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SCUOLA DI INGEGNERIA INDUSTRIALE
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EXECUTIVE SUMMARY OF THE THESIS

Comparative CO2 emissions assessment of online and traditional shopping channels: a multi-purchase perspective

Master of Science in Management Engineering

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Introduction

Over the last fifteen-twenty years, e-commerce expansion disrupted the way of doing business for companies and purchasing habits for consumers. The significant growth of e-commerce led many scholars to wonder if this purchasing process is environmentally sustainable. Indeed, it is still uncertain whether electronic commerce is more environmentally sustainable than conventional shopping. A crucial aspect is how the customer behaviour affects the environmental impact of purchasing processes which is rarely considered in most of Life Cycle Analysis studies collected in the literature review phase (e.g., Matthews *et al.*, 2001 [9]; Weber *et al.*, 2008 [20]). Thus, it becomes crucial to consider variables related to customer behaviour, as the number of purchases made and if and how they are combined in a typical shopping trip, the mode of transport adopted, the distance driven, the frequency of shopping activity for a certain product category and return process management. What emerged from literature review is that what happens if an average number of different purchases, combined in a single order or in a unique shopping trip, is taken into consideration remains still unexplored. Consistently with the above-described premises, the purpose of this thesis is to understand how a **multi-purchase scenario** and **the customer behaviour**, both in the online and offline process, may alter the environmental impact of purchasing process (measured as kgCO2e), and which type of **product category** contributes more to the generation of emissions. The model developed focuses on activities related to the downstream supply chain activities, since they are considered critical to the environmental sustainability of purchasing processes (Hjort *et al.*, 2013 [6]).

Literature review

The predominant subject of literature review concerns the study of e-commerce environmental impact, compared to the conventional shopping scenario from different perspectives. Some studies only focus on transportation related environmental implications (e.g. Patricia L. Mokhtarian, 2004 [10]); others only consider the last mile perspective (e.g. Edwards *et al*., 2010 [5]; Brown and Giuffrida, 2014 [2]; Velazquez and Chankov, 2019 [19]); further papers are related to emissions deriving from production, use and waste of packaging (e.g. G. Song et al., 2017 [17]; H. Duan *et al.*, 2019 [4]; Arunan and Crawford, 2020 [1]); other studies assume a logistics perspective to quantify environmental effects of purchasing choices (e.g., Weber *et al*., 2008 [20]; Mangiaracina *et al.*, 2016 [8]). According to results emerged from literature, it is possible to state that, on the whole, e-commerce option is more environmentally sustainable than conventional shopping (e.g., Reijnders and Hoogeven, 2001 [12]; Sivaraman *et al*., 2007 [15]; Wiese *et al*., 2012 [21]; L. Smidfelt Rosqvist and L. Winslott Hiselius, 2016 [16]; Mangiaracina *et al*., 2016 [8]). The analytical model developed by Mangiaracina and colleagues (2016) [8], shows that the online purchasing process is more sustainable than the offline one, but the logistics, packaging and handling activities are more environmentally impacting in the online process rather than in the conventional shopping while transportation activities generate a higher impact in the offline scenario. Also, according to Pålsson and colleagues (2017) [11], the total energy consumption from transportation is greater in the conventional supply chains, while packaging activities are more impacting in the online sales. Despite the majority of models states that e-commerce is more environmentally sustainable, some studies do not completely support this thesis as Brown and Giuffrida (2014) [2]. Also, many studies take into consideration only dedicated purchasing trips, while if customers combined shopping to other activities, the environmental impact could not be the same (e.g. J. Kim *et al.*, 2009 [7]; Rizet *et al*., 2010 [13]).The majority of studies considers only one item as unit of analysis, without investigating the situation in which a certain number of products can be bought simultaneously, which is a critical factor to assess the real environmental impact (H. Pålsson *et al*., 2017 [11]). So, from literature review an important question that emerges regards the impact of multiple purchases combination and how this variable could affect the results obtained so far.

Objective and methodology

The objective of this thesis is to overcome some of the literature gaps by assessing the level of CO2 emissions generated by both online and traditional purchasing process. An Activity-Based model has been adopted with the purpose of both comparing different average purchases, belonging to different industry sectors, and understanding how the combination of them may lead to emission savings. The main emissions considered in the computation are related to transportation, packaging and return activities. In order to reach the aforementioned purposes, the following questions have been asked:

"Is still the online channel more sustainable than the traditional shopping in the case of multiple purchases situation?"

"How does consumer behave towards purchasing choices? What are their preferences in relation to online/offline purchasing? How many and which types of purchases does he/she averagely make? On how many e-commerce platforms or through how many dedicated/non-dedicated shopping trips? How does the customer choose to handle the return activity in both processes? What are the related effects in terms of environmental impact and from which activity (transportation, packaging) are they mostly generated?"

The model

The developed model aims to contribute to the extant literature regarding the environmental sustainability of the traditional B2C shopping and the B2C e-commerce by comparing these two purchasing processes in the multi-purchase perspective. The innovative contribution of the model is correlated to different factors: firstly, the multi-purchase perspective, by considering as a unit of analysis a basket of online orders and physical purchases instead of the single item; secondly, different scenarios and distribution configurations are included; thirdly, the impact of customer behaviour both in the offline and online processes is considered. For the traditional shopping, the trip can be dedicated to the shopping activity or non-dedicated if the customer does shopping while coming back from work, school and so on. Also, the customer impacts is quantified by changing the distances travelled by the customer and by matching scenarios in which the client goes only in one destination or visits multiple destinations. While for e-commerce process, the case in which the orders are made on one website and the option in which different platforms are used to make the same basket of orders, are compared. Furthermore, the model considers the return phase ad how the consumer has an impact in this sense, through the delivery failures, the decision to return the items to the store or to the collection point or to have the money refund.

The context. The unit of analysis considered in the model is the number of purchases, made by a single customer, higher than or equal to one (each order consists of at least one item). The object of comparison is equal to the kgCO2e emitted for each of the considered phase. Furthermore, the model considers different industry sectors since it is based on a multi-purchase perspective. Additionally, the model does not consider any specific geographical area, being dynamic it can be applied to any context. Regarding the channel typology, the model considers only the B2C market, where e-commerce finds its largest market share. Concerning supply chain phases, the process starts from the warehouse and considers the last mile transportation. The model also considers the return phase, both due to non-compliant products and to the delivery failure for the e-commerce process. Finally, regarding packaging impact, the materials considered are: cardboard boxes in store replenishment and online delivery phases, and the papers bags given to the customers in the stores.

The structure of the model. After a deep analysis of the case study conducted by Mangiaracina and colleagues (2016) [8], the model structure is designed by adopting an activity-based approach, which is considered suitable for measuring the performance of logistics processes (Drew *et al*. 2004 [3]). According to this approach, the purchasing process is split into four different macro-phases: Pre-sale & Sale, Replenishment, Delivery, Post-sale. Each of them is further divided into activities which are grouped in specific categories: transportation, warehouse/handling (e.g. Van Loon *et al*., 2015 [18]), management, purchasing, communication (e.g. Mangiaracina *et al*., 2016 [8]) and packaging. The same structure of Mangiaracina and colleagues (2016 [8]) model has been maintained but some parameters have been changed (especially in the transportation emissions assessment), since different distribution networks are considered. For the online process, the model considers the distribution from central to local warehouse and from local warehouse to customer' house or pick-up point. Indeed, for what concerns the offline process, the distribution configuration is represented by the production plant, the central warehouse, the shops and finally the transport between the customers' houses and the boutiques. In order to set the distribution network configurations not only literature review has been consulted. The structure of distribution network has been designed also with the support of the logistic specialist and the supply chain manager of Nespresso who has been interviewed to have a real and concrete contribution to validate the network designed.

Input data.
General input data. First inputs are the number of purchases made by the customer and the number of items for each purchase, the number of websites on which the orders are made, and the number of store locations visited in each trip.
<u>Activities input data</u>.
Transportation activities: vehicle emission conversion factors, percentage value of space occupied by items on truck and van; *Packaging activities*: consumption of cardboard material for each product category, average number of items contained in a shopping bag; *Customer and retailer activities*: power supply of retailer and customer devices used during the online activity; *Return phase activities:* return rate for each product category.
Activities durations data: duration value of each sub-activity for Purchasing, Communication and Management phases; *Distances input data:* warehouse-customer house distance value (online process), customer house - store/s and central warehouse-store distance values (offline process). See Table 6-17 for more details.

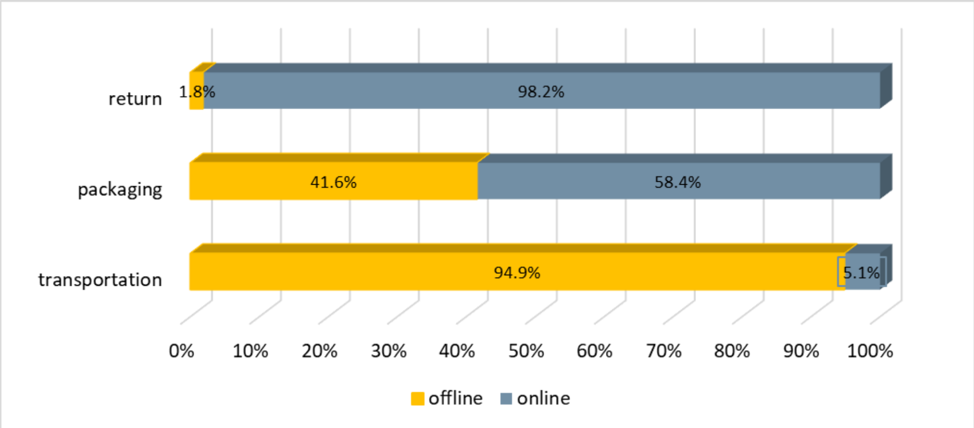
The algorithm. For each of previously described purchasing phases, all the activities that contribute to the CO2 emissions have been identified. Summing up all the contributions made by each phase, for both the purchasing processes, the kgCO2 emitted are computed. See Chapter 5.5 for all detailed formulas. For what concerns the online process, two possible macro-scenarios are considered: the case in which the customer buys different items from one website (therefore a single delivery for all items is performed) and the case in which the consumer places the orders on different websites. Hence, the transport of each order is carried out by different carriers. For what concerns the traditional channel, the algorithm identifies different scenarios according to the distance travelled by the customer to reach the shopping locations and by considering if the trip is dedicated or non-dedicated to the shopping activity.

Output. The output is the value of kgCO2e related to the number of purchases considered, both for the online and offline scenarios that can be split up according to the different phases involved (pre-sale, sales, replenishment, delivery, and post-sale) and also for each phase by the types of activities (e.g. communication, management, transportation).

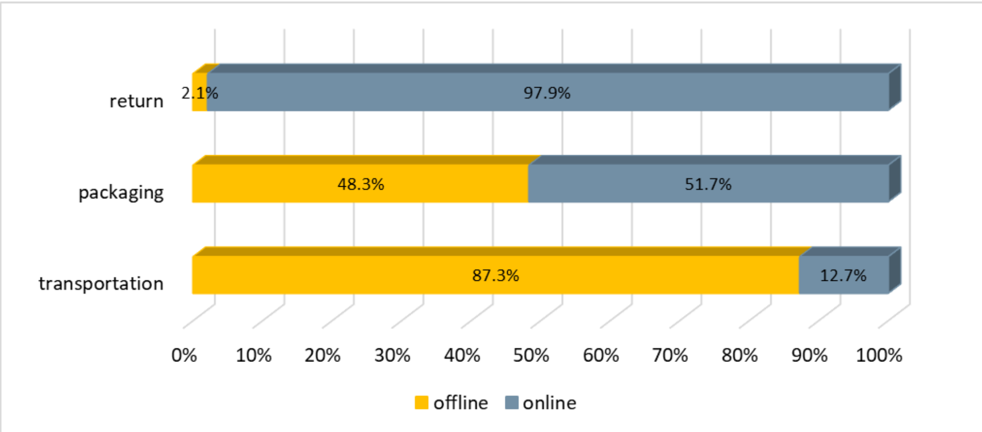
The model application

Application context. The model previously described is characterised by a dynamic structure which can be adapted to several different contexts of application. Among the different product categories, three specific average purchase typologies have been selected: Clothing, accessories, and footwear, Books and Electronics. The objective of the analysis is twofold: on one side to understand the impact of each separate purchase typology; on the other side to comprehend how the gradual combination of these purchases in one shopping trip/online order can contribute to the reduction of CO2 emissions. Thus, the first step consists in analysing the scenario in which the three purchases are made independently. Then, the combination of two purchases is considered and compared to the previous case. Finally, the environmental impact generated by the combination of all three purchases is assessed and compared to the previous two cases. The discussion of results is split into a Base-Case and a Sensitivity Analysis. It has been decided to compare values of transportation, packaging, and return activities, since they represent the three major contributors to emissions generation, as reported by Weber and colleagues (2008) [20].

Base case analysis. Regarding the offline purchasing process, the base case refers to the situation in which the customer travels a distance shorter than 5 km, to reach only one destination through a dedicated trip. For the online process, the option in which the distribution configuration is characterized by the presence of both central and local warehouses and the return process happens when the product received is not compliant and a second delivery is made, is analysed as a base case. In the base case scenario, the offline purchasing process results to be more sustainable than the online one: when the three purchases are made independently, when two of them are combined and when all purchases are combined in one trip/online orders. The respective offline total emissions are: 5.62, 4.78, 3.94 kgCO2e/3 purchases; the respective online total emissions are: 6.45, 5.41-5.22-6.00, 4.08 kgCO2e/3 purchases. As it is possible to notice, for the online scenario three different results have been obtained, according to the type of purchases combined: Clothing, accessories & footwear purchase with Books purchase, Clothing, accessories & footwear purchase with Electronics purchase and Electronics purchase with Books one. That is because the different purchases combinations lead to different reduction in packaging material consumed and return emissions (packaging, communication and management emissions). On the contrary, for the offline purchasing process, the result is always the same since what only changes the EI value is the last mile distance travelled by the customer (both in the delivery phase and in the eventual return phase). From these results, it can be deducted that, by gradually combining purchases, the level of CO2 emissions decreases in both processes. In the offline case, emissions decrease proportionally with respect to the number of trips made; while in the online process, the environmental impact decreases more than proportionally with respect to the number of websites in which the purchases are made. Instead, by comparing different purchases combination scenarios the offline process does not always result more sustainable. In fact, if the customer decides to make the three purchases by three different shopping trips, but through the e-commerce channel he/she has the possibility to combine them all in the same order, the online process results to be the more sustainable. The same happens by comparing the 3-trips offline scenario with the 2-websites online scenario. For all the possible purchases combinations, results show that **transportation activity impacts more in the offline process, while packaging and return actions in the online one**. In case the three purchases are made independently, the respective transportation emissions estimated are: 2.63 kgCO2e in the offline process and 0.14 kgCO2e in the online one. While for packaging, emissions are equal to 2.95 kgCO2e in the offline and 4.15 kgCO2e in the online. Lastly, 0.04 and 2.16 kgCO2e respectively in the offline and online return. By **combining** the three purchases in one trip or in one order, **last mile transportation emissions are reduced** since the consumer makes less shopping trips. In case only two purchases are combined, last mile transportation emissions pass from 2.48 kgCO2e to 1.65 kgCO2e. In case in which all purchases are combined a further last mile transportation emission reduction occurs: from 1.65 to 0.83 kgCO2e. Regarding the **online** purchasing process, **transportation emissions remain unchanged**, since even if the number of deliveries is reduced, the emission is related to the single item. Concerning **return emissions**, they **are reduced** since, if purchases are combined and the related items are defective, it is possible to reduce packaging, management, and communication related emissions. The related emissions pass from 2.16 to averagely 1.47 kgCO2e in case in which two purchases are combined and to 0.78 kgCO2e in case three purchases are combined. Concerning **packaging emissions**, the environmental impact value shifts from 4.15 kgCO2e to averagely 3.93 kgCO2e in case of two purchases combined, and to 3.16 kgCO2e in case of all purchases combined.



Graph 1: Impact per phase of each process - three independent purchases



Graph 2: Impact per phase of each process - three united purchases

Sensitive analysis. A sensitivity analysis is carried out to examine how the results change by altering the main input values and to better compare the differences between the online and offline processes, as it is not possible to declare that in any case, the online purchasing process is better than the offline one. The sensitivity analysis is conducted by considering, for the offline process, the distance from the warehouse to the store constant and by varying the distance from the store and the customer's house, using a range from 2.5 km to 32.5 km, taking constant the conditions of the different online processes. Three analyses have been conducted: the first one in which three purchases are made separately on three online websites/offline trips (scenario 1), then two purchases have been combined (scenario 2), and finally a unique offline trip and a single online order for all the three purchases are considered (scenario 3). More specifically, for each e-commerce scenario, all the distribution configurations have been considered (see chapter 6.6.2 for more details about distribution configurations); while, for each offline scenarios, the customer could choose for a dedicated or non-dedicated trip and different distances are considered, linked to the scenarios in which the customer goes to one single destination, two destinations or three destinations (1D, 2D and 3D).

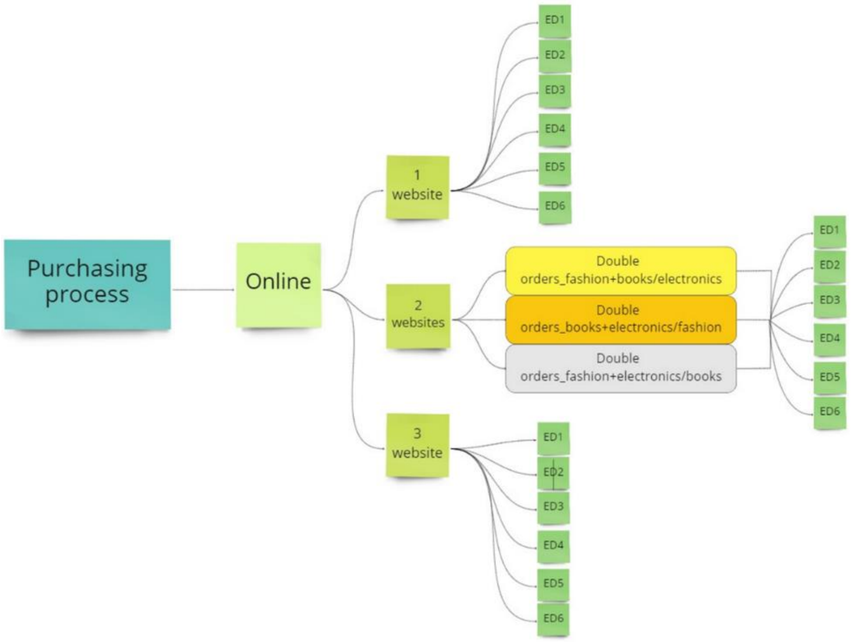


Figure 1: Sensitivity Analysis Online Scenarios

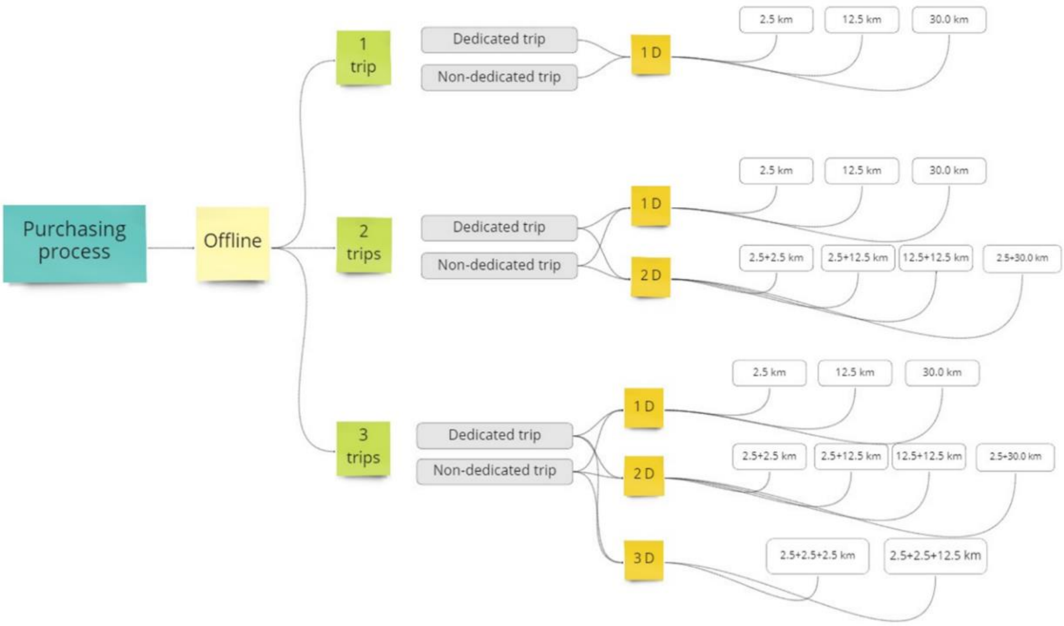
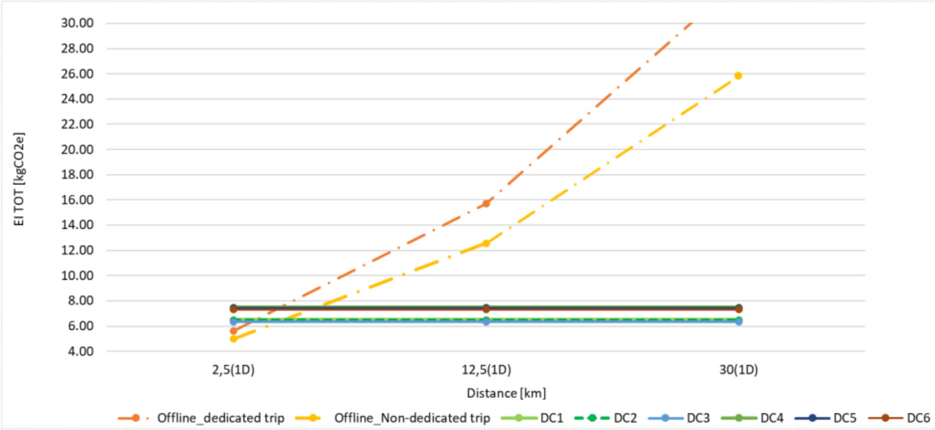


Figure 2: Sensitivity Analysis Offline Scenarios

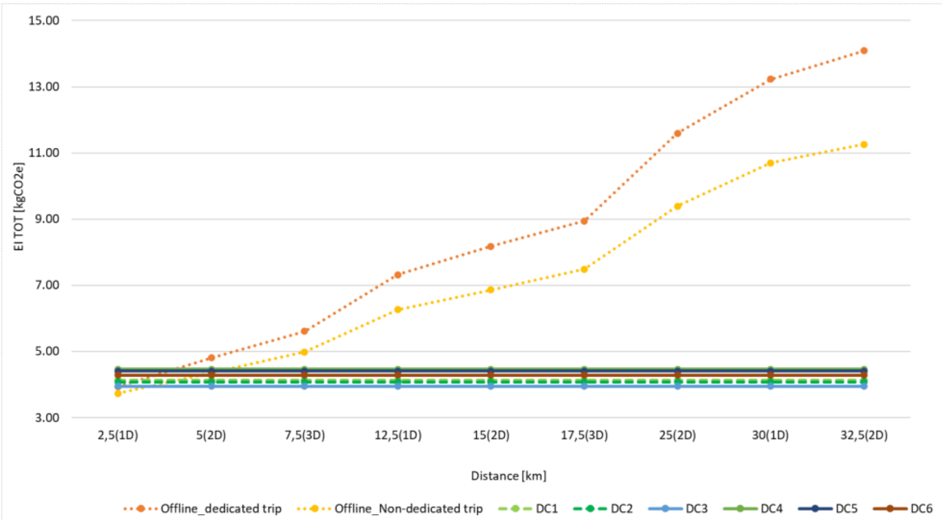
What results is that the customer's trip has a huge impact. In fact for the scenario 1, if the distance between the customer and the shop is around 2.5 km the offline process is 16% and 30% (respectively dedicated and non-dedicated trip) more sustainable than online one, while by increasing the distance travelled by the customer till a limit of 30 km, the online process is 80% and 75% (dedicated and non-dedicated case) more environmentally sustainable than the offline one (for the distribution configuration ED1[1], but results are very similar also for the other distribution configurations). So, it is possible to conclude that the offline is more sustainable only if the distance travelled is about 2.5 km.

[1]ED1= the company delivers directly from the central warehouse (CW) to customers' home;



Graph 3: Sensitivity analysis - three independent purchases

By combining two purchases (scenario 2) the offline is more sustainable only if the distance travelled by the customer to reach the shop is lower than 5 km. Finally, considering the scenario 3, the offline process becomes more sustainable with respect to the scenario 1 and 2 but also in this case as long as the distance between the customer and the shop is around 2.5 km: the offline process is 4.8% and 11% (dedicated and non-dedicated case) more sustainable than online, while by increasing the distance travelled by the customer till a limit of 32.5 km, online process is 70.5% and 63% (dedicated and non-dedicated case) more environmentally sustainable than the offline one.



Graph 4: Sensitivity analysis - three unified purchases

Results generalization. The model application focused on three main average purchases (clothing, books and electronics). However, final results can be generalised by considering different products categories, which are: Clothing, accessories & footwear; Beauty & cosmetics; Books; Electronics; Construction products, gardening, DIY, joinery, lighting; House products; Stationery and Sport equipment. These products categories can be grouped in macro clusters, according to two main variables:

- *Similarity of the return rate*;
- *Similarity of the mean size*, that means having similar packaging footprint and similar % of space occupied in the truck/van.

So, according return rate values, packaging footprint and percentage of space occupied in the truck/van, three main clusters of product categories have been created. More in details cluster 1, an average purchase belonging to the clothing or sport world, cluster 2, an average purchase of beauty & cosmetics, books, house and/or stationery products and cluster 3, an average purchase belonging to electronics or construction, gardening world. Therefore, it is possible to obtain similar results also by combining these product categories.

Conclusions and discussions

This study presents an Activity-Based model aiming to compute the environmental impact of the traditional in-store and B2C e-commerce purchasing process by comparing different average purchases belonging to different industry sectors, with a strong focus on the logistics activities.

What has been found is that, considering the three above described clusters separately, if the customer travels a distance of 2.5 km the offline process is always better both for the dedicated and non-dedicated trip, while by increasing the distance between the customer and the store, the online process becomes more sustainable, both using a single website or multiple website option. Another important conclusion is that cluster 2 is the most sustainable one, while cluster 1 is the worst option. This is due to the different number of items belonging to each cluster. But by considering an online order composed only by one item the result changes due to the impact of product categories. One item belonging to cluster 2 represents the most sustainable purchase, while cluster 1 is the second-best option, and cluster 3 the worst one. This because the CO2 emissions depend on the item **size** and **weight**. Indeed, electronics items, characterized by big size and significant weight, result to be more polluting than other product categories.

Regarding the combination of purchases in one shopping trip/online order, different significant results should be highlighted. By gradually combining purchases, the environmental impact in the offline case decreases proportionally with respect to the number of trips. In the offline purchasing process, only transportation emissions are reduced (both in the delivery and return phase). In this regard, it is possible to conclude that the customer plays a fundamental role in determining the final environmental impact of the offline process. According to that, shorter distances should be favoured and shopping should be combined with other activities.

By gradually combining purchases in the online process, the emissions value decreases more than proportionally; what affects the result is return and packaging emissions reduction. If the distance travelled by the customer is higher than 5 km, the online purchasing process results to be more sustainable in every case. On the contrary, if the distance is lower, the offline purchasing process results to be more sustainable than the online one, only if purchases are equally combined in both processes. When the three purchases are made independently, emissions are equal to 5.62 kgCO2e/3 purchases in the offline and 6.45 kgCO2e/3 purchases in the online; when two of them are combined emissions are equal to 4.78 kgCO2e/3 purchases in the offline and averagely 5.54 kgCO2e/3 purchases; when all purchases are combined in one trip/online order, emissions are equal to 3.94 kgCO2e/3 purchases and 4.08 kgCO2e/3 purchases. Despite this, it is possible to notice that comparing the case in which the customer makes the three purchases through three different shopping trips, and the case in which combine them in a unique online order, the e-commerce results to be the most sustainable option. In conclusion, consistently with Pålsson *et al*. (2017) [11], Edwards *et al*. (2010) [5], S. Seebauer *et al*. (2016) [14], what can be deducted is that the **purchases combination increases the environmental sustainability** of both processes, since it allows to reduce emissions related to three of the most impacting activities in both purchasing processes: transportation in the offline one, while packaging and return in the online one (Mangiaracina *et al*., 2016 [8]; Pålsson *et al*., 2017 [11]).

The return activity. Concerning the return environmental impact, the customer plays a crucial role in both purchasing processes. By testing the items in the traditional scenario and by taking attention when the online order is placed, the return rate can be reduced. In addition, also the way in which the customer chooses to handle the return process has an impact. For instance, if he/she prefers to just return the unwanted item and request a money refund the incidence of return process is lower than the case in which a second delivery is needed. Moreover, the place in which the customer decides to return the product (the store or a pick-up point) and the probability of delivery failure significantly affect CO2 emission level.

Another important conclusion is linked to the ***packaging typology impact.*** Online packaging has a huge impact since it is crucial to prevent products from being damaged or broken during transport. By considering the online scenario and comparing plastic with cardboard boxes, both for the single-website and multiple-websites scenarios, it is possible to see that the use of plastic pollutes more than three times than cardboard.

Distribution network configuration choice. The results show that if the network is well optimized and the transport activities are well managed, the closer the retailer is to the customers' homes, the more sustainable

the network is. Another important conclusion is linked to the presence of pick-up points. Findings show that the scenarios in which pick-up points are adopted result less sustainable than home delivery option. This is due to the fact that, in recent years, due to the Covid-19 pandemic, people spend most of time at home. Therefore, considering the return rates linked to this historical period, the model calculated that it was preferable sending packages to home rather than to collection points, since additional customer trip is avoided. However, these results could change with the return to pre-Covid life. Therefore with different rates of failed deliveries, the use of pick-up point could be more sustainable.
The Figure 3 summarizes the effects of each variable, considered in the analysis, on the amount of kgCO2e generated by purchasing processes.

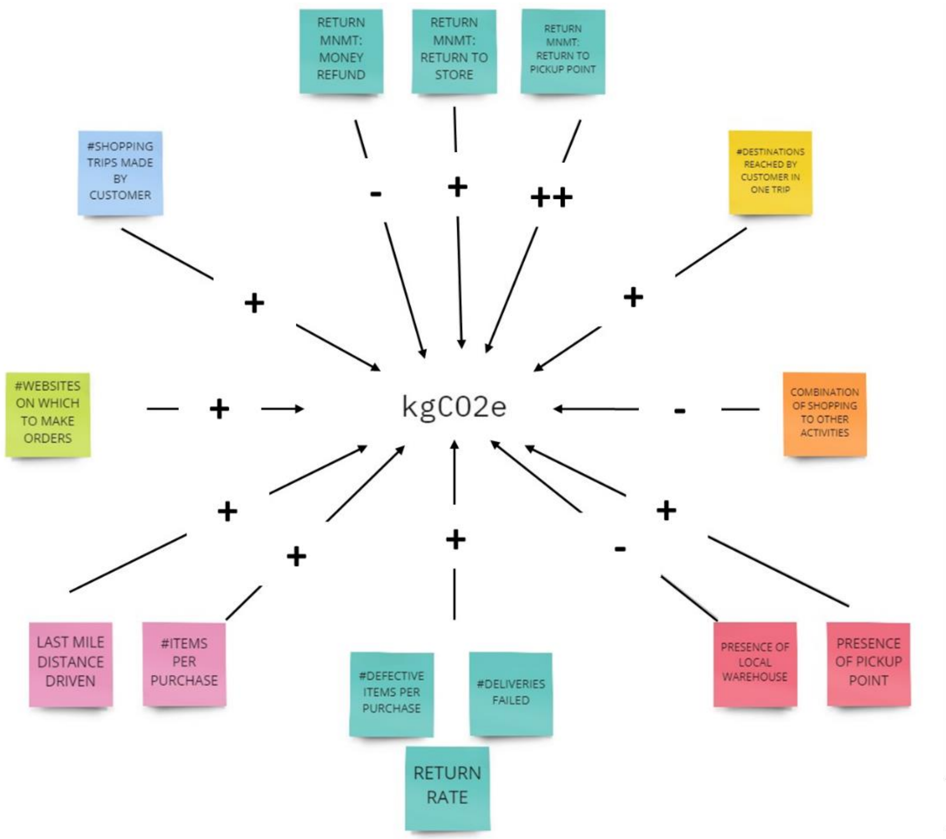


Figure 3: Causal diagram

Limitations and future developments. The analysis conducted presents some limitations. Firstly, a portion of input data used in the analysis was extracted by the survey, whose sample population consists of 211 respondents. Moreover, it was not possible to apply the model also for warehousing activity, both for the online and the offline process. Secondly, the model does not include the grocery product category since it is characterised by significant differences with respect to other product categories. Thirdly, only trucks have been considered as replenishment transportation mode while sea or air transportation is ignored.
Consistently with the above-described limitations, future research directions are suggested in order to amplify and fine-tune our results: effect of combination of grocery purchase with other purchases; including warehousing activity in the application phase; also including sea and air transportation for replenishment activity (international contexts).

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Academic Year: 2020-2021

Abstract

Over the years e-commerce market share has shown a significantly growth around the world, leading many scholars to wonder if this purchasing process is environmentally sustainable. However, it is still uncertain whether electronic commerce is more environmentally sustainable than conventional shopping, and numerous academics and practitioners have analysed the environmental impact according to different perspectives. In the majority of cases, the e-commerce process was found to be more sustainable than conventional shopping, but there is not yet a unique conclusion which demonstrates the absolute e-commerce environmental sustainability. This thesis presents an Activity-Based model aiming to compute the environmental impact of the traditional in-store and B2C e-commerce purchasing process by comparing different average purchases belonging to different industry sectors, with a strong focus on the logistics activities. The purpose of this thesis is to understand how a **multi-purchase scenario**, both in the online and offline process, may alter the environmental impact of purchasing process (measured as kgCO2e), which type of **product category** contributes more to the generation of emissions and how the **customer behaviour impacts** the final result. Overall, the results indicate that the main variable that affects the result is the distance travelled by the customer to go to a physical store. If this distance exceeds about 5 km the online purchase process is more sustainable.

Key-words: environmental impact; sustainability; e-commerce; logistics; multi-purchase; customer behaviour.

Abstract in lingua italiana

Negli ultimi anni si è registrata una crescita considerevole dell'e-commerce in tutto il mondo che ha portato molti ricercatori a domandarsi se questo processo di acquisto sia sostenibile dal punto di vista ambientale. Tuttavia, nonostante innumerevoli studi abbiano trattato l'argomento tramite differenti e molteplici prospettive, non è tutt'ora chiaro quale tra i due processi (acquisto in negozio fisico e acquisto online) sia più sostenibile a livello ambientale. Nella maggior parte degli studi il processo e-commerce è risultato essere più sostenibile rispetto allo shopping convenzionale, ma non esiste ancora una conclusione univoca, che dimostri l'assoluta sostenibilità ambientale dell'e-commerce. Il seguente lavoro di tesi presenta un Activity-Based model che mira a calcolare l'impatto ambientale del processo di acquisto tradizionale e dell' e-commerce B2C, confrontando diversi acquisti medi appartenenti a molteplici settori industriali, focalizzandosi specificatamente sulle attività logistiche. Lo scopo dell'elaborato è confrontare le emissioni di CO2 dei due processi di acquisto considerando non il singolo item, ma differenti acquisti composti anche da molteplici prodotti appartenenti a diverse categorie merceologiche e studiare come il comportamento del cliente influisce sul risultato finale. Nel complesso, i risultati indicano che la variabile principale che influenza il risultato è la distanza percorsa dal cliente per recarsi in un negozio fisico. Se questa distanza supera i 5 km circa, il processo di acquisto online è più sostenibile.

Parole chiave: impatto ambientale; sostenibilità; e-commerce; logistica; multi-acquisto; comportamento del consumatore.

Contents

1. E-commerce and its environmental impact

1.1 Introduction

The advent of the Internet and e-commerce has disrupted both purchasing and distribution models and production models globally. E-commerce has created a new way of producing, selling, and buying products that has strongly influenced and changed the consumer's buying habits. In fact, in the last fifteen / twenty years the e-commerce systems have become one of the most important and obvious commercial applications of information and communication technology (ICT), allowing consumers to buy and exchange goods and services quickly and conveniently (Kim et al. 2009 [54]). These technologies have grown fast because they have allowed customers to shop quickly, comparing products and prices easily. Furthermore, they have made shopping less expensive and less time-consuming. The main effects of e-commerce are in terms of cost optimization and reduction of the environmental impact. Unfortunately, however, it is not yet clear whether e-commerce is more sustainable than the traditional shopping system due to the many variables to be taken into consideration. When comparing the two purchasing processes, in fact, it is essential to consider non-deterministic variables such as customer behaviour that make it difficult to have a unique result. In particular, climate change constitutes the greatest contemporary environmental challenge and e-commerce may be a solution for coping with the climate challenge. Surely e-commerce allows to reduce inventories by eliminating the presence of shops, logistics become more efficient since the products are directly shipped from retail to the final consumer. Furthermore, internet has made the market much more transparent and competitive, and the stress on prices has increased significantly with its advent. However, it is not clear how the return phase and packaging, impact the new business model of e-commerce.

In this chapter different aspects of the e-commerce are analysed and described in order to prepare the lecturer on the topic to better understand the following discussions exposed in our thesis. More in detail, the next sections are:

- *Definitions.* In this part all the definitions of e-business, e-commerce, internet economy and digital economy are explained;
- *E-commerce history and evolution*. The main steps of the online shopping are described, and some pioneers are analysed. Then also some numbers related to the e-commerce evolution are reported;
- *Evolution of Trade-related aspects of e-commerce*. This section is dedicated to the explanation of the history of the main aspects linked to the trade for the e-commerce market;
- *Impact of COVID on the e-commerce market.* The main aspects and trends that characterised the e-commerce during the pandemic are shown;
- *Advantages and disadvantages of the e-commerce.* Costs and benefits of e-commerce are discussed and compared with the traditional shopping organisation ones;

1.2 Definitions

Words such as e-business, e-commerce, internet economy, digital economy are normally used in common language, however they are relatively recent constructs and often there are misinterpretations of their meanings.

Starting from the concept of ***internet economy***, both Kelly (1998) [53] and Wirtz (2001) reported that it is based on three key characteristics: internet economy is founded on digital technologies, intensively interlinked, and global. Klaus Fichter, 2003 [36] supposed that the term ""Internet economy" emphasizes the networking of economic actors and processes by means of electronic communication media and the related change in structures of value creation, mechanisms of market function, professional life, and consumption patterns. The notion of "Internet economy" comprises both micro and macro perspectives and covers the whole range of economic transactions (profit oriented or not)".

Regarding the term ***E-commerce*** it is possible to note different categories of e-commerce which differ basing on the nature of the actors involved in the transaction:

- *Business to Consumers (B2C).* This type of e-commerce is the most known and discussed one. It refers to a business which sells products or services to final customers. Laudon and Traver (2014) argued that B2C commerce includes purchases of retail goods, travel services, and online content. Sarkar & Das (2016) defined e-retail or electronic retail or e-tail as "the sale of goods and services via the Internet or other electronic channels, for personal or household use by consumers." Examples of B2C e-commerce are Amazon, OTTO in Germany and JD.com in China.
- *Business to Business (B2B).* In this case the online transactions are between two companies as a raw material company which sells to a manufacturer or a manufacturer which sells to a wholesaler. Two examples are Alibaba in China and Indiamart in India.
- *Consumer to consumer (C2C).* This type of e-commerce considers as actors two final customers. C2C refers to an online market environment in which people can trade to each other. The most well-known example is eBay.

Furthermore, the two main definitions of e-commerce are proposed by the WTO[1] and the OECD[2] [70]. The WTO work program on e-commerce refers to e-commerce as "the production, distribution, marketing, sale or delivery of goods and services by electronic means". Regarding the OECD [70], Organisation for Economic Co-operation and Development, in 1998 there was a Ministerial Conference on E-commerce in Ottawa to create an Action Plan for Electronic Commerce. After that, the OECD [70] has developed several definitions for e-commerce that vary in scope. In April 2000 the OECD [70] approved two definitions of electronic transactions, based on a narrower and broader definition, as it is explained in the paper *E-Commerce: Sorting Out the Environmental Consequences, Klaus Fichter, 2003* [36].

Narrow definition. "An Internet transaction is the sale or purchase of goods or services, whether between businesses, households, individuals, governments, and other public or private organizations, conducted over the Internet. The goods and services are ordered over the Internet, but the payment and the ultimate delivery of the good or service may be conducted on- or off-line".

Broad definition. "An electronic transaction is the sale or purchase of goods or services, whether between businesses, households, individuals, governments, and other public or private organizations, conducted over computer-mediated networks. The goods and services are ordered over those networks, but the payment and the ultimate delivery of the good or service may be conducted on- or off-line".

The last update of the definition was in 2011 where the OECD [70] defines e-commerce as "the sale or purchase of goods or services, conducted over computer networks by

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[1] WTO: World Trade Organisation
[2] OECD: Organisation for Economic Co-operation and Development

methods specifically designed for the purpose of receiving or placing of orders. The goods or services are ordered by those methods, but the payment and the ultimate delivery of the goods or services do not have to be conducted online. An e-commerce transaction can be between enterprises, households, individuals, governments, and other public or private organisations" (OECD, 2011 [69]).

Kende & Sen, 2019 and Hufbauer & Zhiyao, 2019 specified that the terms "e-commerce" and "digital trade" are often used interchangeably, but, while for the e-commerce there is well-defined definition, for the term digital trade it does not exist. So, in this perspective in 2017 López González & Jouanjean [40] developed an analytical framework for digital trade, and they observed that digital trade "encompasses digitally enabled transactions in trade in goods and services which can be either digitally or physically delivered and which involve consumers, firms and governments" (López González & Jouanjean, 2017, p. 4) [40]. So, in 2019 OECD added that "digital trade involves business-to-business transactions, including within global value chains GVCs, as well as transactions between consumers or businesses through online platforms. All of these transactions are underpinned by data, which is the lifeblood of digital trade" (OECD, 2019b, p. 1 [70]). Furthermore, by considering a single country, different definitions of e-commerce exist, as the Australian Government that defines e-commerce and digital trade as: "the trade of goods and services using the internet including the transmission of information and data across borders" (Department of Foreign Affairs and Trade, n.d.) [22]. Meanwhile, the United States defines digital trade as "The delivery of products and services over the Internet by firms in any industry sector, and of associated products such as smartphones and Internet connected sensors. While it includes provision of e-commerce platforms and related services, it excludes the value of sales of physical goods ordered online, as well as physical goods that have a digital counterpart (such as books, movies, music, and software sold on CDs or DVDs)" (U.S. International Trade Commission, 2017, p. 33) [102]. Consequently, this interchangeable use of terms means that the e-commerce topic is already a matter of debate around the world.

Finally, the term ***e-business*** is the business processes, commercial activities, or other economic tasks conducted over the Internet or computer mediated networks (Intranet, etc.). E-business processes are carried out using ICT equipment and applications (Klaus Fichter, 2003 [36]).

1.3 E-commerce history and evolution

E-commerce had a rapidly grown during the years. The year Nineteen ninety-three is recorded as the year in which the Internet economy was born with the World Wide Web. Since then, the Internet has developed into a service integrated global network with a diversity of multimedia uses (Picot et al. 2000 [75]). In the fourth quarter of 2000, retail e-commerce sales were up 70 percent, yet represented only 1 percent of total retail sales (Matthews et al. 2001 [60]). In 2001 the worldwide internet users were over 300 million. More in details the next session describes the history timeline of the main events that characterized the e-commerce.

The first time Internet appeared was in the **1960**`s, in particular the US army had the need to exchange information, and this led to the creation of the Advanced Research Projects Agency Network (ARPANET). Starting from this, a lot of others network were created. Indeed, in the **1969** the first e-commerce company, CompuServe, was founded by Dr John R. Goltz and Jeffrey Wilkins by utilizing a dial-up connection. Subsequentially, in the **1979** Michael Aldrich created the electronic shopping by connecting a transaction-processing computer with a modified TV through a telephone connection. After that in the 1982 there was the launch of the first e-commerce platforms by Boston Computer Exchange thanks to the continuous improvement of the available technologies. Despite this, the birth of Internet is considered to be on the 1st of January **1983**, when the Transfer Control Protocol/Internetwork Protocol (TCP/IP) was created allowing networks to interact and in the **1984** when EDI, or electronic data interchange, was standardized through ASC X12 to guarantee transactions between companies in a reliable way. During the 1990`s Internet gained popularity also due the development of security protocols as (SSL) and (DSL). In the **1992** CompuServe offered online retail products to its customers giving people the first possibility to buy online with their computers and also Charles M. Stack introduced Book Stacks Unlimited as an online bookstore. In **1994** Netscape Navigator by Marc Andreessen and Jim Clark arrived, giving to users a browser to surf the Internet and a safe online transaction technology called Secure Sockets Layer. After that, entrepreneurs started to understand the potentiality of this business. The pioneers of e-commerce were Amazon, eBay and Otto in the **1995**, PayPal as first e-commerce payment system in **1998**, JD.com and Alibaba during the year **1999** and Google AdWords as a way to help retailers to utilize the pay-per-click (PPC) context in **2000**. Comparing Amazon and JD.com, the first one was found in 1995 but started to be profitable only in 2003, while the Chinese rival (JD.com) achieved profitability in December 2001, only two years after the launch in 1999. Amazon was known for its multi-level sales strategy (B2C, B2B, C2B, C2C) and to give the users the possibility to rate the products and make comments. In 2015, Walmart, another American giant, was surpassed by Amazon.com Inc and nowadays this company having established an affiliate marketing program gains almost of its sales by using affiliates and third parties which sell goods on the platform. For what concern JD.com, it was founded in 1999 by Liu Qiangdong with the name 360buy.com, then in 2007 became Jingdong Mall and again in 2013 to JD.com. the first business was focused on selling online magneto-optical equipment while in 2004 also the B2C platform was created, and the company started to sell electronics as computers, communication, and consumer electronics. In the 2007 they started to implement a new service: the same day delivery for these products in the main cities by using its in-house courier. Finally, after having introduced the first mobile POS system, in 2012 they launched their first English website and they passed from revenues of 3 billion dollars in 2011 to $18.6 billion in 2014 and $28.8 billion in 2015 to at the end signed an alliance with Walmart in June 2016 in order to establish a strategy to serve consumers across China through an outstanding combination of retail and e-commerce (Carrew, R., Abkowitz, A., Nassauer, S., 2016).

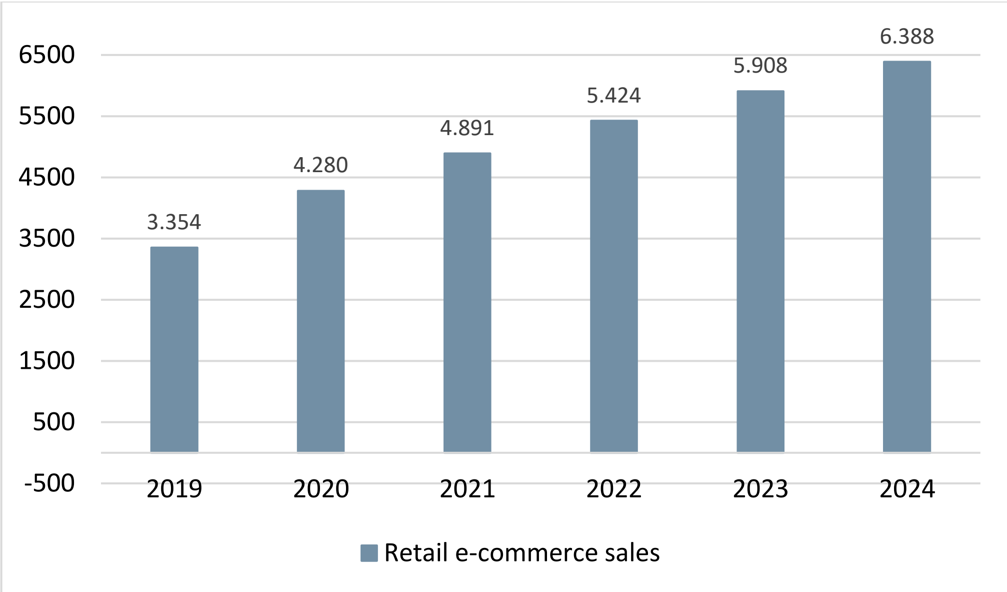
To continue with the e-commerce history, during the year 2005 lots of innovations are introduced:

- Amazon Prime membership was launched,
- Etsy was launched to enable small and medium retailers to sell goods online. **2005**: Square, Inc as an app-based service is launched
- Eddie Machaalani and Mitchell Harper launched BigCommerce as an online storefront platform.

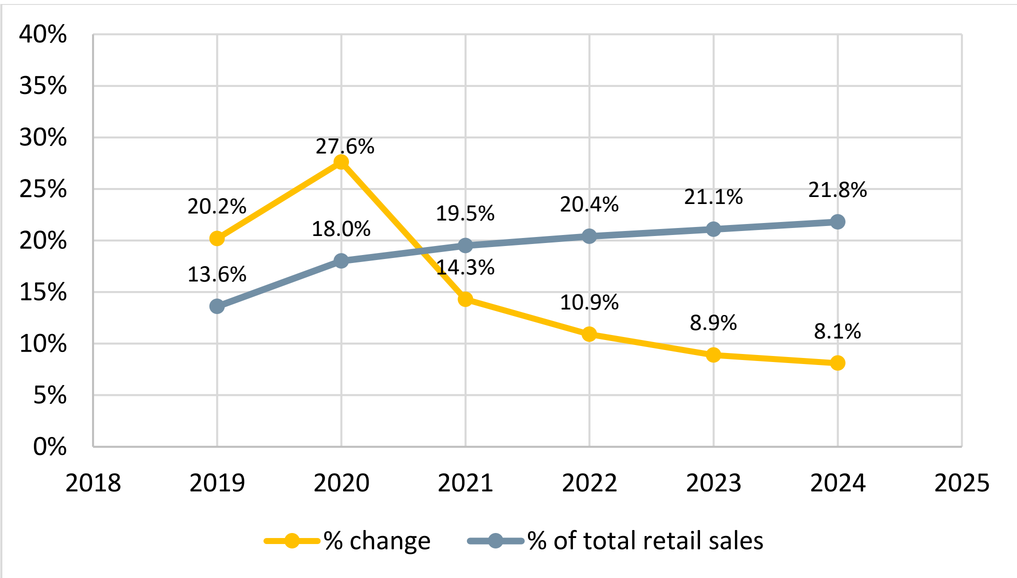
Finally, from **2011** till today there was a massive development of e-commerce, such as the launch of online wallet payment app of Google (2011), the creation of Apple Pay, an online payment application by Apple in 2014 and in **2017** Instagram introduced shoppable tags to enable customer to directly buy and sell from the social media [119].

The market for online shopping is growing at a remarkable rate as it is reported in lots of papers. Starting from the past, for example Dykema (2000) [25] reported that on-line retail sales of goods and services were projected to grow from $45 billion in 2000, or 1.5 percent of total retail sales, to $269 billion in 2005, or 7.8 percent of total retail sales projected for that year. In addition, consumers increasingly relied on online information and then buy through the traditional channel. Such purchases influenced by the Internet were estimated to grow from $13 billion in 2000 to $378 billion in 2005 (Dykema, 2000), [25] or 10.8 percent of projected retail sales. In 2000 the main categories of products bought online were leisure travel with 27.2 percent of online sales, followed by books, music, videos and software (14.9 percent), computers and electronics (13.6 percent) and apparel (11.3 percent). By 2005, consumables (like food, beverages, supplies, health and beauty aids, and pet supplies) were projected to amount to 18 percent of on-line retail sales, followed by apparel (16 percent), computers and electronics (12.4 percent), automobiles (12.2 percent) and leisure travel (12.1 percent), while the share of books, music, videos and software will fall to 9.6 percent (Dykema, 2000) [25]. (*The Emerging Landscape for Retail E-Commerce, Yannis Bakos* [4]).

Looking at the present, the new trend is the global e-commerce which means selling products or services across geopolitical borders, into non-native countries. As Harvard Business Review wrote: "Business leaders are scrambling to adjust to a world few imagined possible just a year ago. The myth of a borderless world has come crashing down. Traditional pillars of open markets—the United States and the UK—are wobbling, and China is positioning itself as globalization's staunchest defender." The global e-commerce market at the end of 2021 is expected to be $4.89 trillion and it will grow over the next years. eMarketer, 2020 showed these results regarding the retailer e-commerce sales worldwide, estimating the value till 2024. In the following graphs from eMarketer, December 2020, are presented the data about the year 2019, 2020 and the forecast from 2021 to 2024 of the retail e-commerce sales worldwide. These graphs include products or services ordered using internet, regardless of the method of payment or fulfilment, they exclude travel or event tickets, payments such as bill pay, taxes or money transfers, food services and drinking place sales, gambling and others vice goods sales (eMarketer, 2020). Data are in trillions.

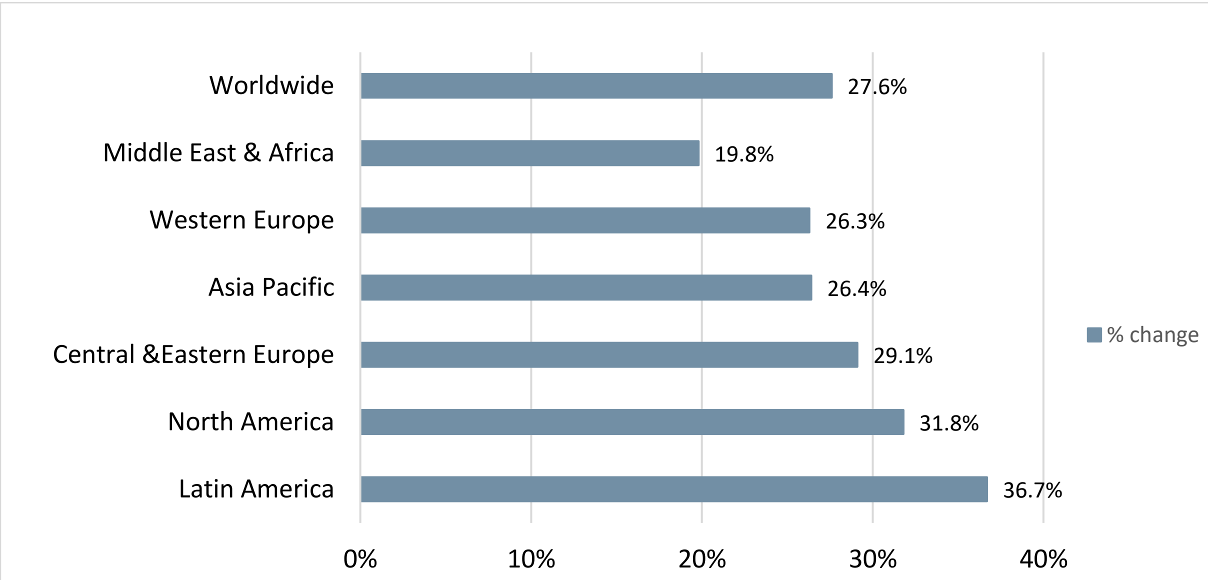


Graph 1-1: Retail e-commerce sales worldwide, 2019-2024



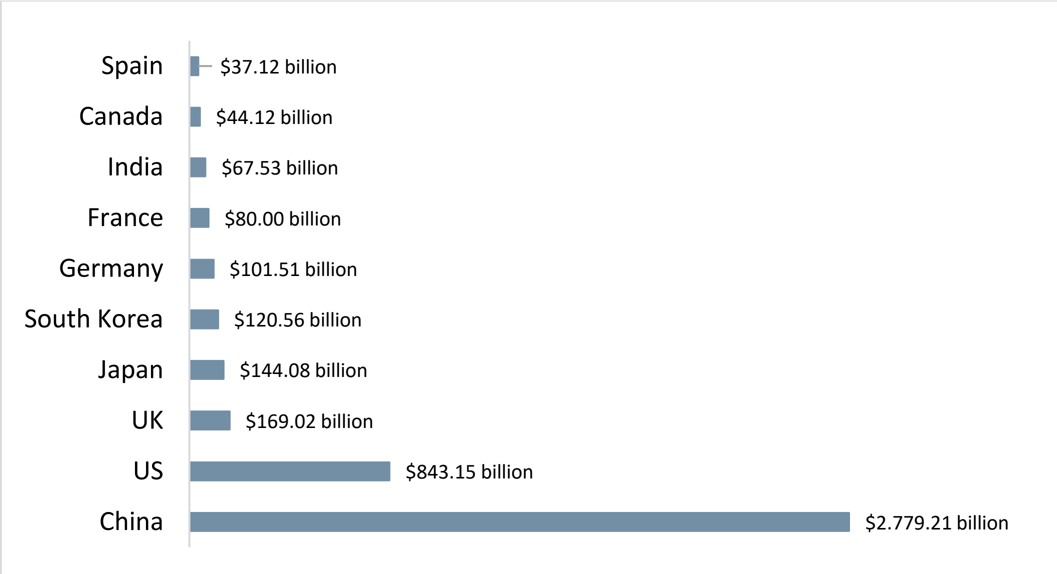
Graph 1-2: Retail e-commerce sales worldwide, 2019-2024

The e-commerce market share will continue to grow and according to eMarketer the online sales will reach $6.39 trillion and e-commerce sales will be 21.8% of the total retail sales. During 2020 there was double-digit e-commerce growth, for example in Latin America the e-commerce increased by 36.7%, in Argentina 79% and in Singapore 71.1%, as documented by eMarketer. In the next graph the sales growth by region are shown, data are taken by eMarketer, 2020 and include products or services ordered using internet, regardless of the method of payment or fulfilment, they exclude travel or event tickets, payments such as bill pay, taxes or money transfers, food services and drinking place sales, gambling and others vice goods sales.



