parcels delivered per tour, whose ratio is substantially lower in the present study. In addition, the average basket size is significantly lower in respect to the one considered for the present work (2 compared to 65), since the paper is based on the analysis of generic FMCG rather than food&grocery deliveries.

On the contrary, according to Shahmohammadi et al. (2020) the GHG emissions associated with the storage of products are small (<0.01 KgCO_2eq) in all cases, while emissions from warehousing accounts for more than the half of the emissions both in scenario 1 and 3 of the present work. In this case, indeed, the authors chose a different allocation base for the emissions, namely the number of items per square meter. Moreover, even though the secondary source for the emissions of buildings is the same of the present work, Shahmohammadi et al. (2020) does not consider refrigerated warehouses, as the study is based on dry products only. The GHG emissions of the last mile packaging are considered only for pure players and range between 0.003 and 0.09 KgCO_2eq/item, higher in respect to the emissions in the present model, since the packaging considered is cardboard rather than recyclable or compostable plastic. Moreover, both brick and mortar retailing and warehouse home delivery present a huge variability in results compared to the one of the values obtained through the present simulation, as the number of variables considered in the study of Shahmohammadi et al. (2020) is greater.

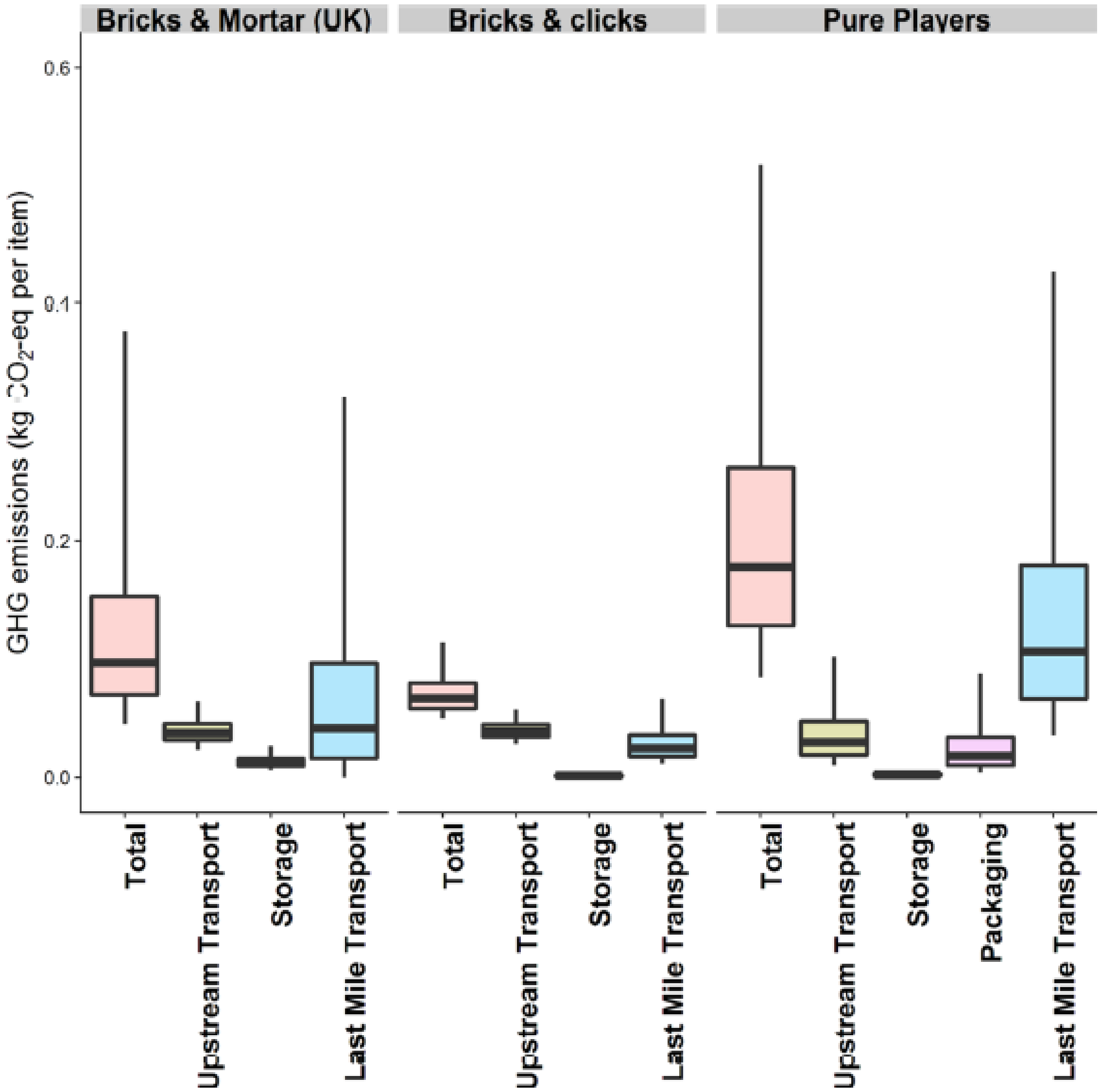


Figure 4.20: GHG footprint of different retail channels by phase in $KgCO_2eq$/item, from Shahmohammadi et al., (2020)

Looking at the contribution to variance, basket size is the dominant source of variability in both brick and mortar and bricks-and-clicks channels, while the second major contributor is the last-mile travel distance, with a share of 32% for brick and mortar, 15% for bricks and clicks, and 34% for pure players. This is in line with the fact that both variables are related to last mile delivery, which is by far the most impacting phase. Indeed, in respect to the present study, product weight and buildings energy consumptions are less impacting the variability of results, since upstream transportation emissions are not allocated on the weight and storage activities are less polluting.