Graph 1-3: Retail e-commerce sales growth worldwide, by region 2020

The most interesting country in that sense is China, which is set to become the first country in which e-commerce has a higher market share respect to the traditional channel, with 52.1% of retail happening through ecommerce. The second country with a higher online market-share is the US with a forecast to reach over $843 billion at the end of 2021. Finally, the third country is UK with a total ecommerce sale expected to be $169 billion at the end of 2021. In the next graph from OBERLO, the forecast at the end of 2021 for the countries with a higher market share for e-commerce are reported.



Graph 1-4: E-commerce sales by Country (2021)

1.4 Impact of COVID

The COVID-19 pandemic made a significant impact on ecommerce trends around the world accelerating the shift to the online shopping by almost five years.

Rae Yule Kim, 2020 [55] in the paper "The Impact of COVID-19 on Consumers: Preparing for Digital Sales" explained in detail how the e-commerce changed due to the pandemic. "The COVID-19 pandemic has affected everyone's daily lives, people have been asked to stay at home, business shifts to the smart working and many employees quickly adapted to the digital transformation. Online video conference software Zoom reports a 78% growth in profits, and Google Meet reports an approximately 60% increase in user traffics, where people spend 2 billion minutes in online meetings every day" (Kim, 2020 [55]). So, the entire culture is changed together with consumers and the market behaviours. In this perspective the e-commerce market has shown a great growth. Kim, 2020 [55] reported that during a survey conducted in 1998 when e-bay introduced the new way of shopping online, the 46% of early adopters were using e-commerce frequently, while only 8% of late adopters had an experience of web shopping (D. Howland, 2020 [46]). However, the recent survey on online shopping behaviour indicates that the pandemic played a key role: in fact, a recent survey of 2200 adults in the U.S., discovered that 37% of survey respondents have considered shifting to online shopping after COVID-19. Furthermore, a significant portion of late adopters who were averse to shop online have inflowed into electronic markets after COVID-19. Among those surveyed, 11% of Generation Z (Gen Z), 10% of Millennials, and 12% of Generation X (Gen X), and 5% or Boomers have bought something online for the first time due to the pandemic. Consequently, at least 66% of Gen Z, 68% of Millennials, and 73% of Gen X, and 68% of Boomers have adopted online shopping after the sharp increase in the number of online shoppers due to the pandemic (Morning Consult, Crosstabulation Results, National Tracking Poll #200394, March 26, 2020 [67]).

Kim 2020 [55] reported that “the online shopping was already increasing before COVID-19 but it has accelerated the change, for example the daily downloads of grocery apps have doubled during a week since March 11th when the World Health Organization officially declared COVID-19 a pandemic” [112]. Furthermore, U.S department of commerce reported that sales in e-commerce have increased five times faster compared to in-store retail and managers expect that Millennials and Gen Z, also known as “digital natives (DNs),” are more comfortable with online shopping (Kim, 2020 [55]).

In the next session the evolution of e-commerce under the trade perspective is explained, reporting the main trade-related aspects from 1995.

1.5 Evolution of Trade-related aspects of e-commerce

In 1995, during the last round of negotiations under the old General Agreement on Tariffs and Trade (GATT) system, the WTO and its rules-based system were validated, and the agreements covered many cross-border trade aspects, including some related to e-commerce. UNCTAD's 2019 defines "The digitalization of the global economy as "the transition of businesses through the use of digital technologies, products and services" and this definition facilitated the trade in physical goods. Subsequentially, The General Agreement on Trade in Services (GATS) promoted the "technological neutrality" so, it allows the GATS to address "digital products" such as e-books and downloadable movies and music. This means that some products are reclassified as services instead of physical goods. Furthermore, the Information Technology Agreement (ITA) covers MFN commitments among the agreement's participants to eliminate tariffs on certain ICT products. In the 2015 WTO Ministerial Conference, another update of the product's classification was done, known as ITA-II, to reflect the new IT realities and goods of the digital era. Finally, others important agreements for the e-commerce are the Agreement on Trade-related Aspects of Intellectual Property Rights (TRIPS) which sets out intellectual property rights protections for technologies and the recent WTO Trade Facilitation Agreement (TFA) which entered into force in February 2017, and it requires governments to implement measures for facilitating import and export processes.

1.6 Advantages and disadvantages of the e-commerce

E-commerce has become increasingly important in the contemporary world where people often no longer have the time to shop in the traditional way. There is no system that is better than the other, it is possible to identify the advantages and disadvantages of both e-commerce and the traditional channel. The first category of advantages and disadvantages of the online shopping is linked to the customers and companies' perspective. Starting from the advantages, firstly, with the online shopping there is a clear advantage in term of time, customers do not have any more the need to go to a shop and can save time. Secondly, the variety of items that you can buy online is bigger than offline and the customer has direct access to both home and abroad platforms, having in this sense an unlimited selection. Third, there is no time limit in term of accessibility to the store, customer can buy online during every hour of the day (online stores are open 24h per day), in every part of the word. Then another advantage is that there is a reduction of information asymmetry: prices and products features are online, and customer can easily compare different websites having the possibility to do the better choice. Theory suggests that Internet retailers will offer lower prices than their store-based counterparts, due to the lower costs of search for the buyer, and lower costs of market entry and operations for the seller (Brynjolfsson & Smith 2000) [12]. Furthermore, it is important to underline how factors as trust, brand loyalty and habits are even more important in the e-commerce context where the links among buyer, seller, and product are detached from the physical cues afforded by a bricks-and-mortar store (Jarvenpaa et al. 2000 [50]). Finally, with the e-commerce companies can easily sell customized and personalized items and they can track and trace the products.

Regarding the disadvantages, for some companies having an e-commerce channel is costly and the benefits do not overcome the costs. Moreover, not all the products are suitable for the online shipping, for example some type of services or enterprise's goods are not frequently sold online. Another important critical factor are the problems related to the ICT security or data protection and the security of the online payments. Furthermore, for the retailer there are additional costs, respect to the traditional scenario, linked to the management of the data, the optimization of the logistic, in particular the transportation phase is completely managed by the retailer and also some specific taxes. Finally, from the customers' perspective there can be also some criticisms linked to the poor internet connections.

Instead, for what concern the traditional channel, some potential advantages are explained: firstly, the possibility of see, feel, smell, taste, or try a particular item cannot be substitute. Secondly, the immediate possession of the product is another variable that contributes to the magnitude of the traditional shopping.

The second category of criticism and positive aspects of e-commerce concern the environmental sustainability. Starting from the advantages:

- The online purchasing process needs a shorter supply chain and related logistic chain respect to the traditional one. In fact, it is fundamental to underline that e-commerce distribution configurations differ from traditional ways of distribution, and this has a consequence in term of energy usage. In this perspective, with the online shopping, goods are transported directly from a wholesaler or manufacturer to the final customer, while in the traditional shopping there is a step further: goods are delivered to the physical retailer and then customer goes to the stores to buy the products. Thus, another difference is due to the fact that in the online process the customer physically goes to the shop while the action of visiting the retailer in the online process is substituted by visiting a web-site using a computer;
- an efficient e-tailer can operate with a smaller sales staff (L. Reijnders and M. J. Hoogeveen, 2001 [79]);
- e-commerce sales require minimal physical infrastructure and reduce the inventories, so, less space requirements than a traditional retailer thus implying less energy consumption;
- with the e-commerce there is not the necessity of using the paper/plastic bags;

However, as described by Edwards et al, 2011 [27] several authors have considered the environmental effects through a wider perspective (e.g. Webster, 2007 [108]; Matthews et al., 2001 [60]; European Information Technology Observatory, 2002; Abukhader and Jo¨nson, 2003 [1]; Sarkis et al., 2004 [85]) and different criticisms in term of sustainability have been found.

- E-commerce causes an increase in home deliveries, many of which are relatively inefficient (Romm, 1999; Kro¨ger et al., 2003 [82]);
- E-commerce induces customer to do smaller orders (often of single items) to highly geographically-dispersed delivery locations (Simchi-Levi and Simchi-Levi, 2002);
- Customers have the tendency to purchase separate items from several different web-based companies (each requiring separate delivery);
- E-commerce needs an additional sortation to combine multiple customers' orders prior to delivery (de Koster, 2002) [20];
- Trip substitution can generate additional travel when the time saved by online shopping is converted into other out of-home activities (Gould and Golob, 1997 [41]; Daduna and Lenz, 2005);
- E-commerce may be associated with price reductions, and thus increased buying power. Furthermore, internet-browsing encourages people to go shopping for additional and/or supplementary purchases (Skinner et al., 2004) [93]. So, customers have the propensity of buying more and this has energetic implications. (L. Reijnders and M. J. Hoogeveen 2001 [79]).

2. Literature review

The literature review is a fundamental step for an academic project in order to have a transversal and a complete knowledge about the topic and to find possible gaps that are not already studied.

With the exponential growth of the e-commerce channel, amplified even more with the advent of the COVID-19, the importance of studying its environmental consequences has become fundamental. This chapter aims to explore the already available literature in the shield of the sustainability of the e-commerce in order to find unconsidered aspects and deepen them.

The chapter is organised in four main sections: Introduction to literature review, Material collection and selection, Descriptive analysis and Discussion of results.

I. *Introduction to literature review:* an induction about the purpose of this chapter, the topics considered and discussed in our analysis and the methodology adopted for the analysis.

II. *Material collection and selection*: this section is composed by two sub-sections, which are the *Articles collection* and the *Articles selection* in which all the steps followed for the search of articles and the creation of the database are deeply described.

III. *Descriptive analysis*: after having obtained the database with fifty papers, in this paragraph we started to investigate them through two analyses. The first one is described in the sub-section *Papers characteristics* where the authors, the year of publication, the country addressed, the journal of publication, the title and the research method have been taken into account. The second analysis, available in the sub-paragraph *Content based analysis*, mainly focused on examining the content of the papers through the use of different axes of classification.

IV. *Discussion of results:* in this section, firstly the effective results emerged from analyses are reported and secondly the discussion of the identified gaps is presented.

2.1 Introduction to literature review

In order to start an academic project, the first fundamental step is going through a literature review because it is essential to have a clear vision of the context of the research and the different directions that previously have been taken. An in-depth literature review aims to understand the level of maturity of the field of research, the results already achieved and where the research is still far in reaching some valuable results. So, collect, select and examinate the literature review allows to have a wide knowledge of the topic and to highlight any gaps in the literature.

Hart (1998) [43] argues that literature reviews help to narrow down the research topic as well as explaining and justifying research objectives, overall research design, and methodology used.

Seuring & Gold, 2012 [88] said that "literature reviews may be seen as a scholarly contribution in its own right, which map, consolidate and develop theory of a certain research area, thus facilitating subsequent research to build onto this ground".

Saunders et al. (2009) [86] depict the process of reviewing literature as an iterative cycle of defining and refining parameters and keywords, searching for literature on the basis of these keywords, and evaluating and recording the body of literature. The aims of literature reviews are twofold: mapping, consolidating and evaluating the intellectual territory of a certain field, and identifying knowledge gaps to be filled in order to develop the existing body of knowledge further (Tranfield et al., 2003 [99]). In this chapter we analysed the literature review linked to the topic of e-commerce and its implications on the sustainable aspects. The relevance of sustainable aspects is growing fast, and, in this perspective, it is becoming more and more important quantifying the e-commerce environmental benefits and costs and compare the results with the performances of the traditional channel. We initially considered both the B2B and B2C channels and we did not do any discrimination related to the type of industries, in fact all the sectors are included in our research. In particular, we went through papers that focus more on the distribution phase and on the impact of CO2 gas emissions linked to the transportation from plant to warehouse and from warehouse to the final customers and other ones that focus more on the problems related to the packaging and to the recycle phase. Furthermore, other scientific articles turned its attention on the comparison between online and offline shopping in term of energy use and others gave their contribution considering the entire supply chain. We investigated literature reviews, conceptual frameworks, analytical methods, simulations, case studies, surveys and action researches, following the categorisation suggested by Meixell and Norbis (2008) and Perego, Perotti, and Mangiaracina (2011), without imposing limits in term of years of publication. For our analysis we decided to use a three-steps approach. The phase 1 consisted in material collection and selection where the methodology followed for the selection of the used papers and the keywords are described. The second phase is focused on the analysis of the papers and their classification. In particular, in this section we referred to two main classifications: the first one regards the main characteristics of the selected papers as the years of publication, the typology of paper, the authors and the country of origin, while the second one concerns the content of the papers and the main axes of classification we used to investigate. Finally, the phase 3 is about the description of the results, future discussions and the research of potential unexploded areas or gaps in the literature. We chose this method because it is useful to catalogue some characteristics of different papers and it makes easier to explore the main contents and to find the latent ones. Moreover, the summary table with all the papers involved in the analysis is reported.

2.2 Material collection and selection

The first step of the literature review is the papers' collection and selection as it is described by Seuring and Gold, 2012 [88]. In this section we described the methodology used for this preliminary step of collection and selection of papers related to the topic of e-commerce and its impact on sustainability and the way in which we defined the limits to decide if a paper was supposed to be included in our research database. More specifically, we included both papers related to the comparison between online and offline shopping and their impact on the environment and also papers only related to online or offline sales. In our research we also take into consideration both the B2B and B2C perspectives in order to understand how these two channels have been impacted in that transition to the e-commerce world and so their implications on the sustainability. However only one paper considered the B2B perspective since e-commerce channel is mainly used in the B2C channel. Finally, we did not limit the research to some specific industries, but we considered all the sectors available.

2.2.1 Articles collection

As Seuring & Gold (2012) [88] suggested, the first step is to define the unit of analysis. We decided to include in our analysis both English-speaking peer-reviewed papers and conference papers on the sustainability of the e-commerce. So, the unit of analysis is a single scientific paper published in an international journal. We decided not to limit the years of publication because of two reasons. Firstly, the topic can be considered a new and not a mature topic because e-commerce is a growing phenomenon. So, it was important to include also papers published in the 2000's to have as complete and varied database of scientific articles as possible. Secondly, the older papers are useful to better understand how e-commerce is changed during the years and especially how its influence on sustainability aspects is changed. For example, mostly of the oldest papers compare online vs offline studying more the last mile perspective and in general terms the distribution phase, without considering packaging and return phase in term of reuse and recycle as Matthews *et al.*, (2001) [60], Reijnders *et al.*, (2001) [79], Williams *et al.*, (2003) [110], and Siikavirta *et al.*, (2002) [90]. On the contrary, more recent papers strongly consider the reuse and recycle aspects and the importance of the packaging impact as Duan *et al.*, (2019) [24], Velazquez *et al.*, (2019) [104], Yuehuan Su *et al.*, (2020) and Travis Tokar *et al.*, (2021) [98]. For filling out our database, we used two of the primary sources of online literature databases which are Scopus and Google Scholar. Furthermore, to have a deeper knowledge of the topic and also to have different perspectives, other references have been investigated using the same keywords.

The keywords used in the first step of scientific articles collection are "e-commerce", "sustainability", "online sales", "environmental impact", "carbon footprint" and their combinations. During this preliminary collection phase, about 500 papers have been collected. In a second moment other keywords, related to other topics as the packaging impact, have been added and combined with the oldest ones ("packaging", "packaging recycles" "recycle", "green"). Furthermore, in order to be sure to have considered all the significant papers, if needed, we also added some cited contributions as Marchet *et al.*, 2014 recommended.

2.2.2 Articles selection

The first step of the article selection phase was to create a list of possible useful papers. After having collected a database composed by almost 500 papers, as described in the previous section, the selection phase started in order to create a subset of articles to analyse in detail. For the first step of the selection phase and to narrow down potential articles, we used a defined methodology: firstly, we analyse the title of the paper, if it was in line with the topic, we examined the abstract. If the title and the abstract fully addressed the theme, we added the paper inside a list. To create this initial database, we also used a specific paper "A review of the environmental implications of B2C e-commerce: a logistics perspective", (Mangiaracina *et al.*, 2015 [58]), which is a literature review about the topic of B2C e-commerce environmental sustainability. The purpose of this paper is to offer an up-to-date literature review on the topic of B2C e-commerce environmental sustainability, specifically from a logistics perspective (Mangiaracina *et al.*, 2015 [58]). So, to be sure to not omit some important articles about that topic, we cross-check our list of papers with the articles proposed by Mangiaracina and colleagues.

Once we had this initial set of papers, we started to examinate the papers and select in the final database the most relevant and significant ones. So, a subset of papers was sampled: 50 papers from 2001 to 2021 were considered for our research. The literature was then analysed, and we created different categorizations, both according to the typology of paper, years of publication and nationality and according to the content of the papers, as it is shown in the next chapter.

2.3 Descriptive analysis

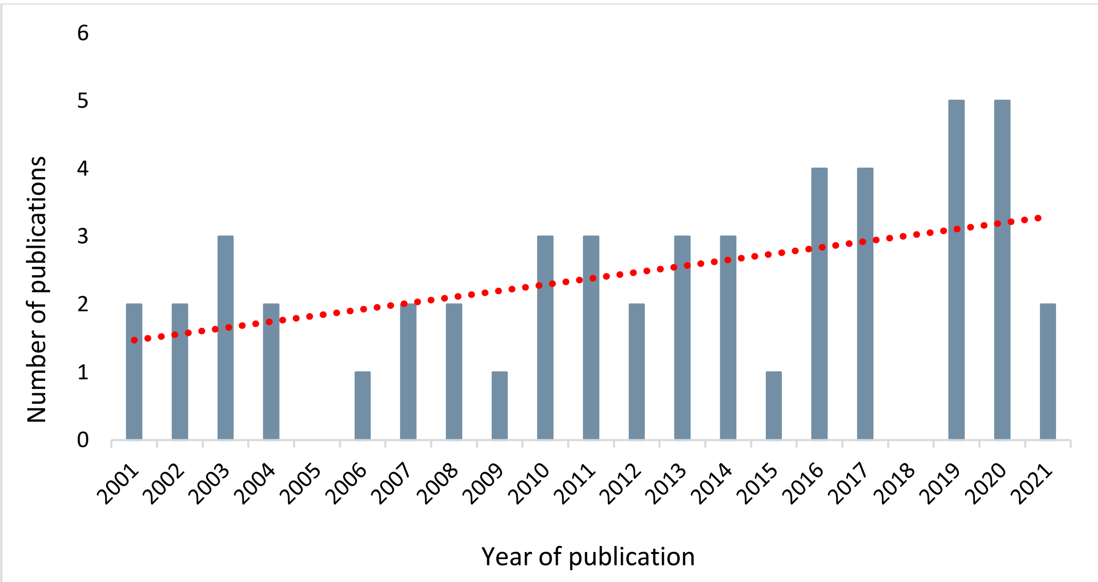
In this chapter the description of our analysis is reported. After having obtained the database with 50 papers, we started to analyse them. In particular, we created two main excel files referring to two different analyses. The first Excel sheet focuses on the main characteristics of each paper, considering the authors, the year of publication, the journal of publication and also the typology of each paper. Instead, the second analysis concerns the content of each paper: different axes have been created in order to classify each paper according to different variables. Some examples of the axes we used are the "sector", "B2B or B2C", "supply chain phases involved", "geographical area", "packaging impact "and "unit of analysis". The purpose of using these axes of classification was to make papers as schematic as possible both to easier understand the content and find the latent information and to transform their descriptive content into quantitative and statistical data in order to be able to draw conclusions and find patterns. Hence, by using this classification, we were able to transform the information read in the papers into data that is easily readable and quantifiable. In the next sub-sections, there will be a wide description of the two analysis that have been done.

2.3.1 Papers' characteristics

In this section six axes have been considered, which are the authors, the year of publication, the country addressed, the journal of publication, the title and the research method. For each of the 50 papers we considered all these information and we organised the papers in a chronological order as Perego *et al.,* (2011) suggested, starting from the year 2001 to the year 2021 to show the evolution of the sustainability issues related to the e-commerce. The 50 papers investigated were published in 29 different scientific journals. The mean value of the contribution of each journal is about 1.7 papers. Scientific journals can be classified under four categories: environmental journals (38 percent), logistics and transportation journals (34.5 percent), information and communication technologies (ICT) (7 percent), or others (20.5 percent).

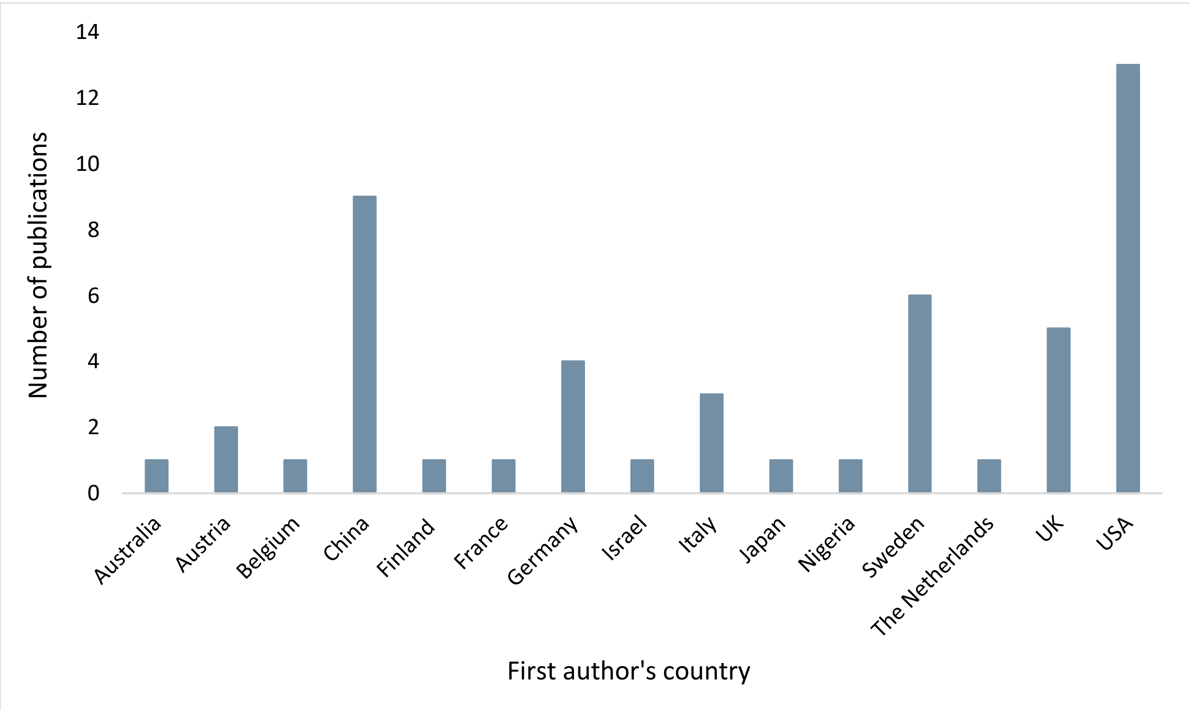
For what concern the year of publication, different considerations can be done. Firstly, we considered a time period of 20 years: papers selected are from 2001 to 2021 in order to have enough material to study the evolution of the e-commerce and the environmental sustainability issues linked to this topic. We did not consider any limit in term of years of realize because of the topic can be considered new and to better explore its evolution. Focusing on the year of publication **52** percent of the papers were realized from 2010 and, in particular, **40** percent and **71** percent of them were published from 2015, so, most of the papers belonging to our database are recent. This is reasonable because of the continuous growth of the e-commerce and the related studies about e-commerce and the correlated environmental sustainability issues.

In the table 2-1 it is shown the distribution of the reviewed papers: on the x-axis there is the year of publication of the paper and on the y-axis the number of papers that have been published in that specific year.



Graph 2-1: Papers' publication year

From this graph it is possible to notice the increasing trend of the published papers which is in line with the growing trend of the e-commerce and with the increasing sensitivity to the issues of environmental sustainability. Regarding the year 2021, the publications number is low since this review has been done in early 2021 but we expect a coherent growth rate. Furthermore, examining the first author's country of origin of the reviewed papers, the **26** percent of contributions is from USA, the **18** percent from China, **12** percent from Sweden, **10** percent from UK and **8** percent from Germany. All together, these contributions count for the **74** percent on the total papers. These results are in line with the spread of e-commerce in USA, Germany, UK and China and with the high sensitivity about the theme of environmental sustainability in Sweden. In the graph below the details about each country of origin of the first author and the number of publications.



Graph 2-2: Papers' publication country

Finally, papers were examined and classified also according to the research methods used by the authors. In particular the papers' classification has been done taking into account the methodology proposed by Meixell and Norbis (2008) and also used by Perego, Perotti, and Mangiaracina (2011). So, seven research methods have been identified which are analytical or mathematical models, conceptual models or conceptual frameworks, case studies, interviews, surveys, simulation and literature reviews.

A quick overview of the definition of the different methods follows:

- **Analytical or mathematical model**: a scientific analysis that uses mathematical functions to solve a problem.
- **Conceptual model or conceptual framework**: a scientific analysis using causal maps, diagrams, matrices to propose a solution.
- **Case study**: an analysis in a real and well-defined context and location. Usually, it is used to test some theoretical models and to apply the models in a concrete situation.
- **Interview**: a report with information obtained from people.
- **Survey**: a statistical survey using a sample of people to find patterns, preferences, feedbacks about the field of the research. There are structured, unstructured and semi-structured surveys.
- **Simulation**: a scientific paper that uses simulations to predict the results, find patterns and to anticipate the events.
- **Literature review**: a collection of scientific articles about a specific topic that analyse them as impartially as possible.

Research Method	Number of Papers	Percentage
Analytical model	19	37%
Conceptual model	12	23%
Case study	11	21%
Interview	0	0%
Survey	4	8%
Simulation	4	8%
Literature review	2	4%

Table 2-1: Research methods identified in literature

As it is shown in the table, mostly of the papers are analytical models (**19**) or conceptual models (**12**). Others are case studies (**11**) or surveys (**4**), simulations (**4**) or literature reviews (**2**). No interviews about the topic have been taken into consideration. It is important to mention that some papers consider two research methods. In particular two of them are both case studies and analytical models as the *"Comparative energy, environmental and economic analysis of traditional and e-commerce DVD rental networks"*- Sivaraman *et al.*, 2007 [92], and *"Transport-related C02 effects of online and brick-and-mortar shopping: a comparison and sensitivity analysis of clothing retailing"* - Wiese *et al.*, 2012*)* [109]. The first one, for example, is a comparative life cycle assessment of two DVD rental networks: the e-commerce option and the traditional one. The authors proposed an analytical model specific for a customer living in the city of Ann Arbor, Michigan, USA. The results showed by the papers are that the e-commerce alternative consumed 33% less energy and emit 40% less CO2 than traditional shopping. Furthermore, one paper elaborated both a conceptual model and a survey*: "The impacts of E-retail on the choice of shopping trips and delivery: Some preliminary findings* - Rotem-Mindali *et al.,* 2007 [81]. The paper presents a conceptual model of the decisions households make with regard to information gathering, purchase transactions and delivery modes using data collected in the Tel-Aviv Metropolitan area. Finally, the paper *"E-commerce as a strategy for sustainable value creation among selected traditional* *open market retailers in Enugu State, Nigeria-* Ogbo *et al*., 2019" [72] presents a statistical model that is based on a survey design with a population of 234 retailers in the selected traditional markets.

We did not find a direct relationship between the types of research methods and the topics of the papers. However, it can be noted that empirical studies as case studies and surveys compare the e-commerce and traditional channels analysing the environmental impact of the two channels of a specific industry (e.g. Reijnders *et al*., 2001 [79]; Siikavirta *et al.,* 2002 [90]; and Sivaraman *et al.,* 2007 [92]). Furthermore, for what concern analytical models, they have been introduced starting from 2001 aiming to study the environmental impact of e-commerce (e.g. Matthews *et al.,* 2001 [60]). Finally, some papers made a comparison of the CO2 emissions or other measures as NO_x and CO, between traditional and online channel (e.g. Edwards *et al.,* 2010 [26]; Weber *et.al.,* 2010 [107]; Kim *et al.,* 2009 [54]).

No.	Authors	Year	Country[a]	Journal	Title	Research method(s)
1	H. Scott Matthews, Chris T. Hendrickson, Denise L. Soh	2001	USA	*Transportation Research Record: Journal of the Transportation, Research Board*	Environmental and Economic Effects of E-Commerce A Case Study of Book Publishing and Retail Logistics	Analytical model
2	L. Reijnders, M. J. Hoogeven	2001	The Netherlands	*Journal of Environmental Management*	Energy effects associated with e-commerce: A case-study concerning online sales of personal computers in The Netherlands	Case study
3	Daniel Z. Sui, David W. Rejeski	2002	USA	*Environmental Management*	Environmental Impacts of the Emerging Digital Economy: The E-for-Environment E-Commerce	Conceptual model
4	H. Scott Matthews, Eric Williams, Takashi Tagami, Chris T. Hendrickson	2002	USA	*Environmental Impact Assessment Review*	Energy implications of online book retailing in the United States and Japan	Simulation
5	Hanne Siikavirta, Mikko Punakivi, Mikko Ka¨rkka¨inen, Lassi Linnanen	2002	Finland	*Journal of Industrial Ecology*	Effects of E-Commerce on Greenhouse Gas Emissions. A Case Study of Grocery Home Delivery in Finland	Case study
6	Eric Williams, Takashi Tagami	2003	Japan	*Journal of Industrial Ecology*	Energy use in sales and distribution via e-commerce and conventional retail - A case study of the Japanese book sector	Simulation
7	Klaus Fichter	2003	Germany	*Journal of Industrial Ecology*	E-Commerce: Sorting Out the Environmental Consequences	Conceptual model
8	Patricia L. Mokhtarian	2004	USA	*Trasportation*	A conceptual analysis of the transportation impacts of B2C e-commerce	Conceptual model
9	Sajed M. Abukhader, Gunilla Jönson	2004	Sweden	*International Journal of Technology Management*	E-commerce and the environment: a gateway to the renewal of greening supply chains	Conceptual model
10	Fraser McLeod, Tom Cherrett, Liying Song	2006	UK	*International Journal of Logistics Research and Applications*	Transport impacts of local collection/delivery points	Case study
11	Deepak Sivaraman, Sergio Pacca, Kimberly Mueller, Jessica Lin	2007	USA	*Journal of Industrial Ecology*	Comparative Energy, Environmental, and Economic Analysis of Traditional and E-commerce DVD Rental Networks	Case study; Analytical model
12	Orit Rotem-Mindali, Ilan Salomon	2007	Israel	*Transportation Research Part A*	The impacts of E-retail on the choice of shopping trips and delivery: Some preliminary findings	Conceptual model; Survey

(continued)

Figure 2-1: Summary of Papers collected in literature review

No.	Authors	Year	Country[a]	Journal	Title	Research method(s)
13	Christopher L. Weber, Chris T. Hendrickson, H. Scott Matthews, Amy Nagengast, Rachael Nealer, Paulina Jaramillo	2008	USA	*2009 IEEE International Symposium on Sustainable Systems and Technology*	Lifecycle comparison of traditional retail and e-commerce logistics for electronic products: a case study of buy.com	Case study
14	Michael Browne, Christophe Rizet, Jacques Leonardi, Julian Allen	2008	UK	*Lyons, A.C. (ed.) Proceedings of the Logistics Research Network Annual Conference 2008 University of Liverpool, UK, 10th-12th September 2008 Liverpool University Press. pp. 395-401*	Analysing energy use in supply chains: the case of fruits and vegetables and furniture	Analytical model
15	Junbeum Kim, Ming Xu, Ramzy Kahhat, Braden Allenby, Eric Williams	2009	USA	*Environmental Science & Technology*	Designing and Assessing a Sustainable Networked Delivery (SND) System: Hybrid Business-to-Consumer Book Delivery Case Study	Case study
16	Christophe Rizet, Eric Cornélis, Michael Browne, Jacques Léonardi	2010	France	*Procedia Social and Behavioral Sciences*	GHG emissions of supply chains from different retail systems in Europe	Survey
17	Christopher L. Weber, Jonathan G. Koomey, H. Scott Matthews	2010	USA	*Journal of Industrial Ecology*	The Energy and Climate Change Implications of Different Music Delivery Methods	Simulation
18	Julia B. Edwards, Alan C. McKinnon, Sharon L. Cullinane	2010	UK	*International Journal of Physical Distribution & Logistics Management*	Comparative analyisis of the carbon footprints of conventional and online retailing - A "last mile" perspective	Analytical model
19	Clara Borggren, Åsa Moberg, Göran Finnveden	2011	Sweden	*The International Journal of Life Cycle Assessment*	Books from an environmental perspective— Part 1: environmental impacts of paper books sold in traditional and internet bookshops	Analytical model
20	Clara Borggren, Åsa Moberg, Göran Finnveden	2011	Sweden	*The International Journal of Life Cycle Assessment*	Books from an environmental perspective— Part 2: e-books as an alternative to paper books	Analytical model
21	Julia Edwards, Alan McKinnon, Sharon Cullinane	2011	UK	*Supply Chain Management: An International Journal*	Comparative carbon auditing of conventional and online retail supply chains: a review of methodological issues	Conceptual model

(continued)

No.	Authors	Year	Country[a]	Journal	Title	Research method(s)
22	Anne Wiese, Waldemar Toporowski, Stephan Zielke	2012	Germany	*Transportation Research Part D*	Transport-related CO2 effects of online and brick-and-mortar shopping: A comparison and sensitivity analysis of clothing retailing	Analytical model; Case study
23	Florian Kellner, Johannes Igl	2012	Germany	*Logistics Research*	Estimating the effect of changing retailing structures on the greenhouse gas performance of FMCG distribution networks	Analytical model
24	Lixia Wang, Yinghua Yu	2013	China	*Information Technology Journal*	E-commerce promote the development of low-carbon economy in Jilin province	Case study
25	Liyi Zhang, Yi Zhang	2013	China	*Journal of Industrial Ecology*	A Comparative Study of Environmental Impacts of Two Delivery Systems in the Business-to-Customer Book Retail Sector	Analytical model
26	Tao Jia, Kenneth Carling, Johan Håkansson	2013	Sweden	*Journal of Transport Geography*	Trips and their CO2 emissions to and from a shopping center	Simulation
27	Janice E. Carrillo, Asoo J. Vakharia, Ruoxuan Wang	2014	USA	*European Journal of Operational Research*	Environmental implications for online retailing	Analytical model
28	Jay R. Brown, Alfred L. Guiffrida	2014	USA	*International Journal of Logistics Research and Applications*	Carbon emissions comparison of last mile delivery versus customer pickup	Analytical model
29	Patricia Van Loon, Lieven Deketele, Joost Dewaele, Alan McKinnon, Christine Rutherford	2015	UK	*Journal of Cleaner Production*	A comparative analysis of carbon emssions from online retailing of fast moving consumer goods	Conceptual framework
30	Riccardo Mangiaracina, Gino Marchet, Sara Perotti and Angela Tumino	2015	Italy	*International Journal of Physical Distribution & Logistics Management*	A review of the environmental implications of B2C e-commerce: a logistics perspective	Literature review
31	Lena Smidfelt Rosqvist, Lena Winslott Hiselius	2016	Sweden	*Journal of Cleaner Production*	Online shopping habits and the potential for reductions in carbon dioxide emissions from passenger transport	Survey
32	R. Mangiaracina, A. Perego, S. Perotti, A. Tumino	2016	Italy	*International Journal of Logistics Systems and Management*	Assessing the environmental impact of logistics in online and offline B2c purchasing processes in the apparel industry	Analytical model
33	Sebastian Seebauer, Veronika Kulmer, Martin Bruckner, Eva Winkler	2016	Austria	*Journal of Cleaner Production*	Carbon emissions of retail channels: the limits of available policy instruments to achieve absolute reductions	Survey

(continued)

No.	Authors	Year	Country[a]	Journal	Title	Research method(s)
34	Qiuhong Zhao, Jie Jin, Xiuquan Deng, Donghai Wang	2016	China	*Journal of Cleaner Production*	Considering environmental implications of distribution channel choices: A comparative study based on game theory	Analytical model
35	Henrik Pålsson, Fredrik Pettersson, Lena Winslott Hiselius	2017	Sweden	*Journal of Cleaner Production*	Energy consumption in e-commerce versus conventional trade channels - Insights into packaging, the last mile, unsold products and product returns	Literature review
36	Weiguo Fan, Ming Xu, Xiaobin Dong, Hejie Weia	2017	China	*Resources, Conservation & Recycling*	Considerable environmental impact of the rapid development of China's express delivery industry	Analytical model
37	Yi Yi, Ziyi Wang, Ronald Wennersten, Qie Sun	2017	China	*ScienceDirect*	Life cycle assessment of delivery packages in China	Conceptual model
38	Guanghan Song, Hui Zhang, Huabo Duan, Ming Xu	2017	China	*Resources, Conservation & Recycling*	Packaging waste from food delivery in China's mega cities	Conceptual model
39	Ann Ogbo, Chinelo Constance Ugwu, Joy Enemuo, Wilfred Isioma Ukpere	2019	Nigeria	*Sustainability*	E-Commerce as a Strategy for Sustainable Value Creation among Selected Traditional Open Market Retailers in Enugu State, Nigeria	Survey and statistic model
40	Heleen Buldeo Rai, Koen Mommens, Sara Verlinde, Cathy Macharis	2019	Belgium	*Sustainability*	How Does Consumers' Omnichannel Shopping Behaviour Translate into Travel and Transport Impacts? Case-Study of a Footware Retailer in Belgium	Case study
41	Huabo Duan, Guanghan Songa, Shen Qu , Xiaobin Don, Ming Xu	2019	China	*Resources, Conservation & Recycling*	Post-consumer packaging waste from express delivery in China	Analytical model
42	R. Velazquez, S. M. Chankov	2019	Germany	*Proceedings of the 2019 IEEE IEEM*	Environmental Impact of Last Mile Deliveries and Returns in Fashion E-Commerce: A Cross-Case Analysis of Six Retailers	Case study
43	Yi-Bo Zhao, Guang-Zhou Wu, Yong-Xi Gong, Ming-Zheng Yang, Hong-Gang Ni	2019	China	*Science of the Total Environment*	Environmental benefits of electronic commerce over the conventional retail trade? A case study in Shenzhen, China	Case study

(continued)

No.	Authors	Year	Country[a]	Journal	Title	Research method(s)
44	Indumathi Arunan, Robert H. Crawford	2020	Australia	*Resources, Conservation & Recycling*	Greenhouse gas emissions associated with food packaging for online food delivery services in Australia	Conceptual model
45	Miguel A. Figliozzi	2020	USA	*Transportation Research Part D*	Carbon emissions reductions in last mile and grocery deliveries utilizing air and ground autonomous vehicles	Analytical model
46	Miguel Jaller, Anmol Pahwa	2020	USA	*Transportation Research Part D*	Evaluating the environmental impacts of online shopping: A behavioral and transportation approach	Analytical model
47	Susanne Feichtinger, Sonja M. Russo and Manfred Gronalt	2020	Austria	*International Workshop on Simulation for Energy, Sustainable Development & Environment*	Analysing the environmental impact of transport activities on the last mile for in-store and online shopping from a system dynamics perspective	Conceptual model
48	Yuehuan Su, Huabo Duan, Zinuo Wang, Guanghan Song, Peng Kang, Dongjie Chen	2020	China	*Journal of Cleaner Production*	Characterizing the environmental impact of packaging materials for express delivery via life cycle assessment	Analytical model
49	Chiara Siragusa, Angela Tumino	2021	Italy	*International Journal of Logistics Research and Applications*	E-grocery: comparing the environmental impacts of the online and offline purchasing processes	Analytical model
50	Travis Tokar, Robert Jensen, Brent D. Williams	2021	USA	*ScienceDirect*	A guide to the seen costs and unseen benefits of e-commerce	Conceptual model

Note: [a]First author's country is reported

2.3.2 Content based analysis

The papers were secondly analysed based on their content. Several themes have been identified according to the type of research method analysed. On the whole, we can note that the most prevailing theme concerns the study of environmental impacts of e-commerce (alone or compared to the conventional shopping scenario) from different perspectives. For example, some studies focus only on transportation related environmental implications (e.g., Patricia L. Mokhtarian, 2004 [66]); other researches concern the environmental impacts of different delivery systems (e.g., Kim *et al.*, 2009 [54]; L. Zhang and Y. Zhang, 2013 [114]); still others takes into consideration the "last mile" perspective (e.g., Edwards *et al.*, 2010 [26]; Brown and Giuffrida, 2014 [11]; Velazquez and Chankov, 2019 [104]); we also found papers related to emissions deriving from production, use and waste of packaging (e.g., G. Song *et al.*, 2017 [95]; H. Duan *et al.*, 2019 [24]; Arunan and Crawford, 2020 [3]); other studies assume a logistics perspective to quantify environmental effects of purchasing choices (e.g., Weber *at al.*, 2008 [106]; Mangiaracina *et al.*, 2016 [59]). In general, among these analyses, we can discriminate between quantitative and qualitative papers: analytical models, case studies, simulations and surveys usually provide a quantitative result, while the collected conceptual models provide a more qualitative output.

Several axes of classification were identified in order to organize the information and to find results from each article and, in the end, to deduct a clear and coherent outcome from the whole literature review. We can differentiate between two main typologies of axes with two different objectives: the first one identifies the macro context of each article, the second one enters in the detail of each analysis/work and result discussed. The macro context classification consists of four main axes: sector, geographic area, B2B/B2C, offline/online purchasing process.

(i)Sector. It is defined as the industry, or the business explored by the authors in the analysis. This first classification takes into consideration the different businesses interested by the analysis and studies performed, regarding the theme of e-commerce sustainability. In the majority of papers (47 papers over the 50 selected), especially in the *case study* or *simulation* paper typology, there is the specification of the sector in which the study has been conducted, but there are also cases in which there is no description of it (3 papers over 50). By scanning the literature, we identified about 10 classes of sectors: apparel (14 percent), books (22 percent), food (10 percent), electronics (12 percent), grocery (12 percent), fast moving consumer goods (4 percent), music/DVD (6 percent), agricultural (2 percent), furniture (2 percent), and general (42 percent)[3]. The following table summarizes data on sectors occurrence.

Type of Sector	Percentage
General sector	42%
Books	22%
Apparel	14%
Electronics	12%
Grocery	12%
Food	10%
Music	6%
FMCG	4%
Agricultural	2%
Furniture	2%

Table 2-2: Industry Sectors incidence of analysis

Books represent the most popular product sold online (Zhang, 2013 [114]): in 2009 books had a user penetration of 15.2% (iResearch 2010). Although the price of a book

[3] It refers to the case in which the industry sector is not specified or if many sectors together are considered in the study.

sold online and offline was similar, the average price dispersion of books sold online is greater (Clay *et al.*, 2002). As a matter of fact, books retailing is one of the most deeply investigated sector regarding the theme of online purchasing sustainability. The analyses conducted within this sector started in the nineties and continued for about twenty years, in fact as demonstrated by our research, the selected articles regarding books retailing sector belong to the years 2001-2013. The book retailing is an interesting industry to study in order to assess the environmental impacts, since books are regularly purchased online as well as through conventional stores and, in addition, this sector is characterized by a high number return rate due to unsold, discarded, and recycled items (Matthews *et al.*, 2001 [60]). **Food and grocery** industry is another relevant sector investigated in order to assess the environmental sustainability of related purchasing process. The fast development of e-commerce made the food delivery service increasingly popular in metropolitan cities (Song *et al.*, 2017 [95]). Siragusa and Tumino (2021) [91] reported three main peculiarities of grocery industry, that differentiate this sector from other ones. Firstly, the typical e-grocery order is, in the majority of cases, a multi-item order characterized by a large range of different products (Agatz *et al.*, 2008 [2]; Gee *et al.*, 2019 [38]). Secondly, the distribution centres that fulfil the grocery orders are located near the customer to shorten the transportation lead time (Hays *et al.*, 2005 [44]). Thirdly, the return rate is negligible, almost null (Cairns, 2005) [15]. Usually, when the food and grocery industry is addressed, the perspective used to compare online and offline purchasing processes is the supply chain approach, used to considers different options as, for example, the location of distribution centres, the sourcing strategies, the transport modes, and transport distance (Browne *et al*, 2008 [10]). As suggested by Rizet, Cornélis, Browne and Léonardi (2016) [80], particularly referring to European context, consumers today have several options for buying their products: supermarket, corner shop, at a trader in an open-air market, directly from the producer, or through a website and get them through a delivery at home. So, all these different purchasing choices correspond to different supply chain structures with different level of efficiency from energy and GHG emissions point of views. The supply chain approach consists of measuring the emissions at each step of the supply chain and identifying strategic logistics options to increase the efficiency level and reduce emissions (Rizet *et al.*, 2016 [80]). After books and electronics, **clothing industry** is the third most important category in online retailing (Datamonitor, 2011). This sector is characterized by a very high return rate in online shopping. The clothing retailer has several stores in different cities and consumers are willing to travel also long distances to reach them (Wiese *et al.*, 2012 [109]). The apparel industry is characterized by a very high growth in the last years, and in many big cities, in 2013, it represented the industry with the largest online-sales value (eMarketer, 2013; Evans, 2010; Mulpuru, 2013). This sector presents high level of complexity in managing the entire supply chain, due to relevant uncertainty of demand, consumers' trends, high level of variability and volatility. This has impacts also in terms of logistics choices as risk of obsolescence, variability in mix, volume, and delivery, etc. (Mangiaracina *et al.*, 2016 [59]). Sustainability aspects are increasingly considered by firms operating in fashion industry, in order to improve efficiency and to gain the so called Sustained Competitive Advantage (SCA) (Hart and Milstein, 2003; Porter and Kramer, 2006 [76]; Samarrokhi et al., 2014 [84]). So, the objective is to obtain a sustainable outcome, and to do this it is crucial to consider and to measure the environmental impacts of purchasing processes, both through online and offline sale channels.

(ii)Geographic Area. It refers to the taxonomy of geographic places considered in the analysis. Looking at the geographic locations in which researchers have conducted and contextualized their studies, we decided to group them in six different typologies of

areas: city/town/urban, metropolitan area, province/suburban, rural, region, country, continent. In addition, this categorization is fundamental in order to understand the level of awareness about sustainability in shopping activity in different countries of the world, but also to compare different environmental effects deriving from consumers purchasing choices according to the type of population density and distribution, logistics configurations, stores availability, distances to travel. From our collection of papers, it is resulted that the majority of analyses has been performed at country level (43 percent); only two papers out of 50 concern case studies set a European level (continent) and just the 8 percent of the analyses have been set at region level[4]. Lastly, we have the following geographic contexts: urban (18 percent), metropolitan area (14 percent), province/suburban (14 percent) and rural (8 percent). Some of these studies are specifically set in one area (4 urban, 4 metropolitan area, 1 suburban), instead other ones aimed at comparing the environmental effects, in terms of emissions and energy consumed, in different scenarios: urban, metropolitan, suburban, rural (6 papers out of 50).

(iii)B2B/B2C. This axis considers if the analysis concerns the environmental impact of consumers' purchasing behaviour or of companies' purchasing choices. Among the 50 papers collected, the 90 percent is about B2C (43 papers), the 2 percent is on B2B (1 paper), and the remaining 8 percent comprehends both options (4 papers). Two papers do not report a specification in this sense.

(iv)Offline/Online. This classification considers if the analysis performed by authors regards a comparison between traditional purchases (offline) and e-commerce (online)

[4] For region we mean a part of country (for example, North of Belgium) or group of cities in a continent (for example, western Europe cities).

or if it investigates only a single and separate typology of purchasing process. Among the 50 articles selected, the 60 percent (30 articles) concerns both online and offline channels with the objective to compare the different environmental implications in the two scenarios; the 32 percent (16 articles) is focused only on online purchasing process, while the remaining 6 percent (3 articles) refers to the traditional shopping. In one paper there is no specification in that sense.

Secondly, the detailed analysis of the content of each paper falls into the following categories:

- Modes of Transport: this area of classification looks at the different modes of transportation used in the various purchasing processes, not only by consumers but also by couriers, transportation companies along the logistic chain in order to move the goods from one point to another one;
- Supply Chain Phases: this axis refers to the main steps that we can go through in a general supply chain (from production to distribution and, in turn, to sale and use of the product);
- Return Impact: this axis considers if a purchasing process described in the analysis also involves the return phase, seen as return of defective goods, return due to failed deliveries, or return for recycle/reuse the good;
- Packaging Impact: this area of classification takes into consideration if an article deals with the packaging aspect and if it considers its environmental impact on the purchasing process;
- Unit of Analysis: defined as the functional unit considered in the analyses to assess the environmental impact and it refers to the number of items in a single order and/or the number of orders in a single delivery for the same consumer;

- Store Typology & Location: it refers to the location of stores considered in the analysis and also to the typology (retail store, local store, distribution centre, etc.).

	Macro Context	**Micro Context**
Axes of classification	*Sector*	Modes of transport
	Geographic area	Supply chain phases
	B2B/B2C	Return impact
	Offline/Online	Packaging impact
		Unit of analysis
		Store typology & location
		Results, Object of comparison, Parameters affecting the result

Table 2-3: Axes of classification identified in the literature review

(i)Modes of Transport. In this section, we scan all the literature with the objective to identify specific groups of modes of transports adopted both in the online and offline purchasing processes, for the distribution, delivery and sales of goods. This axis is one of the most crucial one since the transportation activity, in the purchasing process, represents a significant variable in the measurement of GHG emissions and energy consumed. The environmental effects derived from shopping activity are deeply influenced by the choice of the means of transport. According to the supply chain phase we refer to, the transportation activity has different roles: distribution from a factory to a warehouse, or from a warehouse to a store, or from a distribution center to another one, but also transportation for the final delivery of goods to consumers' home and consumers' travel to the stores in the offline scenario. We grouped the different modes of transport according to the type of process in which they are used: online/offline and in which phase of the supply chain are involved. From literature review, what results is that, in general, the only difference between online and offline shopping, regards the last mile phase in the supply chain. The means for the

transportation activity used before the purchasing phase are the same in both processes: trucks (heavy-duty trucks, light-duty trucks, FTL, LTL), vans, and, more seldom, also sea and air options are included. In the last mile, the traditional shopping sees mainly the adoption of cars, followed by public transport (bus and train), bike, and walking. On the contrary, in the online process, mainly light-duty trucks and vans are used for the delivery of goods from distribution centres or transit points to consumers' home or pick-up points/collection points.

(ii)Supply Chain Phases. The papers were also analysed and classified based on the type of steps in the supply chain involved in the analysis in order to assess the environmental effects of activities. By scanning the literature, we identified approximately seven phases taken into consideration by authors: extraction of raw materials, production, transportation/distribution, warehousing & packaging, last mile, post-sale[5]. What came out from the investigation of the articles, is that the majority of studies focuses on the last mile phase (28 percent), followed by the transportation/distribution activity (22 percent), the post-sale (18 percent) and warehouse & packaging activities (14 percent). The production activity (12 percent), and the extraction of raw materials (5 percent) are rarely considered for the measurement of the emissions and energy consumed. The following table summarized the incidence values of each phase.

[5] In the post-sale phase we include the consumer's behaviour with respect to the reuse, recycle and return of the products bought.

Supply Chain Phases	Percentage
Extraction of raw material	5%
Production	12%
Warehousing & Packaging	14%
Transportation/distribution	22%
Last mile	28%
Post-sale	18%

Table 2-4: Supply chain phases incidence of analysis

What we can also observe is that, in most of the cases, there is not a clear and precise definition of the supply chain activities involved in the analyses, but we find different perspectives. For example, Siikavirta and colleagues (2002) [90] considered mainly five steps: sourcing, production, distribution, retailing and consumption. Their case study demonstrated as the GHG emissions in food production and consumption system had different effects (increase/decrease) according to the step in the supply chain considered. On the contrary, other studies as the one of Edward, McKinnon, and Cullicane (2011) [28], set the assessment of carbon emissions of conventional and online supply chains by starting from the point of divergence in the respective supply chains: the focus is on carbon emissions in the movement, storage and handling of physical goods and particular attention is given to the last mile phase. Moreover, we found also other studies focused only on transportation activity. For example, the case study of Wiese, Toporowski, and Zielke (2012) [109] compares the transport-related CO2 effects of online and brick-and-mortar shopping in the sector of clothing retail: through a sensitivity analysis showing how specific factors as distances travelled by customers, return rates, use of public transport and information behaviour via different channels impact in different ways the level of emissions caused only by transportation. Other studies focus just on the comparison between online and offline purchasing processes by considering only the last mile and return phases. An example of this is the analytical model developed by Cullicane and colleagues (2010) through which they compared the carbon footprints of conventional and online retailing by focusing on a last mile perspective, i.e. deliveries of goods from local depots to the home, and personal shopping trips. In addition to transportation activity, also the environmental impact in the warehousing phase was considered in some studies (as example, Rizet *et al.*, 2010 [80]; Van Loon *et al.*, 2015 [103]; Mangiaracina *et al.*, 2016 [59]). Rizet and colleagues (2010) [80] developed an approach to quantify the GHG emissions from logistics activities for products supply chain, including warehousing activity, that together with stores and shops, are mainly responsible for the consumption of energy in terms of electricity. The quantity of GHG emitted per kWh highly depends on the primary energy from which the electricity is generated: nuclear electricity generates very few GHG emissions in comparison with fossil fuels power stations (Rizet *et al.*, 2010 [80]). Van Loon and colleagues (2015) [103] developed a Life Cycle Analysis model applied to different online retailing of fast-moving consumer goods in UK. They found that, among the various factors that contribute to climate change potential, one is related to the energy efficiency at shops and e-fulfilment centre operations. Mangiaracina and colleagues (2016) [59] developed an Activity-based model to compare the environmental impact of online and offline purchasing processes in the apparel industry, focusing on logistics activities (transport and warehousing). These activities are recognised to be crucial in the environmental sustainability of purchasing processes (Hjort *et al.*, 2013 [45]). In addition, warehousing activities are strongly impacted by unattended deliveries (McLeod *et al.*, 2006 [62]) and handling of consumer's returns (e.g. Park and Regan, 2004) since they lead not only to additional travel but also to additional warehousing operations so increasing the quantity of GHG emissions (Mangiaracina *et al.*, 2016 [59]).