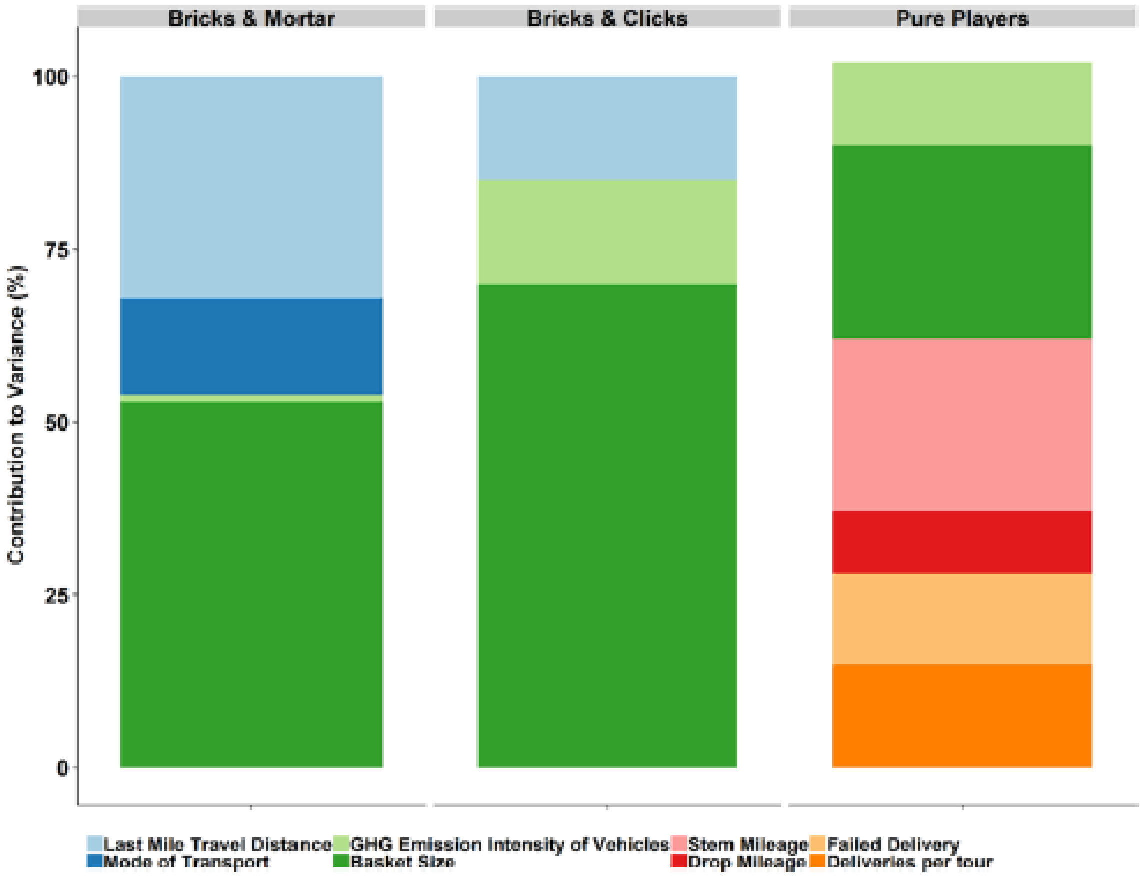


Figure 4.21: Contribution of input variables to the variance in the total GHG footprints, from Shahmohammadi et al., (2020)

Apart from those studies, it is interesting to underline that the environmental superiority of e-grocery against traditional retailing is confirmed by the LCA study of Heard et al. (2019) as well. According to the author, indeed, brick&mortar retailing is calculated as having 2 KgCO_2eq per meal higher emissions than an equivalent meal kit. More specifically, the average emissions were calculated to be 6.1 KgCO_2eq/meal for a meal kit and 8.1 KgCO_2eq/meal for a grocery store meal, with the latter exceeding meal kit emissions by a 33% difference. The results of this model state that median grocery store meal emissions exceed the median meal kit emissions for four out of five meal types examined, namely salmon, chicken, pasta and salad, while only for cheeseburgers grocery retailing was less impacting in 90% of runs.

For what concerns the comparison with previous studies belonging to different industries, the first consideration which can be done is that the results presented in this study are in accordance with the 58% of the studies analyzed in the literature review, as they confirm the potential positive impact of e-commerce on environmental sustainability compared to traditional retailing. However, looking at GHG emissions per item, the number presented by the LCA model of Weber et al. (2010) for CD retailing and home delivery are substantially different, ranging from 3200 gCO_2eq for the former scenario to 400 gCO_2eq for the latter. This difference is due to the fact that the study presents different system boundaries, considering CD and packaging production as well, which are accounting for one third of the emissions related to traditional retailing. Moreover, differences in the distribution network and in conversion factors might impact the results of the analysis, considering also that the distance considered for customer trips to store is twice as high as the one considered for the present study.

On the contrary, the study from Giuffrida et al. (2016) reports numbers regarding last mile delivery in the urban case scenario which are closer to the one of the present simulation, 0,3 $KgCO_2eq$ per parcel related to home delivery and 0,1 $KgCO_2eq$ per parcel for what concerns parcel lockers, considering that the average number of items per parcel is significantly lower than the basket size considered for the present study. On the other hand, the extra-urban scenario reports 1,4 $KgCO_2eq$ and 0,14 $KgCO_2eq$ per parcel for home delivery and pick-up at lockers, respectively. However, the results are highly influenced by the number of parcel delivered per day, which are much more than in the grocery industry, and by the fact that the paper considers at maximum three re-deliveries in case of failed deliveries, which are more impacting for FMCG.