(iii)Return Impact. The post-sale phase is the process following sale, in which different activities are identified, depending on the customer behaviour. (Mangiaracina *et al.*,

2016 [59]). Basically, what triggers the start of this phase is the customer intention to return the product for different reasons, among which, the main one is that the product is defective or unwanted. This phase ends with the delivery of the new item in the online process, while in the offline one, it includes the trip to the store and the return trip to home with the new product (Mangiaracina *et al.*, 2016 [59]). Moreover, by scanning the papers, we decided to include in this axis of classification also the analyses regarding the return for disposal or recycling, the return of unsold items in the store and, with respect exclusively to the online scenario, the return trip due to first failed deliveries. What emerged by literature is that only 23 articles over the 50 selected deal with this theme and many of them considered it solely in qualitative terms: return of unwanted/defective items (7 papers), return trip due to first failed delivery (7 papers), return for disposal or recycling (6 papers), and return of unsold items (3 papers). Typically, between 25 and 30 percent of non-food goods bought online are returned (de Koster, 2002) [20], compared with just 6-10 percent of goods purchased by traditional shopping methods, thought this varies widely according to the type of product and geographic area (Nairn, 2003; Fernie and McKinnon, 2009). The environmental effects of return rate in online purchasing processes strongly depend on both parcel carriers' returns policies and consumers' preferred habits (Edwards *et al.*, 2010 [26]). In our research, we found different considerations in terms of return rate. For example, Matthews and colleagues (2001) [60], in the model developed, included only the return of unsold books from retailers in the traditional channel, equal to the 35% of produced books, since it represented the most impacting issues in this sense, by involving additional truck leg which could be assumed as 805 km. McLeod and colleagues (2006) [62] presented a study aimed at assessing the transport impacts of local collection/delivery points (CDP). Among the key factors identified and combined in the model, the delivery failure rate of small package deliveries has been considered. They designed a questionnaire with the aim to determine the attitudes towards the home shopping (online) of Winchesters householders including experience with failed deliveries. From the results, what emerged was that the average household yearly deliveries were 12, with a first time missed delivery rate of around 25%. In their model, in order to test the sensitivity of the results, first time delivery rates of 10, 30 and 50% were considered. The results suggested that by increasing the rate, the collection delivery point method (CDP) was becoming more efficient for the carrier in terms of time taken; the break-even point would have been around the 20% delivery failure rate. Edwards and colleagues (2010) [26], in their model, aimed at comparing the carbon footprints of conventional and online retailing in the last mile perspective, assumed 25, 12 and 2 percent of failed first-time deliveries and 25% of returned orders (40% for clothing). What resulted was that the actual quantity of CO2 per online order is very sensitive to the proportion of products returned and the method of return (the unwanted good is collected on a subsequent delivery round or, the worst scenario, separate trip to return the item).

Furthermore, mainly starting from 2017 papers concerning the topics linked to the recycle and reuse phase have increased. We considered 7 papers that covered that theme. In particular, G. Song *et al.,* (2017) [95]; Y. Yi *et al.,* (2017) [113] and Y. Su *et al.,* (2020) [96] documented in their studies the increase and the linked consequences of the waste of packaging materials coming from the express delivery sector and the importance of the recycle and reuse phase. T. Tokar *et al*., (2021) [98] instead, in their paper tried to shed light on unseen benefits and costs of the e-commerce. They considered the packaging waste as one of the main costs and the recycle phase as the strategy that retailers should pursue, and that policymaker should incentive.

As reported in section *(i)*, the grocery industry the return rate is almost null, both in online and offline purchasing processes, so this is the reason why in the related models to measure the environmental impact, it is not considered.

(iv)Packaging Impact. In the reviewed analyses and studies the environmental impact of packaging is not regularly considered: among the 50 papers selected only 26 include packaging impact as a factor in the analysis, and in some of them, the theme is explored only in qualitative terms, without specifying the impact in terms of energy consumed and CO2 emissions generated by packaging production and consumption. As example, Reijnders and Hoogoven (2001) [79] include packaging in the primary energy use among pre-use stages of personal computers, but they do not provide a quantitative contribution in this regard. Usually, products are packaged individually, and the packaging may not be reused (Matthews *et al.*, 2002 [61]). So, this is the reason why it is fundamental to consider this factor in the assessment of environmental effects of purchasing processes. Packaging materials consumption is linked mainly to the warehousing activities (Siragusa and Tumino, 2021 [91]). The entire quantity of packaging material used in e-commerce is bigger than the one consumed in the traditional channel: for example, Matthews and colleagues (2001) [60] estimated that the total cost of packaging (both individual and bulk packaging) for a specific number of books units in the online process was about of $ 155,000 against the $ 51,000 of the traditional retailing channel. Packaging consumption not only makes the online purchasing process more expensive, but also increase the GHG emissions by reducing the environmental sustainability of e-commerce option (Matthews *et al.*, 2001 [60]). Generally, e-commerce uses more packaging than the traditional model for plenty of goods, causing an additional energy consumption related to packaging production; in addition, e-commerce distribution requires more energy than bulk shipping not only because of additional travel to consumer's home, but also because of space taken by

extra packaging (William and Tagami, 2003 [74]). Another quantitative contribution is given by a LCA conducted by Sivaraman and colleagues (2007) [92], showing that package selected for delivering an object is responsible for 67% of the difference between the e-commerce option and the traditional business option. Weber and colleagues (2008) [106], in their analysis concerning a lifecycle comparison of traditional retail and e-commerce logistics for electronic products, among the different factors fixing the boundary of the system, considered the different effects of bulk packaging (offline scenario) and individual packaging (online scenario), expressed in terms of energy and CO2 intensities of corrugated cardboards. Among the 5 major contributors that differentiate life cycle CO2-emissions of the two systems there is cardboard individual packaging (22% of e-commerce), after transport to and from retail store and wholesale warehouse. Packaging can account for a significant portion of the greenhouse gas emissions if cardboard packaging is used (Van Loon *et al.*, 2015 [103]). The impact of shopping bags, used in van based home deliveries and consumer shopping trips, is relatively limited resulting in less than 11 g CO2-eq. This is because the amount of packaging is much lower, i.e. an average of 9/15 bags, weighing as little as 8 g per bag, are used for a typical purchase of 30 items (Barrow, 2010; Green, 2008). To sum up, we can conclude that B2C e-commerce is negatively impacted by individual packaging needed to deliver products to consumers' home (e.g. Borggren *et al.*, 2011 [7]; Van Loon *et al.*, 2015 [103]). Pålsson and colleagues (2017) [73], through their literature review aiming at summarizing the knowledge regarding energy consumption in e-commerce and conventional trade channels, found that the main reason for home delivery option (online purchasing) being less energy-efficient depends only on packaging. Another important issue regarding packaging environmental impact in purchasing processes was raised by W. Fan and colleagues (2017) [32] in China. It concerns the environmental impact of the rapid development of China's express delivery and how it leads to a huge amount of additional packaging production. They calculated pollution emissions from the production and distribution processes of six different types of express packaging materials (packaging boxes, plastic bags (PO), plastic bags (PE), woven bags, envelopes, tape) and what emersed is that the packaging boxes generate the largest CO2 emissions.

Furthermore, the topic of the huge increase of packaging waste is exploded starting from 2017 especially in China as G. Song *et al.,* (2017) [95]; Y. Yi *et al.,* (2017) [113] and Su *et al.,* (2020) [63] documented in their studies.

G. Song et al., [95] for example, underlined as the fast-food delivery service in China has become more popular and this resulted in a significant amount of packaging waste. So, they estimated that that the total amount of packaging waste surged from 0.2 million metric tons in 2015 to 1.5 million metric tons in 2017.

Y. Su et al., (2020) [96] adopted a life cycle assessment method to quantify the implicit environmental impacts (CO2e) of packaging materials' raw material production, boxes/bags manufacturing, and end-of-life stages. The results indicate that the waste of express delivery packaging materials has surged from 0.2 million metric tons (Mt) in 2007 to 9.2 ± 5% Mt in 2018 in China.

According to a study of R. Velazquez and S. M. Chankov (2019) [104] regarding the environmental impact of last mile deliveries and returns in fashion e-commerce, packaging in e-commerce causes 60% more emissions than plastic bags and this is mostly due to the use of individual packaging to separate orders and sufficiently protect objects during long journeys. In addition, only 23% of the customers return their orders with the original packaging, meaning that the packaging volume of 77% of the returns is roughly doubled (Velazquez and Chankov, 2019 [104]). Tumino and Siragusa (2021) [91] in their model aiming at comparing the environmental impacts of online and offline purchasing processes in the grocery industry, included among the input data, the packaging type, size, capacity, weight, and the amount of raw materials used in the warehousing activity (order picking and assembly phase). They calculated the impact of plastic bags and cardboard boxes in terms of KgCO2e/Kg, but without separate the packaging effect from other warehousing activity.

(v)Unit of Analysis. A crucial variable, according to which we decided to investigate the literature, concerns the unit of analysis, the functional unit considered in the models, frameworks and case studies collected, on which to allocate the environmental impacts, for example in terms of CO2 emissions or energy consumed during a specific process or activity. Among the articles selected, only 35 of them report indications regarding the unit of analysis. We identified five typologies according to which classify papers according to this axis: single item, more "peer" items, more different items (multi-item option), order/s, delivery/shipment/passenger transport. What emerged is that in most of the cases (36 percent), authors refer to a generic order, assessing emissions, for example, per a single transaction (Wiese *et al.*, 2012 [109]) or for a specific number of orders fulfilled per day (Mangiaracina *et al.*, 2016 [59]), and so on; then, the 30 percent of the cases is represented by the "single item" category, in which researchers refer for example to energy use per single article (Reijnders and Hoogeven, 2001 [79]) or one book per purchase (Matthews *et al.*, 2002 [61]), or GHG emissions per product unit (Rizet *et al.*, 2010 [80]), and so on. Moreover, delivery/shipment/passenger transport unit of analysis represents the 18 percent of cases, where emissions or energy were calculated basing on a delivery of a certain number of items (e.g. delivery of 100 books to 100 customers, (Kim *et al.*, 2009 [54]), or number of drops for each round (Edwards *et al.*, 2010 [26]) and others similar cases. In other analyses, we found assessments based on more items (14 percent), but belonging to the same typology, for example, an average group of books per person (Williams

and Tagami, 2003 [110]); Sivaraman and colleagues (2007) [92] developed a comparative energy, environmental and economic analysis of traditional and e-commerce DVD rental network, by considering the renting of 3 DVDs per two times a month; Edwards and colleagues (2011) [27], in their study on carbon auditing of conventional and online retail supply chains, considered, as unit of analysis the product's category total weight or volume/quantity of goods sold. Only one paper considers the case of a purchase order consisting of more items, but of the same category, in the sector of fast-moving consumer goods: Van Loon and colleagues (2015) [103] examined the total environmental impact of different fulfilment methods considering different basket sizes (1, 5, 20, 100 goods).

(vi)Store Typology & Location. Within this axis, we want to collect information regarding the typology of store and its location, included in the traditional purchasing process (offline scenario). What emerges by scanning the papers is that there is not a regular type of store considered and also the locations are very different among the different analyses. In the majority of cases, when the environmental impact of offline scenario is taken into consideration, researchers typically refer to a general local store, situated in the town centre, in the peripheral area and/or in a rural area. For example, Siikavirta and colleagues (2002) [90] referred to an average distance to the grocery store of 3.5 km; Williams and Tagami (2003) [110] in their study, considered typical distances between bookstores by assuming that bookstores were uniformly distributed in a prefecture: the resulting store-to-store distances are 1, 5.2, and 13.4 km for Tokyo, Tochigi, and Hokkaido, respectively (Williams and Tagami, 2003 [110]). Not only local and close stores are considered, but, in some analyses, wider areas are studied: for example, H. B. Rai and colleagues (2019), set their analysis in the entire area of northern Belgium, considering the 70 stores spread there. In other cases, we did not find the specification of the store location, but only the typology, as example: supermarket,

hypermarket, round the corner shop, trader in an open-air market, direct sale from producer, greengrocer shop, outlying supermarket, minimarket in town (Rizet *et al.*, 2010 [80]); largest shopping mall of the city (T. Jia *et al.*, 2013 [51]).

2.4 Discussion of results and future directions

In this section, we decided to report the effective results by focusing on analyses and case studies, with the objective to understand what the most sustainable purchasing process at the moment is: e-commerce (online scenario) or traditional shopping (offline scenario). In addition to that, we considered fundamental to understand how in the different studies the environmental impact has been assessed, i.e. GHG emissions (as CO2, NOx), energy consumed and so on. Moreover, the parameters/variables affecting the results in the model have been classified in a separate axis. In the end of this section, the results will be discussed with the aim of finding gaps in the literature, which will trig our thesis.

Concerning the unit measured for quantifying the environmental impact of a process, in the review literature, the most frequent discussions of environmental effects are about energy consumption and usage (MJ or TJ), and GHG emissions, among which the most common is the CO2 emission (expressed in grams or kg). In other cases, we have also the measurement of impacts of some processes just from a monetary point of view. The assessment of emissions or energy can be expressed by taking into consideration different units of measure: for example, GHG emissions as grams of gas per km driven (Siikavirta *et al.*, 2002 [90]), or grams of CO2 per item and MJ per item (Weber *et al.*, 2008 [106]). In addition, some studies estimate results by looking at the emissions generated/energy consumed in a specific activity along the supply chain (e.g., last mile, or packaging), while other ones take into consideration the entire supply chain, from production to use phase and post-sale stage.

Moreover, we made a classification of the main parameters considered in the models review, on which the results - in terms of environmental impact - depend. The most considered variables affecting the results are the distance travelled by customers from their house to the store (offline) (e.g., H. Siikavirta *et al.*, 2002 [90]; M. Browne *et al.*, 2008 [10]; C. Borggren *et al.*, 2011 [7]; P. Van Loon *et al.*, 2015 [103]), the shipping distances (online), the delivery failure rate, the product return rate and how they are treated (e.g., K. Fichter, 2003 [36]; Brown and Giuffrida, 2014 [11]), the mode of transportation, the type of vehicle used, the incidence of packaging reuse and waste, the time available for shipping, the density population, the geographical scope (urban, suburban, rural areas), the shipment structure, average load per tour (e.g., A. Wiese, 2012 [109]), the number of customers served in a shipping tour. In few cases, instead, the number of items purchased and the consumers purchasing behaviour (e.g., J. Edwards *et al.*, 2011 [27]) are considered.

Among the 50 papers analysed, the majority concerns studies and analyses aiming at understanding which purchasing process, online or traditional, is more sustainable. According to results from literature, we can state that, on the whole, e-commerce option is more environmentally and economically sustainable than conventional shopping, from different perspectives. In many studies, it was estimated that the energy use and CO2 emissions generated by the online channel are lower (e.g., Reijnders and Hoogeven, 2001 [79]; Sivaraman *et al.*, 2007 [92]; Wiese *et al.*, 2012 [109]; L. Smidfelt Rosqvist and L. Winslott Hiselius, 2016 [94]; Mangiaracina *et al.*, 2016 [59]). A lifecycle comparison of traditional retail and e-commerce logistics for electronic products (Weber *et al.*, 2008 [106]) shows as among the logistics differences between online and offline processes, the three major contributors are customer transport, packaging and last mile delivery. A Finnish study, measuring the effects of e-commerce on GHG emissions in the grocery sector, estimated that e-commerce creates a traffic reduction reducing the distance driven and GHG emissions generated by grocery shopping by 18% to 87% in comparison with the traditional channel, in which the customer goes to the store (Siikavirta *et al.*, 2002 [90]). The analytical model assessing the environmental impact of logistics in online and offline B2C purchasing process in the apparel industry, developed by Mangiaracina and colleagues (2016) [59], shows that in general the online purchasing process is more sustainable than the offline one, but the logistics, packaging and handling activities are more environmentally impacting in the online process rather than in the conventional shopping while transportation activities generates a higher impact in the offline scenario. In addition, they considered some crucial parameters to study the sustainability of e-commerce processes: the distance between customer's house and the store, the location of costumer's house, **the number of items ordered**, the energy consumption in from machinery and buildings, time required for each activity in the process. Also, according to Pålsson and colleagues (2017) [73], the total energy consumption from transportation is greater in the conventional supply chains, due to the fact that passengers' transportation impacts more than transport in home deliveries, while packaging activities are more impacting in the online sales. The same study makes a discrimination in the return of products: unsold product returns have a higher impact in the traditional channel, while the product returns (due to errors, defective items, etc.) are greater in e-commerce. Also, in the grocery sector it seems that the online process is more sustainable, in particular a study developing an analytical model to compare the environmental impacts of offline and online purchasing processes in the grocery sector (Siragusa and Tumino, 2021 [91]), shows as e-grocery is potentially more sustainable than bricks-and-mortar shopping, with emissions ranging from 10%–30% lower.

Discussion. Despite the majority of developed models states that e-commerce is more environmentally sustainable than conventional shopping, we found some studies in literature refuting this thesis. For example, Williams and Tagami (2003) [110], in their simulation designed to quantify the energy use in sales and distribution via e-commerce and conventional retail in the book sector, estimated that e-commerce consumes more energy per item in urban areas, due to the need of additional packaging, while in the suburban and rural areas the difference between online and offline energy consumption is negligible. The higher efficiency of transport for home deliveries compared to the consumer's travels in the offline scenario balances out the impact of additional packaging. Moreover, they concluded that e-commerce is sustainable only in the case of single-purpose shopping trips by car. Brown and Giuffrida (2014) [11], in their study regarding the carbon footprint comparison between last mile delivery and customer pick-up, identified a break-even point of customers requiring delivery at home, under which the carbon emissions result higher than the case in which the customers pick up their purchases themselves (traditional shopping). Moreover, another important case is the analysis conducted by M. Jaller and A. Pahwa (2020) [49], regarding the evaluation of the environmental impacts of online shopping through a behavioural and transportation approach, in which the results confirm the higher sustainability of e-commerce, but they pointed out how the emissions reduction is sensitive to how receivers consolidate their order requests and how vendors consolidate the shipments. This explains how the orders consolidation is a crucial factor to consider a potential in the reduction of emissions when online and offline purchasing processes are compared.

So, what we can conclude is that, despite there is a majority of cases in which the online process is considered to be more sustainable than conventional shopping, several limitations to the models exist, since the related results are very sensitive to the contexts in which the models were designed or to specific parameters set. **There is not an absolute result**. Also, many studies take into consideration only dedicated purchasing trips, while if customers combined their shopping trips the results in terms of environmental impact could not be the same (e.g. J. Kim *et al.*, 2009 [54]; Rizet *et al.*, 2010 [80]).

Another limitation is that many analyses consider only one item ordered by the customer in the online process, without considering the impact deriving from multiple purchases both in the online and offline processes. For example, Mangiaracina and colleagues (2016) [59] highlighted how highlighted how the CO2 emissions level grows less than proportionally with respect to the number of items purchased by the customers, in both online and offline purchasing processes. So, what we want to point out is that from literature review an important question that emerges regards the impact of **multiple purchases in a single occasion** and how this variable could affect the results obtained so far. Households might reduce their carbon emissions on the last mile by purchasing goods from several product categories at a single occasion and the same shopping situation, e.g. buying both groceries and clothing during a visit to a shopping mall (S. Seebauer *et al.*, 2016 [87]). Instead, the majority of studies do not involve the situation in which a certain number of products can be bought simultaneously, which is a critical factor to assess the real environmental impact (H. Pålsson *et al.*, 2017 [73]). Also M. A. Figliozzi (2020) [37] highlights how the number of products purchased is a critical factor affecting the relative efficiency of driving to the store vs home delivery. Moreover, J. B. Edwards and colleagues (2010) [26], in their study, highlight how the number of goods bought in a single shopping trip and the willingness to combine shopping with other activities, both in the online and offline purchasing process, represent decisive elements in the assessment of the sustainability of purchasing activity. The authors pointed out how there is no information regarding the number and the type of items purchased per shopping trip and it represented a limitation of their study.

In the literature scanned, the most recent study raising the question of the multi-purchases situation in a single occasion is the one of Siragusa and Tumino (2021) [91], in which they confirm that the basket size is of fundamental importance, since when the number of items purchased increases the e-commerce environmental advantage starts decreasing with respect to the offline scenario.

So, the main objective of our research is to understand how a **multi-purchases scenario** may alters the environmental impact of purchasing process, by comparing online and offline scenarios.

In conclusion, it is important to underline that the above-described literature review presents some limitations regarding the topic of interest. Despite the efforts to include the majority of studies in this field, we are aware of the fact that some other significant papers have not been incorporated in the collection. However, we believe that the gathered knowledge is sufficient to set the basis for our work.

3. Customer behaviour

This chapter has the purpose to investigate how the role of customer with his/her behaviour is related to purchasing activity, in order to better understand how it can affect the level of environmental sustainability of different purchasing processes. Chapter 3 is organized as follows:

- Firstly, an overview on the main current knowledge about this topic is provided;
- Secondly, the results of the survey we spread, with the purpose of collecting consumers' behaviour information and supporting the model application activity, are deeply analysed in different sections (in line with the parts in which the related questions have been split).

3.1 Introduction

One of the main limitations of the majority of the studies assessing the carbon footprint of online and conventional shopping consists in the lack of involvement of the impact of customer's purchasing habits within the set of critical variables according to which results should depend on. However, it is fundamental to also include customer related parameters to have a more comprehensive assessment of the environmental sustainability of purchasing processes. Unfortunately, the effects of consumer's behaviour are rarely considered in most of Life Cycle Analysis studies collected in the literature review phase (e.g., Matthews *et al.*, 2001 [60]; Weber *et al.*, 2009 [106]). Considering customer choices in the study is fundamental not only to understand how they contribute to the alteration of results, but also to understand the way in which to drive consumers towards better and more sustainable behaviours regarding shopping habits. The objective is to raise as far as possible the level of awareness regarding the environmental impact of their purchasing actions. In order to achieve this purpose, it is necessary to identify which are the primary factors driving the final environmental impact outcome.

The main variables. Customer behaviour, in the assessment of carbon footprint of purchasing processes, can be grouped in a specific set of variables:

- The **number of purchases** made in a generic shopping trip: if a consumer combines in a single trip more purchases, instead of dedicating one trip to each, it is possible to reduce emissions produced by passenger's vehicles;
- The **mode of transport**: adopting public transport, bike or walking for shopping trip, instead of cars or motorbikes, ay lead to a significant reduction of GHG emissions;
- The **distance** driven by consumer and the type of **trip chaining**: it is fundamental to understand if a shopping activity is combined with other activities or if the trip is totally dedicated to it;
- The **frequency of shopping activity** related to each product category, and through which **channel** the consumer prefers to make his/her purchases (**online or traditional one**);
- The **return** management in case of defective/non-compliant items and failed deliveries;
- For the online purchasing process, the **location** in which the customer chooses **to receive goods** (home, pick-up points); also, the **number of websites** the customer relies on for buying; the average size of an online order.

It is necessary to point out that all these factors are not results-impacting in the same way, but they depend on the specific context considered. The totality of consumers' preferences derives from different circumstances, and they are related to other macro-factors. S. Farag, T. Schwanen, Martin Dijst, J. Faber (2007) [33] identified a list of factors explaining the customers' habits towards shopping: socio-demographic characteristics, land use features, lifestyle and personality indicators, shopping attitudes, shopping behaviour, and internet behaviour. First of all, empirical studies found that more educated people and higher-income clusters are more likely to do shopping online, while less educated and lower-income groups prefer the traditional channel (Li et al., 1999; Swinyard and Smith, 2003; Forsythe and Shi, 2003). The land use characteristics are associated to the level of shops accessibility and to the urbanization level. In particular, the higher the level of urbanization and the number of activities places such as school, work offices, restaurants, shops, etc., the higher the frequency of in-store trips. Farag and colleagues (2007) [33] found that the relationship between urbanization level and shop accessibility on one side and frequency of shopping online or through the traditional channel on the other side is twofold. In fact, they affirm that a higher shop accessibility reduces the frequency of buying online, because the effort to reach a store is lower and it is easier to have contact with the items the consumer desires to buy. At the same time, however, in a more urbanized area it is more likely that people search their products online and then also buy them online, with respect to less urbanized and rural areas. In general, by considering the majority of studies, it seems to have the largest support the theory according to which the higher the shop accessibility the higher the trips frequency (Meurs and Haaijer, 2001; Srinivasan and Bhat, 2004). Moreover, lifestyle and personality may play a role that influences the frequency of shopping online or in store. In this regard, most of the authors shares the idea according to which time pressure increases the online purchases. Schwanen and Mokhtarian (2004) [66] explain how people characterized by an adventurous personality prefer to travel miles to reach a store and do shopping, especially by using their private vehicle. On the contrary, other studies take sociodemographic characteristics (for example the number of children in a family) to identify the entity of time pressure that push consumers towards the online channel (Ferrell, 2005).

The different attitudes towards online and in-store shopping represent the main factor which drives customer preferences with regard to the channel through which to make purchases. Indeed, people have different and several reasons to shop: for someone shopping means just purchasing new goods, for others it is an opportunity to socialize and interact with other people, for others still it means knowing new trends, promotions (Cheuk Fan Ng, 2003). In particular, Cheuk Fan Ng (2003) categorized consumers in two groups: task-oriented and leisure-oriented consumers. The first ones are those who want to minimize time to dedicate to shopping activity, while the second ones usually associate shopping to more than the simple purchasing action, in fact shopping is perceived as an experience from which to derive enjoyment and satisfaction. Moreover, people who like to handle and test the product before purchasing prefer to opt for in-store shopping rather than relying on e-commerce websites (Li *et al.*, 1999).

Through their study, S. Farag, T. Schwanen, Martin Dijst, J. Faber, (2007) [33] wanted to show how the frequencies of online searching and buying and in-store shopping trips were related to each other's. It was found that the relationship between online and offline purchasing choices was characterized by a *circular effect*: in fact, online searching positively affects the frequency of shopping trips, that in turn tend to increase the frequency of online shopping activity. In particular, the evidence from their study shows how people who search products online make more frequently non-daily shopping trips, but consumers who frequently opt for the traditional channel are also online buyers. Thus, it is possible to state that, the online and offline purchasing processes are complementary, and they affect each other's. In addition, a link between the place in which the consumer lives and the type of purchasing process chosen was found: people living in an urbanized area are more likely to buy online since the internet connection is faster with respect to, for example, a more rural area. At the same time the high level of shop accessibility, higher in urban areas, reduces the frequency of online buying. Then, consumers with a strong internet experience as younger and more educated people are more likely to buy online.

A limitation of their study is that the type of choices regarding shopping do not differ in relation to the type of product, but they refer to a general case. Instead, the type of product may represent a significant factor that contributes to the selection of the channel through which the consumer prefers to buy. For example, if we think to the price as decision variable, there are goods elastic to price variation and other goods, as luxury ones, whose demand is not affected by price increase. Consequently, considering that usually through the e-commerce websites it is more probable to find price promotions and reductions, the online channel will be preferred in case of products elastics to price.

The majority of studies assessing the carbon footprint of purchasing processes, as previously discussed in the literature review chapter, sees in the online channel the most environmentally sustainable option, thanks for example to the reduction of transportation emissions or also to the decrease in the number of inventories. In addition, the consumer awareness regarding the environmental impact linked to purchasing habits is growing (Carrillo, Vakharia, Wang, 2014 [16]). As a matter of fact, the results of a poll conducted in 2010 and published on an article appearing in the Wall Street Journal showed that 17 percent of US consumers and 23 percent of

European ones are disposed to pay more for environmentally friendly products (O'Connell, 2010). Carrillo, Vakharia and Wang (2014) [16] in their study (*Environmental implications for online retailing*) showed the links between customer's channel choice and environment related consequences. They found that customer becomes more aware of the consequences of his/her purchasing choices because firms start to promote the idea of online channel as more environmentally sustainable choice. They specified how the possibility for a retailer to have a double channel is not the best solution in any case, but it depends on some factors, first of all the population density in a specific geographic area. For example, Matthews, H. S., Williams, E., Tagami, T., & Hendrickson, (2002) [61] explained how in Japan, where cities are characterized by highly concentrated populations, the most energy efficient solution for books selling involves one only channel, the traditional one.

One of the few research projects concerning the assessment of purchasing processes environmental impact which also considers customer behaviour impact, is the one carried out by Patricia van Loon, Deketele L., Dewaele J., McKinnon A., and Rutherford C., (2015) [103]. They include in a comparative analysis of carbon emissions from online retailing consumer behaviour related variables: transport mode, trip length and trip frequency, basket size. The results show that these parameters were decisive in determining to what extent the e-commerce was environmentally sustainable. Regarding basket size, for example, it was found that the emissions per item increase inversely with basket size. So, consumers should concentrate in one order/shopping trip as many items as possible in order to reduce the number of trips and deliveries. Basically, the study identified how the online purchases can be more environmentally preferable than the traditional channel with the objective to induce customers to reduce the number of complementary shopping trips and to maximize the number of items per delivery.

In order to realize the environmental sustainability of e-commerce, a reduction of passengers' travels is essential (Hesse, 2002; Matthews et al., 2002 [61]; Rizet et al., 2010 [80]). Mokhtarian (2004) [66] stated that online buying leads to changes in consumer travel in terms of shopping frequency, transport mode and distance travelled to reach a specific shop. Moreover, it is important to consider how failed deliveries and product returns lead to an increase of the carbon footprint of purchasing process. The incidence of these events depends on customer behaviour. For example, if customers prefer receiving their products in a pick-up point, rather than home, the number of failed deliveries significantly decreases and, at the same time, customer could combine the picking of the item to other activities. In fact, also trip chaining (including shopping trip into another transportation purpose, as travel back from work, school or university drop-off) and browsing trips, to inspect a product before buying it online or in a store, represent a significant contribution to the generation of emissions (Edwards and McKinnon, 2010 [26]). Browne and colleagues (2005) [10] agreed on the idea by which, based on the distance travelled, the number of items purchased, and the mode of transport, the customer trip can consume more energy than the entire transportation energy consumed to move items from factory to shop. According to Cairns (2005) [15], if consumers totally substitute conventional shopping with e-commerce the miles travelled by passenger's vehicles can be reduced up to 70 percent.

As reported by a significant number of studies, one of the main consumer related factors to consider is the distance driven in the home deliveries compared to the one travelled to reach a physical store (Punakivi and Saranen, 2001 [77]; Siikavirta *et al.*, 2002 [90]).

In addition, in the current digital era, it is fundamental to consider how Internet has changed the way in which customers approach products before buying them. Nowadays, connection to internet is a sort of requisite in people's life, especially in the

Western society. Through websites, it is possible to rapidly compare different brands, different suppliers and to find discounts; through just few clicks, it is possible to buy products and save time to dedicate to a full shopping trip. On the other side, Internet and real time connection can lead to an increase of shopping trips, since the web generates new knowledge, people know new products to buy in store (Farag S., Schwanen T., Dijst M., Faber J., 2007 [33]). In line with some empirical studies, people nowadays, tend to start shopping activity online with the searching information phase, but they conclude the purchase in the physical store. (Ward and Morganosky, 2002).

3.1.1 The impact of COVID-19 on consumers

The COVID-19 pandemic has undoubtedly affected everybody's lives. Lockdown and social distancing have disrupted businesses choices and consumer's habits at the same time. So, we think it is essential to dedicate a section to the description of the effects generated by the pandemic on consumers and their lifestyles. Due to COVID-19 pandemic, consumers had to learn new habits and some of them can be long-lasting even after the end of the emergency condition. Some authors believe that COVID-19 is considered an accelerator of the growth of e-commerce: the pandemic is accelerating the structural changes in products consumption and of the shops' digitalization process (Rae Yule Kim, 2020 [55]; Gu S. *et al.*, 2021 [42]). Pandemic has been considered one of the most impacting threats to businesses (Smith P. W. *et al.*, 2007). The majority of businesses had to rapidly adapt to the transition to the online reality. Together with businesses, also consumers had to change their shopping habits, their priorities. In fact, a survey conducted in April 2020 shows how about 46% of sample population declared to plan to reduce their spending during the pandemic (Bhargava S. *et al.*, 2020).

The objective is to understand how pandemic has pushed consumers towards the online channel to make their purchases. A study conducted in US on 2,200 adult people found that 37% of sample population shifted to the online marketplaces only after Coronavirus diffusion (Morning Consult, Crosstabulation Results, National Tracking Poll #200394, March 26, 2020 [67]). The same survey makes a distinction between different people generations. Results revealed that 66% of Generation Z, 68% of Millennials, 73% of Generation X, and 68% of Boomers embraced online purchasing channel after the significant increase of online buyers due to the pandemic.

Among reasons why consumers, who prefer the physical shop for making a purchase, are adverse to the online shopping, regards the cost of learning, consisting in the time investment for learning how to make your purchases through a digital marketplace (Morning Consult, Crosstabulation Results, National Tracking Poll #200394, March 26, 2020 [67]). Indeed, the offline channel is characterized by immediacy product possession and social interaction (Rangaswami A. and Gupta S., 2000), characteristics that miss in the online purchasing process. Some authors argued that a pandemic may represent a new inducing factor that stimulates consumers to change their shopping habits and become confident with the online purchasing process (Peres R. *et al.*, 2010).

A study conducted by Shengyu Gu and colleagues (2021) [42] revealed that consumers became more experienced in the online spending activity and their level of awareness and confidence with the online marketplaces increased. The study showed that online buyers became interested in finding high-quality products at a lower price, so the online shops with a wider products range were preferred.

More in particular, the number of transactions on supermarket and retail websites shifted from 73.4% to 49.9%, respectively. The main sectors interested have been: household products (28.7%), jewellery and watches (26.4%), sporting goods (26.2%), etc. On the other side, online sales in the travel services industry, fashion and luxury industry have been affected by a decreased equal to 33%, 5.2% and 2.8%, respectively.

In conclusion, in the light of what has been said, it is possible to affirm that, after the pandemic, the purchasing online channel will be interested by a progressive and unstoppable growth. This is due also to the fact that consumers, previously adverse to the shifting to online shopping, have experienced several advantages previously unknown, as the higher economic conveniency, the greater flexibility in terms of time, product variety range and location (A. J. Rohm A. J. *et al.*, 2004).

3.2 Survey analysis

3.2.1 Introduction

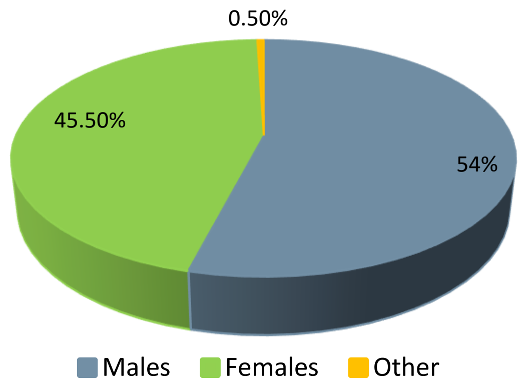
A questionnaire was designed in order to gather information regarding shopping habits of consumers. We asked respondents to answer specific questions regarding their personal characteristics and their preferences concerning online and offline shopping. In about little more than one month, it was possible to collect 211 answers. The main purpose of the survey dissemination was to collect information regarding consumer's preferences related to different product categories, whose items are purchased both online and offline. The data were collected in the months of September and October 2021.

The 29 questions proposed to respondents are structured in five main sections: General personal information (6); General shopping preferences (4); Online purchases (9); Offline purchases (7); Return management (3). The sub-sections, containing the results explanation, will be provided by following the structure of the survey.

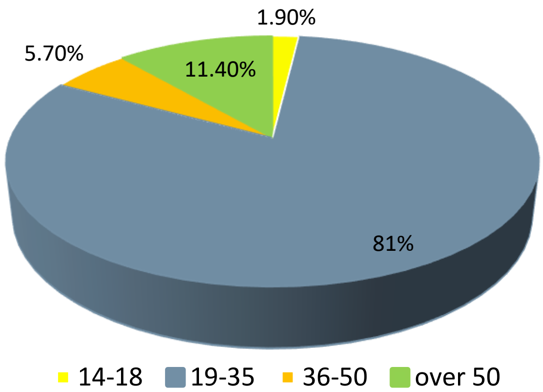
3.2.2 General personal information

Before analysing the core of survey results regarding consumers' shopping habits, it is fundamental to understand the characteristics of respondents populating the sample.

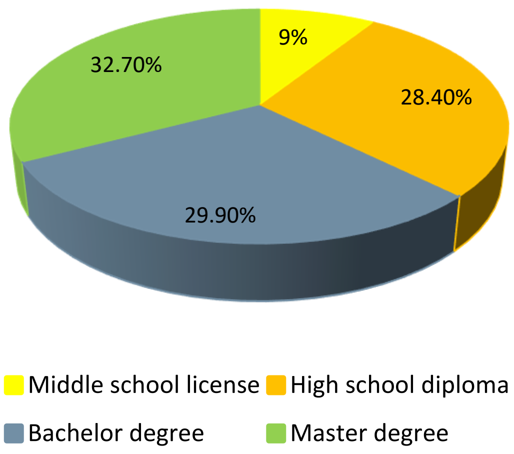
First of all, for each interviewee, information about gender, age, and education level was requested. Regarding gender, the two clusters are almost balanced: 54% females and 45.5% males (and 0.5% other). What has resulted in terms of age is that the predominant age (about 80%) is ranging between 19 and 35. Among respondents, about 60% is graduated, 30% obtained the high school diploma and among the remaining 9% we find people earned the middle school license.



Graph 3-1: Gender Sample Population



Graph 3-2: Age Sample Population



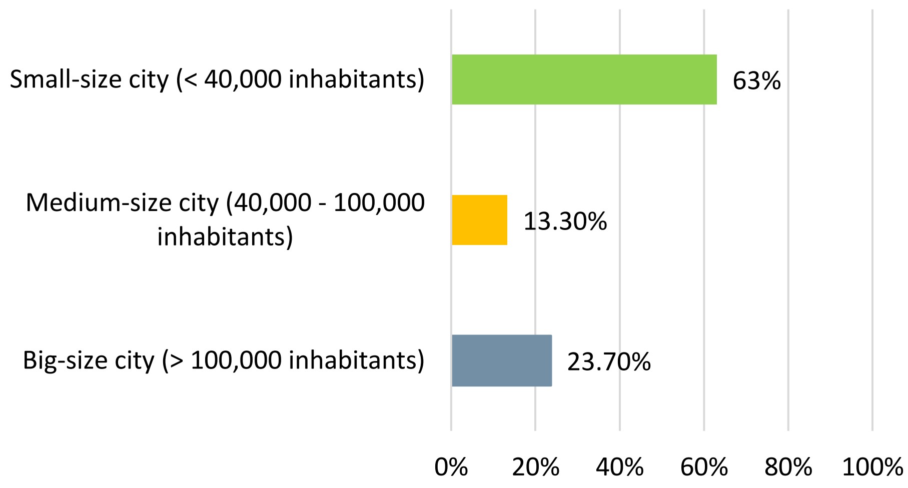
Graph 3-3: Education level Sample Population

The survey was mostly spread in Northern Italy, especially between Milan and Novara. In this regard, in fact about 60% of respondents have declared to live in Milan and province, and about 15% in Novara and province. The remaining 25% is dislocated in the rest of Northern Italy, with some exceptions in central Italy.

Figure 3-1: Geographic Area Sample Population

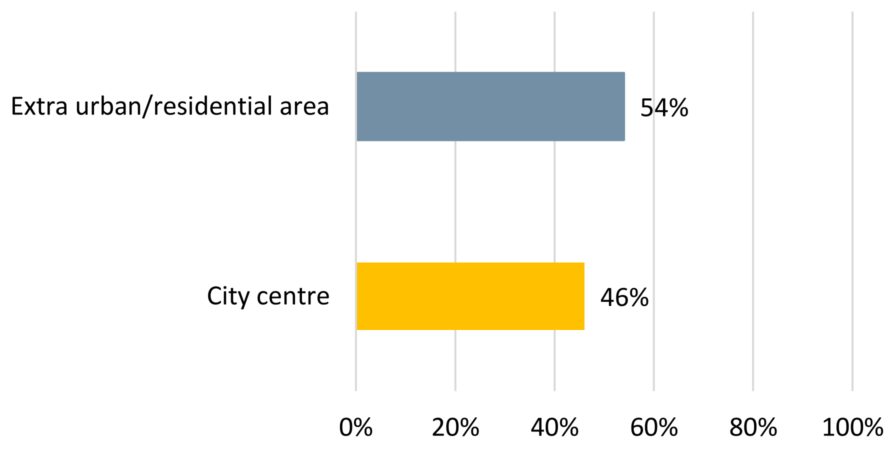
In addition, in order to better understand the type of geographic area in which interviewee live we asked the following questions:

What is the size of the city in which you live? The majority (about 63%) lives in a small town (less than 40,000 inhabitants); almost 24% lives in a big city (more than 100,000 inhabitants) and the remaining 13% lives in a medium-size city (between 40,000 and 100,000 residents).



Graph 3-4: City size

In which type of area is your residence? 54% of respondents lives in an extra-urban or residential area, while 46% in the city centre.



Graph 3-5: Type of area

If we consider that the most people (about 76%) do not live in a big city or in a metropolitan area where the level of shop accessibility is higher than in a small town, and about 60% of them live in a sub-urban area, we may assume that most of respondent consumers is likely to travel long distances to reach a store and make a purchase. On the other side, for the same reason, it is possible to assume that the online channel is preferred since the effort of reaching a store through your own vehicle is superior. The choice depends on the type of shopping attitude and transportation means availability of each individual. Because of this double interpretation of results, we decided to suppose different distance ranges in the model application phase but giving a higher weight to higher distance values.

3.2.3 General purchasing preferences

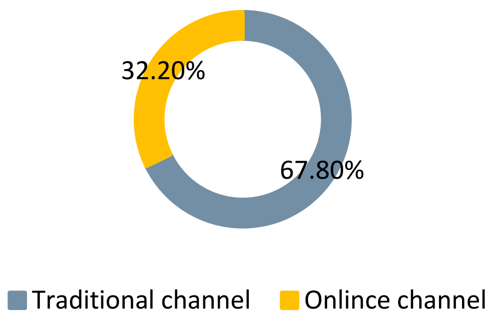
Once collected data regarding personal profiles of respondents, a preliminary screening concerning general shopping habits was necessary to cluster the sample population in two groups: online buyers and traditional buyers. The following questions have been addressed:

Do you prefer to buy online or go to a physical shop?

What is the reason of your previous answer?

Do you usually shop through e-commerce websites? If not, what is the reason?

Almost 70% of respondents prefers to buy in a physical shop, while little more than 30% relies on the online channel.



Graph 3-6: Shopping channel preference

This result shows how, despite the strong digitalization phenomenon that characterizes the period we are living, the traditional shop is still largely chosen as channel through which people have their purchases. In order to better investigate this type of information, we asked the respondents to explain the reasons that motivate them to prefer the traditional channel or the e-commerce one. People who declare to prefer the online channel believe that e-commerce allows them having purchases in a more convenient and faster manner. Somebody else affirms to be lazy, so the e-commerce websites represent to them the optimal solution since it allows, with just few clicks, to save time and efforts for buying goods. In addition, who prefers the online channel believes that on Internet there is a greater possibility of comparing more products, from different websites at the same time, allowing thus to find the cheapest solution or the fastest delivery, for example. In support of e-commerce, the main reason that motives consumers to opt for it is that it allows to save time and to have the possibility not to move for reaching a store: it is simpler and faster. Moreover, through the virtual shops it is easier to find the same product available in store, but at a discounted price. Another portion of respondents, who prefers the online channel, concerns people who live in small towns or in residential areas of a city, where the shop accessibility level is quite low. So, for them, the online channel represents the more convenient and effort-minimizing solution. Besides, especially in this kind of geographical areas, it is more difficult to find shops since they are gradually being cannibalised by big shopping malls and franchising shops.

Another portion of interviewees believes that they do not have an absolute preference between the two channels, but it depends on the type of desired product. In fact, they affirm that for more important and significant goods the physical store represents the favourite purchasing channel, since it is possible to test the item and its quality, to have a direct contact with the item and a greater awareness about the product. In addition, through the traditional channel, there is the possibility to receive the advice of an expert person. On the contrary, for more ordinary purchases the online channel is preferred. More in detail, the majority sees in the clothing, accessories & footwear the category for which there is the strongest necessity to actually see and test the item. Another segment of respondents, among who prefers the offline channel, thinks that a shopping trip is more than simply reaching a store to buy something. In fact, they see in the shopping trip a hobby, but also an experience with the purpose to have fun, to socialize with other people. Among 70% which opts for the physical shop, there are also consumers who think that online there is a too large choice that creates confusion, and it may lead consumers to lose the real purchasing objective. An interesting contribution derives from people who declare to favour the conventional channel in order to sustain the local economy of small boutiques, especially in areas far away from big city centres and metropolises. Among people who prefers the offline channel, there are also ones who want to avoid (or reduce) product return rate since the product is tested before to be bought and so the non-compliance probability is lower.

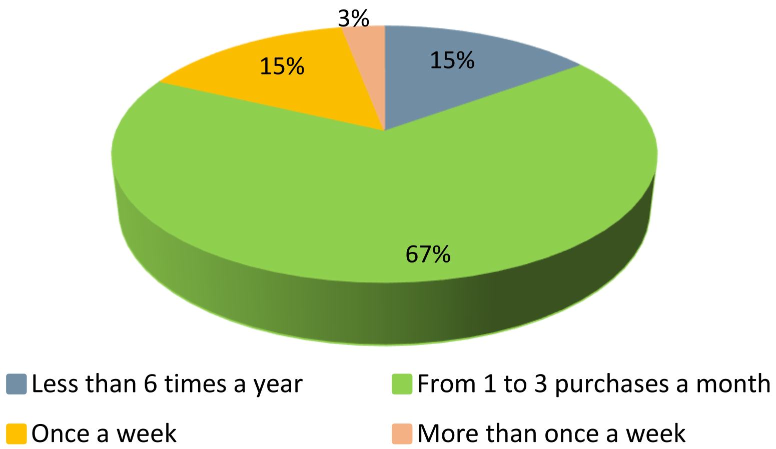
A minority of people declared to exploit both channels but with different purposes: the physical shop is reached by the customer just to see and test the product, while the online channel is adopted for the final purchase. That is because on the web there is higher probability to find the same product at a discounted price.

Some consumers believe that, after almost two years of pandemic, the online order is seen as the safest channel which allows to avoid gatherings of people inside the stores.

An interesting result concerns the difference between people's preferences in terms of channel to make purchases and what they actually and usually do. In fact, it was found that even if the majority of sample population would prefer the physical shop to buy, 126 respondents over 211 (about the 60%) usually rely on e-commerce websites for buying a product. On the contrary, the most of respondents (about 80%) who prefer the offline channel wants to have a direct and concrete contact with the item before buying it and to receive some advice from an expert. Another 8% of respondents is not willing to wait time between the purchase of a product and the related delivery; a minority group affirms to be not confident to technology or not to be at home during daily hours for receiving deliveries.

3.2.4 Online purchases

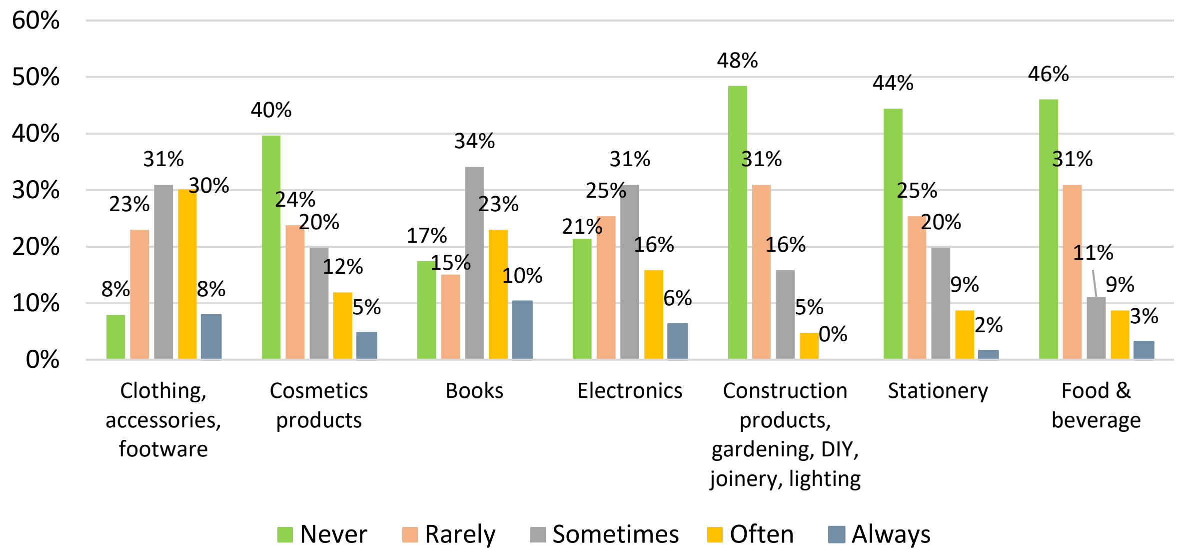
The third sub-section is composed of questions only related to online purchasing habits. The objective is to understand the frequency of online buying, the main product category purchased online, the dimension of a general order, and which activities precede the effective purchase.



Graph 3-7: Online shopping frequency

Concerning the shopping online frequency, it was found that the 67% of the sample makes online orders from one to three times per month; about 15% of respondents buys online once per week; another 15% realizes its purchases less than 6 times a year; the remaining 3% buys products online more than once a week.

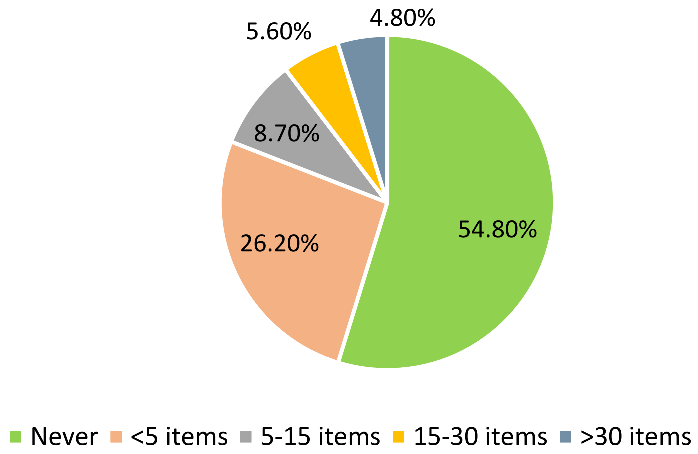
In order to better understand the frequency value of online shopping, we asked again the same question, but divided per product category. Seven product categories have been selected: Clothing, accessories & footwear, Cosmetics, Books, Electronics, Construction products, gardening, DIY, joinery & lighting, Stationery products, Food & beverage (grocery). The main products purchased online belong to the following categories: Clothing, accessories & footwear (60% of respondents purchases this type of items sometimes or often), Books (almost 60% of respondents purchases books online sometimes of often), and Electronics products (about 50% buys these products online sometimes or often). For the remaining categories, the most of people (about 70-80%) rarely, or even never, buys the related item through the online channel.



Graph 3-8: Online shopping frequency per product category

Moreover, another necessary information, needed to understand how to design the application context of our model, regards the dimension of the basket order, specifically for each product category. Focusing on the mostly online purchased types of items, it was found that the average basket size for clothing, accessories & footwear is 2.4, while 1.39 and 0.89 respectively for books and electronics products. By making an average among these values, we can affirm that the average online order consists of 2 items.

Regarding Food & beverage category, we decided to deeply understand in which manner consumers approach the related kind of shopping, since the online food shopping represents a phenomenon in expansion in these last years. Within the interviewed sample, most people (about 55%) never does food shopping through the online channel. Among people who do it, the most frequent basket size is very small: about 26% of consumers buys less than 5 items, about 9% does an online shopping consisting of 5-15 items, the remaining population realizes considerable orders, including more than 15 items.



Graph 3-9: Grocery online shopping incidence

As results demonstrate, the grocery online shopping is still in expansion. The grocery sector and related purchasing processes emissions have been studied by several researchers (e.g., Siikavirta H. *et al.*, 2002 [90]; Cairns, 2005 [15]; Browne M. *et al.*, 2008 [10]). Most of the studies based on grocery shopping realized as the online channel can lead to considerable reduction in the level of emissions through the substitution of cars with vans in the last mile delivery. This because food shopping represents the main type of shopping each consumer dedicates his/her shopping trips. So, a change in consumers' habits may lead to significant reduction in the level of emissions: Cairns

(2005) [15] found that the complete substitution of cars with vans would result in about 70% emissions reduction.

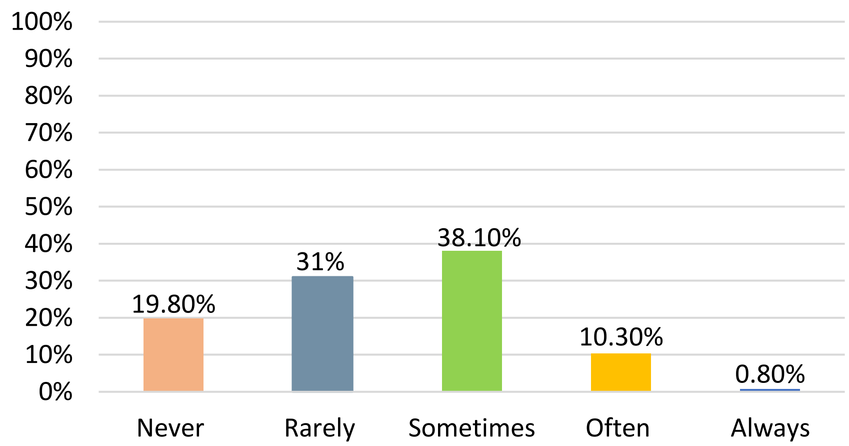
The second part of questions of this sub-section regards the main activities performed by consumers before making the final purchase. Thus, the objective is to understand how people approach products when they want to buy them online. The questions proposed to the sample are the following:

Before making an online purchase do you go to a physical store to test the product?

How many websites/social pages do you compare on average before making an online purchase?

How many times do you visit the same site on average before making the purchase?

It emerged that almost 40% of respondents sometimes reaches a physical shop to test a product before buying it on a website and about 10% often does it. 31% of the sample population rarely visits the store before making an online order and about 20% never does. This means that averagely, 50% of people buying online generate emissions to reach a store just to test the product, but not to purchase it. From that result we can conclude that buying products through the online channel does not definitely mean to save shopping trips.



Graph 3-10: Browsing trips

Regarding websites/social pages compared before making an online order, it was found that only 15.9% relies only on the website on which they want to buy the product; in fact, more than 46% always compares at least two websites and about 37% more than two websites. In addition, the purchase is not immediate, but the most of respondents declares to visit the same website 2 or 3 times before buying the related product; the remaining portion of interviewees also 4 times or more. These data suggest how the online activity, prior to the effective purchasing moment, should not be underestimated. Indeed, it leads to an increase in the energy consumption in terms of power supply of consumers' devices. This happens especially through social networks, the main means through which people approach new products, new brands and can directly make the purchase. In fact, nowadays, social media pages and the majority of websites are overrun by advertisements, influencing people's shopping preferences and increasing their propension to products buying. This happens especially among new generations (under 35 people), who spend a considerable portion of their time on smartphones. In support of this, our survey results show how almost 40% of online buyers thinks to fill their online carts with more items than in case in which they realized the same purchases through the traditional channel. So, if on one side, the reduction in shopping trip frequency results in a reduction of passengers' vehicle emissions, on the other side the larger number of online orders may lead to an increase in the number of deliveries. We need to understand how the two effects and related emissions are counterbalanced and estimate the actual carbon footprint generated.

The last question related to this sub-section regards the preference of customers about the place in which they prefer to receive the product. Preponderately, people prefer receiving their deliveries at home (almost 90%), while the minority prefers a pick-up point (as lockers, newspaper stands, tobacco shops, etc.) or the store (about 10%).

3.2.5 Offline purchases

The offline purchases survey sub-section has the aim of understanding how consumers approach the traditional channel to make their purchases. What emerged from results is that the clothing, accessories and footwear items together with food & beverage products are the mostly purchased through the physical shop, while for the other product categories, averagely 80% of respondents declares to make less than six purchases a year through the offline channel. More in particular, grocery results to be still the main product category bought in the physical supermarket: about 75% of people makes the grocery shopping once a week or more than once a week.

From these results, together with the ones related to the online scenario, it is possible to state that the most frequently purchased products belong to the following categories: Clothing, accessories & footwear, Books, and Electronics. This is the reason why in the subsequent model application phase we decided to create a virtual basket containing items related to these categories. The first category related items are purchased with a similar frequency both online and through the traditional channel, while the other two product typologies are mainly purchased through e-commerce websites.

Subsequently, two different questions concerning the way in which people behave before making an in-store purchase, were proposed to the sample interviewed:

Before making a purchase in a physical shop how many stores do you visit on average?