In the apparel industry, the study from Mangiaracina et al. (2016) calculates 2,95 $KgCO_2eq$ per item related to the online channel, while the offline channel emits 6,62 $KgCO_2eq$ per item. Also in this industry return rate contributes to raise online channel emissions, while pre-sale and sale is the most polluting phase of the offline selling process. The main difference in respect to the grocery industry stands in the basket size, which is significantly lower. Indeed, the numbers reported are pretty close to the median emissions presented in this study related to the whole order for traditional retailing and warehouse home delivery.

At last, Zhang et al. (2013) reports that last mile delivery related to the book industry accounts for 0,058 $KgCO_2$ per book for van-based home delivery, while a distribution network based on electric bikes and customer self-pick-up at collection point would emit only 0,052$KgCO_2$ per item. The difference with the values reported in this study is significant and it is caused by the different average basket size (2,5 versus 65) and the differences in the two distribution networks, as the one related to books present an additional tier for the sortation of items.

4.4 GHG reduction potentials

The carbon footprint of the various fulfilment method analyzed could be reduced both by online pure players, such as Esselunga, and through the behavior of the final customer. Indeed, on one hand the e-tailer controls the majority of the emission sources, namely product storage, replenishment and van home delivery, and it could work to optimize the processes and reduce the environmental impact. For example, by improving the routing algorithm, through a VRP, or by increasing the delivery time window, as suggested by Leyerer et al. (2018), the efficiency of last mile delivery could grow and the failed delivery rate would probably fall (Van Loon et al., 2015). Another possible source of improvements could be represented by the usage of electric vehicles, or alternative vehicles such as electric cargo bikes, as suggested by Shahmohammadi et al. (2020). In fact, the simulation run in this study shows that the median GHG emissions associated with last-mile transport are 42% lower and the median footprints are 26% lower when fossil fuel vans are replaced by electric cargo bikes, even though this alternative is feasible only for small urban distances, hence deliveries from local stores.

Regarding buildings energy efficiency, apart from the local optimization of single processes, e-tailers might invest in renewable energy sources, such as solar energy, both for warehouses and stores, or in alternatives to ammonia as refrigerant fluids like CO_2. In fact, carbon dioxide, apart from its negligible Global Warming Potential, offers a number of other advantages over HFC refrigerants, which include better heat transfer performance and smaller components for a given refrigeration load (Tassou et al., 2010). In this sense, Esselunga declares on its website to be on the right path: as part of the renovation project of one of the stores in Milan, the first refrigeration unit that uses carbon dioxide for medium and low temperatures was built in 2015, while in every newly built shop photovoltaic panels are used for the production of electricity, whose reduction of CO_2 released into the atmosphere is estimated at over 60 tons of CO_2 per plant, with the aim of reaching a coverage of energy produced with renewable sources of more than 5% of the store's energy needs. Esselunga claims also that all the vehicles used for replenishment and last mile delivery are at least Euro 5, whilst is starting the experimentation of electric vehicles for e-commerce deliveries in central urban areas. In addition, considering scenario 5 and 6 only (C&C and C&D), customer trip emissions would be significantly reduced with the growth in the number of locker and drive through stations, as the distance factor that increase the distance to stores would approach 1. This consideration is in line with the aim of Esselunga to further increase the service level, as well as the geographic coverage.

For what concerns packaging, as described in section 4.1, the impact on total carbon footprint was never above 5%, despite the possibility to use reusable plastic bags for brick&mortar were not considered. However, something could be done also in this direction: Esselunga currently uses plastic bags at least 80% recyclable for home delivery, which are extremely less impacting in respect to compostable packaging, as showed by Chaffee et al. (2007). As a consequence, the use of compostable plastic bags should be avoided when possible.

On the other hand, the final customer might have a substantial impact on e-grocery environmental impact as well. For instance, increasing the basket size and delivery time window, maybe reducing order frequency, would decrease the $KgCO_2eq$ per item. Moreover, consumers who shop traditionally (i.e., via brick and mortar) could reduce their GHG footprints by applying trip chaining (e.g., shopping when returning home from work), adopting reusable bags and by choosing cleaner modes of transport.