Before making a purchase in a physical shop how many websites do you visit on average?

What emerged from both answers is that the average number of stores and websites visited before making an in-store purchase is 2. This result explains how the online and the offline purchasing processes are complementary and support each other's. People may know the product to buy online, but the purchase is then realized in the physical shop. Moreover, considering that consumers averagely visit two stores before making the final purchase, it is not guaranteed that for each offline purchase the consumer makes one only shopping trip (for example, in case in which the store previously visited is not in the same location of the store in which the final purchase is realized). This customer behaviour may lead to a considerable increment in the emissions level with respect to the online scenario in which there is one only delivery for each purchase.

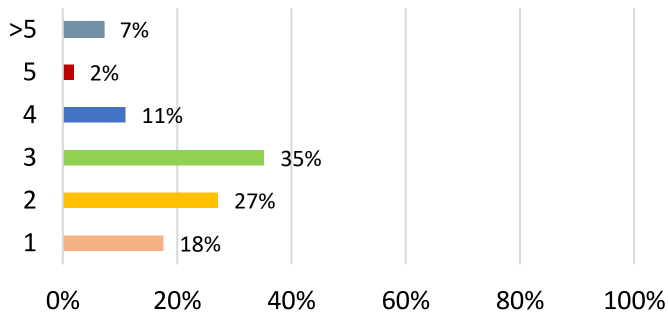
Regarding the traditional channel scenario, it is interesting also to understand in which type of shopping location customers prefer to buy the desired products. We distinguished among shopping malls, shops located in the city centre and shops located in an extra-urban area and we asked the interviewees to declare their preference in this sense. In addition, we wanted to know the distance consumers are willing to travel to reach the specific destination, distinguishing among three specific distance ranges: distance shorter than 5 km, between 5 and 20 km, and longer than 20 km. It was found that the higher the shopping trip frequency, the lower the distance the customer is willing to drive, both for shopping mall and shop in a city centre. About 37% of the sample population declares to make from 1 to 3 purchases a month in a store located less than 5 km far away. On the contrary, about 80% of consumers is willing to travel a higher distance if the number of shopping trips are reduced. Instead, if the store is located in an extra-urban area the number of purchases that the customer (about 74% of respondents) usually makes is lower than six a year. In addition, according to the type of shopping location the distance consumers are willing to drive is different. In fact, consumers usually reach shops located in the city centre by travelling a distance lower than 5 km, while for reaching shopping malls they are disposed to drive higher distances.

The central and most important question of this sub-section regards a specific information: the average number of purchases that a customer usually makes in a single shopping trip. In this regard, the following question has been addressed to the sample:

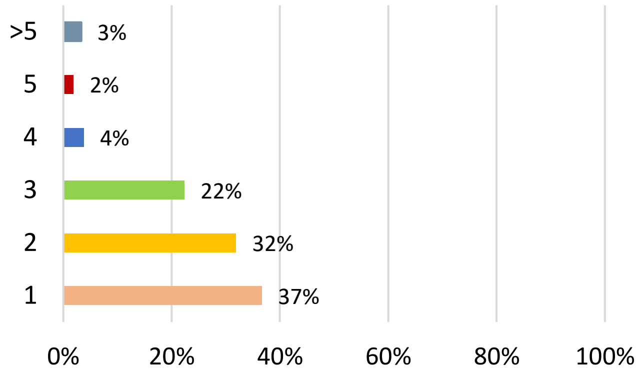
How many purchases do you make on average in the same occasion but in different stores? And where?

What emerged is the following: if the destination is a shopping mall, the average number of different purchases made by a customer is 3 in mostly of the cases (about 35%), and 2 for about 27% and more than 3 for about 20% of respondents. If the destination is a shopping city centre, about 37% buys in one only store, 32% in two ones, 22% in three ones. If the destination is a shop located in an extra-urban area mostly of consumer makes one only purchase. Thus, by rounding up the average number of purchases in one shopping trip the result is equal to 3.

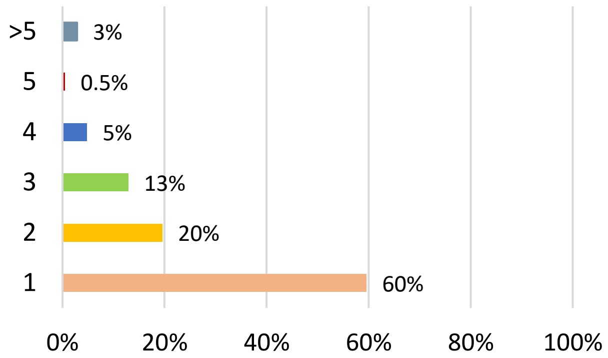
According to this result, together with what came out in the online scenario, it is possible to assume the unit of analysis in the model application phase, composed by 3 different purchases (orders in the online scenario).



Graph 3-11: Number of purchases – shopping mall



Graph 3-12: Number of purchases – city centre shops

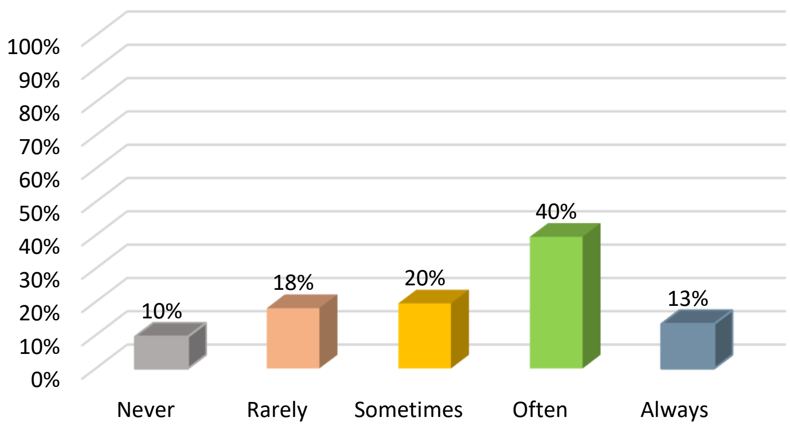


Graph 3-13: Number of purchases – extra-urban area shops

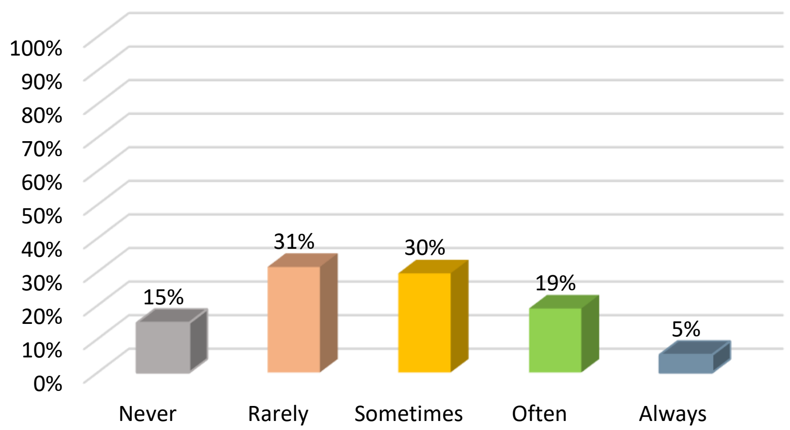
The last question of this sub-section has the objective to understand if consumers usually combine or not the shopping trip with other scopes with a different purpose (for example, going for shopping in the way back from work, or school, or restaurant, etc.). In this regard, the following question has been addressed:

Do you usually decide to make your purchases through a dedicated trip to or coming back from work place or school or university (other)?

The results show that more than 50% of respondents usually or always prefers to entirely dedicate a trip to the shopping activity, while 46% never or rarely combines the shopping activity with other errands, 30% only occasionally. Thus, also in this regard, a change in customer behaviour is desirable: combination of trips may lead to a significant reduction of vehicle's emissions.



Graph 3-14: Dedicated trip incidence



Graph 3-15: Non-dedicated trip incidence

3.2.6 Return management

In order to understand how people approach the return of non-compliant products or how they manage failed deliveries, three specific questions have been proposed to interviews:

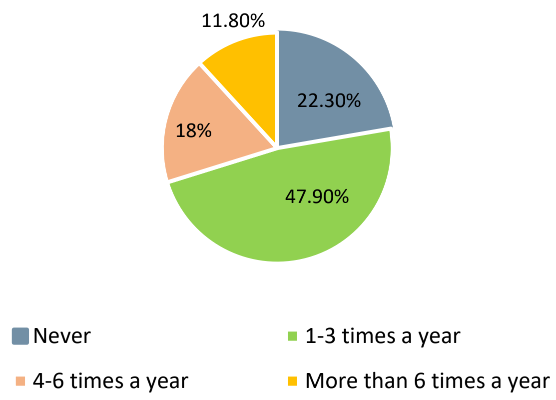
How often do you return back a product purchased online?

How often do you return back a product purchased online in a physical store?

Thinking to the last year, on average how many times you were not at home when delivering a package?

What emerged from results, it is that more than 90% of respondents declares to return back products ordered online rarely or even never. This result is similar for each product category, except for clothing, accessories & footwear, for which the return rate is slightly higher: 32% of interviewees returns back this type of item sometimes or often due to non-compliance problems. It is necessary to point out that for categories different from clothing, accessories & footwear, books, and electronics, the return rate is almost null also because the related online purchase incidence is very low. Usually, stationery products, construction products, gardening, DIY, joinery & lighting related products, and grocery related items are bought preferably through the traditional channel. Still in the offline scenario, the results regarding return rate seem to confirm what happens for the online channel. Indeed, in any case more than 90% of people rarely or never returns products to the store, except for clothing, accessories & footwear, for which 17% of respondents sometimes return non-compliant items to the store.

Concerning failed deliveries, it was found that, in the last year (September 2020 - September 2021), in about 22% of the cases a failed delivery never occurred for each consumer, in almost 50% of cases from 1 to 3 failed deliveries occurred for each consumer, in 18% of cases from 4 to 6, in almost 12% of cases more than 6 failed deliveries occurred for each respondent. It is necessary to underline that these results may be not fully representative of the real failed delivery rate and consequently of the true return rate due to second delivery. That is because these data have been affected and distorted by COVID-19 pandemic phenomenon. As everyone knows, following the anti-COVID rules aimed at containing contagion, all students and the majority of workers needed to move to smart working. This situation has forced people to spend most of their time at home, so it is clear how the probability of missing a delivery has drastically reduced. Thus, considering this aspect, we can affirm that the actual probability of failed delivery is higher than what emerged from our results.



Graph 3-16: Failed delivery incidence

4. Methodology

This chapter has the objective to describe the process and the reasoning that we adopted in order to lead our research, from the gathering of qualitative and quantitative information to the model designing and its subsequent application and results discussion.

4.1 Research objectives and methodology

Sustainability is defined as "the development that meets the needs of the present without compromising the ability of future generations to meet their needs" (World Commission Report on Environment and Development – Brundtland Report (WCED, 1987) [111]). According to the Triple Bottom Line principle, "Sustainability" encompasses three main pillars: Protect and conserve the environment through efficient use of natural resources (Environmental pillar); Advancing economic competitiveness (Economic pillar); Improving social life standards (Social pillar).

Nowadays, being sustainable is no more an option, it is necessary both for businesses and people. The object of this thesis is focused on the first pillar, the environmental one, but it also includes both businesses and people choices since they affect each other's. The purpose is to analyse online and offline purchasing processes in different business sectors, considering as unit of analysis **multiple purchases**. In the last about twenty years researchers, academics and practitioners studied several typologies of purchasing processes through e-commerce channel, comparing it to the traditional one, with the objective to assess the environmental impact generated by them. As already shown in the literature review chapter, the problem was studied from many different perspectives, according to different variables and parameters evaluated, scenarios set, actors involved, supply chain processes considered. The majority of studies states that the online purchasing processes are more sustainable than the offline ones, from different point of views. What seems to be still unexplored is the comparison between the emissions generated and/or energy consumed by purchasing activity, in the case in which the consumer decides to make multiple different purchases and combined them in a single shopping trip (in case of offline process), or in a single order (in case of e-commerce channel.)

Another crucial aspect that we decided to include in our research and to apply to the designed model is the impact of consumers' behaviour with respect to purchasing process. In fact, one of the main limitations of the studies collected in the literature review activity, concerns the lack of customer's purchasing habits involvement in the assessment of purchasing processes environmental impact. Variables as the number of purchases, the distance travelled by consumers, the type of trip chaining are not considered in the majority of Life Cycle Analyses. However, the existence of direct relationships between consumer's preferences and environment related consequences is shown by some authors who believe fundamental the inclusion of consumer related variables into models applied (e.g. Carrillo, Vakharia and Wang, 2014) [16].

Thus, in the light of what just mentioned, the aim of our thesis is to solve the limitations previously described in order to give a contribution to fill the related gap in the literature. Consequently, the following research questions that trigged our thesis were:

"Is still the online channel more sustainable than the traditional shopping in the case of multiple purchases situation?"

"How does consumer behave towards purchasing choices? What are their preferences in relation to online/offline purchasing? How many and which types of purchases does he/she averagely make? On how many e-commerce platforms or through how many dedicated/non-dedicated shopping trips? How does the customer choose to handle the return activity in both processes? What are the related effects in terms of environmental impact and from which activity (transportation, packaging) are they mostly generated?"

In order to answer, two different sources of information were used to obtain an overview of the main level of knowledge about the topic and to subsequently conduct the analysis through the designing of a model able to quantify emissions generated by purchasing processes. The main sources used are papers collected in the literature review activity and data extracted by a survey dissemination (primary sources).

Literature Review. It represents the first fundamental step to follow, in academic research, in order to acquire as much possible knowledge about the topic of interest and to understand the different perspectives under which it was investigated. The literature review activity allowed us to have a clear vision regarding the object of our thesis. It was possible to analyse the different models proposed by previous studies, the different scenarios and variables considered, and, above all, the results achieved. Moreover, the analysis of literature review was crucial to understand the limitations of previous models and the future directions of research. It was useful to set the conditions from which to set our work and the boundaries of action. We filled several Excel sheets to collect all the information, which has been categorized through different axes of classification, as described in chapter 2. The two main channels used to find academic papers were Scopus and Google Scholar. The articles have been selected through the use of keywords such as "e-commerce", "sustainability", "online sales", "environmental impact", "carbon footprint" and their combinations. As previously said, we are aware of the fact that, despite the efforts, not all significant papers were included in the collection, but we considered the level of knowledge reached sufficient to start our project.

Primary Sources. In order to acquire information about consumer behaviour, it was fundamental to design a survey and to spread it among people. In fact, information regarding consumer's purchasing habits were not fully found and investigated in previous studies analysed papers collected. The survey we designed has the objective to gather different data from people: general personal information, online shopping and traditional shopping habits, management of items return in both purchasing processes. We were able to collect 211 responses in about one month. The information gathered was useful to specifically understand how people approach shopping activity when multiple purchases are realized. A portion of data extracted have been used in the model application. For more detailed information about survey structure and related questions see appendix A.

Model. After the information gathering phase, we designed an analytical model able to quantify and compare the quantity of CO2 emissions generated by different phases of online and offline purchasing process: pre-sale and sale, replenishment, delivery, post-sale. In order to structure the model, we firstly consulted previous models analysed in the literature review. This, in order to have a framework from which to start and to be subsequently adapted to our context of analysis.

Once designed the model, we applied it to a specific environment by considering data coming from questionnaire results. The application foresees a base-case analysis and a subsequent sensitivity analysis to show how results are altered by changing specific values of some variables.

The following schema summarizes the main phases of the process that was implemented.

Figure 4-1: Seven Phases Methodology adopted

5. The model

The developed model has the purpose of comparing and quantifying the environmental impact of online and offline purchasing processes, taking as unit of analysis a **number of purchases greater or equal than one**; in addition, each order must contain at least one item. In the online purchasing process the different items can be bought from one or more websites; in the traditional channel, the purchases must be made in different stores, through a shopping-dedicated or non-dedicated trip.

The chapter is organized as follows:

- *Introduction:* it provides a brief explanation of the purpose of the model and of the innovative contributions proposed;
- *The context of the model*: in this section we described the purchasing environment in which the model can be applied, by referring to classification axes adopted in the literature review activity to categorize information extracted;
- *The structure of the model*: here, the e-commerce and brick-and-mortar purchasing processes are deeply explained by dividing them into macro-phases, which are furtherly split into different activities, as it is reported in some previous studies as Melacini and Tappia 2018 [63]; Giuffrida et al. 2019 and Siragusa and Tumino 2021 [91];
- *The algorithm:* both for the online and offline purchasing processes the entire algorithm to calculate the amount of kgCO2e is described.

5.1 Introduction

This model aims to provide a contribution to the extant literature, regarding the environmental sustainability of the traditional B2C shopping and the B2C e-commerce by comparing the two purchasing channels, not considering the single item perspective (as it is presented in the previous literature), but by assuming a multi-purchase point of view. Therefore, an **analytical model** was developed, as it is very frequent in the literature (e.g. Scott Matthews, Hendrickson, and Soh 2001 [60]; Bertram and Chi 2018 [6]; Melacini and Tappia 2018 [63]; Giuffrida et al. 2019, Siragusa and Tumino 2021 [91]). The innovative contribution of the model is correlated to different factors, which have not been previously investigated in the literature:

- *The multi-purchases perspective*: we consider as a unit of analysis a basket of orders (for the online process) and purchases (for traditional process) and not the single item;
- The consideration of *different scenarios* and *distribution configurations* that have not been previously examined;
- *The impact of the customer behaviour* both in the offline and online processes. For the traditional shopping, it is included by taking into consideration scenarios in which the customer makes a dedicated trip to reach the store and scenarios in which he/she does shopping while coming back from work, school and so on (non-dedicated trip perspective). Also, the customers impact is quantified by changing the distances travelled by the customer and by matching scenarios in which the client goes only in one destination (e.g., shopping centre) or visits multiple destinations in a single shopping trip. While, for the e-commerce, we compare the case in which the orders are realized on only one website (e.g., Amazon) and the option in which a single platform is used to make the same basket of orders. Furthermore, the model considers the return phase and how

the consumer has an impact in this sense, through the delivery failure rate, and the way in which the customer handles the return process: returning the items to the store or to the collection point (pick-up point) or to opting for money refund.

So, in the following sections, the main context of model application is defined; secondly, a detailed explanation of assumptions, hypotheses, and input data for the model creation is presented. Subsequently, the reference processes for the online and offline channels are mapped; finally, a deep description of the formulas and algorithm functioning is provided.

5.2 The context of the model

In this section, we report, referring the classification axes used to categorize the papers collected in the literature analysis, the context in which the model is developed.

I. ***Unit of analysis***: the unit of analysis considered in the model is the multi-purchase. This means that the model considers a shopping basket consisting of at least one order and each order consists of at least one item. For the online purchasing process, different items can be bought from one or more websites while in the traditional channel, the purchases can be made in different stores through a dedicated or a non-dedicated trip, and by visiting only one shopping location or multiple ones.

II. ***Focus:*** our model aims to compare online and offline processes by considering not a single order, as previously has been done by several authors, but by considering the multi-purchases perspective. Furthermore, different scenarios and distributions configurations are examined and also the customer behaviour has been taken into account by comparing for the offline shopping the dedicated and the non-dedicated trips, the fact that the customer can decide to go to a single destination for buying different purchases or to visit different locations and so, the distance travelled by the customer significantly changes.

III. ***Object of comparison***: the model focuses on the calculation of the kgCO2e emitted (EI: environmental impact) for each of the considered phases.

IV. ***Sector:*** we do not focus on a specific industry sector for two different reasons:
   - ❖ by considering a multi-purchases perspective, it is assumed that different purchases may belong to different product categories. Therefore, having a focus on a specific sector would not make any innovative contribution to what it is already present in the literature;
   - ❖ the purpose of the model is also to provide an analysis as general as possible, that can be transversally used, also by changing the sectors involved.

More specifically, the model considers all the sectors already investigated in the literature so far. The only exception, considering the available input data, is the grocery since it is characterized by different peculiarities compared to other sectors, such as:

   - ✓ the average order consists of many more items than an average order in any other sector;
   - ✓ the return rate is almost always null;
   - ✓ the distribution network is quite different due to the importance to be closed to the final customer to reduce the transport lead time because of the perishability of the products (Siragusa and Tumino et al., 2021 [91]).

V. ***Geographic area***: the model does not consider any particular geographical area, being dynamic it can be applied to any context. Despite this, the application of the model also depends on the data obtained from the survey we diffused; therefore, it mostly reflects Italian reality.

VI. ***Channel typology***: as most of the studies examined, the model considers only the B2C market, where e-commerce finds its largest market share. Furthermore, B2C and B2B markets differ both in the organization of the whole supply chain and, in particular, in the impact that the last mile phase has on the B2C market, and also in the fact that the purchasing behaviour and habits of the final consumers are totally different and not comparable with the purchasing habits of the companies. Therefore, we chose to restrict our model to the B2C world.

VII. ***Supply chain phases:*** the model computes the kgCO2e emitted without considering the production plant and the transport from the production plant to the warehouse. Therefore, the process starts from the retailer warehouse, and it ends to the customer's home. More in details the e-commerce and brick-and-mortar purchasing process are described in the section: *The reference purchasing processes*, in the chapter 5.4.

VIII. ***Mode of transportation***: in the online process, the model considers trucks for the transport from the central warehouse to the local warehouse, vans for the transport from local warehouse to customer's house or pick-up point; finally, for passenger transportation both cars and motorbikes are included. Instead, in the offline process, the model considers trucks for goods transportation from warehouse to store and cars and motorbikes passenger transport from store to consumer's house.

IX. ***Return***: the model includes the return phase by considering return due to items non-compliance (both for online and offline processes) and due to delivery failure for the e-commerce purchasing process.

X. ***Packaging impact***: for the online case the model calculates the packaging using the cardboard boxes in the replenishment phase, while for the offline process, both the kgCO2e emitted for packaging consumed in the replenishment phase (cardboard boxes) and the papers bags consumed by customers to collect the purchased items are computed.

XI. **Store typology & Location**: the type of store considered in our model may be or a specific shop dedicated to a specific brand and a specific product category, or a shopping mall including different and separate stores. Stores can be located in the centre of a city (urban areas), or in extra-urban area.

5.3 The structure of the model

After a deep analysis of the case study conducted by Mangiaracina and colleagues (2016) [59] we decided to design the structure of our model by adopting the same approach: an activity-based model, which is considered suitable for measuring the performance of logistics processes (Drew et al. 2004) [23]. According to this approach, the purchasing process is split in different macro-phases which are furtherly divided into activities, both in the online and offline scenarios. Each activity consumes resources and produces an environmental impact to be quantified. The purchasing process is split in four main phases, both in the online and offline scenario: *Pre-sale & Sale*, *Replenishment*, *Delivery*, *Post-sale*. Each phase is subsequently split in sub-activities, grouped in specific categories: transportation, warehouse/handling (e.g. Van Loon *et al.*, 2015 [103]), management, purchasing, communication (e.g. Mangiaracina *et al.*, 2016 [59]) and packaging. We decided to maintain the same structure of the model, changing some parameters (especially in the transportation emissions assessment), since we considered a different distribution network. More in detail, the distribution networks considered are the following.

For the online process, the model considers the goods distribution from the central warehouse to the local warehouse and then from the local warehouse to the customer' house or to the pick-up point. If the order is delivered to the collection point, then the transportation from the customer's home to the pick-up point is added.

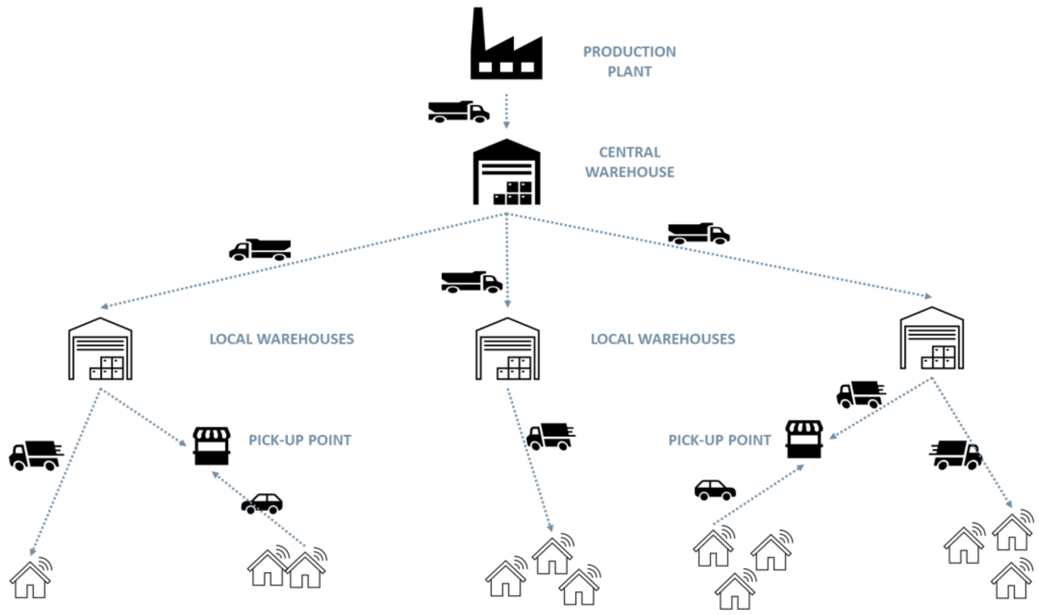


Figure 5-1: Online Distribution Network Configuration

Instead, for what concerns the offline process, the distribution configuration considers the goods moving from a central warehouse to replenish the stores; in the last mile, customers reach the store to buy the product.

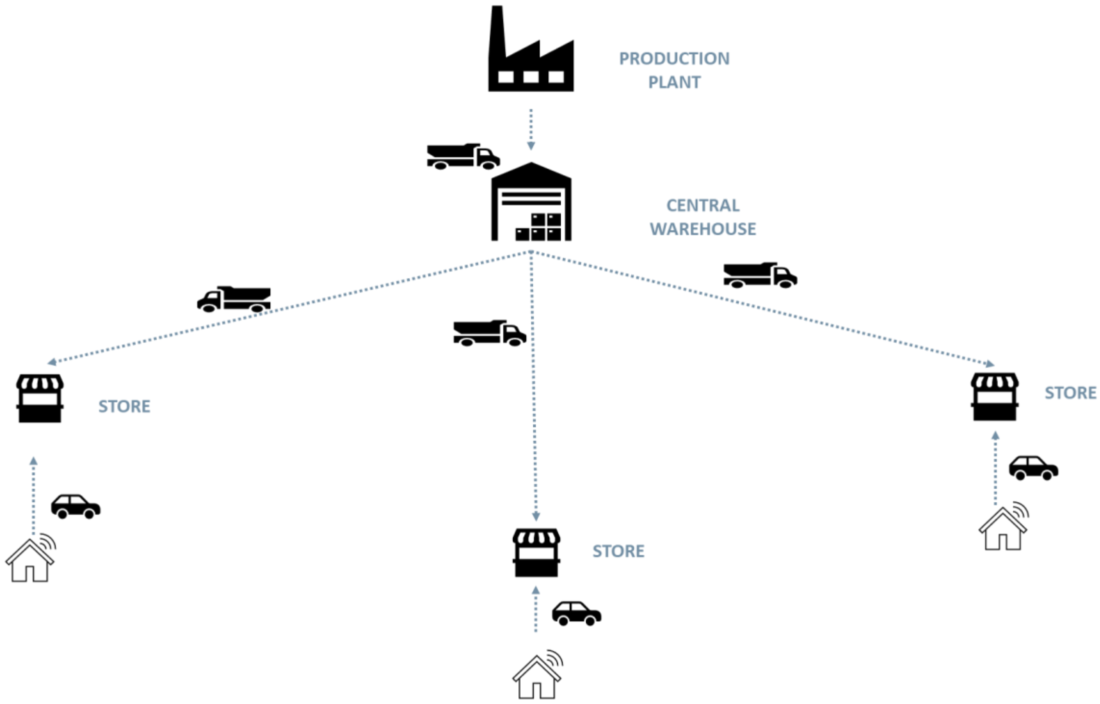


Figure 5-2: Offline Distribution Network Configuration

5.3.1 The reference purchasing processes

This section makes a definition of the reference processes for both the e-commerce and bricks-and-mortar channels, considering the distribution configurations explained in the previous paragraph. As it is anticipated before and reported by Siragusa and Tumino (2021) [91], Melacini and Tappia (2018) [63], and Mangiaracina et al. (2016) [59], each of the two processes was divided into macro-phases, and the macro-phases were further divided into activities. To decide how to set the two purchasing processes we adopted two main sources: the literature review, and for the online process interviews with the logistic specialist and the supply chain manager of Nespresso and the visit of the Nespresso warehouse. During the visit we asked for details about the execution of processes and these two interviews helped us to having a clear and realistic view of the context.

5.3.2 The e-commerce purchasing process

The online purchasing process has been composed by four macro-phases:

- **Pre-sale & sale**: in that phase all the activities made before and during the purchase are included as the search of the product and the comparison of different websites. So, customers choose the items and pay them, all the activities are made completely online.

  In particular, we identified two sub-categories:

  i) *Purchasing phase*: it includes activities as the product research, the comparison of different websites and the product check;

  ii) *Communication phase*: it encompasses activities as the data insertion, the interactions between the customer and the retailer and the payment confirmation mails.

- **Replenishment**: in that phase all the activities performed for the warehouse side order management are included in our analysis. The order is received and managed by the retailer that also creates the picking list, then the picking activities are performed in the dedicated warehouse that depends on the distribution configuration selected. In fact, the warehouse could be a central warehouse or a local one. After the picking phase the sorting activities follow, and products are inserted in the packages. More into details we identified:

  i) *Management:* in that section are included activities as the orders emission and reception, the creation of the picking list and the orders fulfilment;

  ii) *Warehouse/ handling:* it includes picking activities, goods movement and sorting;

  iii) Packaging: in that subsection is described the packaging impact in term of C02 emissions;

iv) *Communication:* activities as information request about delivery, interaction with the warehouse about delivery like claims and tracking service activation.

- **Delivery**: after the order fulfilment in the warehouse the products are delivered to the final customers considering the different distribution configurations. So, this phase encompasses all the activities for the delivery of the goods, not only considering the transport but also the interactions between customers and retailers to collect information about the delivery and the track of the items.
  More specifically:
  i) *Transportation*: the impact of the transport of the boxes to the final customer;
  ii) *Communication*: activities as information request and the track and trace of the boxes.
- **Post sales**: this stage includes all the activities that are made after the delivery of the order to the customer, including the inverse transport process from the final customer to the retailer.
  The main activities identified are:
  i) *Communication*: it encompasses activities as the product insertion for the return of the item;
  ii) *Management*: activities as the reception and the management of the returned product;
  iii) *Packaging in the return phase*: the further environmental impact that packaging has in the return phase.
  iv) *Transportation in the return phase*: the impact of the reverse transport from the customer to the retailer.

5.3.3 The brick-and-mortar purchasing phase

The offline purchasing process has been composed by three macro-phases:

- **Pre-sale**, **Sale & Delivery**: in this first stage the customer leaves the house and goes to the shopping location/s, visits the store/s, and makes the payments for the item/s bought. After the purchase of the different items, the customer returns back to home. The main activities considered in this stage are:
  i) *Transportation*: the activity through which the customer reaches the store in which realizes his/her purchases and, in the end, goes back to home by his/her car or motorbike;
  ii) *Communication*: it includes product search in the store, interaction of the customer with the salesman, interaction of the salesman with the customer;
  iii) *Purchasing*: it incorporates three sub-activities: product purchase, receipt release, packaging.
- **Replenishment**: this phase is about store replenishment. We assumed that the store is replenished from a generic central warehouse. This phase starts when the store manager emits an order, and it ends when the shelf is replenished with the desired items. The model assumes that the store manager emits an order when the stock level for the different items decreases till a pre-defined threshold.

  The replenishment phase includes several sub-activities, in the order:

  i) *Management* of order emission and order fulfilment;

  ii) *Warehouse/handling*: it includes all the activities performed in the central warehouse, picking, sorting, packaging, goods moving, etc.;

  iii) *Transportation* of goods to the store;

iv) Communication: it refers to the interaction with the point of sale for requesting information about delivery and to track it along the travel;

v) Management of goods reception in the storage area.

- **Post-sale**: The post-sale phase refers to the case in which the customer may return a defective product back to the store. It includes two main activities:

  i) Transportation: the return process starts with the return trip to the point of sale and ends when the customer goes back to home with the new items;

  ii) Communication: it refers to the energy consumed in the interaction between the customer and the salesman about return.

5.4 The Algorithm

In order to set the algorithm used to calculate the value of kgs of CO2 emitted by the two different purchasing processes, we decided to rely on the models analysed in the literature, in particular, the model of Siragusa and Tumino [91] (2021, *E-grocery: comparing the environmental impacts of the online and offline purchasing processes*). In the next two sections, the algorithms for the online and offline models are reported.

5.4.1 Online purchasing process

As described before, the online purchasing process relies on four macro-phases:

1. **Pre-sales and sales** with the *Purchasing* phase and the *Communication* phase;
2. **Replenishment** with the *Management, Warehouse/ handling,* Packaging and *Communication* phases;
3. **Delivery** with sub-phases as *Transportation and Communication;*
4. **Post sales** with the activities as *Communication*, *Management*, *Packaging* in the return *phase* and *Transportation* in the return phase.

For each of these phases, we have identified all the activities that contribute to the CO2 emissions. Summing up all the contributions made by each of the four phases of the online purchasing process, then we have identified the CO2 value emitted considering the multi-purchase model in the online perspective. So, this data has been compared with the CO2 value resulting from the offline multi-purchasing process to understand which of the two processes is more environmentally sustainable.

For what concern the online process, we considered two possible macro-scenarios:

- the customer buys from one website different items. This means that we assume that the transport is carried out by a single carrier for all items purchased, therefore a single delivery. This hypothesis is fundamental for our model.

Hp1: *if the online purchase of different items takes place on a single website, then the transport is carried out by a single carrier for all purchases, therefore a single delivery for all the purchased items.*

- The consumer places several orders on different websites. Hence, the number of websites considered is equal to the number of purchases made. This means that we assume that the transport of each order is carried out by different carriers (different deliveries for different orders made on different platforms).

Hp2*: if different orders are bought on different websites, then the transport of each order is carried out by a different carrier, therefore there will be a number of deliveries equal to the number of orders purchased.*

More specifically, we have tried to make the model as general as possible, thus identifying different possible distribution configurations:

- the company delivers directly from the central warehouse (CW) to customers' home;

- the company delivers firstly from the central warehouse to the local warehouse (LW) and then from LW to customers' home;
- the company delivers directly from the LW to customers' home;
- the company delivers firstly from the CW to the pick-up point (PP) and then customer goes from home to the PP;
- the company delivers firstly from the CW to the LW, then from the LW to the PP and then customer goes from home to the PP;
- the company delivers directly from the LW to the PP and then customer goes from home to the PP.

The general layout of all the distribution configurations that are taken into account is shown in the figure 5-1.

For what concern all these configurations, an assumption has been made: the same distribution configuration is used for all the companies in which the orders have been purchased. So, if a customer buys from two different websites and the first company directly delivers from the local warehouse to the final customers, also the second company involved has the same distribution processes. We are aware that this is a limitation of the reality and to make the model more realistic a combination of all these configurations should be done.

***Hp*$_{3}$:** *all the companies in which the orders have been made, follow the same distribution configuration.*

In the next section a detailed description of the model for the online purchasing process has been presented, considering each phase as stand-alone step.

Pre-Sale & Sale

The customer starts the process searching the product online and comparing different web-sites. The phase ends with the online payment. So, below the two sub-phases are modelized: the purchasing and communication phase.

Purchasing activity. The purchasing phase comprises different activities:

- Online products search on search engines or comparison websites;
- Customer re-direction to the retailer website;
- Product check;
- Product insertion into cart;
- Payment info insertion;

The impact in term of CO2 emissions is calculated as the sum of the contributions of all these four activities for all the orders purchased. If the entire order is made using one web-site, n will be equal to 1, otherwise n will be equal to the number of orders placed in different websites. Each order can be composed by one or more items.

$$EI^{6} = \sum_{i=0}^{n} \sum_{j=5} AD_{i;j}\,[h] \,*\, PSCD_{i;j}\,[kW] * ECF_j\,[\frac{kgCO2e}{kWh}] * I_i\,[\frac{\#items}{order}]$$

i: the i_th purchase; $i \in [0; \infty]$

j: the j_th activity;

n: number of purchases made;

ECF = electricity conversion factor;

I = number of items per order;

AD = activity duration;

[6] EI: Environmental impact [kgCO2e]

PSCD = power supply of customer device.

So, for each of the five activities the CO2 emissions are calculated as the duration of the activities multiplied by the power supply of the customer device multiplied by the energy conversion factor and by the number of items for each order. Once the CO2 emissions have been calculated for all the activities, then we summed up all of them, considering this calculation for every order made.

Communication. The communication phase encompasses activities as:

- Information request to retailer;
- Answer to consumer request;
- Information insertion and interaction with the retailer;
- Interaction with the customer about data to insert;
- Payment confirmation mail.

Through this formula we calculate the CO2 emissions caused by the sum of these five activities, summing up the CO2 value for each purchase that has been made. If the entire order is made using one web-site, *n* will be equal to 1, otherwise *n* will be equal to the number of orders placed in different websites.

$$EI = \sum_{i=0}^{n} \sum_{j=5} AD_{i;j}\ [h] * PSCD_{i;j}\ [kW]\ * ECF_j\ [\frac{kgCO2e}{kWh}]$$

i: the i_th purchase;   i ∈ [0; ∞]

j: the j_th activity;

n: number of purchases made;

ECF = electricity conversion factor;

AD = activity duration;

PSCD = power supply of customer device.

So, for every order made and for each of the five activities the CO2 emissions are calculated as the duration of the activities expressed in hours, multiplied by the power supply of the customer device and by the energy conversion factor. Finally, the contributions in term of CO2 emissions made by the purchasing phase and communication are summed up.

Replenishment

After the customer has selected and paid the product, we directly considered the warehousing phase, omitting the production one. This phase starts when the retailer receives and manages the order, and it finishes when the cartons are ready to be delivered by the couriers. The order is picked following a batch-picking policy (Eriksson, Norrman, and Kembro 2019) [31]. Then after the sorting phase, products are packed, brought in the shipping area and shipped. The warehousing phase consists in four main activities:

Management. The management phase encompasses activities as:

- Replenishment order emission;
- Replenishment order reception and management;
- Order fulfilment;
- Picking list emission.

Considering all these activities we calculate the CO2 emissions for each order. Even in this case if the order is made on one website n is equal to 1, otherwise n is equal to number of orders made on different websites.

$$EI = \sum_{i=0}^{n} \sum_{j=4} AD_{i;j}\ [h]\ *\ PSRD_{i;j}\ [kW] * ECF_j\ [\frac{kgCO2e}{kWh}]$$

i: the i_th purchase; i ∈ [0; ∞]

j: the j_th activity

n: number of purchases made

ECF = electricity conversion factor

AD = activity duration

PSRD = power supply of customer device

Warehousing/handling. The warehouse phase encompasses the below described activities.

- Picking

The first activity is the picking, we assumed that the storage area is shared with the offline channel and the fact that the orders are selected following a batch picking approach in order to fill multiple orders with the same SKU. So, for each order we calculated the CO2 emissions as the picking consumption per item multiplied by the electricity conversion factor multiplied by the number of items per order. Even in this case if the customer buys on only one website the number of purchases made is equal to 1.

$$EI\_picking = \sum_{i=0}^{n} ACP[kWh] * ECF \; [\frac{kgCO2e}{kWh}] * I_i \; [\frac{\#items}{order}]$$

i: the i_th purchase; i ∈ [0; ∞]

n: number of purchases made;

ACP = activity consumption per piece (picking consumption per piece);

ECF = electricity conversion factor;

I = number of items per order;

- Warehouse consumption

The CO2 contribution is also made by the warehouse energy consumption. In fact, each item occupies a space in the warehouse, so the energy consumed for the daily warehousing activities is split up between the products inside the warehouse. So, multiplying the warehouse energy consumption, divided by the number of items per day, with the electricity conversion factor and the number of items per order, we obtained the CO2 emissions for each order made. Even in this case, if the customer buys on only one website, the number of purchases made is equal to one.

$$EI\_Wh = \sum_{i=0}^{n} \left(\frac{WEC\ [kWh]}{\#ITEMS\ PER\ DAY} * ECF\ [\frac{kgCO2e}{kWh}] \right) * I_i\ [\frac{\#items}{order}]$$

i: the i_th purchase; i ∈ [0; ∞]

n: number of purchases made;

ECF = electricity conversion factor;

I = number of items per order;

WEC = warehouse daily energy consumption.

- Sorting

The third activity is the sorting, we considered a manual sorting as Mangiaracina *et al.* (2016) [59]. So, we multiplied the sorting consumption per piece by the electricity conversion factor and the number of items. This process is made for each orders purchased, considering one order if the customer acquired on one website or multiple orders if customers bought on different websites.

$$EI\_sorting = \sum_{i=0}^{n} ACP[kWh] * ECF\ [\frac{kgCO2e}{kWh}] * I_i\ [\frac{\#items}{order}]$$

i: the i_th purchase; i ∈ [0; ∞]

n: number of purchases made;

ACP = activity consumption per piece (sorting consumption per piece);

ECF = electricity conversion factor;

I = number of items per order.

- Goods moving

Inside the warehouse, goods passed through different areas as the shipping area and so, it is also important to consider the consumption of energy for the movement of the goods. Even in this case we considered the multi-purchase perspective, summing up the contribution made by each order if the orders are closed in different websites.

$$EI\_goods\ moving = \sum_{i=0}^{n} ACP[kWh] * ECF\ [\frac{kgCO2e}{kWh}] * I_i\ [\frac{\#items}{order}]$$

i: the i_th purchase; i ∈ [0; ∞]

n: number of purchases made;

ACP = activity consumption per piece (goods moving consumption per piece);

ECF = electricity conversion factor;

I = number of items per order.

- Shelves replenishment

Finally, there is the contribution in term of CO2 emissions of the shelves replenishment activity. Also, in this case considering the multi-purchase perspective.

$$EI\_shelf\ rep. = \sum_{i=0}^{n} ACP[kWh] * ECF\ [\frac{kgCO2e}{kWh}] * I_i\ [\frac{\#items}{order}]$$

i: the i_th purchase; i ∈ [0; ∞]

n: number of purchases made;

ACP = activity consumption per piece (goods transfer consumption per piece);

ECF = electricity conversion factor;

I = number of items per order;

Then all the contributions made by picking, the warehouse consumption, the sorting, the goods moving, and the shelves replenishment activities are summed-up to find a unique value of CO2 emissions.

$$Tot.EI_{Warehouse} = E.I\_picking + E.I\_Wh + E.I\_sorting + E.I\_goods\ mov. + E.I\_shelf\ rep$$

Packaging. The packaging impact changes if we consider the case in which all the items are bought on one website or the case in which the customer made different orders on different websites.

- **<u>One web site for *n* purchases (so one delivery)</u>**

Starting from the first case, the customer buys all the products on one website so, the assumption we made, is that all the items are shipped through one delivery. We calculated the impact in term of CO2 emissions of the packaging by considering the multiplication of the number of bags multiplied by the consumed of CO2 related to the quantity of packaging. In particular, the number of bags has been estimated as the number of items per order plus one, because usually, when products are delivered online, they are packed one to one and then they are placed inside a big carton/bag. At this stage, we did not consider a specific category of bag, but the results differ by changing the material composition of bags, that could be cartons, plastic bag and so on. So, the environmental impact caused by the packaging in the first 1-website scenario is calculated as follows:

$$EI_{1,Packaging} = NB * PFC\ [\frac{kgCO2e}{bag}]$$

$$NB = \frac{\#items}{purchase} + 1$$

NB = number of bags;

PFC = packaging footprint for cardboard (consume of CO2 related to the quantity of packaging).

- <u>**N web-sites for *n* purchases (different deliveries for different orders n)**</u>

The second case is when the customer made orders on different websites. This means that for each order there will be a specific delivery. Also in this case, we calculated the impact in term of CO2 emissions of the packaging by considering the multiplication of the number of bags multiplied by the consumed of CO2 related to the quantity of packaging. In this scenario we considered the multi-purchase perspective so, this calculation has been done for all the orders *n*.

$$EI_{2,Packaging} = \sum_{i=0}^{n} NB * PFC\ [\frac{kgCO2e}{bag}]$$

$$NB = \frac{\#items}{purchase} + 1$$

i: the i_th purchase;   i ∈ [0; ∞]

n: number of purchases made;

NB = number of bags;

PFC = packaging footprint for cardboard (consume of CO2 related to the quantity of packaging).

So, the total CO2 emissions for the packaging phase is the E.I1 if the first scenario is considered and the E.I2 in the n-websites scenario. A further step can be the study of the probability of occurrence of the first scenario and second scenario.

Communication. The last activities we considered for the warehousing phase concern the interaction and communication between the customer and the retailer:

- Info request about delivery;
- Interaction with the warehouse about delivery;

- Tracking service activation.

Through this formula, we calculate the CO2 emissions caused by the sum of these three activities, summing up the CO2 value for each purchase that has been made. If the entire order is completed using one web-site, n will be equal to 1, otherwise n will be equal to the number of orders placed in different websites.

$$EI = \sum_{i=0}^{n} \sum_{j=3} AD_{i;j}\ [h] * PSCD_{i;j}\ [kW]\ * ECF_j\ [\frac{kgCO2e}{kWh}]$$

i: the i_th purchase; i ∈ [0; ∞]

j: the j_th activity

n: number of purchases made

ECF = electricity conversion factor

AD = activity duration;

PSCD = power supply of customer device.

Finally, the contributions in term of CO2 emissions made by the management, warehouse, packaging and communication activities are summed-up.

Delivery

The delivery phase starts when the couriers pick-up the cartons and it ends when the products are in the customer's home. It includes the transportation from the warehouse to the final customer, but also the interaction between the client and the retailer.

Transportation. This is the most impactful phase for our model, because of the multi-purchase perspective. Indeed, during this phase also the customers' behaviour plays a key role which is clearly difficult to be predicted. The number of trips depends both on the number and the frequency of orders done by the customer. So, the results of our study vary depending on these two situations:

- a customer frequently makes orders composed by a low number of items;
- a customer occasionally makes one unique order for lots of items.

There are other two scenarios in which we divided the analysis: the case in which the customer buys on only one website (single delivery) and the case in which the customer buys from different websites (number of deliveries equal to the number of orders). Starting from this, we created multiple sub-scenarios considering different distribution configurations, as it is reported at the beginning of the section *Online purchasing process,* chapter 5.5.1. We took into consideration also various types of vehicles and their related CO2 emissions. The model is parametric so, changing the vehicle the results will change. We assumed that the distance from the central warehouse to the local warehouse has been covered by a truck, while the distance from local warehouse to the customer's house or to the pick-up point (last mile distance) is made by a van. Finally, the distance between customer's home and the pick-up point is covered by cars or motorbikes. Starting from the first scenario (one website for lots purchases) we modelized all these sub-scenarios calculating the CO2 emissions as the product of the vehicle CO2 emissions/km multiplied by two times the distance travelled (considering the outward and return journey), multiplied by the percentage of space occupied by each item and by the number of items per order. Then the same calculation is done considering different websites so different deliveries for different orders. Below the full algorithm for the transportation phase is explained.

- **One website for *n* purchases (so one delivery)**

- If the company delivers directly from CW to customers' home **(1)**

The first formula considers the case in which the customer buys different items from one website and the company distribution configuration is made by the central warehouse. So, the average distance between the central warehouse and the customers' house is relevant. We calculate the environmental impact of this first scenario: the event 1 occurs (customer buys from 1 website) under the condition DC1 (distribution configuration 1) as follows:

$$EI\ (E1/DC1) = TCF\left[\frac{Vehicle\ kgCO2e}{km}\right] * AB * 2[km] * PS\left[\frac{\%\ space\ occupated}{item}\right] * I\ \left[\frac{\#items}{order}\right]$$

TCF = truck vehicle emission conversion factor $\left[\frac{Vehicle\ \text{kg}CO2e}{km}\right]$;

AB = average distance from central warehouse to the customer's house;

PS= percentage of space allocated to each single item $\left[\frac{\%\ space\ occupated}{item}\right]$;

I = number of items per order;

E1= Event 1: customer buys more items from one website;

DC1= Distribution configuration 1: the company delivers directly from CW to customers' home.

- If the company delivers firstly from CW to LW and then from LW to customers' home **(2)**

The second formula considers the case in which the customer buys different items from one website and the company distribution configuration is composed by the presence of the plant, the central warehouse and the local warehouse. So, the distances considered are from CW to LW and from LW to customers' house. The formulation for the second scenario follows: the Event 1 occurs (customer buys from 1 website) under the condition 2 (distribution configuration 2).

$$EI\ (E1/DC2) = \left[TCF\ [\frac{Vehicle\ kgCO2e}{km}]\ * AL * 2\ [km] + VCF\ [\frac{Vehicle\ kgCO2e}{km}]\ * LC * 2[km]\right] * PS\ [\frac{\%\ space\ occupated}{item}] * I\ [\frac{\#items}{order}]$$

TCF = truck vehicle emission conversion factor $\left[\frac{Vehicle\ kgCO2e}{km}\right]$;

AL = Avg distance from CW to LW;

VCF = van vehicle emission conversion factor $\left[\frac{Vehicle\ kgCO2e}{km}\right]$;

LC=Avg distance from LW to consumer's house;

PS= percentage of space allocated to each single item $\left[\frac{\%\ space\ occupated}{item}\right]$;

I = number of items per order;

E1= Event 1: customer buys more items from one website;

DC2= Distribution configuration 2: the company delivers firstly from CW to LW and then from LW to customers' home.

- If the company delivers directly from LW to customers' home **(3)**

The third formula considers always that case of 1-website, but the company's distribution configuration is leaner and only multiple local warehouses are present on the territory. So, the environmental impact considering the Event 1 (customer buys from 1 website) under the condition 3 (distribution configuration 3) is estimated as:

$$EI\ (E1/DC3) = VCF\ [\frac{Vehicle\ kgCO2e}{km}] * LC * 2\ [km] * PS\ [\frac{\%\ space\ occupated}{item}] * I\ [\frac{\#items}{order}]$$

VCF = van vehicle emission conversion factor $\left[\frac{Vehicle\ kgCO2e}{km}\right]$;

LC=Avg distance from LW to consumer's house;

PS= percentage of space allocated to each single item $\left[\frac{\% \, space \, occupated}{item}\right]$;

I = number of items per order;

E1= Event 1: customer buys more items from one website;

DC3= Distribution configuration 3: the company delivers directly from LW to customers' home.

- If the company delivers firstly from CW to PP and then customer goes from home to PP **(4)**

The fourth formula considers always that case of 1-website, but the company's distribution configuration takes into account the presence of pick-up points replenished directly by the central warehouse. So, the environmental impact is of the Event 1 (customer buys from 1 website) under the condition 4 (distribution configuration 4) is:

$$EI\ (E1/4) = \left[\left(TCF\ [\frac{Vehicle\ kgCO2e}{km}] * CP\ *\ 2\ [km] *\ PS\ [\frac{\%\ space\ occupated}{item}] * I\ [\frac{\#items}{order}]\right) + \left(PCF[\frac{Vehicle\ kgCO2e}{km}] * PH * [km]\right)\right]$$

TCF = truck vehicle emission conversion factor $\left[\frac{Vehicle \ kgCO2e}{km}\right]$;

CP=Avg distance from CW to PP;

PS= percentage of space allocated to each single item $\left[\frac{\% \, space \, occupated}{item}\right]$;

I = number of items per order;

PCF= passenger vehicle emission conversion factor $\left[\frac{Vehicle \ kgCO2e}{km}\right]$;

PH= Avg route distance from PP to the customer's house;

E1= Event 1: customer buys more items from one website;

DC4= Distribution configuration 4: the company delivers firstly from CW to PP and the customers go from their home to the PP.

- If the company delivers firstly from CW to LW, then from LW to PP and then customer goes from home to PP **(5)**

The fifth formula considers always that case of 1-website, but the company's distribution configuration takes into account the presence of pick-up points replenished by local warehouses that are replenished by the central warehouse. So, the environmental impact of the Event 1 (customer buys from 1 website) under the condition 5 (distribution configuration 5) is:

$$EI\ (E1/5) = \left\{ \left[\left(\left(TCF\left[\frac{Vehicle\ kgCO2e}{km}\right] * AL * 2\,[km] + VCF\left[\frac{Vehicle\ kgCO2e}{km}\right] * LP * 2[km] \right) * PS\left[\frac{\%\ space\ occupated}{item}\right] * I\left[\frac{\#items}{order}\right] \right) + \left(PCF\left[\frac{Vehicle\ kgCO2e}{km}\right] * PH\,[km] \right) \right] \right\}$$

TCF = truck vehicle emission conversion factor $\left[\frac{Vehicle\ kgCO2e}{km}\right]$;

AL = Avg distance from CW to LW;

VCF = van vehicle emission conversion factor $\left[\frac{Vehicle\ kgCO2e}{km}\right]$;

LP= Avg distance from LW to PP;

PS= percentage of space allocated to each single item $\left[\frac{\%\ space\ occupated}{item}\right]$;

I = number of items per order;

PCF= passenger vehicle emission conversion factor $\left[\frac{Vehicle\ kgCO2e}{km}\right]$;

PH= Avg route distance from PP to the customer's house;

E1= Event 1: customer buys more items from one website;

DC5= Distribution configuration 5: the company delivers firstly from CW to LW, then from LW to PP and the customers go from their home to the PP;

- If the company delivers directly from LW to PP and then customer goes from home to PP **(6)**

The sixth formula considers always that case of 1-website, but the Company's distribution configuration takes into account the presence of pick-up points replenished directly by local warehouses. So, the environmental impact of the Event 1 (customer buys from 1 website) under the condition 6 (distribution configuration 6) is:

$$EI\ (E1/6) = \left[\left(VCF\ [\frac{Vehicle\ kgCO2e}{km}] * LP\ *\ 2\ [km]\ * PS\ [\frac{\%\ space\ occupated}{item}] * I\ [\frac{\#items}{order}]\right) + \left(PCF\ [\frac{Vehicle\ kgCO2e}{km}] * PH\ [km]\right)\right]$$

VCF = van vehicle emission conversion factor $\left[\frac{Vehicle\ kgCO2e}{km}\right]$;

LP= Avg distance from LW to PP;

PS= percentage of space allocated to each single item $\left[\frac{\%\ space\ occupated}{item}\right]$;

I = number of items per order;

PCF= passenger vehicle emission conversion factor $\left[\frac{Vehicle\ kgCO2e}{km}\right]$;

PH= Avg route distance from PP to the customer's house;

E1= Event 1: customer buys more items from one website;

DC6= Distribution configuration 6: the Company delivers from LW to PP and the customers go from their home to the PP.

Then the same reasoning has been done considering the case in which the customer buys from lots of websites.

- **<u>N web-sites for *n* purchases (different deliveries for different orders n)</u>**

This is the second scenario in which we considered the multi-purchase perspective. For using all these configurations, an assumption has been made: the same distribution configuration is used for all the companies in which the orders have been purchased. The computation of all the formulas is the same, including the sum of all the different orders made by the customer.

- If the company delivers directly from CW to customers' home **(1)**

$$EI\ (E2/1) = \sum_{i=0}^{n} TCF\left[\frac{Vehicle\ kgCO2e}{km}\right] * AB * 2[km] * PS\left[\frac{\%\ space\ occupated}{item}\right] * I_i\ [\frac{\#items}{order}]$$

i: the i_th purchase; i ∈ [0; ∞]

n: number of purchases made;

TCF = truck vehicle emission conversion factor $\left[\frac{Vehicle\ \mathrm{kg}CO2e}{km}\right]$;

AB = average distance from central warehouse to the customer's house;

PS= percentage of space allocated to each single item $\left[\frac{\%\ space\ occupated}{item}\right]$;

I = number of items per order;

E2= Event 2: customer buys more items from more websites;

DC1= Distribution configuration 1: the company delivers directly from CW to customers' home.