4.5 Limitations

Despite the LCA model elaborated in the present study is sufficiently complete to provide an answer to the research question, potential limitations might be highlighted:

- First of all, the system boundaries of the study exclude the environmental impact of ICT-related tools, as well as the presence of alternative vehicles.
- Due to data limitations, no validation of statistical distribution was performed.
- For the sake of simplicity, complete trip substitution is assumed to calculate the carbon footprint of e-grocery home deliveries compared to traditional retailing, even though a complete substitution of the consumer trip to the store due to home deliveries is probably unrealistic (Van Loon et al., 2015).
- This study compares the different fulfilment methods assuming that the type of products sold between channels is the same. This might not be always true, especially because the online product offer is not as wide as the one of traditional retailing, even though online players are continuously increasing it.
- The presented model does not consider food losses along the supply chain, as well as possible product damage.

- The study presents geographical limitations: indeed, the structure of the model, as it is based on Esselunga distribution network, primary data used and energy conversion factors are typical of Italy. A similar study conducted in another country might provide different results.

4.6 Future developments

Starting from the limitations of the study, future improvements and developments could be suggested:

- The quality and the robustness of results strongly depends on input data. Indeed, with the support of the players involved, large data samples coming from primary sources could be analyzed, in order to validate statistical distribution and to create a more detailed and precise structure of the model, perhaps expanding the system boundaries, with the aim to precisely assess the total carbon footprint of each fulfilment method.

- Further studies might assess the role of renewable energy sources in B2C e-grocery sustainability. In fact, the use of renewable energy sources might significantly contribute to reduce the environmental impact not only of product storage, but also the one related to transportation, packaging and production.

- Some studies in the literature regarding B2C e-grocery are now focusing their attention on food losses and waste along the supply chain, in order to consider this source of GHG emissions as well. Indeed, Heard et al. (2019) claims that food waste comprises an average of 10% of a grocery store meals emissions, while Belavina et al. (2017) states even that, when comparing subscription and per-order revenue models (see section xx), food waste emissions advantage might overcome higher delivery emissions. When analyzing this aspect, the need of primary data is even greater since reliable secondary sources are currently not available.

Chapter 5

CONCLUSIONS

The aim of this master thesis was to elaborate a stochastic Life cycle assessment model though a Monte Carlo simulation, in order to assess the differential impact that e-grocery fulfilment methods have on environmental sustainability, as well as the main variables responsible for those environmental performances. The analysis was limited to the Italian online grocery industry, taken as main reference the distribution network of Esselunga, the most established and developed player in the current Italian scenario. The model wad developed on RStudio by following a modular approach, assessing the carbon footprint of each fulfilment methods as the sum of the GHG emissions pf each sub-process.

Results obtained show that home delivery performed by dedicated warehouse replenished by suppliers is the most environmentally sustainable fulfilment method, while store home delivery presents similar GHG emissions of traditional retailing with the customer reaching the store by foot. On the contrary, considering the current situation and assuming that the customer is reaching the collection point by car, click&collect and click&drive services are definitely more polluting.

According to the author's knowledge, no study has ever analyzed the environmental impact of different e-grocery fulfilment methods in Italy. Moreover, very few examples of LCA models using Monte Carlo simulations can be found in the current literature.

This study provides meaningful insights on the various trade-offs e-tailers have to face when deciding which services to focus on, and aims to be the base for a structural analysis which relies almost exclusively on primary data, with the final purpose to guide future investments towards a more sustainable path. Indeed, as stated in the introduction (section 1.3), Italian e-grocery market is experiencing a fast growth, also due to recent events linked to SARS-COV-2. For this reason, the analysis and understanding of environmental consequences of the choice undertaken by the online grocery players, as well as by the final customer, is fundamental to assure that this growth will be not only economically, but also environmentally sustainable.

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