- If the company delivers firstly from CW to LW and then from LW to customers' home **(2)**

$$EI\ (E2/2) = \sum_{i=0}^{n} \left[TCF\ [\frac{Vehicle\ kgCO2e}{km}] * AL * 2\ [km] + VCF\ [\frac{Vehicle\ kgCO2e}{km}] * LC * 2[km]\right] * PS\ [\frac{\%\ space\ occupated}{item}] * I_i\ [\frac{\#items}{order}]$$

i: the i_th purchase; i ∈ [0; ∞]

n: number of purchases made;

TCF = truck vehicle emission conversion factor $\left[\frac{Vehicle\ kgCO2e}{km}\right]$;

AL = Avg distance from CW to LW;

VCF = van vehicle emission conversion factor $\left[\frac{Vehicle\ kgCO2e}{km}\right]$;

LC=Avg distance from LW to consumer's house;

PS= percentage of space allocated to each single item $\left[\frac{\%\ space\ occupated}{item}\right]$;

I = number of items per order;

E2= Event 2: customer buys more items from more websites;

DC2= Distribution configuration 2: the company delivers firstly from CW to LW and then from LW to customers' home.

- If the company delivers directly from LW to customers' home **(3)**

$$EI\ (E2/3) = \sum_{i=0}^{n} VCF\ [\frac{Vehicle\ kgCO2e}{km}] * LC * 2\ [km] * PS\ [\frac{\%\ space\ occupated}{item}] * I_i\ [\frac{\#items}{order}]$$

i: the i_th purchase; i ∈ [0; ∞]

n: number of purchases made;

VCF = van vehicle emission conversion factor $\left[\frac{Vehicle\ kgCO2e}{km}\right]$;

LC=Avg distance from LW to consumer's house;

PS= percentage of space allocated to each single item $\left[\frac{\%\ space\ occupated}{item}\right]$;

I = number of items per order;

E2= Event 2: customer buys more items from more websites;

DC3= Distribution configuration 3: the company delivers directly from LW to customers' home.

- If the company delivers firstly from CW to PP and then customer goes from home to PP **(4)**

$$EI\ (E2/4) = \sum_{i=0}^{n} \left[\left(TCF\ [\frac{Vehicle\ kgCO2e}{km}] * CP\ * 2\ [km] *\ PS\ [\frac{\%\ space\ occupated}{item}] * I_i\ [\frac{\#items}{order}]\right) + \left(PCF[\frac{Vehicle\ kgCO2e}{km}] * PH * [km]\right)\right]$$

i: the i_th purchase; i ∈ [0; ∞]

n: number of purchases made;

TCF = truck vehicle emission conversion factor $\left[\frac{Vehicle\ kgCO2e}{km}\right]$;

CP=Avg distance from CW to PP;

PS= percentage of space allocated to each single item $\left[\frac{\%\ space\ occupated}{item}\right]$;

I = number of items per order;

PCF= passenger vehicle emission conversion factor $\left[\frac{Vehicle\ \mathrm{kg}CO2e}{km}\right]$;

PH= Avg route distance from PP to the customer's house;

E2= Event 2: customer buys more items from more websites;

DC4= Distribution configuration 4: the company delivers firstly from CW to PP and the customers go from their home to the PP.

- If the company delivers firstly from CW to LW, then from LW to PP and then customer goes from home to PP (5)

$$EI\ (E2/5) = \sum_{i=0}^{n}\left[\left(\left(TCF\left[\frac{Vehicle\ kgCO2e}{km}\right] * AL * 2\ [km] + VCF\ \left[\frac{Vehicle\ kgCO2e}{km}\right] * LP * 2[km]\right) * PS\ \left[\frac{\%\ space\ occupated}{item}\right] * I_i\ \left[\frac{\#items}{order}\right]\right) + \left(PCF\ \left[\frac{Vehicle\ kgCO2e}{km}\right] * PH\ [km]\right)\right]$$

i: the i_th purchase; $i \in [0; \infty]$

n: number of purchases made;

TCF = truck vehicle emission conversion factor $\left[\frac{Vehicle\ \mathrm{kg}CO2e}{km}\right]$;

AL = Avg distance from CW to LW;

VCF = van vehicle emission conversion factor $\left[\frac{Vehicle\ \mathrm{kg}CO2e}{km}\right]$;

LP= Avg distance from LW to PP;

PS= percentage of space allocated to each single item $\left[\frac{\%\ space\ occupated}{item}\right]$;

I = number of items per order;

PCF= passenger vehicle emission conversion factor $\left[\frac{Vehicle\ \mathrm{kg}CO2e}{km}\right]$;

PH= Avg route distance from PP to the customer's house;

E2= Event 2: customer buys more items from more websites;

DC5= Distribution configuration 5: the company delivers firstly from CW to LW, then from LW to PP and the customers go from their home to the PP.

- If the company delivers directly from LW to PP and then customer goes from home to PP **(6)**

$$EI\ (E2/6) = \sum_{i=0}^{n} \left[\left(VCF\ [\frac{Vehicle\ kgCO2e}{km}] * LP\ *\ 2\ [km]\ * PS\ [\frac{\%\ space\ occupated}{item}] * I_i\ [\frac{\#items}{order}] \right) + \left(PCF\ [\frac{Vehicle\ kgCO2e}{km}] * PH\ [km] \right) \right]$$

i: the i_th purchase; i ∈ [0; ∞]

n: number of purchases made;

VCF = van vehicle emission conversion factor $\left[\frac{Vehicle\ \mathrm{kg}CO2e}{km}\right]$;

LP= Avg distance from LW to PP;

PS= percentage of space allocated to each single item $\left[\frac{\%\ space\ occupated}{item}\right]$;

I = number of items per order;

PCF= passenger vehicle emission conversion factor $\left[\frac{Vehicle\ \mathrm{kg}CO2e}{km}\right]$;

PH= Avg route distance from PP to the customer's house;

E2= Event 2: customer buys more items from more websites;

DC6= Distribution configuration 6: the company delivers from LW to PP and the customers go from their home to the PP.

A more detailed analysis can be done considering the probability of occurrences of all these twelve scenarios. A step further is the calculation of the conditional probabilities of each of these cases. Knowing that ***P(B|A) = P(A∩B) / P(A)***, it is useful to calculate all these values and understand if the scenarios which have a stronger impact in term of CO2 emissions are also the most frequent ones.

Communication. Inside the delivery process we also considered the communication activities.

- Info request (e.g. on delivery process);
- Answer to customer request (e.g. on delivery process);
- Tracking service activation.

Through this formula, we calculate the CO2 emissions caused by the sum of these three activities, summing up the CO2 value for each purchase that has been made. If the entire order is made using one web-site, *n* will be equal to 1, otherwise *n* will be equal to the number of orders placed in different websites.

$$EI = \sum_{i=0}^{n} \sum_{j=3} AD_{i;j}\ [h] * PSRD_{i;j}\ [kW]\ * ECF_j\ [\frac{kgCO2e}{kWh}]$$

i: the i_th purchase; $i \in [0; \infty]$

j: the j_th activity;

n: number of purchases made;

ECF = electricity conversion factor;

AD = activity duration;

PSRD = power supply of retailer device;

Finally, the contributions in term of CO2 emissions made by the transportation and communication activities are summed-up.

Post-sale

In this phase the customers' behaviour has a fundamental role. The presence of these activities depends on the customer because the post-sale process may or may not take place according to the specific situation. Indeed, if an item is damaged or the customer dislikes what he/she had bought the product can be picked up from the customer's house and brought to the dedicated warehouse. More specifically, we considered the return process shown below:

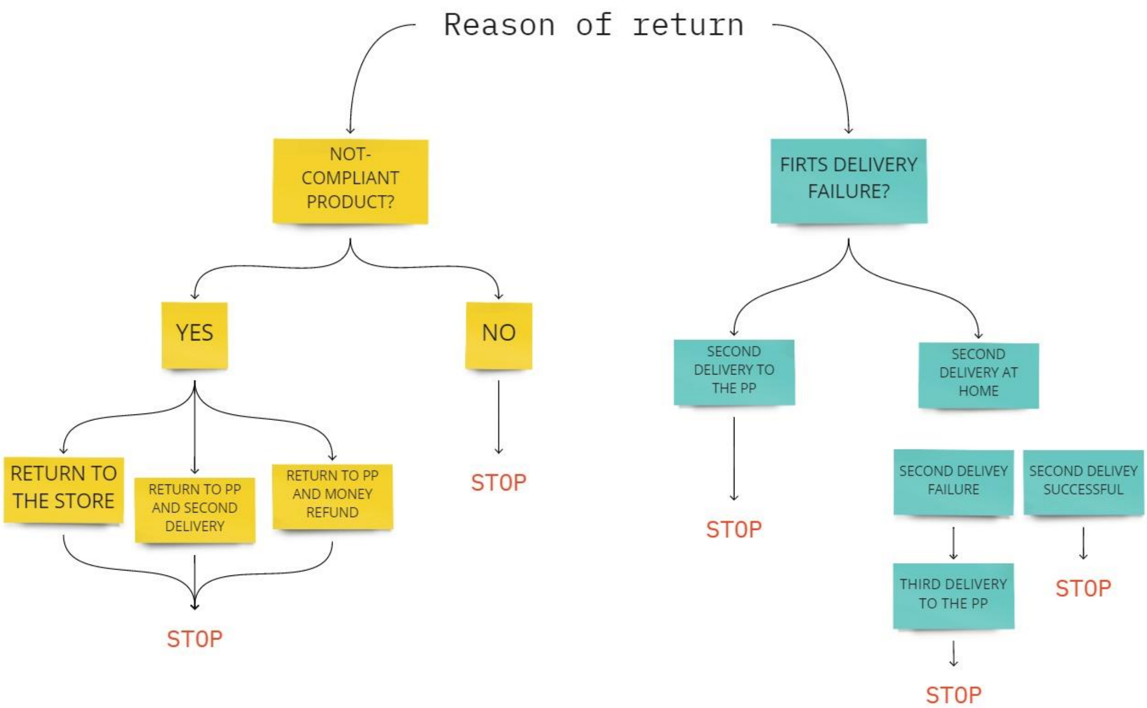


Figure 5-3: Return Process Diagram

In the figure 5-4, the not-compliant products are both the damaged and the disliked ones. For PP instead we refer to collection points as postal offices, newsstands and lockers.

So, in the return phase we identified four main activities: communication, transportation, packaging and management.

Communication.

- Info insertion about return;
- Confirmation mail sending;
- Tracking service activation.

Through this formula we calculate the CO2 emissions caused by the sum of these three activities, summing up the CO2 value for each purchase that has been made. If the entire order is made using one web-site, n will be equal to 1, otherwise n will be equal to the number of orders placed in different websites.

$$EI = \sum_{i=0}^{n} \sum_{j=3} AD_{i;j}\ [h] * PSCD_{i;j}\ [kW]\ * ECF_j\ [\frac{kgCO2e}{kWh}] * RR\ [\%]$$

i: the i_th purchase; $i \in [0; \infty]$

j: the j_th activity;

n: number of purchases made;

ECF = electricity conversion factor;

AD = activity duration;

PSCD = power supply of customer device;

RR= probability of return rate (online).

For every order made and for each of the five activities the CO2 emissions are calculated as the product between the duration of the activities expressed in hours, and the power supply of the customer device, the electricity conversion factor and the probability of return rate. In particular, the latter depends on the type of sector to which the products belong and considering the multi-purchase approach, the results differ depending on the type of orders made by customers.

Transportation return phase. For the transportation phase we considered two macro-scenarios: products are not compliant, or the delivery is failed. For each of these two cases the model individualises also different sub-scenarios. In particular, if the product is not compliant, the customer may decide to:

- return the product to the store;
- return the product to the pick-up point and then the retailer made a second delivery;
- return the product to the pick-up point and then the retailer refunds money.

Furthermore, by analysing the scenario in which the delivery is failed (e.g., the customer is not at home during the delivery) we made the assumption that a second delivery is organised by the courier. So, the sub-cases are:

- the first delivery fails, and the second delivery does not fail;
- both the first and the second deliveries fail, the products are delivered to the pick-up point and the customer goes to the collection point to pick-up the order.

So, for each of those scenarios different formulas are computed. More in detail, to compute the level of CO2 emitted by the post-sale transportation phase was necessary to calculate the probability of occurrence of the return for each case, also known as return rate.

Below, the description of each of those sub-scenarios is reported.

1. Product not-complaint and customer returns the product to the store

If the product received is not compliant and the customer decides to switch at the store the item previously bought with another one, the CO2 calculation considers the distance from the customer's home to the store multiplied by two (to take into consideration the entire round trip):

$$EI_1 = RR * PCF\ [\frac{Vehicle\ kgCO2e}{km}] * (HS * 2\ [km])$$

$$RR = Prob.\,not\ compliant\ product * Prob.\,product\ returns\ to\ the\ store$$

PCF= passenger vehicle emission conversion factor $\left[\frac{Vehicle\ \text{kg}CO2e}{km}\right]$;

HS= average distance from customer's house to the store.

2. Product not-complaint and customer returns the product to the pick-up point and then the retailer made a second delivery

If the product received is not compliant and the customer decides to return it back to the PP, we considered the distance from home to the PP multiplied by two, the distance from PP to the warehouse and the distance from the warehouse to the final customer.

$$EI_2 = RR * \left[PCF\left[\frac{Vehicle\ kgCO2e}{km}\right] * PH * 2[km] + TCF\left[\frac{Vehicle\ kgCO2e}{km}\right] * PS\left[\frac{\%\ space\ occupated}{item}\right] * RI * D\_1\,[km]\right]$$

$$RR = Prob.\,not\ compliant\ product * Prob.\,product\ returns\ to\ the\ PP * Prob.\,of\ a\ second\ delivery$$

PCF= passenger vehicle emission conversion factor $\left[\frac{Vehicle\ \text{kg}CO2e}{km}\right]$;

PH= Avg distance from PP to the customer's house;

TCF= truck vehicle emission conversion factor $\left[\frac{Vehicle\ \text{kg}CO2e;}{km}\right]$

PS= percentage of space allocated to each single item $\left[\frac{\%\ space\ occupated}{item}\right]$;

RI=number of returned items;

$\mathbf{D_1}$ = Avg distance from PP to Wh and from Wh to customer's home.

❖ Product not-complaint and customer returns the product to the pick-up point and then the retailer refunds money **(3)**:

If the product received is not compliant and the customer decides to return it back to the PP, we consider the distance from home to the PP multiplied by two and the distance from PP to the warehouse.

$$EI_3 = RR * \left[PCF \left[\frac{Vehicle\ kgCO2e}{km}\right] * PH * 2[km] + TCF\left[\frac{Vehicle\ kgCO2e}{km}\right] * PS\left[\frac{\%\ space\ occupated}{item}\right] * RI * D\_2\ [km] \right]$$

$$RR = Prob.not\ compliant\ product * Prob.product\ returns\ to\ the\ PP * Prob.of\ money\ refunded$$

PCF= passenger vehicle emission conversion factor $\left[\frac{Vehicle\ \mathrm{kg}CO2e}{km}\right]$;

PH= Avg distance from PP to the customer's house;

TCF= truck vehicle emission conversion factor $\left[\frac{Vehicle\ \mathrm{kg}CO2e}{km}\right]$;

PS= percentage of space allocated to each single item $\left[\frac{\%\ space\ occupated}{item}\right]$;

RI=number of returned items;

$\mathbf{D_2}$ = Avg distance from PP to Wh.

❖ Customer not at home during the first delivery and the second delivery does not fail:

$$EI_4 = RR * \left[VCF \left[\frac{Vehicle\ kgCO2e}{km}\right] * D\_3 * 2\ [km] * PS\left[\frac{\%\ space\ occupated}{item}\right] * I_i \left[\frac{\#items}{order}\right] \right]$$

$$RR = Probability\ of\ only\ the\ first\ delivey\ fails$$

VCF= van vehicle emission conversion factor $\left[\frac{Vehicle\ \text{kg}CO2e}{km}\right]$;

PS= percentage of space allocated to each single item $\left[\frac{\%\ space\ occupated}{item}\right]$;

D_3 = Avg distance from Wh to the consumer's house;

I = number of items per order.

❖ Customer not at home both during the first and second delivery and then the retailer brings the products to the PP:

$$EI_5 = RR * (VCF\ [\frac{Vehicle\ kgCO2e}{km}] * D\_3 * 2\ [km]\ * PS\ [\frac{\%\ space\ occupated}{item}] * I_i\ [\frac{\#items}{order}] + TCF[\frac{Vehicle\ kgCO2e}{km}] * D\_2 * 2\ [km]\ * PS\ [\frac{\%\ space\ occupated}{item}] * I_i\ [\frac{\#items}{order}] + PCF\ [\frac{Vehicle\ kgCO2e}{km}] * PH *\ TRIPS\ \ [km]$$

$$RR = Probability\ of\ both\ the\ first\ and\ second\ delivey\ fail$$

D_3 = Avg distance from Wh to the consumer's house;

VCF= van vehicle emission conversion factor $\left[\frac{Vehicle\ \text{kg}CO2e}{km}\right]$;

PS= percentage of space allocated to each single item $\left[\frac{\%\ space\ occupated}{item}\right]$;

I = number of items per order;

TCF= truck vehicle emission conversion factor $\left[\frac{Vehicle\ \text{kg}CO2e}{km}\right]$;

D_2 = Avg distance from PP to Wh;

PH= Avg distance from PP to the customer's house;

TRIPS= number of websites*2 = number of trips according to the number of websites (round trip).

Management.

- Return reception and management

Below the calculation of the CO2 emission for the return and management of the products:

$$EI = \sum_{i=0}^{n} AD_i\ [h] * PSRD_i\ [kW]\ * ECF\ [\frac{kgCO2e}{kWh}] * RR\ [\%]$$

i: the i_th purchase; i ∈ [0; ∞]

n: number of purchases made;

ECF = electricity conversion factor;

AD = activity duration;

PSRD = power supply of retailer device;

RR= probability of return rate (online).

Packaging return phase. Also, for the return phase the packaging impact has a key importance. The results change if we consider the case in which all the items are bought on one website or the case in which the customer made different orders on different website. As in the warehousing phase, the packaging impact is calculated as number of bags multiplied by consume of CO2 related to the quantity of packaging multiplied by the probability of return rate.

- **One web site for *n* purchases (so one delivery)**

$$EI_{1,Packaging} = NB * PFC\ [\frac{kgCO2e}{cardboard}] * RR\ [\%]$$

$$NB = \frac{\#items}{purchase} + 1$$

NB = number of bags;

PFC = packaging footprint for cardboard (consume of CO2 related to the quantity of packaging).

- **N web-sites for *n* purchases (different deliveries for different orders n)**

$$EI_{2,Packaging} = \sum_{i=0}^{n} NB * PFC \, [\frac{kgCO2e}{bag}] * RR \, [\%]$$

$$NB = \frac{\#items}{purchase} + 1$$

i: the i_th purchase;   i ∈ [0; ∞]

n: number of purchases made;

NB = number of bags;

PFC = packaging footprint for cardboard (consume of CO2 related to the quantity of packaging).

Finally, all these contributions made by the communication, transport, management and packaging activities are summed-up. At the end of the online process, we sum the CO2 emissions made by the pre-sale and sale, warehousing, delivery and post-sale to compare it with the traditional channel results.

5.4.2 Offline purchasing process

Before entering in the detailed description of the model, it is fundamental to understand the network distribution background in which the activities subsequently described are carried out. The process starts from production of goods in the factory (this stage is out of scope for our model) and it ends with the consumption of them when the customer decides to leave his/her home to reach by a personal vehicle of transportation (car or motorbike are the ones analysed in the model) a shopping locations (stores) with the purpose of purchasing goods and consume them. The intermediate stages regard the replenishment of central and local warehouses trigged by orders from retailers; the transportation of goods in these levels is performed through HGVs (articulated or rigid ones according to the types of good transported). (See Figure 5-2).

Pre-Sale, Sale, and Delivery

It is the phase in which the customer leaves the house and goes to the shopping location/s, visit the store/s, and make the payments for the item/s bought. Once the shopping trip is ended, the customer travels back to home. In previous models presented in the literature, the delivery phase in the offline process is considered separately from the pre-sale and sale activities, while in this model we decided to include in one formula the entire round-trip distance. Within this first stage, transportation, communication and purchasing sub-activities are included. Here below, they will be described in detail.

Transportation. It is the activity through which the customer reaches the store in which realizes his/her purchases and, in the end, goes back to home. The first assumption is that we considered only car as mode of transportation for passenger trips.

In order to assess the environmental impact deriving by car CO2 emissions, two main scenarios have been considered: dedicated trip and non-dedicated trip. In the first scenario, the customer has the only objective of purchasing items, while in the second one the shopping activity is a part of another trip: the customer in this case does not leave the house specifically for purchasing something but the shopping activity is performed after another non-shopping location is visited (for example, on the way back from work or university, or whatever place in which the customer visited to run whatever errand). So, if the trip is not dedicated, the assumption is that the average distance travelled by the customer is not the same back and forth.

In addition, within each scenario, it is considered if the customer decides to visit one only shopping location[7] or more ones.

Regarding the "single location" scenario, the formula considers the average distance from consumer's home to the shopping location chosen by the customer, both for the "dedicated trip" scenario and "non-dedicated trip" one. The value of the distance is summed as many times as the purchases made in different stores, so the result is divided by "N" that represent the number of purchases made in the different stores.

Subsequently, the result is multiplied for a "multiplicative factor", that is different for the two scenarios: x2 for the dedicated trip, since the round-trip distance and return trip distance are the same, while for the non-dedicated trip scenario we assumed that the round-trip distance is averagely half the customer's home – shopping location distance, so we choose to multiply x1.5. The final value is then multiplied for the vehicle GHG emission conversion factor [kgCO2e/km].

Regarding the "multiple locations" option, the reasoning is the same, with the only difference that it is not considered the distance between consumer's home and the shopping location, but a sum of the different distances from one location to another one (where $location_1$ is customer's home and we assumed that the customer always moves from the nearest shopping location to the farthest one – that is the last one visited). An important assumption made is that the maximum number of shopping locations that can be visited by the customer in one single shopping trip is 3. That is

[7] A "shopping location" may be: a shopping mall, a city centre in which there is an agglomeration of different shops, a peripheric/extra-urban area in which there are one or more shops.

because, in reality, it is very unlikely that more than three different shopping locations are visited in a single shopping trip.

In the model design phase, we identified seven different product categories in which purchases may belong to:

- Clothing, accessories, footwear;
- Cosmetics products;
- Books;
- Electronics;
- Construction products, gardening, DIY, joinery, lighting;
- Stationery;
- Food & beverage.

It is important to notice that two or more different purchases may belong to the same category. In that case, the assumption is that they are considered similar in terms of emissions in each phase of the purchasing process. So, the user will have to specify the number of stores in which purchases are realized for each product category. The EI of each phase will be assessed for only one store and multiplied for the number of stores initially declared.

In the end, four main results will be obtained:

- EI (dedicated trip | single location);
- EI (dedicated trip | multiple locations);
- EI (non-dedicated trip | single location);
- EI (non-dedicated trip | multiple locations).

Each of these scenarios has a different impact, according to their probability of occurrence. In the model application phase, we will consider the probability values resulting from the spread survey, in this way it is possible to understand which scenario is more impacting and deduct the final result in terms of CO2 emissions.

Dedicated trip

1. Single shopping location (only shopping mall or only city centre or only extra-urban area).

$$EI = \frac{\sum_{i=1}^{N}(AB\ [km])i}{n} * PCF \left[\frac{Vehicle\ kgCO2e}{km}\right] * 2$$

PCF = passenger vehicle emission conversion factor;

AB = average distance customer's home – shopping location;

N = number of shops in which purchases are realized.

2. Multiple locations (maximum three different shopping locations in one trip; stores visited in a single trip are located in different locations, for example one shop is located in a shopping mall, another one in a city centre and another one in another area).

$$EI = \sum_{j=1}^{M} \left(\frac{\sum_{i=1}^{N}(AD\ [km])i}{n}\right)j * PCF\ [\frac{Vehicle\ kgCO2e}{km}] * 2$$

PCF = passenger vehicle emission conversion factor;

j = passes the location;

i = passes the shops in which purchases are realized;

N = number of shops in which purchases are realized;

M = number of locations visited in the entire trip (max 3) (Both the point of origin and the point of destination of the entire trip is always consumer's home; Location 1 = consumer's home; Location 2 = nearest one to location 1; Location M = farthest one from consumer's home;

AD = average distance location j – location j+1;

<u>Non-dedicated trip[8]</u>

1. Single location

$$EI = \frac{\sum_{i=1}^{N}(AB\ [km])i}{n} * PCF\ \left[\frac{Vehicle\ kgCO2e}{km}\right] * 1.5$$

PCF = passenger vehicle emission conversion factor;

AB = average distance customer's home – shopping location;

N = number of shops in which purchases are realized.

2. Multiple locations

$$EI = \sum_{j=1}^{M}\left(\frac{\sum_{i=1}^{N}(AD[km])i}{n}\right)j * PCF\ \left[\frac{Vehicle\ kgCO2e}{km}\right] * 1.5$$

PCF = passenger vehicle emission conversion factor;

j = passes the location;

i = passes the shops in which purchases are realized;

N = number of shops in which purchases are realized;

M = number of locations visited in the entire trip (max 3) (Both the point of origin and the point of destination of the entire trip is always consumer's home; Location 1 = consumer's home; Location 2 = nearest one to location 1; Location M = farthest one from consumer's home;

AD = average distance location j – location j+1;

Communication. In order to assess the environmental impact generated by communication, three main activities are considered:

- Product search in the store;

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[8] In the way back from school, university, work, another place where no purchasing activities are made.

- Interaction of the customer with the salesman;
- Interaction of the salesman with the customer.

The first step consists in the calculation of the energy consumption of each activity through a formula that multiplies the daily energy consumption for the building [kWh] per the percentage of space allocated to the outlined activity, and divides the result per product between the number of customers visiting the store per day (since the unit of analysis of the whole calculation is the single customer), and the number of items purchased averagely by him/her (in the case of interaction of the salesman with the customer the unit of analysis is not the single customer but the average number of customers served by each salesman). The second step is the conversion of the energy consumed in terms of kg of CO2 generated. These two steps are iterated for each store in which the customer has purchased items during the entire trip. In the end, the environmental impacts calculated for each store are summed up.

Calculation of activity consumption per day (AC):

AC = activity consumption per day;

ECB = daily energy consumption for the building;

- *Product search in the store*
- *Interaction of the customer with the salesman*

$$AC = \frac{ECB\ [kWh] * PS\ [\%]}{C\ [\#] * I\ [\#]}$$

PS = percentage of space allocated to the activity (product search in the store, interaction of the customer with the salesman);

C = number of customers per day;

I = number of items per purchase.

- *Interaction of the salesman with the customer*

$$AC = \frac{ECB\ [kWh] * PS\ [\%]}{S\ [\#] * C\ [\#]\ *\ I\ [\#]}$$

PS = percentage of space allocated to the activity (interaction of the salesman with the customer);

S = number of store assistants in each store;

C = number of customers served by each store assistant per day.

$$EI = \sum_{i=1}^{N}(\sum_{j=1}^{3}(AC\ [kWh])j)i * ECF[\frac{kgCO2e}{kWh}]$$

N = number shops visited in one trip but only shops where purchases are realized (there can be also the case in which a shop is visited but no product is bought but we do not consider this case);

3 = number of communication activities in the Pre-sale & Sale phase;

ECF = electricity conversion factor.

Purchasing. It includes three activities:

- Product purchase;
- Receipt release;
- Packaging.

For the first two ones, the reasoning is the same as for communication activities.

Calculation of activity consumption per day (AC):

AC = activity consumption per day;

ECB = daily energy consumption for the building;

- *Product purchase*

$$AC = \frac{ECB\ [kWh] * PS\ [\%]}{C\ [\#] * I\ [\#]}$$

PS = percentage of space allocated to the activity (product purchase);

C = number of customers per day;

I = number of items per purchase.

- *Receipt release*

$$AC = \frac{ECB\ [kWh] * PS\ [\%]}{S\ [\#] * C\ [\#]\ *\ I\ [\#]}$$

PS = percentage of space allocated to the activity (receipt release);

S = number of store assistants in each store;

C = number of customers served by each store assistant per day;

I = number of items per purchase.

$$EI = \sum_{i=1}^{N}(\sum_{j=1}^{2}(AC\ [kWh])j)i * ECF\,[\frac{kgCO2e}{kWh}]$$

N = number shops visited in one trip but only shops where purchases are realized (there can be also the case in which a shop is visited but no product is bought but we do not consider this case);

2 = number of purchasing activities in the Pre-sale & Sale phase (only product purchase and receipt release);

ECF = electricity conversion factor.

Regarding packaging, some assumptions have been made. Firstly, the model considers only paper as typologies of packaging material. The user will specify the number of items contained in one paper bag, in the end, the total number of bags consumed during an entire trip is calculated. An average number of items that can be packed in one bag was assumed. This reasoning is iterated for each purchase realized in a different store. The following formula expresses the calculation:

$$EI = \sum_{i=1}^{N}(IT\ [\#])i * \frac{1\ bag}{CAP\left[\frac{\#}{bag}\right]} * PFPP\ [\frac{kgCO2e}{paper\ bag}]$$

N = number shops visited in one trip but only shops where purchases are realized (there can be also the case in which a shop is visited but no product is bought but we do not consider this case);

IT = number of items purchased in shop i;

CAP = capacity of 1 bag in terms of items (the same for plastic bag and paper bag);

PFPP = packaging footprint for paper bag.

The value of number of bags must be rounded up.

Once the final EI for each of the above-described activities is assessed, they are summed up to obtain the total EI of the Pre-sale, Sale & Delivery phase.

Replenishment

This phase is about store replenishment. We assumed that the store is replenished from a generic central warehouse. This phase starts when the store manager emits an order, and it ends when the shelf is replenished with the desired items. The model assumes that the store manager emits an order when the stock level for the different items decreases till a pre-defined threshold.

The replenishment phase includes several sub-activities, in the order:

- Management;
- Warehouse/handling;
- Transportation;
- Communication;
- Management.

Management. The first management is about the management of the order emission, and it includes the following activities: replenishment order emission, replenishment order reception and management, order fulfilment, picking list emission. For each one, it is requested the value of activity duration [h] and the power supply of retailer device [kW], which are multiplied between each other's. The results of each activity are summed up and multiplied for the electricity conversion factor [kgCO2e/kWh]. This reasoning is iterated for each store in which purchases are realized and the resulting EIs are then summed up.

Formulas:

- Replenishment order emission;
- Replenishment order reception and management;
- Order fulfilment;
- Picking list emission.

$$EI = \sum_{i=1}^{N} \left(\sum_{j=1}^{K} (AD\ [h] * PSD\ [kW])j \right) i * ECF\ [\frac{kgCO2e}{kWh}]$$

ECF = electricity conversion factor;

AD = activity duration;

PSD = power supply of retailer device;

N = number of shops visited in one trip but only shops where purchases are realized (there can be also the case in which a shop is visited but no product is bough but we do not consider this case);

K = number of management activities.

Warehouse/handling. This section includes all the activities performed in the central warehouse. It includes different activities: picking, warehouse consumption in the storage area, sorting, warehouse consumption in the sorting area for sorting activity, packaging, warehouse consumption in the sorting area for packaging activity, goods moving, warehouse consumption in the sorting area for goods moving activity, waybill posting. Here below, the formulas are reported.

Formulas:

- Picking

$$EI = \sum_{i=1}^{N} (ACP\ [KWh] * IO\ [\#])i * ECF\ [\frac{kgCO2e}{kWh}]$$

ACP = activity consumption per piece (picking);

IO = number of items per order;

N = number of shops visited in one trip but only shops where purchases are realized (there can be also the case in which a shop is visited but no product is bought but we do not consider this case).

- Warehouse consumption in the storage area

$$EI = \sum_{i=1}^{N} (\frac{WEC\ [kWh]}{ID\ [\#]} * IO\ [\#])i * ECF\ [\frac{kgCO2e}{kWh}]$$

IO = number of items per order;

ID = number of items per day;

WEC = warehouse daily energy consumption for an activity (storage);

N = number of shops visited in one trip but only shops where purchases are realized (there can be also the case in which a shop is visited but no product is bought but we do not consider this case).

- Sorting

$$EI = \sum_{i=1}^{N} (ACP\ [kWh] * IO\ [\#])i * ECF\ [\frac{kgCO2e}{kWh}]$$

ACP = activity consumption per piece (sorting);

IO = number of items per order;

N = number of shops visited in one trip but only shops where purchases are realized (there can be also the case in which a shop is visited but no product is bought but we do not consider this case).

- Warehouse consumption in the sorting area for sorting activity

$$EI = \sum_{Ei=1}^{N} (\frac{WEC\ [kWh]}{ID\ [\#]} * IO\ [\#])i * ECF\ [\frac{kgCO2e}{kWh}]$$

IO = number of items per order;

ID = number of items per day;

WEC = warehouse daily energy consumption for an activity (sorting);

- Packaging

$$EI = \sum_{i=1}^{N} (NC[\#])i * PFC\ [\frac{kgCO2e}{cardboard}]$$

NC = number of cardboards;

PFC = packaging footprint for cardboard;

N = number of shops visited in one trip but only shops where purchases are realized (there can be also the case in which a shop is visited but no product is bought, but we do not consider this case).

- Warehouse consumption in the sorting area for packaging activity

$$EI = \sum_{i=1}^{N} (\frac{WEC\ [KWh]}{ID\ [\#]} * IO\ [\#])i * ECF\ [\frac{kgCO2e}{kWh}]$$

IO = number of items per order;

ID = number of items per day;

WEC = warehouse daily energy consumption for an activity (in the sorting area for packaging activity);

N = number of shops visited in one trip but only shops where purchases are realized (there can be also the case in which a shop is visited but no product is bought but we do not consider this case).

- Goods moving

$$EI = \sum_{i=1}^{N} (ACP\ [kWh])i * ECF\ [\frac{kgCO2e}{kWh}]$$

ACP = activity consumption per piece (goods moving);

N = number of shops visited in one trip but only shops where purchases are realized (there can be also the case in which a shop is visited but no product is bought but we do not consider this case).

- Warehouse consumption in the sorting area for goods moving activity

$$EI = \sum_{i=1}^{N} (\frac{WEC\ [kWh]}{ID\ [\#]} * IO\ [\#])i * ECF\ [\frac{kgCO2e}{kWh}]$$

IO = number of items per order;

ID = number of items per day;

WEC = warehouse daily energy consumption for an activity (in the sorting area for goods moving);

N = number of shops visited in one trip but only shops where purchases are realized (there can be also the case in which a shop is visited but no product is bought but we do not consider this case).

- Waybill posting

$$EI = \sum_{i=1}^{N} (AD\ [h] * PSD\ [kW])i * ECF\ [\frac{kgCO2e}{kWh}]$$

ECF = electricity conversion factor;

AD = activity duration;

PSD = power supply of retailer device;

N = number of shops visited in one trip but only shops where purchases are realized (there can be also the case in which a shop is visited but no product is bough, but we do not consider this case);

Transportation. It refers to the goods transportation to the store. The formula considers the average route distance travelled by the truck multiplied per the percentage of space occupied by a piece on truck, that is in turn multiplied per the number of items per order. This is calculated for each store in which purchases are realized.

Formula:

$$EI = \sum_{i=1}^{N} \left(AR\ [km] * PP\ [\%] * TCF\ \left[\frac{kgCO2e}{km}\right] * IO\ [\#] \right) i$$

IO = number of items per order;

AR = average route distance;9

PP = percentage of space occupied by a piece;

TCF = truck emission conversion factor;

N = number of shops visited in one trip but only shops where purchases are realized (there can be also the case in which a shop is visited but no product is bough, but we do not consider this case);

Communication. This activity refers to:

- Info request about delivery;
- Interaction with the PoS about delivery;
- Tracking service activation.

As in the management activity, it is requested the value of each activity duration [h] and the power supply of retailer device [kW].

Formula:

$$EI = \sum_{i=1}^{N} \left(\sum_{j=1}^{K} (AD\ [h] * PSD\ [kW]) j \right) i * ECF\ [\frac{kgCO2e}{kWh}]$$

[9] It consists of the total trip.

ECF = electricity conversion factor;

AD = activity duration;

PSD = power supply of retailer device;

N = number of shops visited in one trip but only shops where purchases are realized (there can be also the case in which a shop is visited but no product is bough, but we do not consider this case);

K = number of communication activities.

Management. The second management activity concerns the goods reception and management in the store reserve area, for which the activity consumption is calculated through the same formula described for the previous management activities.

Formula:

$$EI = \sum_{i=1}^{N}(AD\ [h] * PSD\ [kW])i * ECF\ [\frac{kgCO2e}{kWh}]$$

ECF = electricity conversion factor;

AD = activity duration;

PSD = power supply of retailer device;

N = number of shops visited in one trip but only shops where purchases are realized (there can be also the case in which a shop is visited but no product is bough, but we do not consider this case).

Once the final EI for each of the above-described activities is assessed, they are summed up to obtain the total EI of the Replenishment phase.

Post-sale

The post-sale phase refers to the case in which the customer may return a product back to the store. In the offline scenario, we decided to consider only the event in which the product is not compliant (or defective). So, the return process starts with the return trip to the point of sale and ends when the customer goes back to home with the new items.

Here below the schema representing the process.

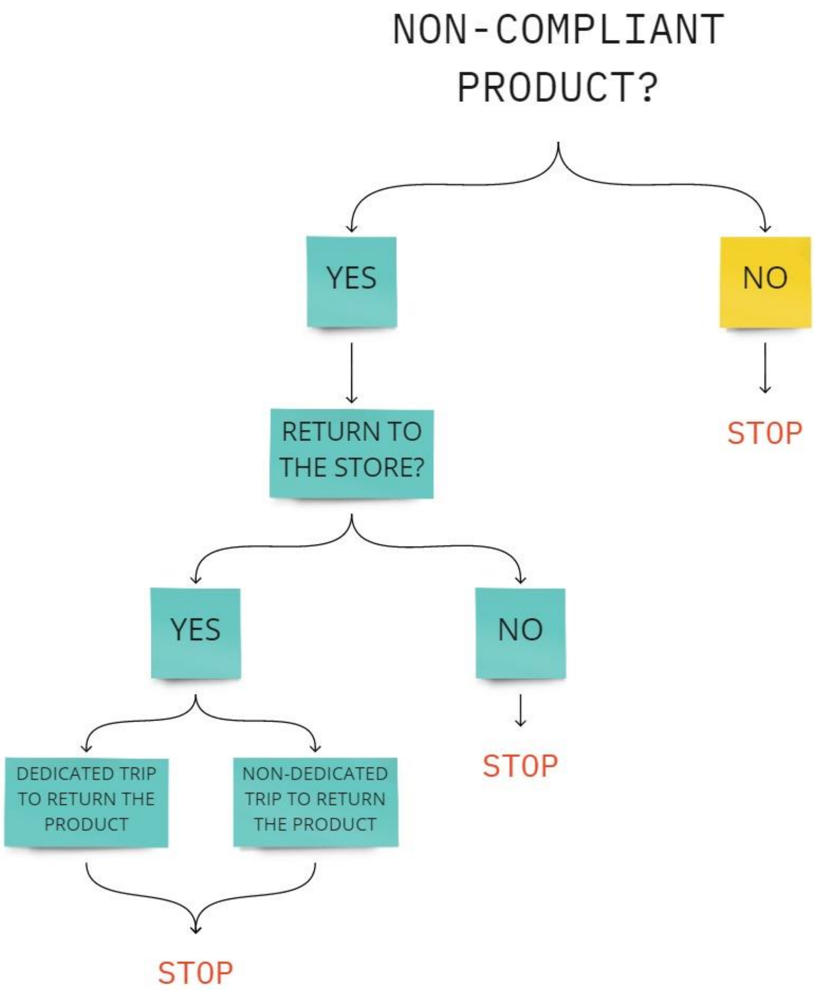

Figure 5-4: Offline Return Process Schema

An important assumption has been made in the post-sale phase: the return of non-compliant items is made in one single shopping location. So, if the products to be returned have been purchased in stores located in different locations, it is assumed that the distance travelled is equal to the average distance value between the distances travelled in the delivery phase. The same four transportation scenarios are considered as in the case of the pre-sale & sale phase and four results are obtained:

- EI (dedicated trip | single location);
- EI (dedicated trip | multiple locations);
- EI (non-dedicated trip | single location);
- EI (non-dedicated trip | multiple locations).

In the "single location" scenario, it is requested to know the distance between the customer's home and the shopping location in which there are the stores of interest and the probability of return rate of each product category in the offline process. Instead, in the "multiple locations" scenario, in order to assess the distance between the customer's home and the shopping location in which the stores of interest are, we assume to consider the average value between the distances travelled by the customer in the sale and delivery phase, as shown in the formula below.

Each of these scenarios, as in the case of pre-sale & sale phase, will have a different impact according to their probability of occurrence.

Formulas:

$$Prob\ (item\ i\ non\text{-}compliant) = \frac{\#items\ i}{\#TOT\ items}$$

Dedicated trip

1. Single location

$$EI = \sum_{i=1}^{N} Prob\ (item\ i\ non - compliant) * (AB)i[km]\ *\ PCF\ [\frac{kgCO2e}{km}]\ *\ Ri\ [\%]\ *\ 2$$

AB = average distance customer's home – shopping location;

PCF = passenger vehicle emission conversion factor;

N = number of shops in which to return items;

R = probability of return rate offline [%].

2. Multiple locations (in the case in which 2 or 3 shopping locations are visited)

$$EI = \sum_{i=1}^{N} Prob\ (item\ i\ non-compliant) * ((AD1 + (AD1 + AD2)/2)i[km]\ *\ PCF\ [\frac{kgCO2e}{km}]\ *\ Ri\ [\%]\ *\ 2$$

$$EI = \sum_{i=1}^{N} Prob\ (item\ i\ non-compliant) * ((AD1 + (AD1 + AD2) + (AD1 + AD2 + AD3))/3)i[km]\ *\ PCF\ [\frac{kgCO2e}{km}]\ *\ Ri\ [\%]\ *\ 2$$

ADj = average distance location j – location j+1;

PCF = passenger vehicle emission conversion factor;

N = number of shops in which to return items;

R = probability of return rate offline [%].

<u>Non-dedicated trip</u>

1. Single location

$$EI = \sum_{i=1}^{N} Prob\ (item\ i\ non-compliant) * (AB)i[km]\ *\ PCF\ [\frac{kgCO2e}{km}]\ *\ Ri\ [\%]\ *\ 1.5$$

AB = average distance customer's home – shopping location;

PCF = passenger vehicle emission conversion factor;

N = number of shops in which to return items;

R = probability of return rate offline [%].

2. Multiple locations (in the case in which 2 or 3 shopping locations are visited)

$$EI = \sum_{i=1}^{N} Prob\ (item\ i\ non-compliant) * ((AD1 + (AD1 + AD2)/2)i[km]\ *\ PCF\ [\frac{kgCO2e}{km}]$$
$$*\ Ri\ [\%]\ *\ 1.5$$

$$EI = \sum_{i=1}^{N} Prob\ (item\ i\ non-compliant) * ((AD1 + (AD1 + AD2)$$
$$+ (AD1 + AD2 + AD3))/3)i[km]\ *\ PCF\ [\frac{kgCO2e}{km}]\ *\ Ri\ [\%]\ *\ 1.5$$

ADj = average distance location j – location j+1;

PCF = passenger vehicle emission conversion factor;

N = number of shops in which to return items;

R = probability of return rate offline [%].

Communication. This last activity refers to the energy consumed in the interaction between the customer and the salesman about return. As previously seen, the formula considers the activity consumption calculated multiplying the daily energy consumption for the building per the percentage of space allocated to return, divided per the number of customers visiting the store each day.

Formulas:

$$AC\ [kWh]\ * ECF[\frac{kgCO2e}{kWh}]\ * R\ [\%]$$

$$AC = \frac{ECB\ [kWh] * PS\ [\%]}{C\ [\#]}$$

ECB = daily energy consumption for the building;

PS = percentage of space allocated to the activity (return);

AC = activity consumption per day;

C = number of customers per day.

Scenario's probability. Once the model will be applied to a specific context, it is necessary to understand the impact of each scenario through the probability of occurrence. The two main typologies of probability that should be assessed regards the type of trip (dedicated/non-dedicated) and the distance value. Regarding distance value we decides to identify 3 main ranges within which the distance value can fall. In order to decides the values of the distance ranges we made an average of distance values found in previous case studies analyzed in the literature with a similar context of application.

Probability of trip scenarios:

- Probability that the trip is dedicated;
- Probability that the trip is non-dedicated;

Probability of distance values scenarios:

- Probability that the distance is lower than 5 km → average value = 2.5 km;
- Probability that the distance is between 5 and 20 km → average value = 12.5 km;
- Probability that the distance is higher than 20 km → average value = 30 km.

Once these probabilities are calculated, they will be multiplied to the results of each scenario through the following procedure:

1. Multiply the EI values obtained in the dedicated trip and in the non-dedicated trip – scenario for the respective probability values;
2. Multiply the above values obtained for the probability that the distance travelled belong to the respective range;
3. Sum the EI values for types of distance values;
4. Sum the two EI values for the type of trips;

The procedure is applied for each type of shopping location scenario: single shopping location, two shopping locations, three shopping locations.

$$WEI_j = EI_j * Prob\ (typology\ of\ trip) * Prob.\ (distance)$$

$$EI\ (1\ location) = \sum_{j=1}^{3} WEIj\ \ DEDICATED\ TRIP + \sum_{j=1}^{3} WEIj\ \ NON - DEDICATED\ TRIP$$

$$EI\ (2\ locations) = \sum_{j=1}^{4} WEIj\ \ DEDICATED\ TRIP + \sum_{j=1}^{4} WEIj\ \ NON - DEDICATED\ TRIP$$

$$EI\ (3\ locations) = \sum_{j=1}^{2} WEIj\ \ DEDICATED\ TRIP + \sum_{j=1}^{2} WEIj\ \ NON - DEDICATED\ TRIP$$

where j = distance scenario;

WEI = weighted environmental impact.

See Table 6-18 for all considered distance scenarios.

6. Model application

The model described in the previous chapter is characterised by a dynamic structure which can be adapted to several different contexts of application. This chapter will provide a description of the particular case study applied to the model designed. Considering the high number of variables, the large number of values they can assume, and the limited availability of resources to extract precise data, it was necessary to set a specific context of application by making hypothesis.

Through the application of a case study, our objective is to show the functioning of the model, understanding how the results change according to the selected scenarios and how the customer behaviour impacts on them. We are aware that the results obtained are not completely and perfectly representative of the entire set of all possible scenarios that can happen. The model can be applied to multiple contexts, considering many different perspectives according to the variables considered. The model application aims to simplify the reality and deduct a result that can be discussed and adapted to different situations.

The chapter is organized as follows:

- *Introduction:* it summarizes the reason why we applied the model designed;
- *Context of application:* the context of application and the relative assumptions are described;
- *Input data:* before showing the results, all the general input data entered in the model are declared and described, with all the hypotheses made. Then, we

described the necessary input data for the specific type of purchasing process: online or traditional;

- *Analysis results.* In the end, the analysis of results is provided in three main sections: analysis of results in the online process, analysis of results in the offline process, comparison of the results between the two processes in order to understand which is the most sustainable.

6.1 Introduction

The case study application consists in testing the model created in different scenarios and understanding how the results vary according to them. In particular, what we have noticed is that in conducting this analysis and understanding which of the two processes was really more sustainable, the customer behaviour plays a key role. In fact, the consumer with his/her purchasing habits and choices, decisively establishes which of the two purchasing processes is more sustainable.

For example, in the online case the results change significantly if we consider the scenario in which a customer purchases many items within the same platform (e.g. Amazon), therefore considering a single delivery for all items, or if we consider the scenario in which the consumer makes different orders on different websites which therefore managed through different shipments. It is essential to point out that buying different items on a single platform and receiving them though a single delivery is one of our hypotheses; however, it is realistic to assume that most of the orders placed by the same customer arrive at their destination with the same courier, although this may not always be the case. Another factor that strongly affects the results is the type of distribution configuration of the company. In fact, distributing directly from a central warehouse makes it possible to saturate the trucks but, at the same time, the distance between the warehouse and the customer substantially increases by generating higher quantity of CO_2.

Regarding the offline purchasing process, the customer choices have an impact in terms of two main aspects:

- The situation in which the customer decides to make a purchase (or more purchases) through a dedicated trip, or the case in which he/she prefers to go for shopping coming back from a location different from home, for example school, university or workplace (non-dedicated trip);
- The willingness of the customer to travel for a certain number of kilometres with the purpose of make a purchase;
- The amount of "shopping locations" the customer is willing to reach in a single shopping trip. In the model and in its application 3 scenarios are considered: *single shopping location*, *two shopping locations* and *three shopping locations*. That's because the consumer usually reaches one or two destinations and rarely three or more than three. Since the 3-destinations scenario is rare to happen, we considered only two cases for that, i.e. when the customers travel very short distances. The number of destinations reached by the customer in a shopping trip also depends on where the customer's house is placed: if the customer lives in the centre of a metropolis or in a city is more likely to visit one location, instead if he/she lives in a peripherical/extra-urban area is more likely to travel a higher number of kilometres to reach different places in which stores are located.

Regarding the weight of each scenario, we were able to extract from our research the probability of occurrence concerning the typology of trip – dedicated/non-dedicated – and the willingness of the customer to travel a certain number of kilometres. No data have been collected regarding the number of locations visited in one shopping trip by the customer: we just compared the data in order to see how the entity of CO2 emissions change from single location scenario to multiple locations scenario.

6.2 Context of application

The application of the model was set in a specific environment, chosen by relying both on data extracted by the survey we diffused and on previous case studies contexts found in literature. The tables below report results obtained through the spread survey.

Product Category	Online Purchase Incidence	Offline Purchase Incidence
Clothing, accessories, footwear	30.6%	28.6%
Cosmetics products	15.9%	14.3%
Books	28.6%	12.7%
Electronics	23.4%	4.9%
Construction products, gardening, DIY, joinery, lighting	10.3%	6.8%
Stationery	14.3%	10.4%
Food & beverage	9.9%	22.3%

Table 6-1: Online and Offline Purchase Incidence of Product Categories

Product Category	Online Average Purchase [# items]
Clothing, accessories, footwear	2.4
Books	1.38
Electronics	0.88
Average	2

Table 6-2: Online Average Purchase (Clothing, accessories, footwear | Books | Electronics)

Shopping Location Typology	Number of Offline Purchases
Shopping mall	2.88
Shops located in city centre	2.19
Shops located in extra-urban area	1.81
Average	3

Table 6-3: Number of Offline Purchases per shopping location typology

As mentioned above, data obtained through the survey are not the only source consulted to define the shopping cart features. By scanning the papers in literature, we noticed that apparel, books and electronics industries are the most analysed and studied by authors in this research field, since the related goods are the most purchased though the online channel. Indeed, among the 50 articles review in literature analysis, 22% regards apparel industry (e.g. A. Wiese, W. Toporowski, S. Zielke, 2012 [109]; Mangiaracina *et. al.*, 2016 [59]), 22% concerns books industry (e.g., L. Reijnders, M. J. Hoogeven, 2001 [79]; E. Williams, T. Tagami, 2003 [110]; L. Zhang, Y. Zhang, 2013 [114]) and 12% is related to electronics sector (e.g., C. L. Weber, *et al.*, 2008 [106]). So, we decided to opt for them also in order to compare our results with the previous one, in a more homogenous manner.

Therefore, according to these analyses, the following context of application has been set. Among the different product categories, three specific purchase typologies have been selected: Clothing, accessories, and footwear, Books and Electronics. For each of them, the number of items has been chosen, still basing on data extracted by survey: 3 items for the first category, 2 items for the books purchase, and 1 item for electronics purchase. Each of them represents the average purchase for the specific product category.

The objective of the analysis is twofold: on one side to understand the impact of each separate purchase typology; on the other side to comprehend how the gradual combination of these purchases in one shopping trip/online order can contribute to the reduction of CO2 emissions. Thus, the first step consists into analysing the scenario in which the three purchases are made independently. Then, the combination of two purchases is considered and compared to the previous case. Finally, the environmental impact generated by the combination of all three purchases is assessed and compared to the previous two cases.

It is important to underline that the model is completely dynamic to the type of product category analysed, and the result changes by also considering other products categories: Clothing, accessories & footwear, Cosmetics, Books, Electronics, Construction products, gardening, DIY, joinery & lighting, House products, Stationery, Sport equipment.

Online purchasing process assumptions. With respect to the online process, we decided to calculate the kg of CO2 emitted for all four phases: Sale & Pre-Sale, Replenishment, Delivery and Post-Sale. The only activities that are not considered in the case study are the warehousing ones: picking, warehouse consumption, sorting, goods moving and shelves replenishment. All these contributors are not computed because of different reasons, explained below.

First of all, it was not possible to obtain all the necessary data to compute the calculation of the kgCO2e, because values as the picking consumption per piece, the warehouse daily energy consumption, the sorting consumption per piece and the goods moving and goods transfer consumption per piece, differ basing on the typology of warehouse (automated or manual warehouse), its size but also the typology of product stored in the storehouse. Secondly, the activities not considered are not sensitive for the comparison between the one website scenario and multi-website scenario. Lastly, the energy consumed by these activities is not differential to the multi-purchases situation because it is computed on the single item.

Offline purchasing process assumptions. As in the online case, also for the offline purchasing process the model was not entirely applied to the case study. The results obtained regards the following activities:

- Last mile transportation and last mile packaging, in the Pre-sale, Sale, and Delivery phase;

- Transportation of goods from warehouse to store and packaging in the store Replenishment phase;
- Return transportation, in the Post-Sale phase.

The other activities of the model, especially warehousing related ones, are not considered in the assessment for specific reasons, explained below. First of all, as for the online process, it was not possible to obtain all the necessary data to compute the calculation for each typology of store. More specifically, the missing data refer to the value of each activity consumption and activity duration, especially in the replenishment phase. In order to compute the activity consumption, the user needs to know the daily energy consumption of the store building allocated to that specific activity, and related to one specific customer, served by one specific salesman. Also, for the activity duration, it was difficult to find the exact values for each sub-activity of management, communication, warehouse/handling of the different phases. Secondly, the activities not considered in the application are not sensitive to the offline purchasing process scenarios studied, which vary according just to the type of trip and the type of distance value.

6.3 Input data

6.3.1 General input data

At the beginning, the user is requested to fill the Excel sheets with some specific data that will be listed and explained in this section. Firstly, for each product category the user has to declare the number of purchases and the number of items. Secondly, it is necessary to know the value of all the conversion factors, values that transform the emission generated by a certain activity in a specific quantity of CO2. Here below, the conversion factors used in the assessment will be explained.

Transportation. For this activity, three main conversion factors are calculated: passenger vehicle emission conversion factor, van emission conversion factor, truck emission conversion factor. In order to estimate the values related to conversion factors we relied on DEFRA REPORT (2021) [21]. The passenger vehicle emission conversion factor is equal to **0.165 kgCO2e/km,** and it was calculated through the following procedure: we firstly calculated the average value of CO2 emissions of petrol and diesel cars divided by market segment, then we made the same but for values of emissions of cars divided by size and we made an average value between these two; secondly, we calculated an average value of CO2 emissions of petrol motorbikes divided by size. Subsequently, we assigned a weight to the two values: **0.8** for cars and **0.2** for motorbikes, considering different traffic scenarios (big, medium, and small city). Regarding van emission conversion factor, it is equal to **0.226 kgCO2e/km,** and it is an average value between different classes of van. Concerning the replenishment transportation, four different values of truck emission conversion factors have been considered: rigid and articulated HGV (heavy goods vehicle) and non-refrigerated and refrigerated HGV. In this case we did not consider an average value, but we chose to use the value of rigid HGV with a weight greater than 17 tonnes, while for articulated HGV we opted for a weight between 3.5 and 33 tonnes, as Mangiaracina and colleagues (2016) [59] did in their study.

For the value of the electricity production conversion factor, equal to **0.491 kgCO2e/kWh**, we relied on data contained in ISPRA REPORT (2017) [48].

Packaging. For this activity, different conversion factors have been considered according to the type of packaging material: plastic, paper, cardboard. In the offline process, plastic and paper bags are consumed especially in the sale and delivery phase, while cardboard in the store replenishment phase. In the online process, especially cardboard is consumed both in the replenishment and in the delivery phases. In order to find the values of packaging conversion factors we relied on two reports: Environment Agency report (2011) [30] and Swedish Environmental and Research Institute report (2010). For plastic bags used in supermarket we considered an average value between a HDPE (high-density polyethylene) bag emission and a HDPE bag with a prodegradant additive, and it was set equal to **1.664 kgCO2e/HDPE bag**. Regarding the purchase of products not belonging to the Food & beverage category, we assumed to consider only paper material, since shops using plastics are less and less. The consumption of a generic paper bag is equal to 0.082 kgCO2e/paper bag, while for a cardboard box the relative consume of CO2 is different for each product category. In fact, it was calculated the consumption of cardboard material according to the average weight of an item belonging to a specific product category. We took as reference value the weight of a corrugated cardboard box associated to a particular box size[10]. Then, we multiplied this value for a factor, ranging between 1 and 4, according to the average dimension of the specific item. The final conversion factor expressing the amount of kgCO2e per cardboard box is given by multiplied the value obtained per kgCO2e/cardboard kg - 1.127 - (kg/box – Yi Yi, Z. Wang, R. Wennersten, Q. Sun, 2017 – "*Life cycle assessment of delivery packages in China*" [113]).

*1.127 [kgCO2e/kg] * 0.64 [kg/corrugated cardboard box * f = 0.721 [kgCO2e/cardboard box]*

The last packaging input data to declare is the average number of items that can be contained in a bag. We used an average value equal to 8 items/bag, derived by rounding up the average number of items contained in a paper bag (7.43).

The table below summarizes the values of conversion factors.

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[10] Average size of corrugated box = 25 cm * 18.5 cm * 12.5 cm. We multiplied for an average factor equal to 4 by assuming an average value between the sizes of a corrugated box containing a general item belonging to: clothing, book and electronics industries.

Phase	Conversion factor	Value	Unit of measure	Source
Transportation - Last mile	Passenger vehicles emission	0.165	kgCO2e/km	DEFRA (2021) [21]
	Van (average (up to 3.5 tonnes)) emission	0.226		
Transportation - Replenishment	HGV (all diesel) - rigid (> 17 tonnes)	0.958		
	HGV (all diesel) - articulated (> 3.5 - 33 tonnes)	0.770		
Pre-sale & Sale communication | Replenishment mntn and communication | Post-sale communication	Electricity production conversion factor	0.491	kgCO2e/kWh	ISPRA (2017) [48]
Packaging	Plastics bag (supermarket)	1.664	kgCO2e/HDPE bag	Environment Agency (2011) [30]
	Paper bag	0.082	kgCO2e/paper bag	H. Lewis et al. (2010), H. Tuomi (2017) [100]
	<u>Cardboard box</u>		kgCO2e/cardboard box	Swedish Environmental Research Institute (2010); Yi Yi *et al. (2017)*; Primary data; [118]
	Clothing, accessories, footwear	0.541		
	Cosmetics products	0.180		
	Books	0.180		
	Electronics	0.721		
	Construction products, gardening, DIY, joinery, lighting	0.721		
	Stationery	0.180		
	Food & beverage	0.180		

Table 6-4: Conversion factors

Another necessary input data to declare for starting the calculations are the values of power supply of retailer devices (average between three different pcs) used during the online activities of retailer and the power supply of customer devices (average between pc, tablet, and mobile phone, 3 each) used during the online activities of customer. The two values, reported in the below table, are taken from Mangiaracina *et al*, 2016 [59].

Energy consumption	Value	Unit of measure	Source
Power supply of device - retailer online activities	0.2313	kW	Mangiaracina et al. (2016) [59]
Power supply of device - customer online activities	0.1157		

Table 6-5: Energy consumption of retailer and customer devices

Moreover, it was necessary to estimate the value of the portion of space occupied by items on truck in order to allocate the emission of it to the specific purchasing basket, in the replenishment transportation for the offline process and for the entire transportation in the case of online purchasing process. We obtained an average value for each product category through the following calculation:

$$\frac{average\ weight\ of\ truck\ *\ average\ utilization}{average\ item\ weight}$$

Data	Value	Unit of measure	Source
Average weight truck (12 tonnes)	5.540	kg	https://www.tdbg.de/it/assistenza/mezzi-di-trasporto-e-container/ [43]
Utilization	90	%	Primary data

Table 6-6: Average weight truck (12 tonnes)

The table here below summarizes the values obtained for each product category.

Product category	Value	Unit of measure
Clothing, accessories, footwear	0.0060	%
Cosmetics products	0.0001	
Books	0.0060	
Electronics	0.1002	
Construction products, gardening, DIY, joinery, lighting	0.0601	
Stationery	0.0001	
Food & beverage	0.0010	

Table 6-7: Percentage of truck space occupied by an item per product category

An additional and fundamental input data is the value of return rate for each product category. In the case of offline purchasing process, we refer to return only to the case in which the product is defective or unliked by the customers, while in the online process the return is triggered by two main events: defective product or failed (first or second) delivery. The table below summarizes the value we used in the assessment: for each product category return rate, we relied on data obtained through the results of the survey diffusion.

Product Category	Offline Return Rate	Online Return Rate	Unit of Measure	Source
Clothing, accessories, footwear	3.37	6.25	%	Primary data
Cosmetics products	0.85	0.63		
Books	0.50	0.40		
Electronics	1.03	1.17		
Construction products, gardening, DIY, joinery, lighting	0.80	0.59		
Stationery	0.27	0.38		
Food & beverage	0.35	0.50		

Table 6-8: Offline and Online Return Rate per product category

6.3.2 Online input data

After making an overview of the calculation of all the data used in our model, in this section we explain in detail the input data used in the CO2 quantity assessment of the online purchase process and how they are computed. First of all, as previously mentioned, the phases considered are the following ones:

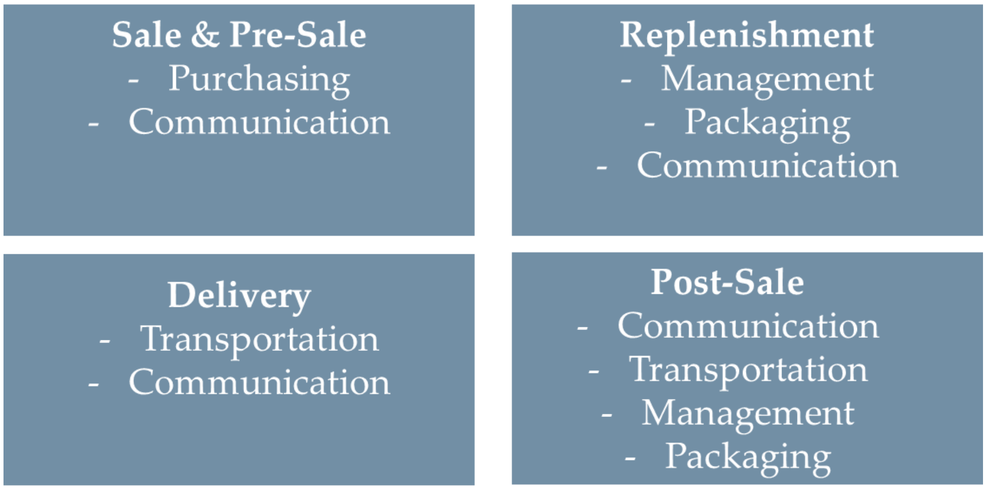


Figure 6-1: Online purchasing process phases and activities

In order to start the analysis in the online purchasing process scenario, the user has to declare different typologies of input data. To be clear in the explanation, we divided the data in three macro-categories: *activity durations data*, *packaging data* and *transportation data.*

Activity durations data. For the phases of *Purchasing*, *Communication* and *Management* we have estimated, for each sub-activity involved, its duration, in order to evaluate the energy consumed during the use of such devices (Weber, Koomey, and Matthews, 2010 [107]). In the tables below it is possible to view all the values assigned to each activity and the linked explanations. Starting from the Sale & Pre-Sale process all the activity durations are shown in the table below.

Purchasing phase	**Activity Duration**	**Unit of Measure**
Online products search on search engines or comparison websites	10	
Customer re-direction to the retailer website	3	
Product insertion into cart	1	min
Product insertion into cart	1	
Payment info insertion	2	

Table 6-9: Sale & Pre-Sale purchasing activities duration

Communication phase	Activity Duration	Unit of Measure
Info request to retailer	1	min
Answer to consumer request	1	
Info insertion and interaction with the retailer	1	
Interaction with the customer about data to insert	1	
Payment confirmation mail	1	

Table 6-10: Sale & Pre-Sale communication activities duration

These values consider the average time that a customer takes to place an online order, starting from researching and choosing the product, placing the order on the platform, and paying online. Therefore, the estimated total duration for the purchasing phase is 17 minutes per order. Furthermore, during the purchase and product selection phase, the customer may need to contact the retailer to ask for information on the products to be purchased or the payment method. Since not all customers contact the retailer, the average duration of these activities is equivalent to 5 minutes for each order placed on the platform.

Instead, considering the Replenishment phase, the activity durations are the following ones.

Management phase	Activity duration	Unit of measure
Replenishment order emission	1	min
Replenishment order reception and management	1	
Order fulfilment	3	
Picking list emission	1	

Table 6-11: Replenishment management activities duration

Communication phase	Activity duration	Unit of measure
Information request about delivery	1	min
Interaction with the warehouse about delivery	3	
Tracking service activation	1	

Table 6-12: Replenishment communication activities duration

We identified these values, considering that most of the companies today work with advanced information systems and tools that make these activities almost automatized. The warehouse receives the order through the system used by the company and, subsequently, once the information is received, the order is prepared. Therefore, the total estimated time is 6 minutes per order. For the *communication* phase, on the other hand, as in the Sale & Pre-Sale process, the request for information and interaction with the warehouse may not occur while the parcel tracking activity takes place, in most of the companies, automatically through dedicated tools. So, the total duration estimated is 5 minutes per order.

Concerning the Delivery process, the activities in the *communication* phase are estimated as in the Replenishment.

Communication phase	Activity duration	Unit of measure
Information request about delivery	1	
Answer to customer request (e.g. on delivery process)	3	min
Tracking service activation	1	

Table 6-13: Delivery communication activities duration

Finally, the last process is the Post-Sale one.

Communication phase	Activity duration	Activity duration
Information insertion about return	1	
Confirmation mail sending	1	min
Tracking service activation	1	

Table 6-14: Post-Sale communication activities duration

Management phase	Activity duration	Activity duration
Return reception and management	10	min

Table 6-15: Post-Sale management activities duration

Post-sale activities may not even occur. In particular, if the item is not compliant, firstly, the product is inserted as a returned item in the company application or website, then the customer receives an email confirming the desire to return the product and finally the return of the package is tracked. All these activities have an average duration of 3 minutes. When the customer decides to return the products or the delivery fails, the items must also be managed at the reception level in the warehouse or in the store and therefore we have estimated this activity to last on average 10 minutes, considering the low percentage of times in which the products are returned to the retailer.

Packaging data. The other category of input data used in the online purchase process concerns the *packaging* phase. In the previous section, the procedures used to calculate the amount of CO2 emitted by the use of packages for each type of material were explained. For the online packaging consumption, we assumed that the orders are packaged using cardboard box and therefore the input data used are the following:

	Values	Unit of measure
Cardboard box	1.127	kgCO2e/kg
Average size of corrugated cardboard box	0.16xf	kg

Table 6-16: Online packaging factors

Transportation data. Finally, the last category of input data, used only in the online scenario, regards the *transportation* phase. Considering the specific application context, with the virtual shopping cart consisting of 1 purchase of 3 clothing items, 1 purchase of 2 books and 1 purchase of 1 electronic item, we decided to set, for the online process, the vehicle CO2 emission of the means of transportation as follows. So, for the Van, we used the average value between diesel and petrol vans belonging to classes I, II and III. While, for the truck we considered the scenario where it is not refrigerated, and the engine is diesel. Finally, for passenger transport we calculated an average value between cars and motorcycles as it is explained in section 6.3.1.

Lastly, we set the average distances between warehouses, customers' houses and pick-up points. In order to find the values of these distances we relied on the paper *E-grocery: comparing the environmental impacts of the online and offline purchasing processes*, (Chiara Siragusa & Angela Tumino [91]*)*; in which they defined the *average last mile delivery route distance* equal to 60 Km. So, in our model we identified the average distance between the local warehouse and the customer's house as 30 km. Then, the second step was to calculate the mean value of distance between the central warehouse and the local warehouse, and the value set is 50 Km. For calculating the distance between CW and customer's house instead, we summed-up the average distance between LW to the final customer and CW to LW. So, the value is 80 km.

$$Avg\ distance\ CW - house = \text{Avg}\ distance\ LW - house\ - \text{Avg}\ distance\ CW - LW$$

Then, in the scenarios with the pick-up points, we defined the mean value between the collection point and the customer's home as a round trip of 2 km because the PPs are placed within the town. So, the distance from LW and PP is computed as:

$$Avg\ distance\ \text{LW} - \text{PP} = \text{Avg}\ distance\ LW - house\ - \text{Avg}\ distance\ PP - house$$

Finally, the distance from central warehouse and the collection point is 78 km, computed as the sum of the average distance from CW to LW and the average distance from LW to PP.

$$\text{Avg distance CW} - \text{PP} = \text{Avg distance CW} - \text{LW}\ - \text{Avg distance LW} - \text{PP}$$

The table below summarizes the values of the average distances already discussed.

Distance	Values	Unit of measure
Central Warehouse - House	80	km
Central Warehouse - Local Warehouse	50	
Local Warehouse - House	30	
Central Warehouse – Pick-up Point	78	
Pick-up Point - House	1	
Local Warehouse – Pick-up Point	28	

Table 6-17: Distance values between nodes in distribution network configurations

6.3.3 Offline input data

In order to start the analysis in the offline purchasing process scenario, the user has to declare different typologies of input data. To be clear in the explanation, we divided the data in three macro-categories: *activity durations data*, *packaging data* and *transportation data.*

Activity duration data. For the phases of *Management and Communication*, in the Replenishment phase, we estimated for each activity involved, its duration.

For management:

- Replenishment order emission = 1 min;
- Replenishment order reception and management = 1 min;
- Order fulfilment = 3 min;
- Picking list emission = 1 min;
- Goods reception and management in the store reserve area = 10 min.

For communication:

- Info request about delivery = 1 min;
- Interaction with POS about delivery = 3 min;
- Tracking service activation = 1 min.

As explained for the online input data, we identified these values, considering that most of the companies today work with advanced information systems and tools that make these activities almost automatised.

In the traditional purchasing process scenario, in addition to the general input data and replenishment activity data, previously described, the user has to declare two types of distance value: the values of the distance travelled to reach one or more shopping locations in the last mile phase, and the value of the distance travelled in the transportation of goods from the central warehouse to the store in the replenishment phase.

The value of the round-trip distance travelled to reach the store from warehouse was put equal to 120 km (60 km x 2): this is an approximated average value between the distance values related to the different distribution configurations described in the online scenario. As shown in Table 6-17, we assume that the average distance between a generic central warehouse and customer's house is about 80 km, while, between a local warehouse and customer's house, is about 30 km. We used the following formula to obtain the final distance value:

$$\frac{(Distance\ CW{-}HOUSE + Distance\ LW{-}HOUSE\ )}{2} + 5\ km$$

With a correction factor = 5 to consider eventual distortions.

The value of the last mile distance chosen for our analysis is an average value that can fall in one of the following range of values (defined in the preliminary design model phase):

- Distance < 5 km;
- 5 km < Distance < 20 km;
- Distance > 20 km.

For simplicity in the calculation, we assumed for each of this range an average value: 2.5 km for the first range, 12.5 km for the second one, and 30 km for the third one. So, we tested the impact of these three distance scenarios in three different situations:

- Stores located in one single location;
- Stores located in two different locations;
- Stores located in three different locations.

In the case of multiple locations, we thought that a number of locations visited in a shopping trip greater than three was unrealistic. Moreover, in the case of multiple locations, we hypothesized that the customer always moves from the nearest location to the farthest one, so the value of kms travelled to reach the second location must not be lower than the value of kms travelled to reach the first one, and the same for the third location with respect to the second and the first one. Only more frequent and realistic scenarios have been considered in the analysis: for example, it is very improbable that if the customer visits three different destinations in a single trip he/she travels a distance higher than 20 km to reach each of them.

It is necessary to specify that in case in which the three purchases are realized separately we considered only the one location scenario for each purchase. And in case of two purchases-combination (2 trips for the three purchases), only the single and 2-locations scenario are considered, since in one trip no more than two purchases are realized. The table below summarizes all the scenarios tested.

Single Shopping Location	Multiple Shopping Location (2)	Multiple Shopping Location (3)	Unit of Measure
2.5 12.5 30	2.5+2.5 2.5+12.5 2.5+30 12.5+12.5	2.5+2.5+2.5 2.5+2.5+12.5	km

Table 6-18: Offline distance scenarios

6.4 Computation analysis of the online process

To understand which of the two processes (online vs offline) is more sustainable, and to make our output as general as possible, we analysed different scenarios. We initially created three standard purchases that reflect the reality of our survey:

1. average purchase composed of three items of the fashion world = average purchase 1;
2. average purchase consisting of two items related to the book world = average purchase 2;
3. average purchase consisting of an item related to the world of electronics = average purchase 3.

Subsequentially, we calculated the CO2 emissions for each of the following purchases, as if they have been purchased separately on three different websites at three different times. Then, we compared that scenario with the outcome of the scenario where all three purchases were made at the same time on the same website. Finally, we have calculated the cases in which two of these purchases were made on a website, as a single order, and the third in a second moment on another website.

So, in the end five macro-scenarios are examined, and for each one some sub-scenarios related to the distribution configurations that the retailer considers and the different return process that the customer performs, are then analysed. So, once all the input data are entered, the results have been analysed and discussed for all the scenarios considered. In this section the analysis of the online process, is organised as follows: for each of the process phase, the results in term of kgCO2e are shown and discussed, comparing the five scenarios.

Sale & Pre-Sale. After entering the input data into our model, explained in section 6.3, we analysed the results by comparing:

- the option in which the customer buys the three average orders separately, on three different websites;
- the option in which the customer made a unique single order on a unique platform, composed by all three average purchases;
- The option in which the customer buys on a unique website the average purchase 1 and 2 while the item related to the electronics (average purchase 3) in another website;
- The option in which the customer buys on a unique website the average purchase 2 and 3 and the average purchase 1 in another website;
- The option in which the customer buys on a unique website the average purchase 1 and 3 while the two books (average purchase 2) in another website.

The result of this analysis is that the "Single order on one website" option is better in terms of CO2 emitted. In particular, by analysing in detail the two phases of the sale and presale, it can be seen that the *communication* phase has an impact in this sense. In particular, for the *purchasing* phase the CO2 emitted is the same in all the cases**.** In fact, the activities considered in this phase depend on the number of items, which is the same in both scenarios (whether you buy six items on a single site or if you buy them on three different sites or two websites). Therefore, the result does not change when the number of websites visited varies (see formula in chapter 5.5).

Instead, for the *communication* activities the results differ depending on whether one, two or three websites are used. The CO2 emitted is higher in the scenario where the three orders are placed on three different websites. This is due to the fact that the communication phase activities, as the information request to retailer, the answer to consumer request and the payment confirmation mail, occur only once if the order is placed entirely on a website. On the contrary, there are three different payments with three different emails and three different data entries (such as address, postcode) in case you use three sites., the same reasoning for the two websites. The tables below summarize the results already shown.

	Multiple orders_3 websites	Single order_1 website	Unit of Measure
Purchasing phase	0.0966	0.0966	kgCO2e
Communication phase	0.0426	0.0142	
Total	**0.1392**	**0.1108**	

Table 6-19: Purchasing and Communication TOT EI - 3 websites/1 website

	Clothing + Books /Electronics	Books+ Electronics /Clothing	Clothing + Electronics /Books	Unit of Measure
Purchasing phase	0.0966	0.0966	0.0966	kgCO2e
Communication phase	0.0284	0.0284	0.0284	
Total	**0.125**	**0.125**	**0.125**	

Table 6-20: Purchasing and Communication TOT EI - 2 websites

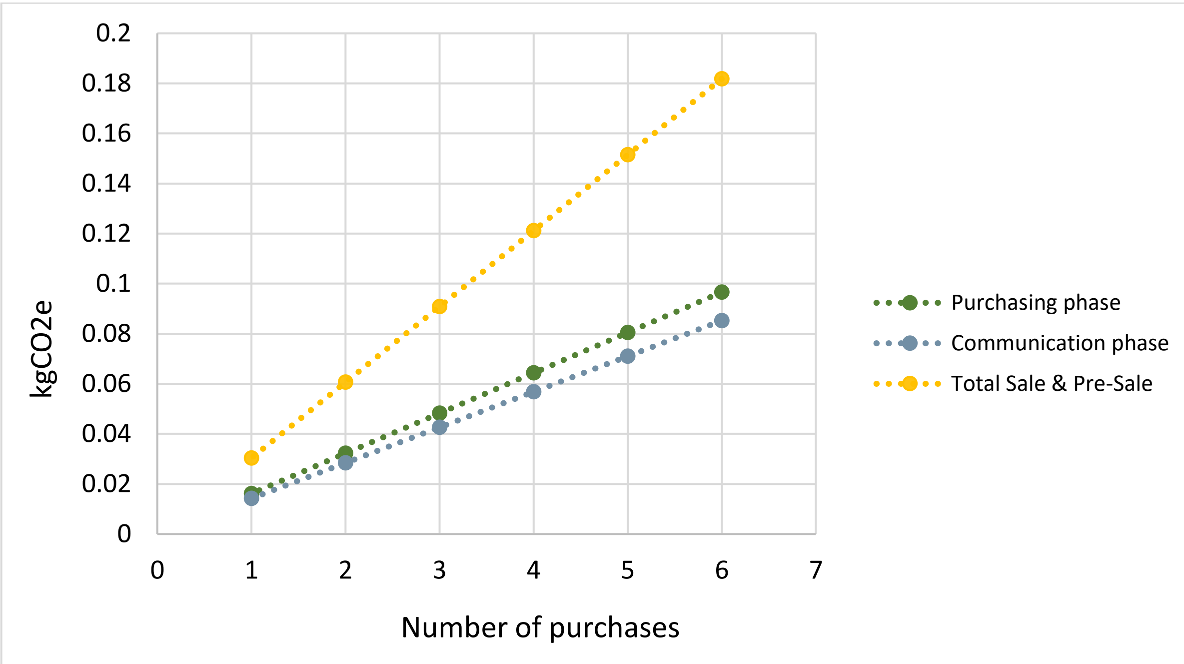
So, the Single order_1website scenario is more environmentally sustainable in term of kgCO2e emitted. This discrepancy between the results, which is minimal in the case considered, increases as the number of websites visited increases, so the more purchases are made on a single site, the less CO2 is emitted in the Pre-Sale & Sale phase.

To better analyse the trend of how the kgCO2e increase with the increasing of the orders, we compared the results in term of kgCO2e in the 1 website and *n* websites situations. In particular the graph 6-1 represents the kgCO2e in the Pre-Sale & Sale divided into the two contributors (Communication and Purchasing phase) in the situation in which the customer made:

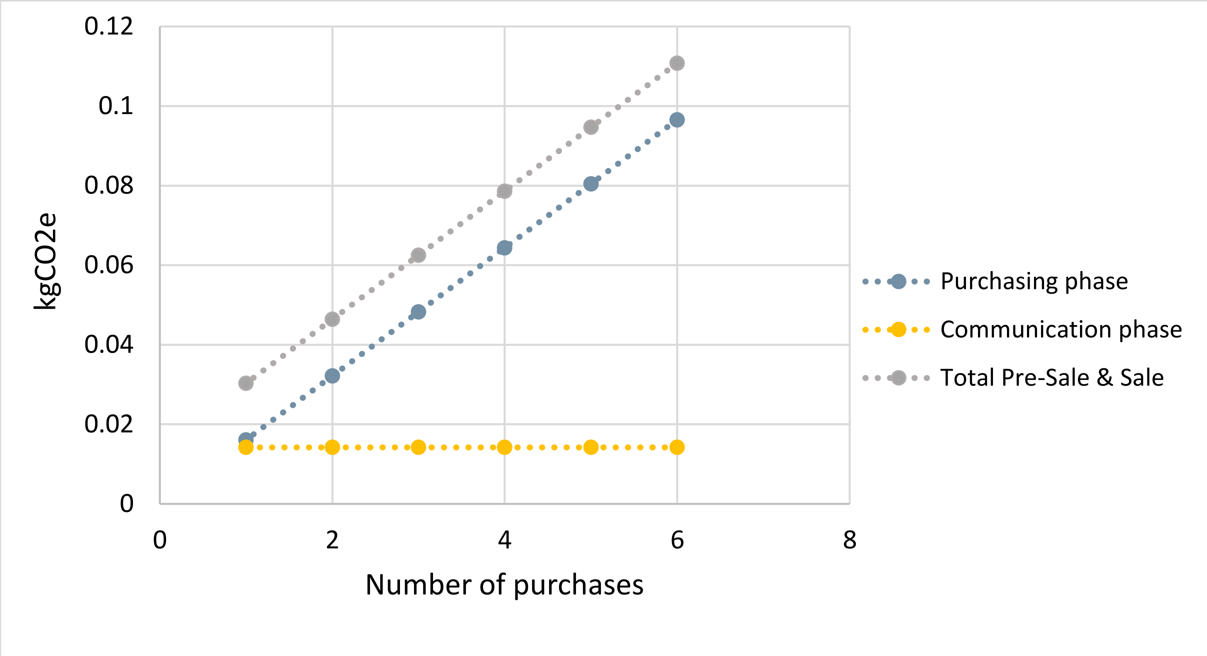
- 1 purchase of 1 item on 1 website;

- 2 purchases of 1 item per order on 2 websites;
- 3 purchases of 1 item per order on 3 websites;
- 4 purchases of 1 item per order on 4 websites;
- 5 purchases of 1 item per order on 5 websites;
- 6 purchases of 1 item per order on 6 websites.

The second graph instead, represent the 1 website case, in which the customer made on a unique website a purchase composed by 1 item, 2 items, …, 6 items.



Graph 6-1: Pre-Sale & Sale trend_n websites



Graph 6-2: Pre-Sale & Sale trend_1 website

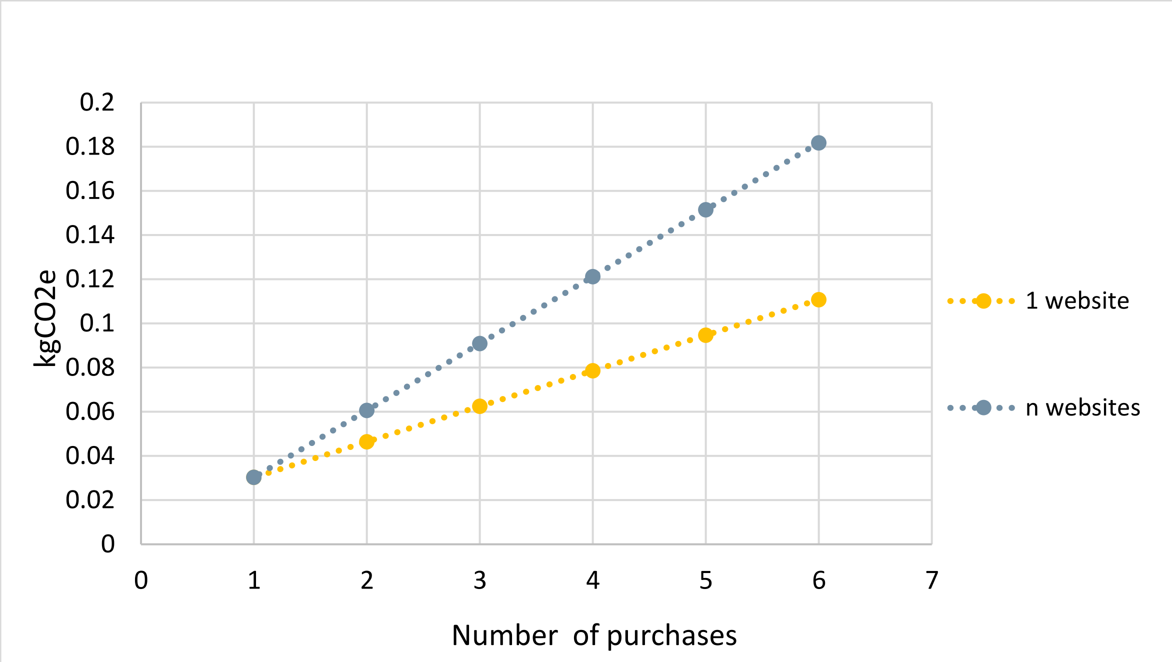
As discussed before, the communication phase emissions are constant in the 1 website scenario, while there is a linear increase in the multi-website ones. So, as it is shown in the following graph, the line of the multi-website scenario has a greater slope respect to the 1 website one.

These are the two equations of the straights:

$$\textit{Multi-websites}\text{: } y = 0.0302979734\, x$$

$$\textit{1 website}\text{: } y = 0.0160957984\, x + 0.0142022$$

Consequently, by increasing the number of purchases, the line representing the CO2e emitted in the multi-website scenario has a slope of **88%** more than in case of 1 website. So, if the number of purchases realized increases, the higher the number of websites the customer relies on, the higher the increase in the quantity of CO2 emitted.



Graph 6-3: Pre-Sale & Sale trend comparison between 1 website and n websites

Replenishment. The next step was to analyse the second phase of the online purchase process, the warehousing phase, which is composed of the following activities:

- Management phase;
- Warehouse/ Handling phase;
- Packaging phase;
- Communication phase.

In particular, in the warehousing phase, the same amount of CO2 is emitted in all the scenarios (1 website or multiple websites). In fact, also in this case the formula considers the number of items, and the CO2 is calculated on the single item, therefore buying from one or more websites does not alter the results. Furthermore, as explained in the previous section 6.2, the CO2 emissions of this phase are not included in our analysis because of the unavailability of data as the picking consumption per piece and the warehouse daily energy consumption that differs basing on the level of automation of the warehouse (automated or manual warehouse), its size but also the typology of product stored in the storehouse.

Instead, as regards the *Management phase* that encompasses activities as the replenishment order emission, reception and management, the order fulfilment and the picking list emission and the *Communication phase* with activities as the interaction with the warehouse about delivery and the tracking service activation, it is possible to repeat the same reasoning previously explained in the Sale & Pre-Sale phase. In particular, a single order is created, a single picking list and a single order receipt occurs in the event that all six items are purchased on a single site while three different items will occur if they are on three sites. Furthermore, if the entire order is placed on a single platform, the customer contacts the warehouse only once to request information on shipping and parcel. Same reasoning if the customer uses two websites.

The *packaging*, on the other hand, has a huge impact. The difference in the results is given by two main aspects:

- the size of the packaging which depends on the type of products. In fact, we considered different size for the different typologies of products involved in the analysis, it is reasonable to think that the packaging size of a shirt is different from the packaging of a television or a book. In this perspective, the CO2 related to quantity of packaging [kgCO2/cardboard] vary, as it is explained in the section 6.3;
- the fact that having different deliveries, the number of cartons used increases compared with the scenario with only one delivery is made. In fact, we considered that for each shipment a number of cartons equal to the number of items plus one is calculated, which contains the entire content of the order.

Therefore, in the case of three purchases on three websites the packaging computation is:

$$\text{N. of cardboard} = 3\text{ cardboards } + 1(\text{Avg. purchase } 1) + 2\text{ cardboard} + 1(\text{Avg. purchase } 2\ ) + 1\text{ cardboard} + 1(\text{Avg. purchase } 3\ ) = 9\text{ cardboards}$$

While, in the case of tree orders (six items) are made on one website:

$$\text{N. of cardboard} = 6\text{ cardboards (one for each item)} + 1(\text{final package}) = 7\text{ cardboards}$$

Instead, in the case in which the customer buys 3 clothes and 2 books on a single site and the electronic products on another website:

$$\text{N. of cardboard} = 5\text{ cardboards (one for each item)} + 1(\text{final package}) + \ 1\text{ cardboard} + 1(\text{Avg. purchase } 3) = 8\text{ cardboards}$$

In the scenario in which the customer buys 1 electronic item and 2 books on a single site and 3 clothes on another website:

$$\text{N. of cardboard} = 3\text{ cardboards (one for each item)} + 1(\text{final package}) + \ 3\text{ cardboard} + 1(\text{Avg. purchase } 1) = 8\text{ cardboards}$$

In the scenario in which the customer buys 1 electronic item and 3 clothes on a unique website and 2 books on another website:

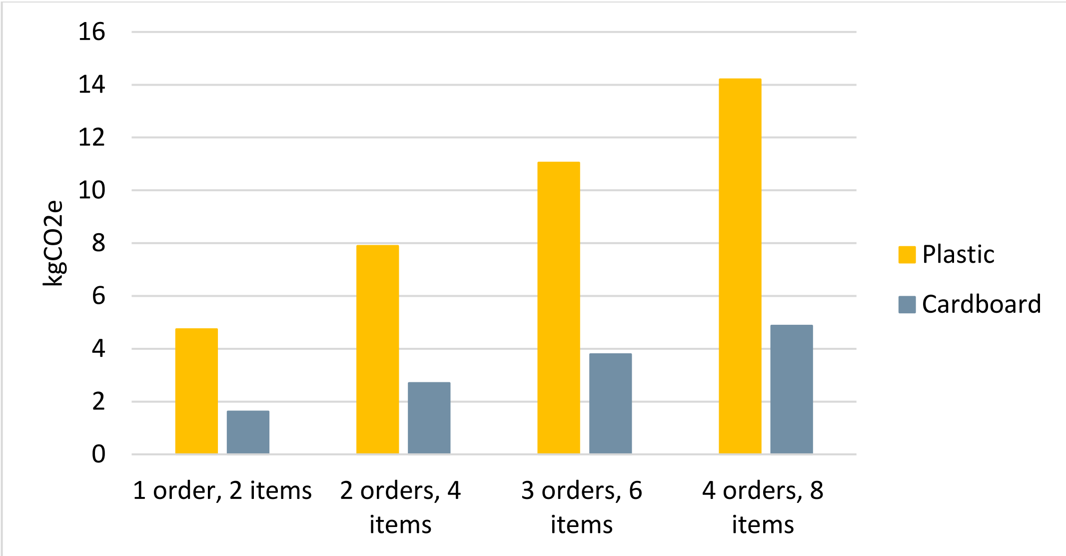
$$\text{N. of cardboard} = 4\text{ cardboards (one for each item)} + 1(\text{final package}) + \ 2\text{ cardboard} + 1(\text{Avg purchase } 2) = 8\text{ cardboards}$$

In the calculations, we used an average size and weight for the package of each products category, even if in the reality the size can have different dimensions and the items can be packaged with packaging of different materials.

If we consider the usage of plastic packages the results change significantly. In fact, the analysis we computed is to compare plastic and cardboards packages both in the single website and multi-websites scenario using different virtual shopping carts related to the world of clothing, as:

- 1 order of 2 items;
- 2 orders of 2 items per order;
- 3 orders of 2 items per order;
- 4 orders of 2 items per order.

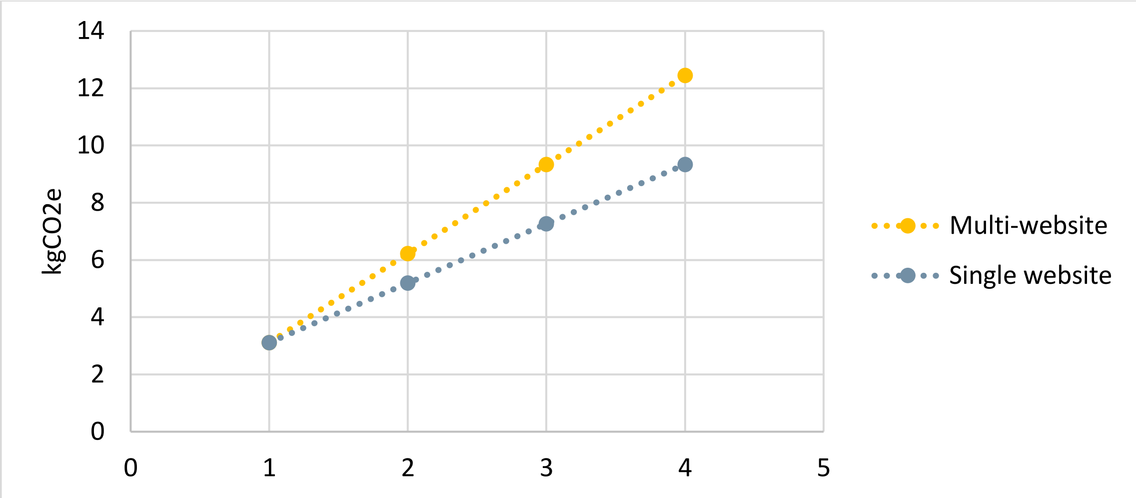
The results show that the plastic packages have a huge impact in terms of CO2e respect to cardboards (as it is shown in the graphs below).



Graph 6-4: Packaging material impact - Single website scenario

Graph 6-5: Packaging material impact - Multi-website scenario

Furthermore, it is interesting to notice that comparing the DELTA between the values of kgCO2e of the plastic and cardboards packages in the two scenarios, in the multi-website perspective the kgCO2e increases with a greater slope respect to the single website perspective.



Graph 6-6: Comparison of DELTA values of Packaging material impact

In the following tables are reported the kgCO2e emitted in both scenarios divided by plastic and cardboard packages.

Multi-websites	Plastic	Cardboard	DELTA	Unit of Measure
1 order, 2 items	4.734	1.623	3.111	kgCO2e
2 orders, 4 items	9.468	3.246	6.222	
3 orders, 6 items	14.202	4.869	9.333	
4 orders, 8 items	18.936	6.491	12.444	

Table 6-21: Packaging materials emission values (multi-websites scenario)

Single-website	Plastic	Cardboard	DELTA	Unit of Measure
1 order, 2 items	4.734	1.623	3.111	kgCO2e
2 orders, 4 items	7.89	2.705	5.185	
3 orders, 6 items	11.046	3.787	7.259	
4 orders, 8 items	14.202	4.869	9.333	

Table 6-22: Packaging materials emission values (single-website scenario)

Finally, the table below represents the results split to the considered phases for all the scenarios and also in the Replenishment phase the single website is more sustainable in term of CO2 gas emissions.

	Multiple orders_3 websites	Single order_1 website	Unit of Measure
Management phase	0.0341	0.0114	kgCO2e
Packaging phase	4.1474	3.1556	
Communication phase	0.0142	0.0047	
Total	**4.196**	**3.1717**	

Table 6-23: Management, Packaging, and Communication TOT EI - 3 websites/1 website

	Clothing + Books /Electronics	Books+ Electronics /Clothing	Clothing + Electronics /Books	Unit of Measure
Management phase	0.0227	0.0227	0.0227	kgCO2e
Packaging phase	3.8228	3.6064	4.3728	
Communication phase	0.0095	0.0095	0.0095	
Total	**3.8850**	**3.6386**	**4.4049**	

Table 6-24: Management, Packaging, and Communication TOT EI – 2 websites

Delivery. This phase in the online purchase process consists of transport and communication activities. The model takes into account all transport activities: from when the goods leave the warehouse until the delivery to the end customer. The transport from the production site to the warehouse was not taken into consideration because it is not a difference between the two online and offline processes. Furthermore, this component of transport is not differential even within the two purchasing processes. In fact, there is not any impact of the final consumer on the management of transport from the production plant to the warehouse and therefore the results do not vary depending on whether we are in scenario "single website" or "multi-website". Furthermore, the results do not vary, even if in the offline purchase process, the consumer uses a dedicated journey to make the purchase or a combined one. Therefore, considering the transport from the warehouse to the final customer, in the case different virtual carts, we have analysed how the different distribution configurations, influence the results and therefore which of these has a greater impact in terms of CO2 emitted. First of all, the general formula for calculating the kgCO2e emitted in the transport phase considers:

$$\text{Vehicle CO2/km} * \text{Avarage distance travelled} * \text{ \% space occupied/item } * \text{\#items/purchase}$$

This generic formula varies as the distribution configurations vary, as explained in chapter 5.4.1. What can be noticed is that in the scenarios where the package is sent directly to home by the retailer, there is no difference between the use of a single platform or several different websites. This is because the kgCO2e emitted are calculated on the single item, considering the percentage of space it occupies inside the truck. So, at transport level, there is not any difference if we consider the scenarios in which the transport is entirely entrusted to the company, since the truck is in any case saturated, regardless of the number of purchases that the individual customer buys. Instead, the customer behaviour has an impact on the results considering the three scenarios in which the pick-up point is present. In fact, the customer goes to the collection point and therefore in this case the difference between a website and multiple websites lies in the fact that in the first case the customer makes only one trip to the pick-up point instead of lots of trips in the second case.

Let's now analyse in more detail all the results of the six distribution configurations, starting from the first three configurations:

- The first scenario is that the company delivers directly from the central warehouse (CW) to customers' home;
- The second scenario is that the company delivers firstly from the central warehouse to the local warehouse (LW) and then from LW to customers' home;

- The third scenario is that the company delivers directly from the LW to customers' home.

The worst option is identified in the first scenario (**0.1997 kgCO2e**), i.e. when the company uses only central warehouses. This is the case of a well-known Italian company Nespresso, which distributes its products directly from two central warehouses, one in Milan that covers the north Italy and one in Rome to supply southern Italy. Instead, the best options in terms of CO2 emissions are the second and third scenarios, namely the use of local warehouses. In particular, the value of the two scenarios may seem very different: **0.1425 kgCO2e** and **0.0177 kgCO2e** respectively. In reality, the second scenario considers both the presence of at least one central warehouse and one local warehouse, while in the third option do not exist any central warehouses. So, the average distance between the production plant and local warehouses is greater than the average distance between the plant and the central warehouse of the distribution configuration 2. So that, the lower results of the third scenario are due to the fact that in our analysis we do not consider the transportation from plant to the warehouse and so, if we compare the total distance from plant to final customer of both the scenarios the results should be similar. However, in general terms, the average distance between the customer and the central warehouse is higher when compared with the average distance between the local warehouse and the final customer, thus the first scenario is the worst.

Transportation phase	1 website	2 websites	3 websites	Unit of Measure
EI_DC1	0.1997	0.1997	0.1997	
EI_DC2	0.1425	0.1425	0.1425	kgCO2e
EI_DC3	0.0177	0.0177	0.0177	

Table 6-25: Transportation TOT EI – 1/2/3 websites – DC1/DC2/DC3

Considering instead the three scenarios in which the pick-up point is present, which are:

- the company delivers firstly from the CW to the pick-up point (PP) and then customer goes from home to the PP **(4)**;
- the company delivers firstly from the CW to the LW, then from the LW to the PP and then customer goes from home to the PP **(5)**;
- the company delivers directly from the LW to the PP and then customer goes from home to the PP **(6)**.

In those cases, the customer has an important role and the decision to buy on one website or on multiple websites has an impact on the CO2 emitted. The three-websites case leads to a greater amount of CO2 and in particular it is noted that the fourth scenario is the worst among all the cases in which PP is present, with an emission of **1.1876 kgCO2e**, **0.8567 kgCO2e** and **0.5257 kgCO2e** respectively for the three, two and one websites options. Instead, the option in which the company delivers directly from the LW to the PP and then customer goes from home to the PP is the best one, with a value of **1.0094 kgCO2e**, **0.6784 kgCO2e** and **0.3474 kgCO2e** respectively.

Transportation phase	1 website	2 websites	3 websites	Unit of Measure
EI_DC4	1.1876	0.5257	0.8567	kgCO2e
EI_DC5	1.1342	0.4723	0.8032	
EI_DC6	1.0094	0.3474	0.6784	

Table 6-26: Transportation TOT EI – 1/2/3 websites – DC4/DC5/DC6

An important aspect to highlight is how the kgCO2e emitted varies if we consider the case “one website” or “multiple website”. This is because the customer behaviour: if the customer makes a single trip to the pick-up point, the CO2 emitted will be lower than in the case in which he/she makes multiple trips.

Finally, for the *Communication* phase, the same reasoning of the communication phase in the Sale & Presale and Warehousing is computed. The activities considered are the customer's request about the delivery, the answer to the customer request and the tracking service activation and they occur only once if the order is placed entirely on a website. Below the total results of the delivery phase for all the five scenarios.

	Multiple orders_3 websites	Single order_1 website	Unit of Measure
Communication phase	0.0284	0.0095	kgCO2e
Transportation phase			
EI_DC1	0.1997	0.1997	
EI_DC2	0.1425	0.1425	
EI_DC3	0.0177	0.0177	
EI_DC4	1.1876	0.5257	
EI_DC5	1.1342	0.4723	
EI_DC6	1.0094	0.3474	

Table 6-27: Communication and transportation TOT EI – 3/1 websites

	Double order_ Clothing+ Books /Electronics	Double order_ Books +Electronics /Clothing	Double order_ Clothing +Electronics /Books	Unit of Measure
Communication phase	0.0189	0.0189	0.0189	kgCO2e
Transportation phase				
EI_DC1	0.1997	0.1997	0.1997	
EI_DC2	0.1425	0.1425	0.1425	
EI_DC3	0.0177	0.0177	0.0177	
EI_DC4	0.8567	0.8567	0.8567	
EI_DC5	0.8032	0.8032	0.8032	
EI_DC6	0.6784	0.6784	0.6784	

Table 6-28: Communication and transportation TOT EI – 2 websites

Post-sale. The post-sale process resumes phases similar to those previously analysed, which are:

- Communication phase;
- Transport phase;
- Management phase;
- Packaging phase.

As regards the *communication* and the *management* phase, the reasoning is the same as previously reported: placing the order on a single platform rather than making many orders on different websites leads to a lower consumption of CO2, since the number of times in which the activities take place (the insertion of information about return, the confirmation mail sending and the tracking service activation) is reduced. However, due to the different return rate of different product categories, in the two websites scenarios results vary by changing the mix of orders. In fact, considering the case in which the customer made a unique order with three items belonging the fashion industry and two items belonging to the books industry and another separate order with the electronic product, the CO2 emitted is different than the case in which the customer buys electronic and books in the same order and clothes in another website.

Also, for the *packaging* phase, a greater waste of CO2 is obtained by using different platforms, as explained before for the packaging in the replenishment phase.

	Multiple orders_3 websites	Single order_1 website	Unit of Measure
Management phase	0.0015	0.0007	
Packaging phase	0.1543	0.1104	kgCO2e
Communication phase	0.0002	0.0001	

Table 6-29: Management, Packaging, and Communication TOT EI – 3/1 websites

	Double order_ Clothing +Books /Electronics	Double order_ Books +Electronics /Clothing	Double order_ Clothing +Electronics /Books	Unit of Measure
Management phase	0.0010	0.0013	0.0010	kgCO2e
Packaging phase	0.1106	0.1450	0.1487	
Communication phase	0.0001	0.0002	0.0002	

Table 6-30: Management, Packaging, and Communication TOT EI – 2 websites

As regards the *transportation* phase, the analysis performed highlights several important aspects. First of all, the transport in the post-sale process is calculated taking into account different scenarios. In particular, we have considered two possible macro-scenarios for which a product is returned:

- ✓ the product is not compliant: there could be a quality problem, defects, but also problems related to wrong sizes etc.
- ✓ the customer is not at home during the delivery, so the delivery fails.

More in detail, in the analysis we considered the following sub-scenarios:

- ❖ Product not-complaint and customer returns the product to the store **(1);**
- ❖ Product not-complaint and customer returns the product to the pick-up point and then the retailer made a second delivery **(2);**
- ❖ Product not-complaint and customer returns the product to the pick-up point and then the retailer refunds money **(3);**
- ❖ Customer not at home during the first delivery while the second delivery does not fail **(4);**
- ❖ Customer not at home both during the first and second delivery **(5).**

In the first three scenarios, CO2 emissions vary depending on whether the model with one, two or three websites is adopted. This happens because the formulas with which the CO2 was calculated depend on the probability that ***an item*** is not compliant inside the order. Therefore, this probability has correlation with the fact that a user purchases from a single platform and so made a unique order or from multiple platforms. This difference is due to the fact that if for example we consider that a user buys six items on a unique platform, in a single order, the probability that one item is not compliant, and the customer decides to return it back is different than the probability that occurs if a customer makes six different orders with six different retailers. Furthermore, there may be a correlation in relation to the company that produces the products, which is the same whether the customer purchases from a generic platform (as Amazon) or from the company's private website. More in detail, however, it is possible to note, that the best case is the first scenario, in which the product is not complaint, and the customer returns the product to the store, that we hypothesized that is near the customer's home, in a range of maximum 7 km. The worst-case scenario is when the customer returns the defective product to the pick-up point and then a second delivery is made. Instead, if we compare the five different scenarios[11], as expected, the best scenario is buying on a unique platform, while the worst is buying on three different ones, as it is shown in the two tables below.

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[11] ***Multiple orders_3 websites***: the customer buys separately the three purchases on three different websites, in three different moments;
Single order_1 website: the customer buys all the three purchases on a unique website, with a unique order;
Double order_ fashion + books/electronics: the customer buys on one platform the purchases related to clothes and books and makes another order on another platform for the electronics product;
Double order_ electronics + books/fashion: the customer buys on one platform the purchases related to electronics and books and makes another order on another platform for the clothing products;
Double order_ fashion + electronics/ books: the customer buys on one platform the purchases related to clothes and electronics and makes another order on another platform for the books.

Transportation	Multiple orders_3 websites	Single order_1 website	Unit of Measure
Product not-complaint and customer returns the product to the store (1)	0.1830	0.0811	kgCO2e
Product not-complaint and customer returns the product to the pick-up point and then the retailer made a second delivery (2).	2.0003	0.6688	
Product not-complaint and customer returns the product to the pick-up point and then the retailer refunds money (3).	1.9930	0.6653	

Table 6-31: Transportation TOT EI – 3/1 websites – Return Conf. 1/2/3

Transportation	Double order_ Clothing +Books /Electronics	Double order_ Books +Electronics /Clothing	Double order_ Clothing +Electronics /Books	Unit of Measure
Product not-complaint and customer returns the product to the store (1)	0.1191	0.1615	0.1251	kgCO2e
Product not-complaint and customer returns the product to the pick-up point and then the retailer made a second delivery (2).	1.3369	1.3296	1.3375	
Product not-complaint and customer returns the product to the pick-up point and then the retailer refunds money (3).	1.3303	1.3267	1.3306	

Table 6-32: Transportation TOT EI – 2 websites - Return Conf. 1/2/3

Furthermore, the results of the two scenarios in which there is the eventuality that the first and also the second delivery could fail are analysed. In the scenario in which the customer is not at home during the first delivery and therefore the package is returned a second time, there are differences between the single website and multi-websites options, because even if the consumption of CO2 it is calculated on the single item that occupies a percentage of space inside the truck, the probability of delivery failure is different by making a single delivery for all the items instead of two or three deliveries. Furthermore, if also the second delivery fails, the package is transported with a third delivery to a collection point and the results differ, not only due to the different probability of occurrence but also because of the CO2 emitted by the customer to go to the PP. In the event that the customer had purchased from three different websites, the three packages would be at different times and/or in different collection points and therefore three different trips would be required to collect the purchases. On the contrary only one trip to the pick-up is needed in the single website scenario or two in the double website one. Below the results in absolute term of the kgCO2e emitted during all the options are reported.

Transportation	Multiple orders_3 websites	Single order_1 website	Unit of Measure
Customer not at home during the first delivery (4)	0.0035	0.0016	kgCO2e
Customer not at home both during the first and second delivery (5)	2.0036	0.6704	

Table 6-33: Transportation TOT EI – 3/1 websites – Return Conf. 4/5

	Double order_ Clothing +Books /Electronics	Double order_ Books +Electronics /Clothing	Double order_ Clothing +Electronics /Books	Unit of Measure
Customer not at home during the first delivery (4)	0.0031	0.0014	0.0033	kgCO2e
Customer not at home both during the first and second delivery (5)	1.3399	1.3309	1.3406	

Table 6-34: Transportation TOT EI – 2 websites - Return Conf. 4/5

6.5 Computation analysis of the offline process

Once all the input data are entered, the results have been observed, analysed and discussed for each scenario set, according to the type of trip (dedicated/non-dedicated) and the value of the distance travelled by the customer during the trip.

The results have been analysed according to different perspectives, in order to comprehend the impact on different phases and activities of the process. Hence, the value of the Environmental Impact in terms of CO2 emission (EI) has been expressed in three ways:

- *TOTAL EI*: including last mile transportation emissions, packaging consumed in the last mile, store replenishment transportation emissions, management and communication activities in the replenishment phase, packaging consumed in the replenishment phase, return transportation emissions;
- *TRANSPORTATION EI*: including both last mile and store replenishment transportation;
- *POST-SALE EI*: including only return transportation to the store.

Three-trips scenario. The first scenario studied is represented by the case in which the three different purchases are made through three different shopping trips, so they are not combined in the same tour. The objective of this analysis is to understand how each product category contributes to the CO2 emissions generation. In addition, it is interesting to understand the percentage variation of the EI when the trip is dedicated or non-dedicated, and different distances are travelled.

Single shopping location	2.5	12.5	30
EI (Dedicated trip)	2.62	6.04	12.03
EI (Non-dedicated trip)	2.41	4.97	9.46

Table 6-35: TOT EI – 1 Trip – Clothing, accessories, and footwear

Single shopping location	2.5	12.5	30
EI (Dedicated trip)	1.33	4.65	10.47
EI (Non-dedicated trip)	1.12	3.61	7.98

Table 6-36: TOT EI – 1 Trip – Books

Single shopping location	2.5	12.5	30
EI (Dedicated trip)	1.79	5.14	10.99
EI (Non-dedicated trip)	1.58	4.09	8.48

Table 6-37: TOT EI – 1 Trip – Electronics

Single shopping location	2.5	12.5	30
EI (Dedicated trip)	**5.74**	**15.83**	**33.49**
EI (Non-dedicated trip)	**5.11**	**12.68**	**25.92**

Table 6-38: TOT EI – 3 Trip

By firstly considering each purchase separately from the other ones, it is possible to understand how results change according to the type of trip and the type of distance travelled by the consumer to reach the store. Considering clothing, the total EI varies from 2.41 kgCO2e/purchase in the more sustainable situation, to 12.03 kgCO2e/purchase, when the distance travelled is the longest one and the trip is dedicated. Regarding books, the results vary from 1.12 kgCO2e/purchase to 10.47 kgCO2e/purchase, while for electronics from 1.58 to 10.99 kgCO2e/purchase.

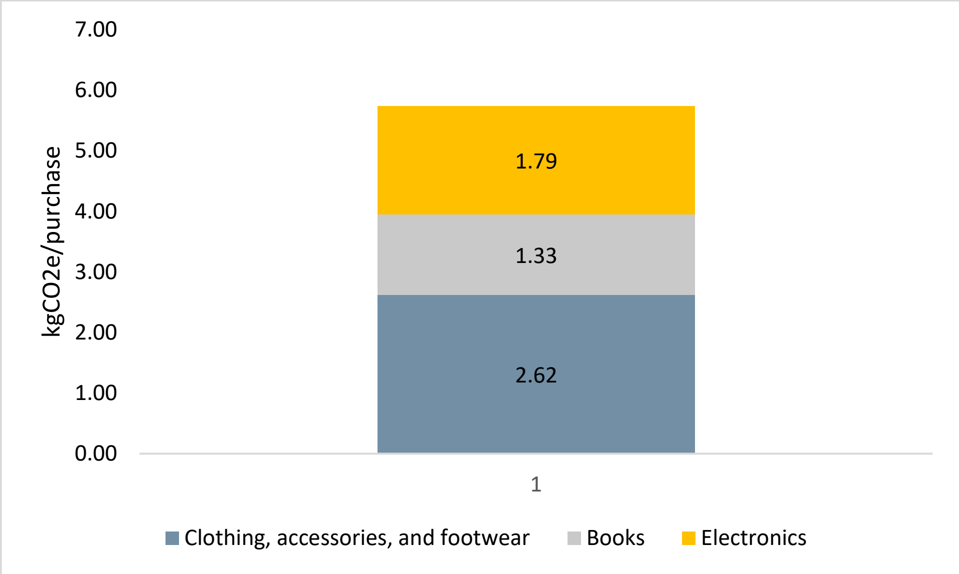
The average emissions saving passing from dedicated trip to non-dedicated trip is about 16% for clothing, 21% for books, and 18% for electronics. Considering the different distance travelled, the average percentual CO2 reduction passing from 30 km to 12.5 km and from 12.5 km to 2.5 km is about 51% for clothing, 63% for books, and

58% for electronics. Thus, it is clear how the EI value significantly increases if the customer opts for dedicated trips and longer distances.

In order to find the most impacting product category we compared the three avrege purchases from different perspectives: total EI, replenishment transportation, replenishment management and communication, return transportation, and replenishment packaging. The consumption related to last mile transportation and packaging is the same for all the purchases, since respectively the distance travelled and the number of bags consumed, are supposed to be the same. In addition, also regarding replenishment management and communication, the impact is the same since we supposed an average value for the duration activity equal for the three different product categories.

In order to compare the results between the different purchases, we take as reference case the one in which the customer decides to travel a distance lower than 5 km and chooses to dedicate the trip to the shopping activity. For the other five situations, the results are the same, but the order of magnitude changes.

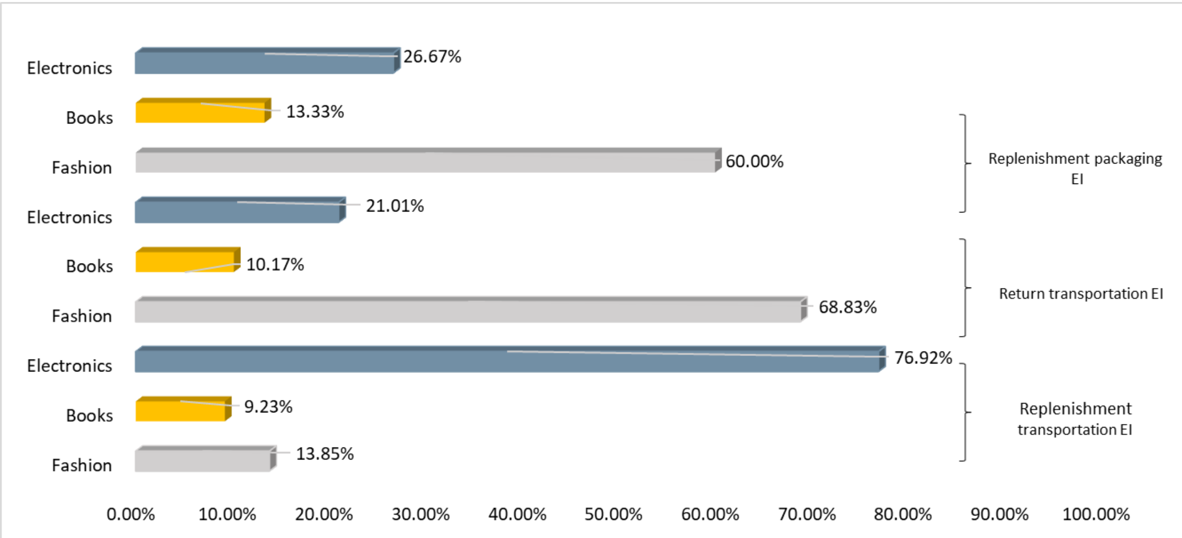
Regarding the total EI, the below graph shows the different contributions to the final value. It is possible to observe that clothing category purchase is responsible for about 46% of the total emissions, while books and electronics related purchases for about 23% and 31% respectively. So, clothing is the purchase which mostly impacts, secondly electronics, and lastly books purchase.



Graph 6-7: Total EI contribution of single purchases

But in order to understand the causes, we have to focus on the different activities and the related emissions. Starting from **replenishment transportation**, the values are different since the **percentage of space occupied by an item on the truck is different**. The results show that the most impacting purchase is the one related to electronics, contributing for about 80% to the total replenishment transportation emission, followed by fashion with about 14% and books with about 9%. This is due to the fact that electronics items occupy more space inside the truck used for replenishing the stores, so the related deliveries are more frequent. Regarding the emissions related to **return transportation**, we can notice that the most impacting purchase is the one related to fashion, contributing for about 69%, followed by electronics with 21% and books with about 10%. This is due to the fact that clothing industry is characterized by a higher return rate (3.4% in the offline purchasing process), while the return rate for books and electronics items is significantly low, equal respectively to 0.5% and 1%. Lastly, if we consider **replenishment packaging EI**, we see how also in this case, fashion purchase is characterized by the highest emissions value, contributing for 60% to the emissions, followed by electronics with about 27% and books with about 13%.

This is due to the quantity of cardboard material consumed during replenishment: 0.54 kgCO2e/clothing item for clothing, 0.18 kgCO2e/book item, and 0.72 kgCO2e/electronic item. Even if the highest unitary consumption is the one related to electronics (due to the averagely bigger size of the related items), a typical clothing purchase consists of three items, so the final material consumption is higher.



Graph 6-8: EI contribution per activity by each purchase

To sum up, we can state that the least impacting purchase is the one related to books, in all types of activity. On the contrary, clothing purchase is the most impacting, especially due to higher return rate, and also to more replenishment packaging material consumption. Electronics purchase is in an intermediate position, even if for the replenishment transportation represents the most impacting.

Two-trips scenario. The subsequent step consists in analysing the same three purchases combining two of them in one single shopping trip and to see how the total EI value changes with respect to the case in which the three purchases are realized through separate shipping trips.

Three different situations have been analysed:

- One shopping trip for clothing and book industry purchases and one for electronics purchase;
- One shopping trip for clothing and electronics purchases and one for books industry purchase;
- One shopping trip for book industry and electronics purchases and one for clothing purchase.

In this case, the objective of analysis is not anymore the product category and its impact on total emissions generated, but it concerns how the combination of multiple purchases may contribute to CO2 emissions saving.

In this situation, we also considered the case in which the two different purchases combined in one shopping trip are realized in different shopping locations (maximum 2). It has been estimated that the percentual reduction obtained, by looking to the base case scenario (distance lower than 5 km), is about **14%**, passing from 5.74 kgCO2e/3 purchases to 4.94 kgCO2e/3 purchases. And even higher, if the distance travelled is longer: about **26%** emission reduction if the distance is in the second range (between 5 and 20 km), and about **30%** if the distance value falls in the third range (longer than 20 km). Similar reductions occur in the case in which the trip is non-dedicated. The table below show the detailed value of total environmental impact generated by the three purchases, for each possible distance scenario.

Single shopping location	**2.5**	**12.5**	**30**	
EI (Dedicated trip)	4.94	11.68	23.47	
EI (Non-dedicated trip)	4.52	9.57	18.42	
Multiple shopping locations (2)	**2.5+2.5**	**2.5+12.5**	**2.5+30**	**12.5+12.5**
EI (Dedicated trip)	5.80	9.17	15.07	12.60
EI (Non-dedicated trip)	5.15	7.65	12.04	10.18

Table 6-39: TOT EI – 2 Trips

If we split the result among the different activities (last mile transportation, replenishment transportation, return transportation, last mile packaging, and replenishment packaging), we see how the total replenishment transportation emissions, last mile and replenishment packaging transportation emissions remain unchanged, while for the last mile and return transportation the emissions EI value change. Regarding last mile transportation the emissions are very different, because in the first case the same distance is travelled three times, while in the second case only twice. If, for example, we refer to the base case scenario (distance lower than 5 km and dedicated trip), the related percentual reduction is equal to **33%**. For return transportation the EI value passes from 0.04 kgCO2e/3 purchases to 0.03 kgCO2e/3 purchases since the model calculates the combination of trips also in the return process if more defective items need to be returned back.

If we consider the multiple destinations scenario, in case in which the customer travels two distances lower than 5 km, the combination results to be almost equivalent, while if distances travelled by the customer in the single trip to reach the two destinations becomes longer (for example, 2.5 + 12.5 or 2.5+30), we have a significant reduction of emissions (about 33%).

In conclusion, what can be deducted from this analysis is that combining purchases in one single trip makes the results more sustainable, since emissions are reduced, especially when long distances are driven, and it is more efficient to combine more impacting purchases.

One-trip scenario. The last step it is similar to the previous one: combining in one single shopping trip all the purchases and to see how results change with respect to both previous cases.

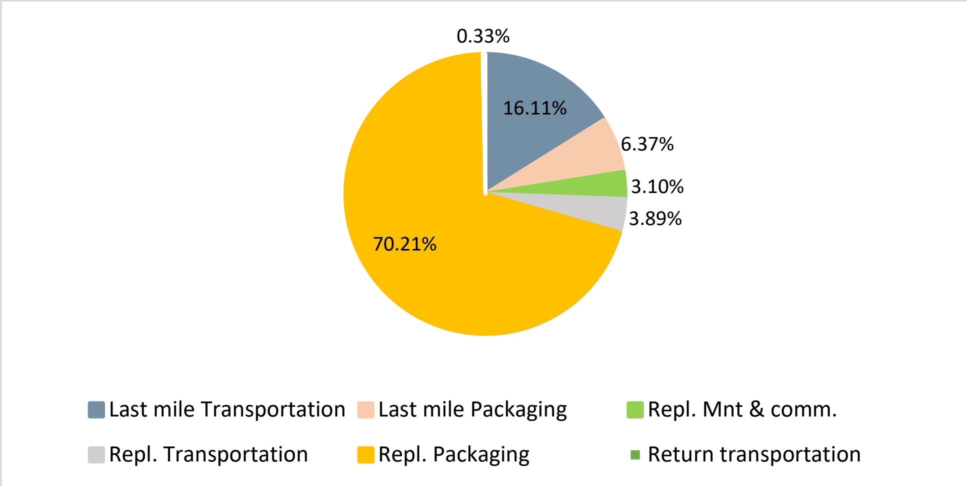
In the tables below, the results for each scenario are reported. The first aspect that has been observed regards the relation between distance value and EI value: as obviously predicted, the greater the distance travelled by the consumer the greater the quantity of CO2 emitted. Regarding the TOTAL EI values, in the single shopping location case, the value of EI varies from about **3.85** to **13.35 kgCO2e** averagely, while in the multiple shopping location situation the EI value varies from about to **4.48** to **14.21 kgCO2e** averagely. Regarding the TRANSPORTATION EI values, in the single shopping location case the EI value varies from about **0.77** to **10.08 kgCO2e** averagely, and from about **1.39** to **10.91 kgCO2e** in the multiple shopping location scenario. Concerning post-sale EI values, the quantity of CO2 emitted varies from **0.013** to **0.201** kgCO2e averagely in all scenarios.

The second direct observation regards the difference between dedicated trip scenario and non-dedicated trip scenario: in the first case the EI is higher than in the second case. More specifically, we calculated the average percentual difference between the two scenarios. Regarding single shopping location case, we observed a reduction of **12.78%** in the TOTAL EI value, **23.31%** in the TRANSPORTATION EI value, and **25%** in the POST-SALE EI value. Regarding the case in which two shopping locations are visited, we registered a reduction of **15.92%** in the TOTAL EI value, **24.10%** in the TRANSPORTATION EI value, and **25%** in the POST-SALE EI value. Lastly, if three locations are visited in the same trip, the percentual gaps between dedicated and non-dedicated trip are the following: **-13.33%** in the TOTAL EI value, **-23.97%** in the TRANSPORTATION EI value, and **-25%** in the POST-SALE EI value. By considering an average value for the TRANSPORTATION EI percentual reduction, equal to about **24%**, between dedicated and non-dedicated trip, we can observe how the customer's habits in this regard are very impacting on the total emissions generated. The problem is that the majority of customers (about 70%) prefers the dedicated trip option, while only 30% the opposite one. So, in order to significantly reduce CO_2 emissions, it is crucial to push customer in this direction: combine shopping to other activities.

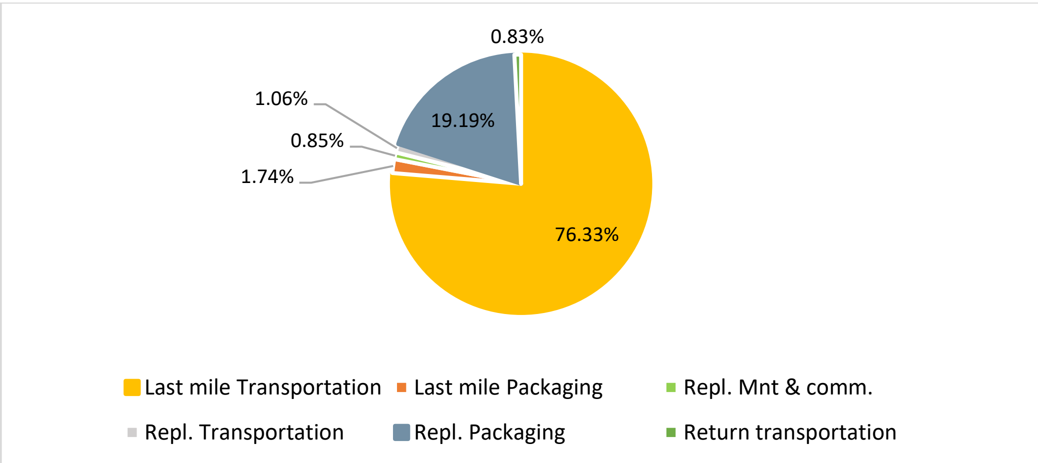
It is important to highlight those emissions related to **packaging** activity, equal to **0.245 kgCO2e** in the pre-sale, sale, and delivery phase, and **2.705 kgCO2e** in the replenishment phase, are not sensitive to the distance travelled by the customer, but they are constant since they only depend on the number of purchases and items for each purchase. The same is for **replenishment transportation** emissions: they are constant and equal to the value equal to **0.150 kgCO2e**, since, for simplicity, one only average scenario has been considered in the distribution network for the stores replenishment.

By observing the results, it is possible to assert that the *best scenario* corresponds to the situation in which the customer reaches one only location, to make his/her purchases through a non-dedicated trip (in the way back from another place), with a **TOTAL EI** equal to **3.85 kgCO2e** emitted, of which **0.77** related to transportation activity (**0.62 kgCO2e** in the **last mile transportation**). The emissions allocated only to **return transportation** is equal to **0.013 kgCO2e**. The *worst scenario* corresponds to the case in which the customer visits two shopping locations, travelling 2.5 km to reach the first destination and 30 km to reach the second one, through a dedicated trip, with a TOTAL EI equal to **14.21 kgCO2e** emitted, of which **10.91** related to transportation activity (**10.76 kgCO2e** in the **last mile transportation**). The emissions allocated only to **return transportation** is equal to **0.117 kgCO2e**.

By comparing the most sustainable scenario and the least one, it is fundamental to analyse how the different emissions calculated impact on the final EI value. The packaging consumed in each phase and the stores replenishment transportation are not sensitive to the scenario in terms of absolute value, but they change in relative terms. In fact, as shown in the graphs below, in the best case scenario (single destination, distance shorter than 5 km, non-dedicated trip) packaging impacts for **76.58%** (**6.37%** in the last mile, while **70.21%** in the store replenishment) and replenishment transportation for **3.89%,** while in the worst case (two destinations, first distance shorter than 5 km and second distance longer than 20 km, dedicated trip) scenario packaging impacts for **20.93%** (**1.74%** in the last mile while **19.19%** in the stores replenishment) while replenishment transportation for the **1.06%.** Regarding last mile transportation, it is possible to notice how in the best scenario its impact on the final result is very limited (**16.11%**) with respect to the worst scenario, when distances travelled become longer, in which the related impact is equal to **76.33%.** Also, for return transportation the entity of the value gap between the two scenario is the same and it is quite negligible with respect to other emissions values: **0.33%** in the best option, **0.83%** in the worst one. What can be deducted from these results is that when multiple purchases – three in this case study – represent the unit of analysis in the emissions assessment of a conventional purchasing process, if distances travelled are short (lower than 5 km) the difference between last mile transportation impact and replenishment transportation impact is not so large while when higher distances are driven by customer last mile transportation impact becomes much higher than the replenishment transportation impact.



Graph 6-9: Best case (single location, 2.5, non-dedicated) Activities impact



Graph 6-10: Worst scenario (two locations, 2.5+30, dedicated) Activity impact

This result shows how the concentration of different purchases in one trip leads to enormous environmental savings in the case in which stores are located in the same location. On the contrary, the more the longer the distance travelled and the more the destinations reached, the higher the impact of last mile on the total quantity of emissions generated. So, it is necessary to highlight that the reduction of last mile delivery emissions can be obtained only when a specific distance is travelled: the best scenario corresponds to the case in which the distance value falls into the first range – distance lower than 5 km – so, when the customer's house is probably located close to the city centre or in the proximity of a shopping mall.

By observing the results reported in Table 6-40, it is possible to assert that the single shopping location scenario remains the most sustainable one only if the distance value falls in the first range. For example, if we compare the case in which the customer reaches one only location situated at 12.5 km far away from his/her house, and the situations in which the customer makes the same purchases but in the 2.5+2.5 km shopping locations scenario, we can state that the single shopping location situation is not the most sustainable anymore. Respectively, the emissions obtained in the dedicated trip case are: **7.44 kgCO2e** and **4.92 kgCO2e**. The same occurs if we compare emissions in case of one single destination and distance travelled longer than 20 km, and three destinations but distances travelled shorter than 5 km: averagely **12.09 kgCO2e** in the first case and **5.42 kgCO2e** in the second one.

To sum up, we can undoubtedly affirm that the major determinant and affecting parameter is the distance travelled by the customer to reach the stores. The variability of EI value can be totally linked to the variability of distance value, through a correlation coefficient equal to 1 for each scenario. It becomes clear how the customer's purchasing habits, in the last mile phase, represent a fundamental aspect to study, monitor and influence in order to move towards more sustainable purchasing process. In this regard, we decided to observe how the results change if each EI value obtained is multiplied for the probability of occurrence of the scenario it belongs to.

Single shopping location	2.5	12.5	30	
EI (Dedicated trip)	4.06	7.44	13.35	
EI (Non-dedicated trip)	3.85	6.38	10.82	
Multiple shopping locations (2)	**2.5+2.5**	**2.5+12.5**	**2.5+30**	**12.5+12.5**
EI (Dedicated trip)	4.92	8.30	14.21	11.72
EI (Non-dedicated trip)	4.48	6.99	11.37	9.51
Multiple shopping locations (3)	**2.5+2.5+2.5**	**2.5+2.5+12.5**		
EI (Dedicated trip)	5.73	9.07		
EI (Non-dedicated trip)	5.11	7.60		

Table 6-40: TOT EI – 1 Trip

Single shopping location	2.5	12.5	30	
EI (Dedicated trip)	0.98	4.29	10.08	
EI (Non-dedicated trip)	0.77	3.25	7.60	
Multiple shopping locations (2)	**2.5+2.5**	**2.5+12.5**	**2.5+30**	**12.5+12.5**
EI (Dedicated trip)	1.80	5.11	10.91	8.42
EI (Non-dedicated trip)	1.39	3.87	8.22	6.36
Multiple shopping locations (3)	**2.5+2.5+2.5**	**2.5+2.5+12.5**		
EI (Dedicated trip)	2.63	5.94		
EI (Non-dedicated trip)	2.01	4.49		

Table 6-41: Transportation EI – 1 Trip

Single shopping location	2.5	12.5	30	
EI (Dedicated trip)	0.017	0.084	0.201	
EI (Non-dedicated trip)	0.013	0.063	0.151	
Multiple shopping locations (2)	**2.5+2.5**	**2.5+12.5**	**2.5+30**	**12.5+12.5**
EI (Dedicated trip)	0.025	0.059	0.117	0.126
EI (Non-dedicated trip)	0.019	0.044	0.088	0.094
Multiple shopping locations (3)	**2.5+2.5+2.5**	**2.5+2.5+12.5**		
EI (Dedicated trip)	0.033	0.056		
EI (Non-dedicated trip)	0.025	0.042		

Table 6-42: Post-Sale EI – 1 Trip

Once analysed the results for the different 18 scenarios, in the three different perspectives, it is fundamental to highlight that they have a different impact according to the different weight we assigned to them. The weight is equal to the probability of occurrence of each scenario. We obtained the probability values through the survey we spread at the beginning of our research. Clearly, it is important to underline that primary data extracted by the survey are characterized by a certain error, since they are not representative of each possible situation, since the observation sample is not so large, and the main geographical area interested is mainly concentrated in the area of Milan. The table below summarizes the probability values used in the analysis.

Scenario Weight	Value	Unit of Measure	Source
Dedicated trip	67	%	Primary data
Non-dedicated trip	33		
Distance < 5 km	16		
5 km < Distance < 20 km	45		
Distance > 20 km	39		

Table 6-43: Scenario weights

By observing the weight value of each scenario, we can understand how the results previously discussed are not fully representative of the real emissions characterizing the offline purchasing process. In fact, the best scenario previously described (non-dedicated trip | single shopping location) is not situation that occurs more frequently if we consider that consumers prefer mostly to dedicate their time to their shopping trip and, they are more likely to travel a higher distance than 2.5 km. The **most frequent scenario** is when the customer dedicates the trip to shopping activity, and he/she is willing to travel a distance that falls in the range 5 km – 20 km. The average emission related to this case is **9.01 kgCO2e**.

Consequently, it is necessary to calculate again the EI values by considering the scenario weights. Firstly, we multiplied the EI values obtained for the probability regarding the type of trip; secondly, the probabilities regarding the distance values are applied to results previously obtained.

In the end, the different EI values weighted for the probability of occurrence of each type of trip have been summed up, in order to obtain the total final result of the analysis that comprehends the occurrence of all the possible scenarios. The table below shows the results. In general terms, we can state that if we have to choose the **most sustainable scenario** in terms of number of locations visited, it corresponds to the case in which the customer visit one only location producing averagely a TOTAL EI equal to **8.70 kgCO2e**, 5.53 of which are related to transportation activity and 2.95 related to packaging one. The **worst scenario** is the one related to two shopping location visited with a total emission equal to **10.32 kgCO2e**, 7.10 of which are related to transportation activity and 2.95 to packaging.

	Single shopping location	Multiple shopping locations (2)	Multiple shopping locations (3)	Unit of Measure
TOT	8.70	10.32	7.78	kgCO2e
TRANSPORTATION (LAST MILE + REPLENISHMENT)	5.53	7.10	4.67	
POST-SALE	0.11	0.10	0.05	

Table 6-44: TOT, Transportation, Post-Sale Weighted EI – 1 Trip

Once analysed the single-trip scenario, it is possible to comprehend how the full combination of the purchases may contribute to CO2 emissions saving, with respect both to the 3-trips scenario and 2-trips scenario.

If we compare the case in which the three purchases are made separately and the case in which they are fully combined in one single shopping trip, it is possible to observe how the total EI values significantly decrease. Indeed, if we consider the reference case (2.5 km, dedicated trip, single location) to compare the results, it was found that, if the three purchases are combined, the related total EI is equal to **4.06 kgCO2e**/3 purchases, instead of **5.74 kgCO2e**/3 purchases in case of three independent purchases. The related reduction is about **29%**. While if we compare the single-trip scenario to the 2-trips scenario the related emission percentual reduction is about **18%**.

If we split the result among the different activities (last mile transportation, replenishment transportation, replenishment management and communication, return transportation, and last mile packaging, replenishment packaging), we see how: the total replenishment transportation, management and communication emissions, last mile and replenishment packaging transportation emissions remain unchanged, while for the last mile and return transportation (case 2.5 km – dedicated trip), the emissions EI value change. Regarding last mile transportation the emissions are very different, because in the first case the same distance is travelled three times, while in the full purchases combination only once. The related percentual reduction is equal to **67%**. For return transportation the EI value passes from **0.04 kgCO2e/3** purchases to **0.017 kgCO2e/3** purchases, since the model also considers the combination of return trips.

In conclusion, we can state that the combination of different purchases results in a significant reduction of CO2 emissions, especially in the last mile transportation. So, we can understand how the customer's purchasing choices can make the difference and contribute a lot in making traditional purchasing processes more sustainable.

6.6 Results comparison between online and offline processes

The last section of this chapter provides the analysis regarding the comparison of the final values of kgCO2e emitted by the two different processes, the online and the traditional one. The objective is to find the more sustainable type of process which emits a smaller quantity of CO2, by analysing different scenarios:

- Three separate purchases: three different shopping trips in the traditional purchasing process, and three different orders made on three different websites in the online purchasing process;
- Two purchases combined and one separate: two different shopping trips in the traditional purchasing process, and two different orders made on two different websites in the online purchasing process;
- All three purchases combined: one shopping trip in the traditional process, and one order made on one unique website in the online purchasing process.

For each of these three scenarios, the comparison of the results is structured in two main steps:

- Base Case analysis, through which the wo simplest and more likely scenarios are compared.
- Sensitivity analysis, through which it is possible to examine the results by varying the value of the distance travelled by the customer to reach the stores and the distribution network configuration of retailers in the online process.

For each analysis, the values of the emissions compared regard: *Transportation, Packaging, Return*.

Before comparing the total results obtained in each scenario, we want to provide a comparison related to the single purchase for each product category/double purchase combination, between online and offline process, in order to understand the impact of the single product category in the two processes. The analysis consists into showing the comparison between total EI values (including transportation, packaging and return activity) and between EI values related to each activity separately. The analysis is related to the case in which distance is equal to 2.5 km, 12.5 km, and 30 km, and the trip is dedicated. For the online process, it is considered a distribution network configuration including both central and local warehouses, and the return process occurs if the item is defective, and a second successful delivery happens.

Single purchase. If the distance travelled by the customer to reach the store is shorter than 5 km, it was found that the online purchasing process is more sustainable only for books purchases with a saving in terms of CO2 emission equal to 5.38% with respect to the offline process; on the contrary, for clothing purchase and electronics purchase the more sustainable process is the traditional one, with a percentual emission reduction equal to 13.56% (from 2.985 kgCO2e/purchase in the online to 5.581 kgCO2e/purchase in the offline) and 21.76% (from 2.242 kgCO2e/purchase in the online to 1.754 kgCO2e/purchase in the offline) respectively. That is because clothing and electronics items, differently from books items, are characterized by a larger size and a higher weight, consequently the packaging related emissions significantly impact in the online process. It is interesting to understand how the different activities (items transportation, items packaging, and items return) impact on this final result. Regarding transportation activity, for each of the three different purchases, the online transportation results to be more sustainable, with a difference in CO2 emissions equal to 0.828 kgCO2e both for fashion and books purchase, and 0.833 kgCO2e for electronics purchase. Concerning packaging consumption, results show that the online consumption is larger than the offline one, in any case; on the total packaging consumption the online consumption represents about 58%. Regarding return, also in this case, the offline process results to be more sustainable with an average saving of 0.78 kgCO2e/fashion purchase, 0.66 kgCO2e/books purchase and 0.68 kgCO2e/electronics purchase. This because, the online return process is characterized by additional management activities, but more importantly by an additional consumption of packaging material in case of a second delivery. So, regarding clothing purchase, what majorly impacts on total EI is packaging activity (72.5% in the online process and 66.1% in the offline one) followed by return (26.9%) in the online process and by transportation (32.9%) in the offline one. Regarding books the most impacting activity in the online process is return process (54.5%), followed by packaging (44.4%); in the offline process, the most impacting activity is represented by transportation (65.3%), followed by packaging (34.4%). Concerning electronics, as in case of fashion purchase, the most impacting activity is packaging in the online process (64.5%) followed by return (30.8%); in the traditional process the most impacting activity is transportation (53.7%), followed by packaging (45.88%).

Instead, if the distance travelled by the customer to reach the store is longer, belonging to the second or third range, the online process results to be the most sustainable one for all three purchases, and the percentual emissions saving become higher and higher. For fashion purchase, the percentual saving by buying the three items online, it is equal to about 50% in case of distance in the second trip and 75% in case the distance is longer than 20 km. For books purchase, the quantity of CO2 emissions saved through the online process is equal to 3.396 kgCO2e/purchase in case of second distance range, and 9.313 kgCO2e/purchase in case in which the distance driven by the customer is longer than 20 km. Regarding electronics, we have a saving through the online process equal to 56% if distance is in the second range and of about 80% in case distance travelled by the customer is longer than 20 km. The table below reports all the emissions value obtained for each activity in every type of purchase.

		TOT		TRANSPORTATION		PACKAGING		RETURN	
		ONLINE	OFFLINE	ONLINE	OFFLINE	ONLINE	OFFLINE	ONLINE	OFFLINE
Distance offline <5 km	FASHION	2.985	**2.581**	0.020	0.848	2.164	1.705	0.802	0.019
	BOOKS	**1.218**	1.288	0.013	0.841	0.541	0.442	0.664	0.004
	ELECTRONICS	2.242	**1.754**	0.110	0.943	1.443	0.803	0.690	0.009
Distance offline 5-20 km	FASHION	**2.985**	6.002	0.020	2.786	2.164	1.705	0.802	0.094
	BOOKS	**1.218**	4.614	0.013	4.151	0.541	0.442	0.664	0.021
	ELECTRONICS	**2.242**	5.098	0.110	4.252	1.443	0.803	0.690	0.043
Distance offline >20 km	FASHION	**2.985**	11.989	0.020	6.666	2.164	1.705	0.802	0.224
	BOOKS	**1.218**	10.435	0.013	9.943	0.541	0.442	0.664	0.049
	ELECTRONICS	**2.242**	10.949	0.110	10.044	1.443	0.803	0.690	0.102

Table 6-45: TOT, Transportation, Packaging, Return EI per single purchase

Two purchase combination. What emerges from results is that if the distance travelled by the customer to reach the store is lower than 5 km, the traditional process results to be more sustainable than the online one, with a percentual saving equal to 4.5% in case fashion and books purchases are combined, 10% in case in which fashion and electronics purchases are combined and 1.4% in case in which books and electronics purchases are combined. So, the difference is quite small. Instead, if distance travelled by the customer becomes longer and longer, the online purchasing process becomes preferable, with a significant emissions reduction: averagely -6.2 kgCO2e in case in which fashion and books are combined, -6 kgCO2e in case in which fashion and electronics are combined, and -6.22 kgCO2e in case in which electronics and books are combined. The table below reports all the emissions value obtained for each activity in every type of purchase combination.

Single Destination		TOT		TRANSPORTATION		PACKAGING		RETURN	
		ONLINE	OFFLINE	ONLINE	OFFLINE	ONLINE	OFFLINE	ONLINE	OFFLINE
Distance offline <5 km	FASHION + BOOKS	3.172	**3.027**	0.033	0.862	2.380	2.147	0.759	0.018
	FASHION + ELECTRONICS	3.882	**3.494**	0.129	0.963	2.930	2.508	0.823	0.023
	BOOKS + ELECTRONICS	2.239	**2.208**	0.123	0.956	1.443	1.245	0.674	0.006
Distance offline 5-20 km	FASHION + BOOKS	**3.172**	6.411	0.033	4.172	2.380	2.147	0.759	0.092
	FASHION + ELECTRONICS	**3.882**	6.896	0.129	4.273	2.930	2.508	0.823	0.115
	BOOKS + ELECTRONICS	**2.239**	5.540	0.123	4.266	1.443	1.245	0.674	0.028
Distance offline >20 km	FASHION + BOOKS	**3.172**	12.331	0.033	9.964	2.380	2.147	0.759	0.221
	FASHION + ELECTRONICS	**3.882**	12.849	0.129	10.065	2.930	2.508	0.823	0.277
	BOOKS + ELECTRONICS	**2.239**	11.371	0.123	10.058	1.443	1.245	0.674	0.067

Table 6-46: TOT, Transportation, Packaging, Return EI per double purchase combination

6.6.1 Base case

The first type of comparison was made on a **base-case scenario** by considering the more sustainable scenario, both for online process and traditional one. In particular, regarding the offline purchasing process, the base case refers to the situation in which the customer travels a distance shorter than 5 km, to reach one only destination, in which all stores interested by the purchases are located. In addition, the customer trip is dedicated: it means that the customer decides to not combine shopping to other activities.

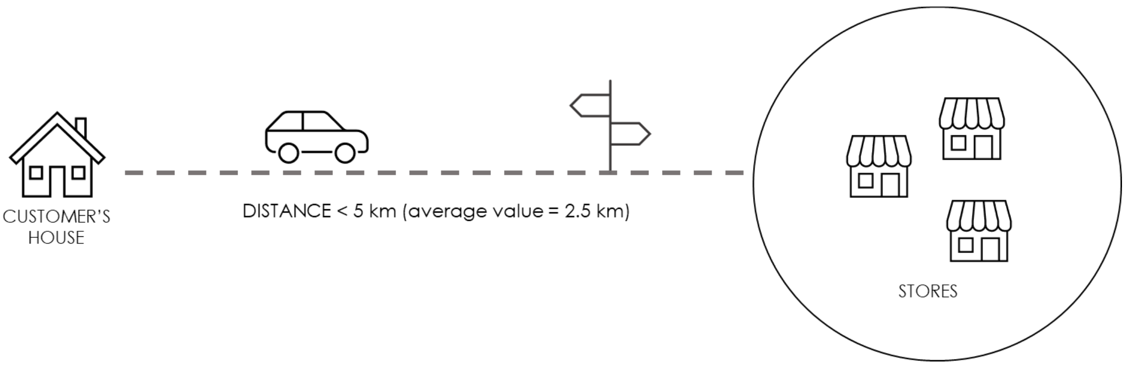


Figure 6-2: Offline Base Case Scenario

On the other side, for the online process, the base case analysed is represented by the following situation: the distribution network configuration is characterized by the presence of both a central warehouse and a local warehouse. That means that the delivery is split in two parts: firstly, from central warehouse to local warehouse and secondly from central warehouse to customer's house. The return process is supposed to happen when the product received is not compliant and a second successful delivery is made.

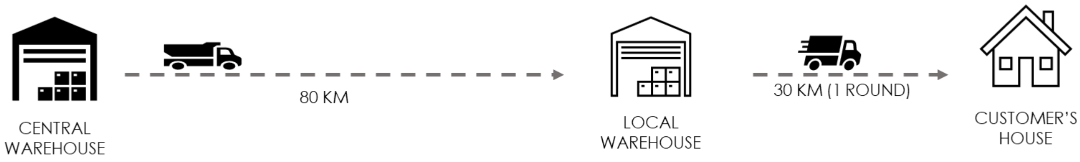


Figure 6-3: Online Base Case Scenario

The below table reports the results about the TOTAL EI values obtained according to the type of purchases combination: when the three purchases are made separately (through three shopping trips or on three different online websites), when two of them are combined in one trip/one website and when they are made all together in one shopping trip/grouped in one single order.

	Online	**Offline**	**Unit of Measure**
3 trips/3websites	6.45	**5.62**	
2trips/2websites	5.41 5.22 6.00	**4.78**	kgCO2e
1 trip/1 websites	4.08	**3.94**	

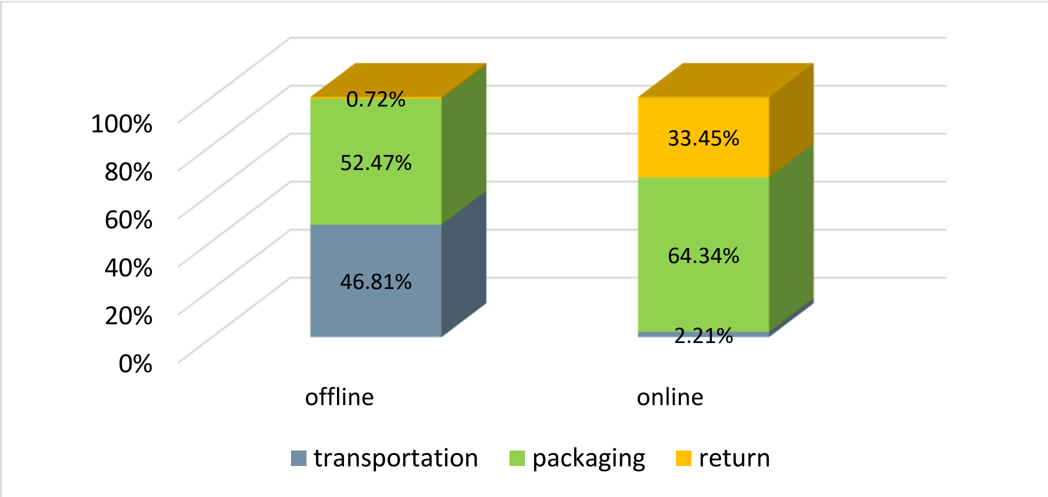
Table 6-47: TOT EI - Online/Offline – per 3 purchases

The first consideration we can comment regards the gradual decrease of quantity of CO2 emissions in both processes, when the different purchases are combined in a trip or in an order. For the combination of two purchases, in the online process, we obtained three different results according to the type of purchases combined: fashion purchase with books, fashion with electronics and electronic with books. On the contrary, for the offline purchasing process, the result is always the same since what only changes the EI value is the last mile distance travelled by the customer (both in the delivery phase and in the eventual return phase). Instead, in the online process, through the combination of purchases we have a reduction in the quantity of packaging material consumed and in the return emissions (packaging, communication and management emissions). In fact, the environmental impact in the offline case proportionally decreases with respect to the number of trips made. Instead, in the online process, the EI impact does not proportionally decreases with respect to the number of websites in which the purchases are made: the difference in the emissions level between 3 websites scenario and an average 2 websites scenario is about 0.9 kgCO2e, while if we pass from 2 websites scenario to 1 website scenario the emission decrease is about 1.5 kgCO2e, so <u>the decrease is more than proportionally.</u>

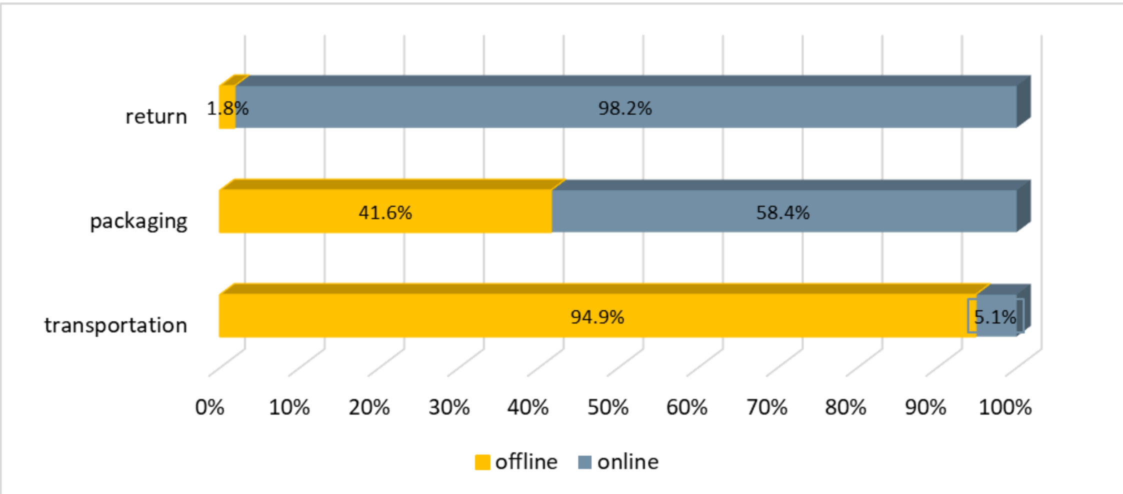
By analysing results, it was found that, comparing the base cases, the offline purchasing process results to be more sustainable in any case, but only if we compare the same scenario both for the online and offline process. In fact, if for example, the customer decides to make the three purchases by three different shopping trips, but through the e-commerce channel he/she has the possibility to combine them all in the same order, the online process results to be the more sustainable. The same happens in case we compare the 3 trips-offline scenario with the 2 websites-online scenario (only when fashion purchase is combined with another one). More specifically, the **environmental impact** of the offline **process** was found to be 12.87% lower than the online one in case of three separate purchase, 13.77% lower in case of two purchases combined, and 3.43% lower in case all purchases are combined.

A further analysis was conducted with the aim to understand the impact of transportation, packaging, and return emissions on final result for both purchasing processes. The analysis was made for all types of purchases combinations, in order to understand how the impact of each activity change.

Three shopping trips/websites. When the different purchases are made independently the most impacting activity results to be packaging for both processes: 64.34% in the online channel, and 52.47% in the offline one (of which 48.10% derives from cardboard material consumed in the store replenishment phase). The second most impacting activity is transportation in the offline process, impacting for 46.81% (of which 44.15% in the last mile), and return activity in the online one, with 33.45% of emissions. Return is substantially negligible in the offline process, as transportation in the online one. So, **we can state that transportation activity impacts more in the offline process, while packaging and return in the online one**. The respective transportation emissions estimated are: 2.63 kgCO2e in the offline process and 0.14 kgCO2e in the online one. While for packaging we have 2.95 kgCO2e in the offline and 4.15 kgCO2e in the online. Lastly, we have 0.04 and 2.16 kgCO2e respectively in the offline and online return. The graphs below summarize the impact of each activity on the total environmental impact for each process.



Graph 6-11: Impact of each phase [%] - three independent purchases



Graph 6-12: Impact per phase of each process - three independent purchases

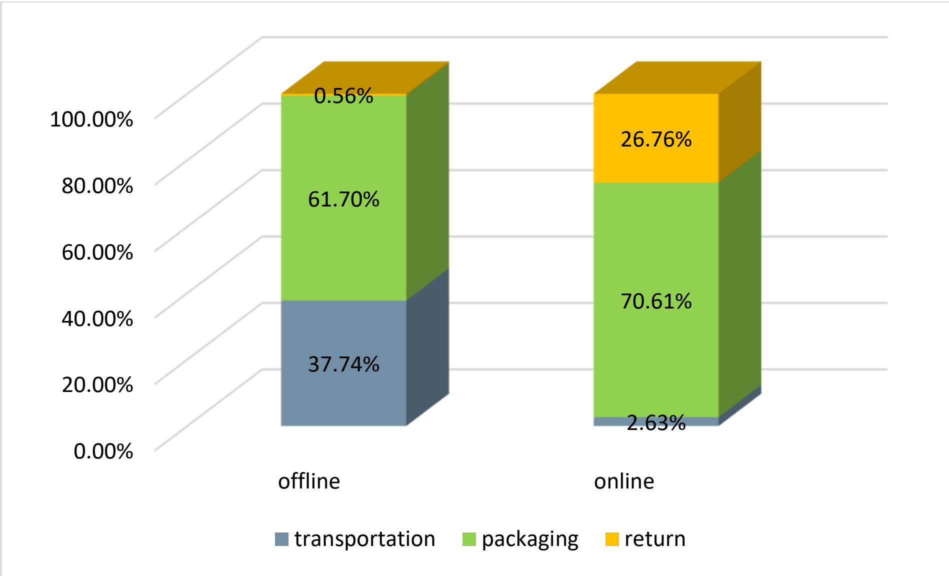
By **combining** the three purchases in one trip or in one order, **not all activities related emissions are affected**. For the **offline** purchasing process, packaging emissions level remains unchanged because the quantity of material consumed, both in the last mile and in the store replenishment phase, is the same. On the contrary, **last mile transportation** emissions are reduced, since the consumer makes less shopping trip, so the related impact on the total EI value is reduced. In case only two purchases are combined, last mile transportation emissions pass from 2.48 kgCO2e to 1.65 kgCO2e.

Its impact shift **from 46.81%** to 37.69%. In case in which all purchases are combined we have a further last mile transportation emission reduction: from 1.65 kgCO2e to 0.83. So, the impact of transportation on the total EI value lowers **to 24.78%. As a consequence**, **packaging impact increases** on the entire process: **from 52.47% to** 61.70%. The same happens in case in which all purchases are combined in one trip, obtaining so the following impact: 24.78% for transportation, **74.80%** for packaging and 0.42% for return (return in 3 shopping trips impacts 0.72%). Also, for return process, the related emissions are reduced since the model considers a combination of return trips if there are more defective items.

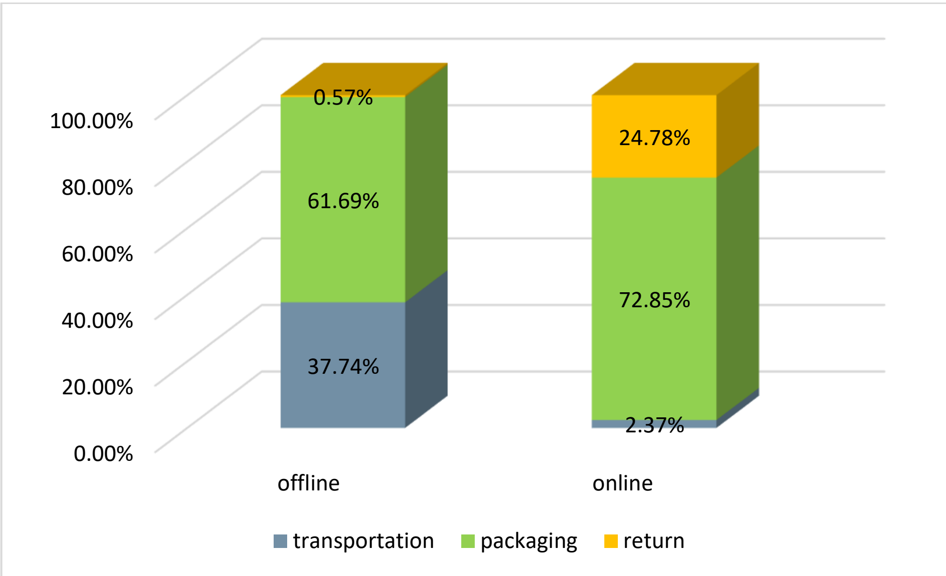
Regarding the **online** purchasing process, **transportation emissions remain unchanged** since even if the number of deliveries is reduced, the emission related to the different items composing the purchases does not change because it is assumed that each truck is fully saturated. Concerning **return emissions**, they **are reduced** since if we combined purchases and, the related items are defective, it is possible to reduce packaging, management and communication related emissions. The related emissions pass **from 2.16 to averagely 1.47 kgCO2e** in case in which two purchases are combined and **from 1.47 to 0.78 kgCO2**e in case three purchases are grouped. **Its impact lowers to 19.13%.** As a consequence, even if **packaging emissions are reduced** the related reduction is lower than one related to return. This is the reason why **packaging impact on the final value increases** and return impact decreases. Packaging emissions **shift from 4.15 kgCO2e to averagely 3.93 kgCO2e in case of two purchases combined, and from 3.93 to 3.16 kgCO2e** impacting so **77.38%** on the total EI value.

What can be deducted is that by the combination of purchases the most significant impact reduction regards: last mile transportation in the traditional purchasing process; packaging and return process in the online one.

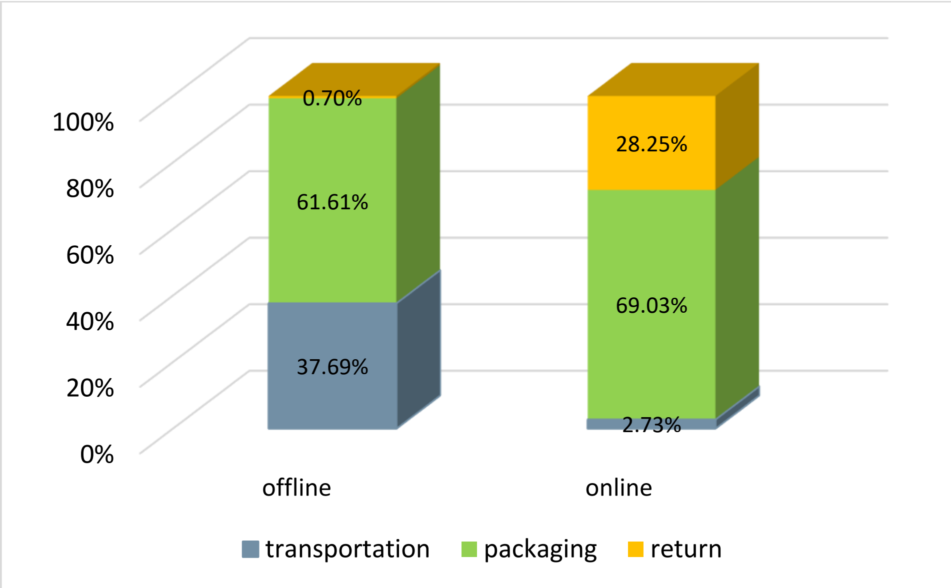
The graphs below show the percentual impact of different activities in both purchasing process and in each type of purchase combination scenario.



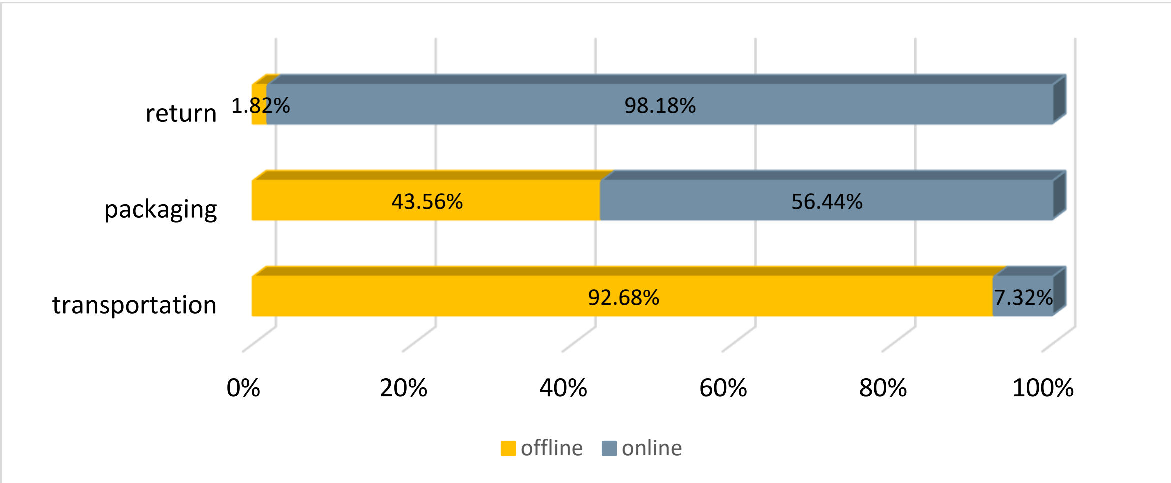
Graph 6-13: Impact of each phase [%] – Clothing + Books



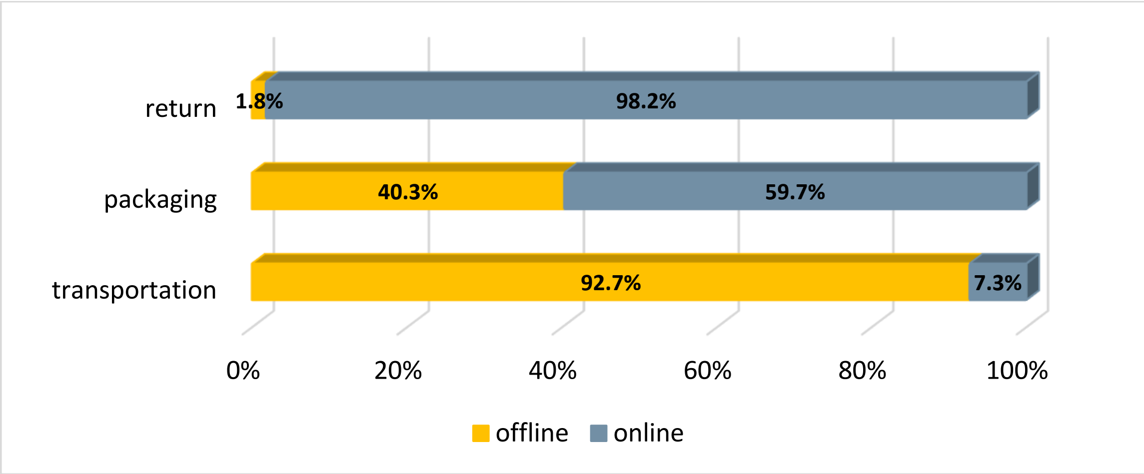
Graph 6-14: Impact of each phase [%] – Clothing + Electronics



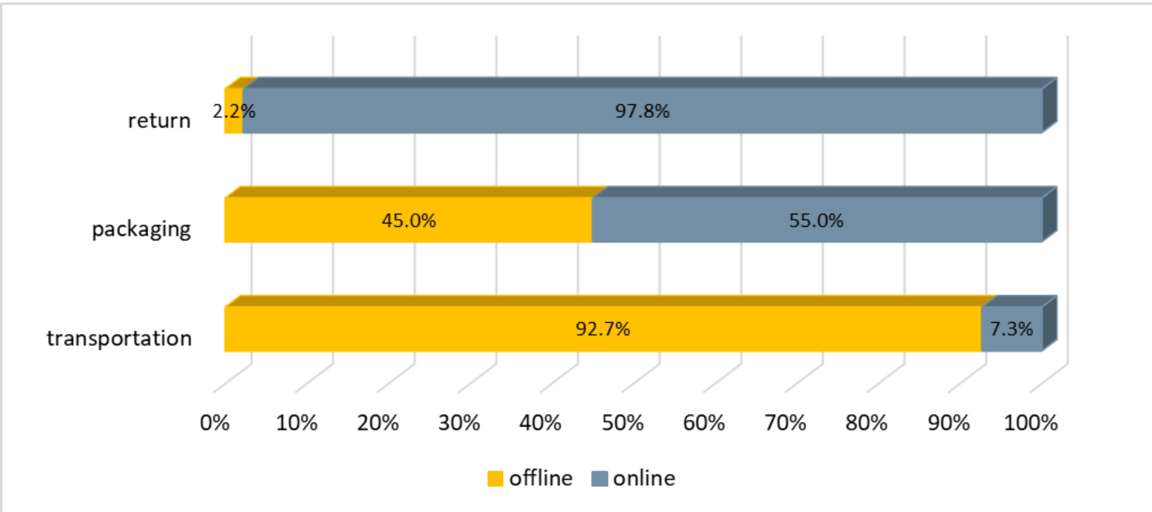
Graph 6-15: Impact of each phase [%] - Electronics + Books



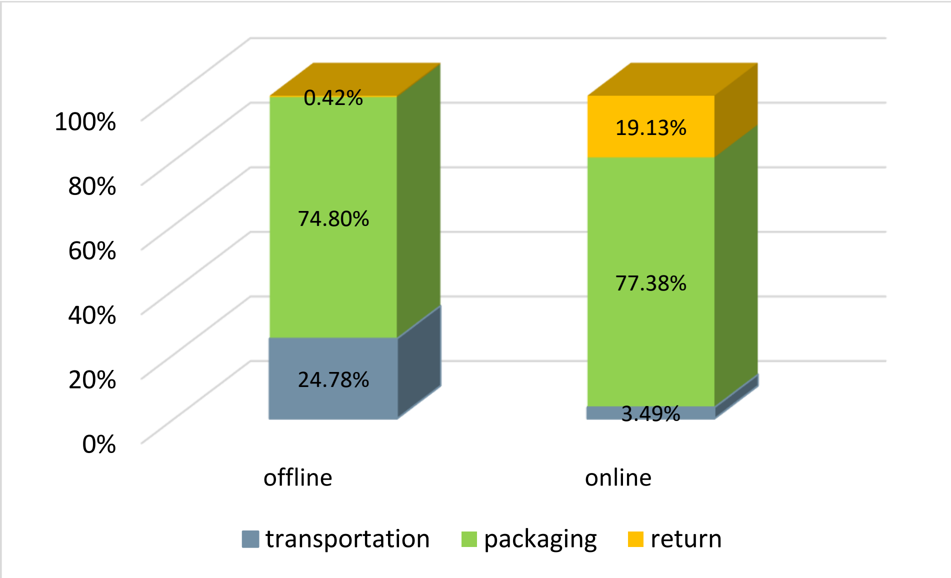
Graph 6-16: Impact per phase of each process – Clothing + Books



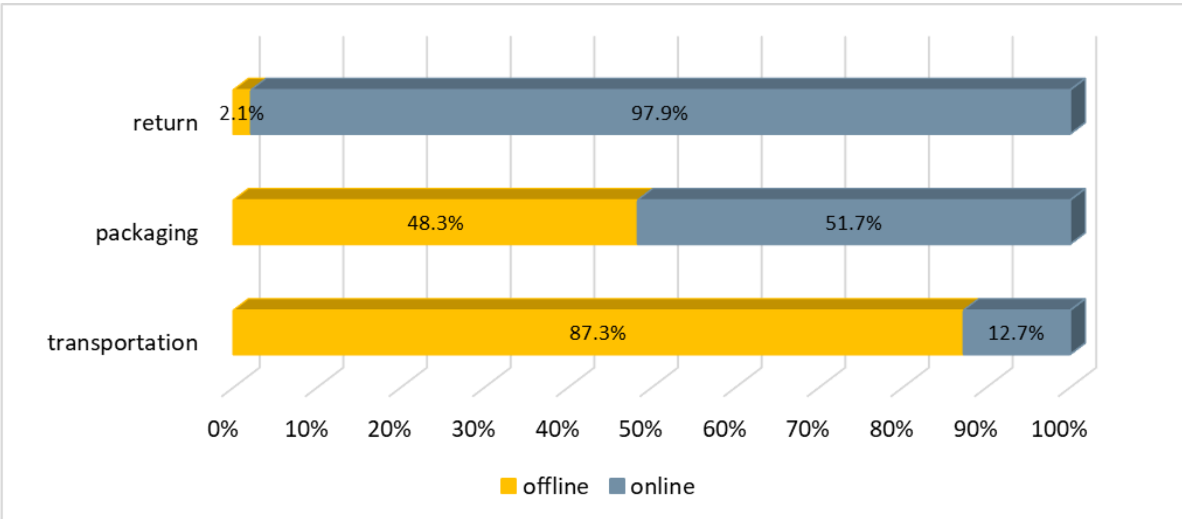
Graph 6-17: Impact per phase of each process – Clothing + Electronics



Graph 6-18: Impact per phase of each process – Books + Electronics



Graph 6-19: Impact of each phase [%] - three united purchases



Graph 6-20: Impact per phase of each process - three united purchases

6.6.2 Sensitivity analysis

A sensitivity analysis is carried out to examine how the results change by changing the main inputs and to better compare the differences between the online and offline processes. In fact, as it is described in the previous sections (analysis of online and offline), it is not possible to declare that in any case, the online purchasing process is better than the offline one, but the environmental impact depends on the different scenarios considered.

Firstly, a tree with all the possible scenarios considered is reported.

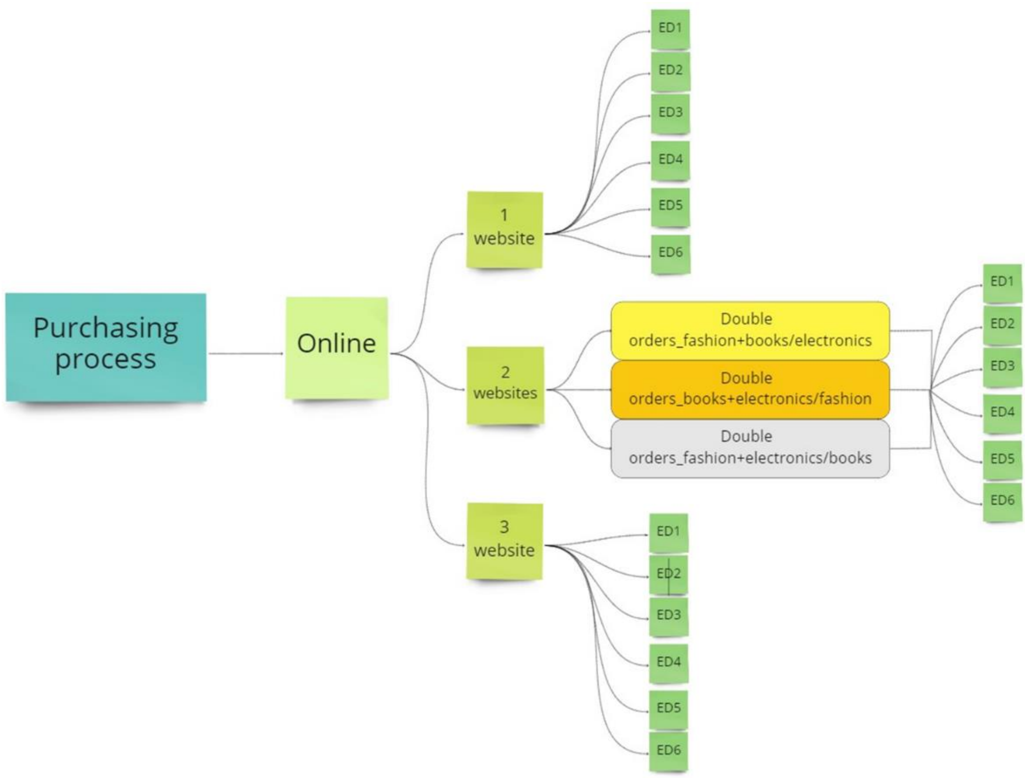


Figure 6-4: Sensitivity Analysis Online Scenarios

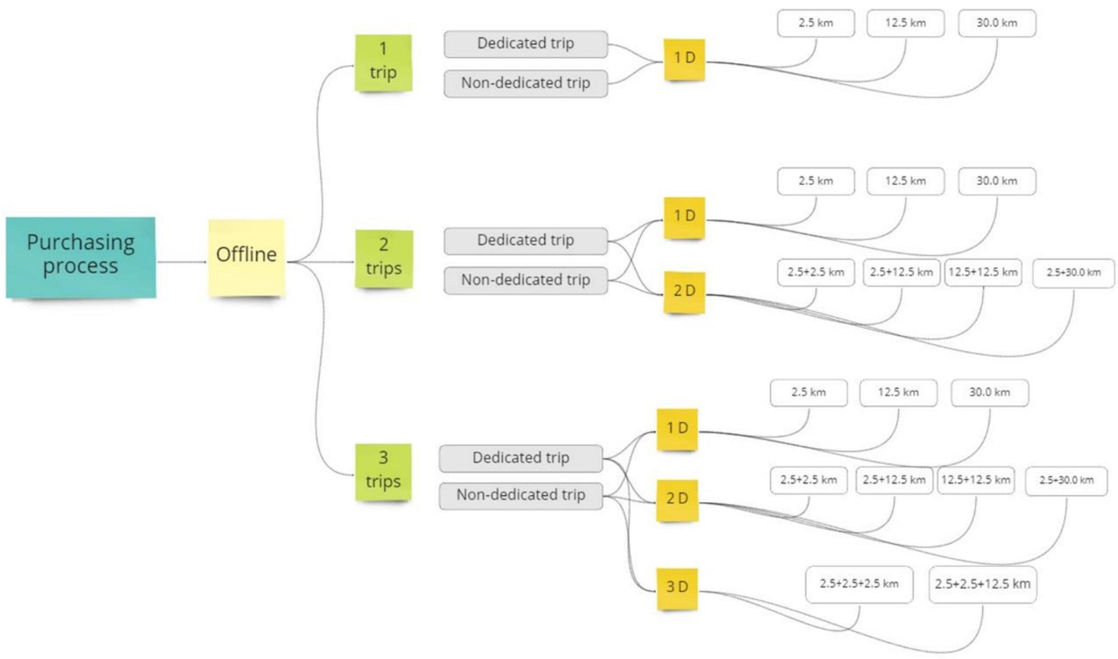


Figure 6-5: Sensitivity Analysis Offline Scenarios

More specifically, the two purchases processes, online and offline, are split in all their sub-scenarios. For the e-commerce, both the single website scenario, the double and triple website options are taken into account and for each one, all the distribution configurations ED1, ED2, ED3, ED4, ED5, ED6[12]) are considered in the sensitivity analysis. Instead, for what concern the offline process, we considered three main cases:

[12]ED1= the company delivers directly from the central warehouse (CW) to customers' home;
ED2= the company delivers firstly from the central warehouse to the local warehouse (LW) and then from LW to customers' home;
ED3= the company delivers directly from the LW to customers' home;
ED4= the company delivers firstly from the CW to the pick-up point (PP) and then customer goes from home to the PP;
ED5= the company delivers firstly from the CW to the LW, then from the LW to the PP and then customer goes from home to the PP;
ED6= the company delivers directly from the LW to the PP and then customer goes from home to the PP.

the customer makes three different trips in three different moments, the customer makes two trips, and the customer makes only one trip. Then, for each of these cases the customer could choose for a dedicated or non-dedicated trip and finally, different distances are considered linked to the scenarios in which the customer goes to one single destination, 2 destinations or three destinations (1D, 2D and 3D).

An important parameter is the distance travelled by either the customer to reach the store and the truck for the replenishment of the store, for the traditional purchasing process, or the delivery from the central warehouse to the customers' houses or pick-up points in the online process. In particular, as it is reported in (Cairns 2005 [15]; Durand and Gonzalez-Feliu 2012 and Siragusa and Tumino 2021 [91]), distances are the key variables in the environmental impact assessment of the traditional shopping. For instance, the sensitivity analysis is conducted by considering for the offline process, the distance from the warehouse to store constant and equal to 60km and by varying the distance from the store and the customer's house using a range from 2,5 km to 32.5 km. In particular, both comparing the dedicated and non-dedicated trip. So, below the table summarised all the distances that have been taken into account (for the traditional shopping) for the sensitivity analysis.

	Distance [km]	EI (Dedicated trip) [kgCO2e]	EI (Non-dedicated trip) [kgCO2e]
1 Destination (2.5)	2.5	20.39	20.18
2 Destinations (2.5+2.5)	5	21.22	20.80
3 Destinations (2.5+2.5+2.5)	7.5	22.05	21.42
1 Destination (12.5)	12.5	23.72	22.68
2 Destinations (2.5+12.5)	15	24.55	23.29
3 Destinations (2.5+2.5+12.5)	17.5	25.36	23.91
2 Destinations (12.5+12.5)	25	27.90	25.78
1 Destination (30)	30	29.55	27.05
2 Destinations (2.5+30)	32.5	30.37	27.64

Table 6-48: Distance driven by customer in the sensitivity analysis

These distance variations are reflected in the presence of different areas, in fact areas with a higher population density tend to have a higher number of stores respect to rural areas, as it is also described in Matthews, Hendrickson, and Soh 2001 [60]; Liese et al. 2007 and Siragusa and Tumino 2021 [91]. So, the consequence of having an higher distance travelled is an higher value of kgCO2e emitted because of the higher consumption of fuel during the transportation activity. Instead, for the online process, the significant–parameters are the number of websites on which the customer has bought the products and the typology of distribution configurations tested (as it is described in detail in the previous sections).

To perform the sensitivity analysis, not all the phases are compared, only the packaging, transportation and post sales are analysed. In particular for the post sales online process, we considered only the case in which the product is not compliant and customer, after having delivered the item in a collection point, receives a second delivery.

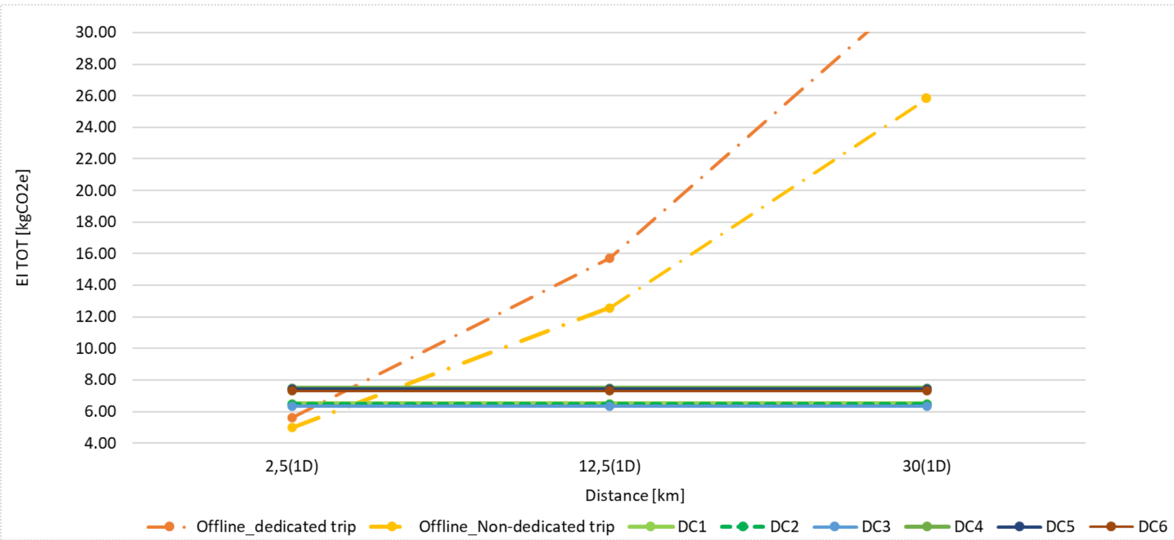
So, the first step of the sensitivity analysis is made by computing the different values of kgCO2e emitted in the offline process by changing the distances travelled and taking constant the conditions of the different online processes. More in detail the analysis is divided in three sections:

1- In the first section there is the comparison between the offline option in which the customer makes three different trips for each of the three purchases and the online option in which the customer makes three orders on three different websites;
2- in the second section there is the comparison between the offline option in which the customer makes two different trips, one for two purchases and another one in a second moment for the third purchase and the online option in which the customer makes two orders on two websites;

3- in the third section there is the comparison between the offline option in which the customer makes a unique trip for all the three purchases and the online option in which the customer makes a single order for all the three purchases.

Triple-trip vs triple-order

The first analysis is to compare the case in which a customer, in order to buy three purchases (3 clothing items, 2 books and one electronics item), makes three different trips in different moments and the case in which the customer makes three different online orders. In particular, for the online purchasing process we represented all the possible results considering the six distribution configurations, by taking constant other conditions. Instead for the offline case we analysed how the kgCO2 emitted change by changing the distances travelled by the client and by considering both the dedicated and non-dedicated trip and the fact that a customer could, during the same trip, visits one, two or three different locations.



Graph 6-21: Sensitivity analysis - three independent purchases

So, without changing other conditions in the online base case scenario, it is possible to affirm that the customer's trip has a huge impact. In fact, the overall percentage difference between offline and online by considering the distribution configuration 1, were found to be from a range of **-16% to 80.5%** (considering the dedicated trip) and from **-30% to 75%** (non-dedicated trip). This means that if the distance between the customer and the shop is around 2.5 km the offline process is 16% and 30% (respectively dedicated and non-dedicated case) more sustainable than online, while by increasing the distance travelled by the customer till a limit of 30 km, the online process is 80% and 75% (respectively dedicated and non-dedicated case) more environmentally sustainable than the offline one. By looking at the others distribution configurations the results are quite similar, as it is shown in the graph 6-21. So, it is possible to conclude that, by finding the points of intersection between the online lines and the offline ones, the offline is more sustainable only if the distance travelled is about 2.5 km.

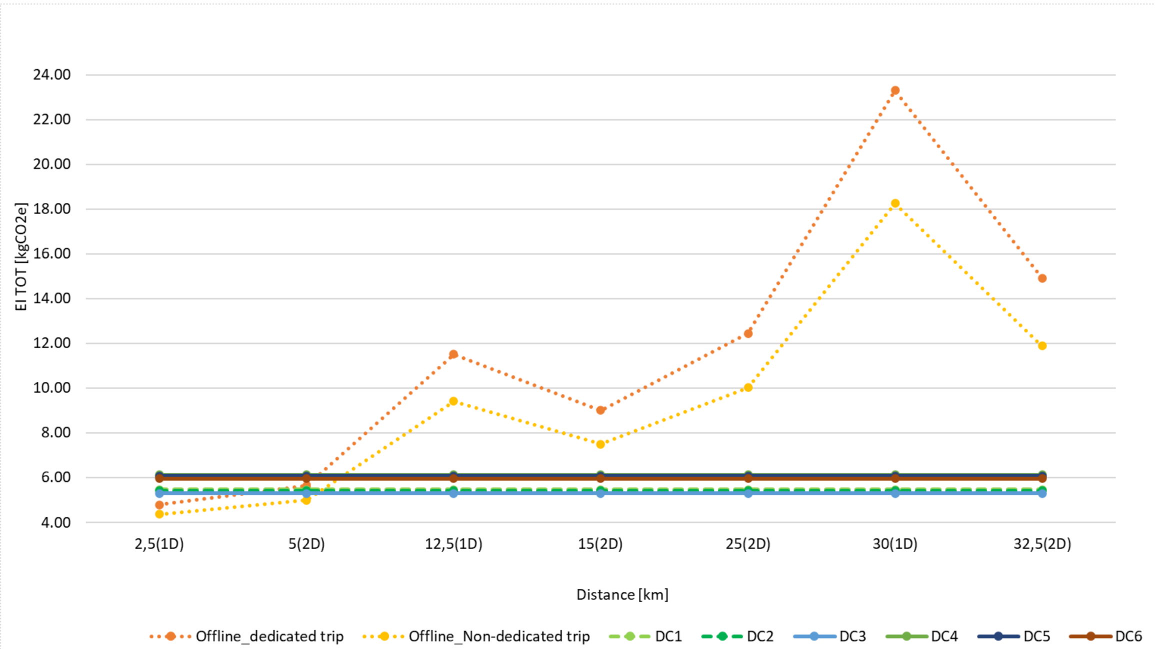
Double-trip vs double-order

The second section of the sensitive analysis aims to compare how the kgCO2 emitted vary by changing the distance travelled by the customer in the offline process in the scenarios in which the customer makes two different trips in two different moments and makes two different online orders. More in details the cases considered are the following:

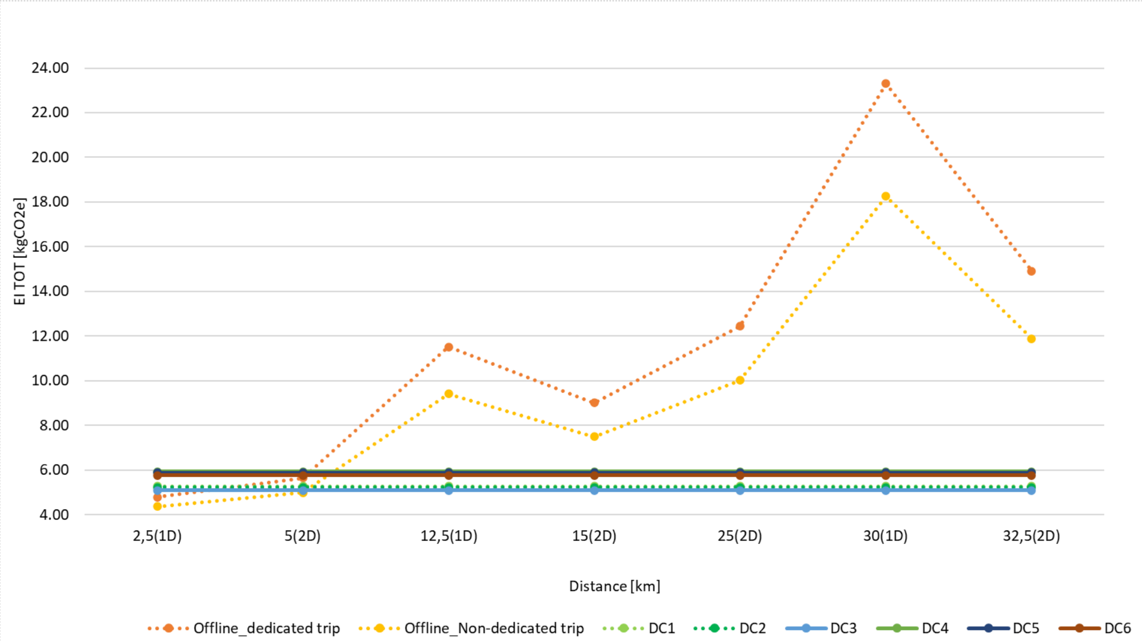
- The option in which the customer buys on a unique website/making a unique trip clothing and books purchases, while the electronic one in another website/during another trip;
- The option in which the customer buys on a unique website/making a unique trip the books electronics purchases and the clothing one in another website/during another trip;

- The option in which the customer buys on a unique website/making a unique trip the clothing and electronics purchases while the books in another website/during another trip.

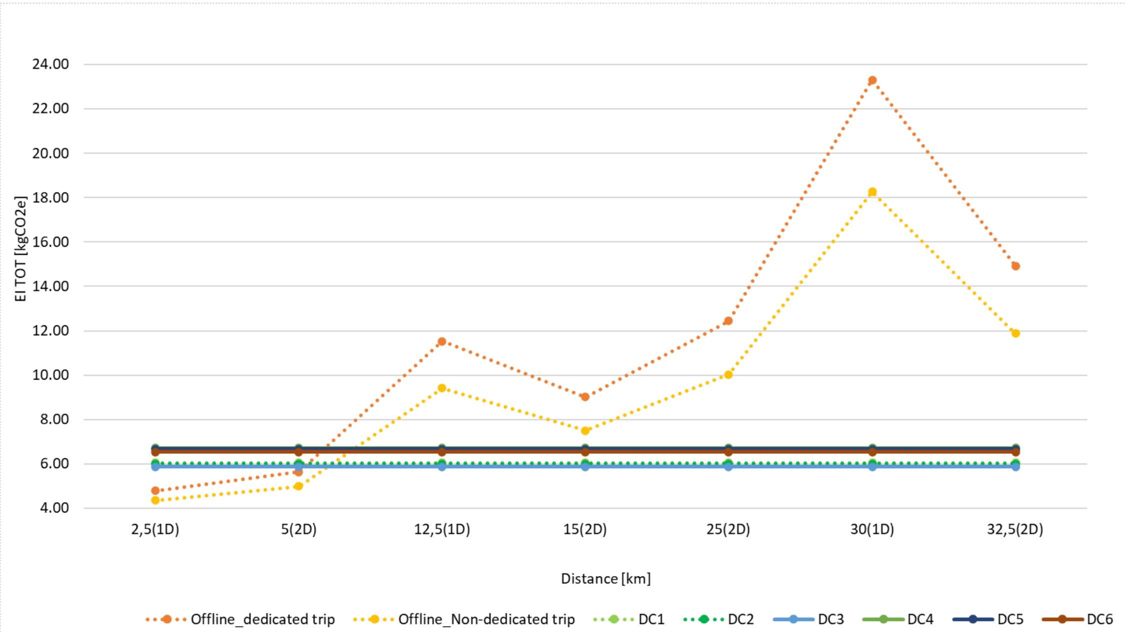
For the offline purchasing process, the kgCO2 emitted are the same in all of the three scenarios while for the online process, the packaging has a huge impact and varies according to the typology of products, so the results are different. In particular, for the online purchasing process we represented all the possible results considering the six distribution configurations, for each of the three scenarios by taking constant other conditions. Instead for the offline case we analysed how the kgCO2 emitted change by changing the distances travelled by the client and by considering both the dedicated and non-dedicated trip and the fact that a customer could, during the same trip, visits one, two or three different locations. Below the results for all of the three scenarios are reported.



Graph 6-22: Sensitivity analysis – Clothing, accessories, and footwear + Books/Electronics



Graph 6-23: Sensitive analysis – Books + Electronics/Clothing, accessories, and footwear

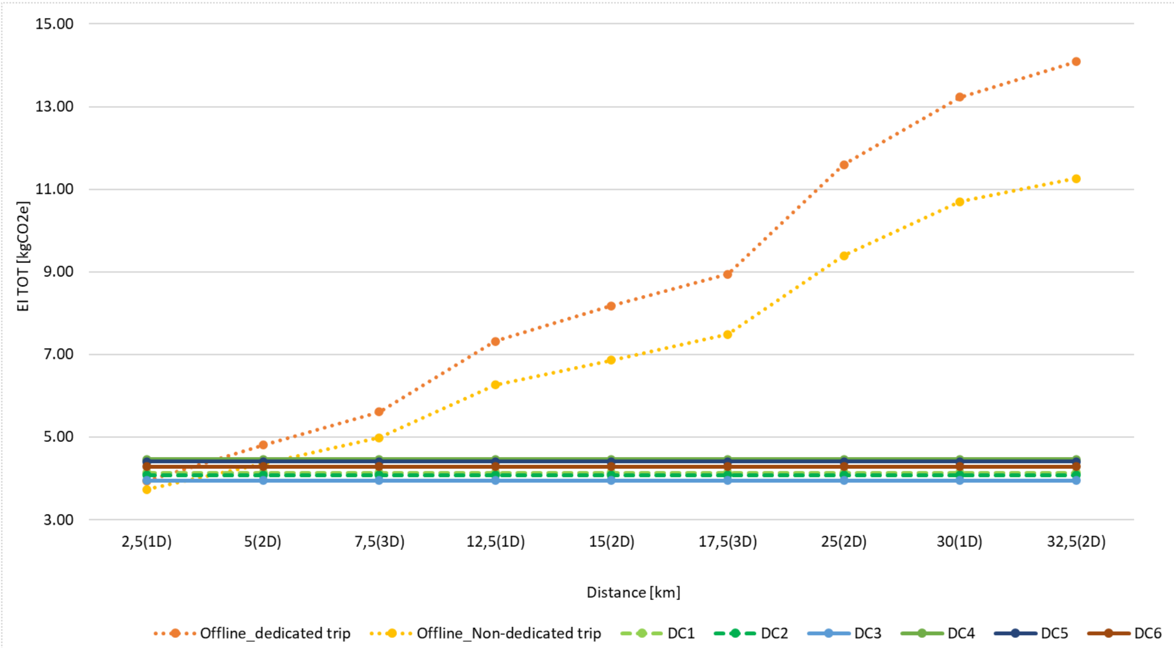


Graph 6-24: Sensitive analysis – Clothing, accessories, and footwear + Electronics/Books

Results are quite similar for all of these cases and the main consequence is that in the double-trip scenario compared with the double orders scenario, the offline is more sustainable only if the distance travelled by the customer to go to the shop is no more than 5 km. Another interesting result is about the offline process: the CO2 emissions do not have a linear increase with the increase of the distance, but it depends also by the fact that the customer visit one, two or three locations during the same trip. This is due to the fact that in the case in which the customer makes two locations for the combined trip the third independent trip distance is always assumed less than 5 km.

Single-trip vs single-order

The third section of the sensitive analysis aims to compare how the kgCO2 emitted vary by changing the distance travelled by the customer in the offline process in the scenarios in which the customer makes only one trip for all the three purchases and makes only one online order. In particular, for the online purchasing process we represented all the possible results considering the six distribution configurations, by taking constant other conditions. Instead for the offline case we analysed how the kgCO2 emitted change by changing the distances travelled by the client and by considering both the dedicated and non-dedicated trip and the fact that a customer could, during the same trip, visits one, two or three different locations. Below the results are reported.



Graph 6-25: Sensitivity analysis - three unified purchases

So, without changing other conditions in the online base case scenario, it is possible to affirm that the customer's trip has a huge impact. In fact, the overall percentage difference between offline and online by considering the distribution configuration 1, were found to be from a range of **-4.8% to 70.5%** (considering the dedicated trip) and from **-11% to 63%** (non-dedicated trip). This means that if the distance between the customer and the shop is around 2.5 km the offline process is 4.8% and 11% (respectively dedicated and non-dedicated case) more sustainable than online, while by increasing the distance travelled by the customer till a limit of 32.5 km, the online process is 70.5% and 63% (respectively dedicated and non-dedicated case) more environmentally sustainable than the offline one. By looking at the others distribution configurations the results are quite similar, as it is shown in the graph 6-25. So, it is possible to conclude that, by finding the points of intersection between the online lines and the offline ones, the offline scenario is more sustainable only if the distance travelled is lower than 5 km.

6.7 Results generalisation

The model application focused on three main average purchases: one average purchase belonging to the world of clothing, one to books world and one average electronic purchase. However, the final results can be generalised by considering different products categories. To generalize the purchases that a customer should buy we considered different product categories:

- **Clothing, accessories & footwear** (in this category all the items related to the world of fashion are considered as t-shirts, shoes, bags);
- **Beauty & cosmetics** (in this group all products linked to the beauty appearance world are considered, as make-up products, air dryer, hair straightener);
- **Books**;
- **Electronics** (in this category all items linked to the technological world are considered as PC, tablet, TV, washing machine, mobile phone, air pods);
- **Construction products, gardening, DIY, joinery, lighting;**
- **House products** (in this classification all items as candles, dishes, glasses, tablecloths);
- **Stationery** (products as pens, staplers, pencil case, notebooks);
- **Sport equipment** (items as sportif tops, gym weights, gym bags).

These product categories can be grouped in macro clusters, according to two main variables:

- *Similarity of the return rate*;
- *Similarity of the mean size* that means having similar packaging footprint and similar % of space occupied in the truck/van.

So, we found the values of return rate, packaging footprint and % space occupied in the tuck/van for each of these products categories. Using the data collected in the survey, we obtained data relating to the return rate for six product categories (clothing, accessories & footwear; beauty & cosmetics; books; electronics; construction products, gardening, DIY, joinery, lighting and Stationery) while, for what concern house products and sport equipment the values are obtained through analysis and assumptions. Furthermore, for the computation of the input data of the packaging footprint and % of occupied space, we considered the average weight and size of each product category items. So, according to the values of return rate, packaging footprint and percentage of space occupied in the truck/van, the three main clusters of product categories are shown and represented by different colours.

	Return Rate online [%]	**Return Rate offline [%]**	**kgCO2e/cardboard**	**% space occupied in the truck/van**
Clothing, accessories & footwear	0.063	0.034	0.5409	0.00006
Beauty & cosmetics	0.006	0.009	0.1832	0.00006
Books	0.004	0.005	0.1832	0.00006
Electronics	0.012	0.010	0.7213	0.00100
Construction products, gardening, DIY, joinery, lighting	0.006	0.008	0.7213	0.00100
House products	0.004	0.004	0.1832	0.00006
Stationery	0.004	0.003	0.1832	0.00006
Sport equipment	0.063	0.034	0.5409	0.00006

Table 6-49: Product Categories Clusters

As is represented in the table, the different colours shown the three macro clusters in which these products categories are split. The first type of average purchase is composed by three items belonging to the clothing or sport world (cluster 1). The second typology of purchase can be composed by two items linked to the beauty & cosmetics, books, house and/or stationery products (cluster 2). Finally, the last average order can be composed by an item of electronics or an item of construction, gardening world (cluster 3).

Therefore, the results obtained in the model application are not valid only for the categories to which the model has been applied, but it can be concluded that a very similar result is obtained also by combining these product categories.

7. Conclusions and discussions

The past studies did not give a definitive answer about which of the two purchasing processes is more environmentally sustainable. In general terms, the e-commerce process is more sustainable if the main variables, as the shipping mode and the packaging material are taken constant, but in a real context, finding a unique result is more complex.

Our thesis presents an Activity-Based model aiming to compute the environmental impact of the traditional in-store and B2C e-commerce purchasing process by comparing different average purchases belonging to different industry sectors, with a strong focus on the logistics activities.

In the model application we studied a specific context of application in which a customer has different alternatives to buy its purchases. The first choice is between the online and offline processes. If the customer decides to use an online platform, ***how many purchases does he/she make?*** And, ***on how many different platforms*****?** Also, ***does the customer decide to have the orders delivered to a pick-up point?*** And ***what is the probability that the customer is not at home during the delivery of the orders***? And ***the probability that a customer receives a non-compliant item and decide to return it back? And if he/she opts for money refund?*** Instead, if a customer decides for a traditional in-store shopping, ***how many purchases does he/she make?*** And, to do these purchases, ***does he/she opt for a dedicated trip or non-dedicated one?*** And ***how long is it the distance travelled by the customer to arrive to the stores?*** Furthermore, ***what***

is the probability of return the product in the traditional channel? And ***how does it change according to the typology of products?*** But also, the customer could combine both online and traditional processes, and, ***what do the results change by combining the two purchasing processes?***

All these questions reflect the importance of the customer behaviour in determining the kgCO2 emitted. There are also other variables that affect the results and do not involve the final customers but the retailers. As, ***what type of packaging material the retailer usually uses to transport the orders? Plastic? Cardboard boxes?*** And also, ***how is it organised the distribution network of the retailer? Is it fully optimised in order to minimize the emissions caused by the transportation phase?***

All these questions summarised the complexity of the analysis and our thesis through an Activity-Based model gave answers to these questions.

The chapter is organised as follows:

- *Conclusions*: in this section the main quantitative results and qualitative conclusions are reported;
- *Limitations and future directions*: since a model is a simplistic way to represent the reality, results are linked to the defined boundaries and in this section all its limitations and future directions are shown.

7.1 Conclusions

Considering the three clusters separately, if the customer travels a distance of 2.5 km the offline process is always better both for the dedicated and non-dedicated trip, while by increasing the distance between the customer and the store, the online process becomes more sustainable, both using a single and multiple website option. Another important conclusion is that by considering these three clusters of average purchases, cluster 2 is the most sustainable one, while cluster 1 is the worst option. This is due to the fact that, the average purchase containing items that belong to the clothing and sport products, is typically composed by three items, while the electronic and construction category by only one item and the books, cosmetics, house and stationery products by two items. However, by considering an online order composed only by one item, how do the product categories impact the results? One item belonging to cluster 2 represents the most sustainable purchase, while cluster 1 is the second-best option, and cluster 3 the worst one (see the table 7-2). This because the CO2 emissions depend on the item **size** and **weight**. Indeed, electronics items, characterized by big size and significant weight, result to be more polluting than other product categories.

	TOT EI	Unit of Measure
1 ITEM of Cluster 1	1.4845	
1 ITEM of Cluster 2	0.7447	kgCO2e
1 ITEM of Cluster 3	2.2714	

Table 7-1: TOT EI per item for each product category cluster

What does it happen if these average purchases are combined?

Regarding the combination of purchases in one shopping trip/online order, different significant results should be highlighted. By gradually combining purchases, the environmental impact in the offline case proportionally decreases with respect to the number of trips. In the offline purchasing process, only transportation emissions are reduced (both in the delivery and return phase). In this regard, it is possible to conclude that the customer plays a fundamental role in determining the final environmental impact of the offline process. According to that, shorter distances should be favoured, and shopping should be combined with other activities.

By gradually combining purchases in the online process, the emissions value decreases more than proportionally; what affects the result is return and packaging emissions reduction.

If the distance travelled by the customer is higher than 5 km, the online purchasing process results to be more sustainable in every case. On the contrary, if the distance is lower, the offline purchasing process results to be more sustainable than the online one, only if purchases are equally combined in both processes. When the three purchases are made independently, emissions are equal to 5.62 kgCO2e/3 purchases in the offline and 6.45 kgCO2e/3 purchases in the online; when two of them are combined emissions are equal to 4.78 kgCO2e/3 purchases in the offline and averagely 5.54 kgCO2e/3 purchases; when all purchases are combined in one trip/online order, emissions are equal to 3.94 kgCO2e/3 purchases and 4.08 kgCO2e/3 purchases. Despite this, it is possible to notice that if the customer makes the three purchases by three different shopping trips, but through the e-commerce channel he/she has the possibility to combine them all in the same order, the online process results to be the most sustainable option. The same happens in case 3 trips-offline scenario and 2 websites-online scenario are compared.

In conclusion, what can be deducted is that the **purchases combination increases the environmental sustainability** of both processes, since it allows to reduce emissions related to three of most impacting activities in both purchasing processes: transportation in the offline one, while packaging and return in the online one.

What about the return rate?

The return activity, as described in previous chapters, has an impact on the final EI value of both online and offline purchasing process. One of the main factors determining the total amount of CO2 consumed in the return phase is the customer

behaviour, both for the offline purchasing process and for the online one. Regarding the traditional process, the customer plays a fundamental role in deciding what to purchase inside the store. In fact, sometimes the customer does not effectively test the items desired, maybe due to lack of time and interest (especially for clothing items), so the result is that once the item is used it may result defective or unwanted. Consequently, the customer should go back to the store and change the product. In this regard, customer awareness about the level of sustainability of his/her purchasing habits, should improve in order to increase his/her level of responsibility. Also in the e-commerce reality, customers sometimes buy items without a particular attention, so that they may result defective or unwanted once they arrive to home. In addition, in the online case, not only the return incidence has an impact but also the way in which the customer chooses to handle the return process. For instance, if he/she prefers to just return the unwanted item and request a money refund, the incidence of return process is lower than the case in which a second delivery is needed. In addition, the place in which the customer decides (the store or a pick-up point) to return, significantly affects the CO2 emission level. This depends also on where the customer lives: usually urban area shop accessibility and pick-up point availability is higher than the case in which the customer lives in an extra-urban area or rural one.
Another important aspect regards the future e-commerce market share explosion: it has been forecasted that the e-commerce market will become higher than traditional one, in future years. That will result in a higher number of product deliveries, and a consequent higher delivery failure rate. This result, not only in more transportation activities, but also larger quantity of packaging consumed. In addition, we have to consider that in the post-COVID era, when people will return to their normal habits, the occurrence of delivery failures is supposed to furtherly increase, since people will spend less time at home. In this regard, what can make the difference to minimize this

future increase of CO_2 is the level of customer responsibility. He/she may contain the problem by, for example, scheduling delivery date or opting for PP for picking items. So, if customer awareness will not improve, the return related emissions would become one of the main concerns in the online purchasing process, and the almost negligible return contribution to the emissions generation would become one of the main concerns.

Another important conclusion is linked to the ***Packaging typology impact.*** Online packaging has a huge impact also considering the fact that it is of fundamental importance to prevent products from being damaged or broken during transport. Therefore, the use of packaging in the online process is a very discussed topic in the literature and the CO_2 emitted varies considerably if we consider plastic or cardboard. By considering the online scenario and comparing plastic and cardboard boxes both for single and multiple-website scenarios, it is possible to see that the use of plastic pollutes more than three times more than cardboard (See tables 6-21, 6-22).

Moreover, the retailer has a huge impact also for the ***distribution network configuration choice.*** A traditional offline retailer is assumed to have stores, a central warehouse to replenish the stores and the dedicated warehouse. Using this configuration, not only transport activities account for an important source of emissions, but also the emissions deriving from store. As reported by Mangiaracina and colleagues (2016) [59], the emissions related to store are about 112 kWh/m^3 per year. Instead for the online purchasing process, the results show that, if the network is well optimized and the transport activities are well managed, the closer the retailer is to the customers' homes, the more sustainable the network is. So, by using both central and local warehouse the transport activities are minimized and also the $kgCO_2$ emitted. Another important conclusion is linked to the presence of collection points. Findings show that the scenarios in which pick-up points are adopted result to be less sustainable than home delivery option. This is due to the fact that, in recent years, due to the Covid-19 pandemic, people spend most of time at home and many workers are still in smart working. Therefore, considering the return rates linked to this historical period, the model calculated that it was preferable to send the packages home rather than to collection points. In this way, the distance that the customer has to travel to go to collect the parcels at the pick-up point is avoided. However, these results could change with the return to pre-COVID life and therefore with different rates of failed deliveries, the use of pick-up point could be more sustainable.

The diagram below summarizes the effects of each variable, considered in the analysis, on the amount of kgCO2e generated by purchasing processes.

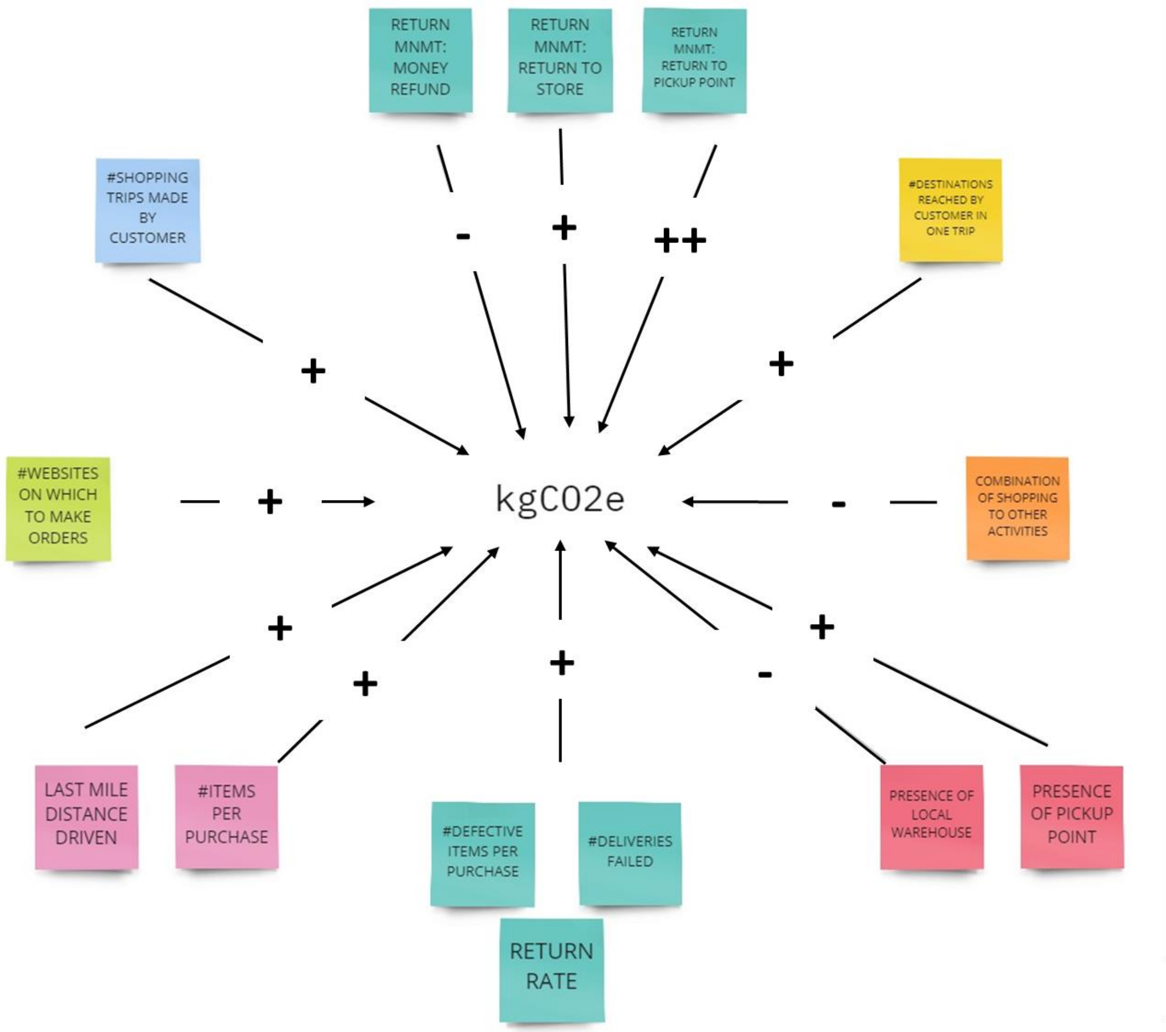


Figure 7-1: Causal diagram

7.2 Limitations and future directions

However, the analysis conducted has some limitations that should be discussed. Firstly, a portion of input data used in the analysis have been extracted by the results obtained from survey; the related sample population consists of 211 respondents, it does not fully represent each type of existing customer and purchasing scenario. So, the results obtained, and the scenarios considered (e.g. number of items for each purchase/product category) in the analysis are subjected to assumptions related to what mostly emersed in the answers given by respondents. Secondly, it was not possible to apply the model also for warehousing activity, both for the online and the offline process; more specifically, emissions related to building energy consumption are not considered. Moreover, our model does not include the grocery product category, since it is characterised by significant differences with respect to other product categories (e.g. the distribution network structure, the frequency of purchase/order and the return rate). Thirdly, only trucks have been considered as mean of transport in the store and warehouse replenishment, but there are cases, especially in the international contexts, in which sea or air transportation is adopted for the same purpose.

In conclusion, considering all described limitations, we suggest future research directions in order to amplify and fine-tune our results: effect of combination of grocery purchase with other purchases; including warehousing activity in the application phase; also including sea and air transportation for replenishment activity (international contexts).

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APPENDIX A

Survey about customer's purchasing behaviour.

Objective of the investigation: gathering information regarding customers' shopping habits both in the online and traditional purchasing channel.

The research was conducted in the months of September 2021 and October 2021. In this period, the questionnaire was diffused among respondents, and it was possible to collect 211 answers. The survey consists of 29 questions, split in five main sections: General personal information (6); General shopping preferences (4); Online purchases (9); Offline purchases (7); Return management (3). The sub-sections, containing the results explanation, will be provided by following the structure of the survey. The questionnaire will be showed in its original format and the graphs showing the results for each question will be reported.

Guidance for filling the questionnaire: "*Ciao a tutti, siamo due studentesse del Politecnico di Milano e stiamo lavorando alla nostra tesi di laurea magistrale, riguardante la misurazione dell'impatto ambientale di acquisti realizzati in negozio fisico o tramite il canale e-commerce. L'obiettivo è quello di mettere a confronto i due processi d'acquisto e identificare quello più sostenibile in determinati scenari. Vi chiediamo qualche minuto del vostro prezioso tempo per rispondere alle domande presenti nel questionario che vi stiamo proponendo. I dati saranno trattati in forma anonima e nel rispetto del REGOLAMENTO UE 2016-679. Vi ringraziamo in anticipo.*"

SEZIONE 1: Informazioni generali

Q1: Sesso

- ☐ *Maschio*
- ☐ *Femmina*
- ☐ *Altro*

Q2: Età

- ☐ *14-18*
- ☐ *19-35*
- ☐ *36-50*
- ☐ *Over 50*

Q3: Qual è il tuo livello di istruzione?

- ☐ *Licenza media*
- ☐ *Diploma di scuola superiore*
- ☐ *Laurea triennale*
- ☐ *Laurea magistrale*

Q4: In quale provincia abiti?

Q5: Abiti in una città di:

- ☐ *Grandi dimensioni*
  (+100.000 abitanti)
- ☐ *Medie dimensioni*

(40.000-100.000 abitanti)

- *Piccole dimensioni*
  (-40.000 abitanti)

Se nella domanda Q5 è stata indicata la risposta "Grandi dimensioni (+100.000 abitanti)", proseguire con la domanda Q6 del questionario, altrimenti passare direttamente alla SEZIONE 2.

Q6: Dove si trova la tua abitazione?

- *Centro città*
- *Zona residenziale di un'area urbana*

SEZIONE 2: Preferenze generali d'acquisto

Q7: Preferisci acquistare online o recarti in un negozio fisico?

- *Online*
- *Negozio fisico*

Q8: Per quale ragione?

Q9: Abitualmente fai shopping online?

- *Si*
- *No*

Se nella domanda Q9 è stata indicata la risposta "Si", proseguire con la SEZIONE 3 del questionario, altrimenti rispondere alla domanda Q10 e passare successivamente alla SEZIONE 4.

Q10: Per quale motivo?

- *Preferisci avere contatto diretto con il prodotto e ricevere i consigli di un esperto*
- *Non hai a disposizione un portale digitale con cui effettuare l'acquisto*
- *Ti trovi spesso fuori casa e non vuoi delegare nessuno a ricevere il tuo acquisto*
- *Ti infastidisce aspettare del tempo tra l'acquisto e la ricezione del prodotto*
- *Non sei affine alla tecnologia o non ti fidi dei pagamenti online*

SEZIONE 3: Acquisti online

Q11: Con quale frequenza compri online?

**Per acquisto si intende un ordine online che può essere costituito da uno o più articoli.*

- *Meno di 6 acquisti l'anno*
- *Da uno a tre acquisti al mese*
- *Una volta a settimana*
- *Più di una volta a settimana*

Q12: Quale tipo di prodotto compri maggiormente online?

	Mai	*Raramente*	*Qualche volta*	*Spesso*	*Sempre*
Abbigliamento, accessori, calzature	☐	☐	☐	☐	☐
Prodotti cosmetici	☐	☐	☐	☐	☐
Editoria (libri)	☐	☐	☐	☐	☐
Elettronica (pc, smartphone, tablet, etc.)	☐	☐	☐	☐	☐
Prodotti per edilizia, giardinaggio, bricolage, falegnameria, illuminazione	☐	☐	☐	☐	☐
Cancelleria	☐	☐	☐	☐	☐
Alimentari (food & beverage)	☐	☐	☐	☐	☐

Q13: In media da quanti articoli è composto il tuo ordine online?

	0	1	2	3	4	5	>5
Abbigliamento, accessori, calzature	☐	☐	☐	☐	☐	☐	☐
Prodotti cosmetici	☐	☐	☐	☐	☐	☐	☐
Editoria (libri)	☐	☐	☐	☐	☐	☐	☐
Elettronica (pc, smartphone, tablet, etc.)	☐	☐	☐	☐	☐	☐	☐
Prodotti per edilizia, giardinaggio, bricolage, falegnameria, illuminazione	☐	☐	☐	☐	☐	☐	☐
Cancelleria	☐	☐	☐	☐	☐	☐	☐

Q14: Relativamente al settore alimentare, da quanti articoli in media è composta la tua spesa online?

- ☐ *<5*
- ☐ *5-15*
- ☐ *15-30*
- ☐ *>30*
- ☐ *Non faccio mai la spesa di alimentari online*

Q15: Prima di effettuare un acquisto online ti rechi in uno store fisico per testare il prodotto?

- ☐ *Mai*
- ☐ *Raramente*
- ☐ *Qualche volta*
- ☐ *Spesso*
- ☐ *Sempre*

Q16: Quanti siti web/ pagine social confronti mediamente prima di effettuare un acquisto online?

- ☐ *Confronto sempre almeno 2 siti*
- ☐ *Confronto più di 2 siti*
- ☐ *Consulto solo ed esclusivamente il sito su cui voglio effettuare l'ordine*

Q17: Quante volte visiti lo stesso sito mediamente prima di effettuare l'acquisto?

- ☐ *2*
- ☐ *3*
- ☐ *4*
- ☐ *>4*

Q18: Dove abitualmente preferisci ricevere il tuo ordine?

	Mai	*Raramente*	*Qualche volta*	*Spesso*	*Sempre*
Presso la tua abitazione	☐	☐	☐	☐	☐
In negozio	☐	☐	☐	☐	☐
Punto di ritiro (locker, edicola, tabaccheria, etc.)	☐	☐	☐	☐	☐

Q19: Quando acquisti online ritieni di riempire il tuo carrello con un numero di articoli maggiore rispetto al caso in cui realizzassi il tuo acquisto in negozio?

- ☐ *Si*
- ☐ *No*

SEZIONE 4: Acquisti in negozio fisico

Q20: Per ciascuna delle seguenti categorie merceologiche indica con quale frequenza effettui acquisti in un negozio fisico.

	Meno di 6 acquisti l'anno	*Da 1 a 3 acquisti al mese*	*Una volta a settimana*	*Più di una volta a settimana*
Abbigliamento, accessori, calzature	☐	☐	☐	☐
Prodotti cosmetici	☐	☐	☐	☐
Editoria (libri)	☐	☐	☐	☐
Elettronica (pc, smartphone, tablet, etc.)	☐	☐	☐	☐
Prodotti per edilizia, giardinaggio, bricolage, falegnameria, illuminazione	☐	☐	☐	☐
Cancelleria	☐	☐	☐	☐

Q21: Quanto spesso fai la spesa di alimentari in un negozio fisico?

**Per rispondere considera te come individuo.*

- ☐ *Meno di 6 acquisti l'anno*
- ☐ *Da uno a 3 acquisti al mese*
- ☐ *Una volta a settimana*
- ☐ *Più di una volta a settimana*

Q22: Prima di effettuare un acquisto in un negozio fisico quanti negozi visiti mediamente?

	Non faccio questo tipo di acquisto	1	2	3	4	5	>5
Abbigliamento, accessori, calzature	☐	☐	☐	☐	☐	☐	☐
Prodotti cosmetici	☐	☐	☐	☐	☐	☐	☐
Editoria (libri)	☐	☐	☐	☐	☐	☐	☐
Elettronica (pc, smartphone, tablet, etc.)	☐	☐	☐	☐	☐	☐	☐
Prodotti per edilizia, giardinaggio, bricolage, falegnameria, illuminazione	☐	☐	☐	☐	☐	☐	☐
Cancelleria	☐	☐	☐	☐	☐	☐	☐
Alimentari (food & beverage)	☐	☐	☐	☐	☐	☐	☐

Q23: Prima di effettuare un acquisto in un negozio fisico quanti siti web visiti mediamente?

	Non faccio questo tipo di acquisto	1	2	3	4	5	>5
Abbigliamento, accessori, calzature	☐	☐	☐	☐	☐	☐	☐
Prodotti cosmetici	☐	☐	☐	☐	☐	☐	☐
Editoria (libri)	☐	☐	☐	☐	☐	☐	☐
Elettronica (pc, smartphone, tablet, etc.)	☐	☐	☐	☐	☐	☐	☐
Prodotti per edilizia, giardinaggio, bricolage, falegnameria, illuminazione	☐	☐	☐	☐	☐	☐	☐
Cancelleria	☐	☐	☐	☐	☐	☐	☐
Alimentari (food & beverage)	☐	☐	☐	☐	☐	☐	☐

Q24: In quale tipo di negozio e con quale frequenza realizzi i tuoi acquisti?

**La distanza indicata tra parentesi si riferisce al tragitto dalla tua abitazione al negozio.*

	Meno di 6 acquisti l'anno	*Da 1 a 3 acquisti al mese*	*Una volta a settimana*	*Più di una volta a settimana*
Centro commerciale (nell'arco di 5 km)	☐	☐	☐	☐
Centro commerciale (tra i 5 e i 20 km)	☐	☐	☐	☐
Centro commerciale (>20 km)	☐	☐	☐	☐
Negozio in centro città (nell'arco di 5 km)	☐	☐	☐	☐
Negozio in centro città (tra i 5 e i 20 km)	☐	☐	☐	☐
Negozio in centro città (>20 km)	☐	☐	☐	☐
Negozio in zona extra-urbana (nell'arco di 5 km)	☐	☐	☐	☐
Negozio in zona extra-urbana (tra i 5 e i 20 km)	☐	☐	☐	☐
Negozio in zona extra-urbana (>20 km)	☐	☐	☐	☐

Q25: Quanti acquisti effettui mediamente nella stessa occasione ma in negozi diversi? E dove?

**Si intende acquisti realizzati in negozi differenti (esempio: negozio 1, negozio 2, negozio 3 che possono essere tutti all'interno di un centro commerciale o localizzati in centro città o al di fuori di essa).*

	1	*2*	*3*	*4*	*5*	*>5*
Centro commerciale	☐	☐	☐	☐	☐	☐
Negozi situato in centro città	☐	☐	☐	☐	☐	☐
Negozi situati in un'area extra-urbana	☐	☐	☐	☐	☐	☐

Q26: Solitamente decidi di fare acquisti:

	Mai	Raramente	Qualche volta	Spesso	Sempre
Tornando a casa da lavoro/scuola/università/altro	☐	☐	☐	☐	☐
Tramite un viaggio dedicato	☐	☐	☐	☐	☐

SEZIONE 5: Ritorno di prodotti difettosi e mancata consegna

Q27: Quanto spesso ti capita di restituire un prodotto acquistato online, per ciascuna delle seguenti categorie?

	Mai	Raramente	Qualche volta	Spesso	Sempre	Non faccio questo tipo di acquisto
Abbigliamento, accessori, calzature	☐	☐	☐	☐	☐	☐
Prodotti cosmetici	☐	☐	☐	☐	☐	☐
Editoria (libri)	☐	☐	☐	☐	☐	☐
Elettronica (pc, smartphone, tablet, etc.)	☐	☐	☐	☐	☐	☐
Prodotti per edilizia, giardinaggio, bricolage, falegnameria, illuminazione	☐	☐	☐	☐	☐	☐
Cancelleria	☐	☐	☐	☐	☐	☐
Alimentari (food & beverage)	☐	☐	☐	☐	☐	☐

Q28: Quanto spesso ti capita di restituire un prodotto acquistato in un negozio fisico, per ciascuna delle seguenti categorie?

	Mai	Raramente	Qualche volta	Spesso	Sempre	Non faccio questo tipo di acquisto
Abbigliamento, accessori, calzature	☐	☐	☐	☐	☐	☐
Prodotti cosmetici	☐	☐	☐	☐	☐	☐
Editoria (libri)	☐	☐	☐	☐	☐	☐
Elettronica (pc, smartphone, tablet, etc.)	☐	☐	☐	☐	☐	☐
Prodotti per edilizia, giardinaggio, bricolage, falegnameria, illuminazione	☐	☐	☐	☐	☐	☐
Cancelleria	☐	☐	☐	☐	☐	☐
Alimentari (food & beverage)	☐	☐	☐	☐	☐	☐

Q29: Pensando all'ultimo anno, mediamente quante volte ti è capitato di non trovarti a casa al momento della consegna di un pacco?

- ☐ *Mai*
- ☐ *1-3 volte*
- ☐ *4-6 volte*
- ☐ *6-9 volte*
- ☐ *Più di 10 volte*

List of figures

List of tables

List of graphs