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Implementing A Sustainable and Efficient Packaging System for E-Commerce: An Empirical Perspective in the Household Sector

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Abstract:

Purpose: The growing importance of e-commerce has negative effects on the sustainability of supply chains, highlighting the need for appropriate packaging system design. Thus, it is increasingly common to see cities where thousands of packages are delivered every day, increasing congestion and pollution, but also increasing the consumption of materials and generation of waste, because these packages are often oversized. Therefore, retailers should consider different strategies for reducing the sustainable impact of their activities. In this context, the main objective of this article is to understand, illustrate and compare the solutions adopted in the e-commerce packaging, measuring their impact on sustainability, and paying a special attention to household products.

Design/methodology/approach: To achieve this main purpose, firstly a conceptual description of the problems associated with this design process is developed. This fist part is followed by a field study using a sample of twelve orders to analyse and compare the efficiency and sustainability of the packaging system for e-commerce adopted in the household products.

Findings: The results of the analysis show not only the diversity of packaging solutions adopted by each retailer analysed, but also their inefficiencies and the opportunities for improvement from an economic and environmental perspective, particularly regarding the selection and quantity of materials, as well as the volumes of the external packaging. This last aspect seems to be the differential factor for the best retailers.

Originality/value: Design decisions in e-commerce packaging systems have a direct impact on the consumption of materials (and waste), as well as an indirect impact on the efficiency of many logistics operations, in particular, last-mile transport. Despite this importance, however, little academic attention has been paid to this field, particularly with the applied approach proposed in this article and combining economic and environmental perspectives.

Keywords: packaging, e-commerce, sustainability, household products

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1. Introduction

Since it emerged at the end of the 20th century, e-commerce has boosted the sales and purchasing possibilities for companies and consumers in markets that are increasingly global but at the same time increasingly turbulent. This commercialization channel, which complements more traditional ones based on bricks-and-mortar shops (Taylor, Brockhaus, Knemeyer & Murphy, 2019), has seen its worldwide market share grow continually in recent years (Mangiaracina, Marchet, Perotti & Tumino, 2015; Lim & Srai, 2018), and at an even greater pace since the COVID-19 pandemic (García-Arca, González-Portela-Garrido, Prado-Prado & Fernández-González, 2024). Thus, worldwide e-commerce retail sales reported estimated revenues of 5.8 trillion US dollars in 2023 (www.statista.com). This volume of sales has not only meant an increase of $400 billion on the previous year but it was also the highest turnover of the last five years (which include the years of greatest impact from the pandemic). Indeed, the forecast is for this growth to continue in the coming years to reach 8 trillion US dollars in 2027.

However, the massive rollout of this trading channel has brought with it a number of challenges and problems when designing and configuring supply chains (Colla & Lapoule, 2012; Rai, 2019; Nogueira, de Assis-Rangel, Croce & Peixoto, 2022), in a context that is also facing growing social awareness because of the implementation of sustainable policies to promote the circular economy (Nguyen, Parker, Brennan & Lockrey, 2020). By way of illustration, a European Union study from 2021 (Crippa, Guizzardi, Solazzo, Muntean, Schaaf, Monforti-Ferrario et al., 2021) stated that goods transport was responsible for approximately 20% of global CO_2 emissions. In this sense, according to Pörtner, Roberts, Tignor, Poloczanska, Mintenbeck, Alegría et al. (2022), urban goods transport accounted for 20% of all emissions generated by goods transport; e-commerce deliveries plays a very important role in those urban movements (not only in direct product deliveries but also reverse logistics for potential returns, and the management of waste linked to orders). Other studies (Rai, 2019), indicate that transport associated with online orders may account for 36.4% of all goods transport emissions. Furthermore, the logistics aspects linked to e-commerce deliveries are an inevitable part of the consumers' own perception of quality and the purchasing experience (Ignat & Chankov, 2020; Pålsson & Olsson, 2023).

All these aspects fully affect one of the overarching elements that support the efficiency and sustainability of supply chains, that is, the packaging systems for e-commerce (Duan, Song, Qu, Dong & Xu, 2019; Zarei, Carrasco-Gallego & Ronchi, 2019; Escursell, Llorach & Roncero, 2021; García-Arca, González-Portela-Garrido & Prado-Prado, 2023; González-Romero, Rai, Ortiz-Bas & Prado-Prado, 2024). The justification for this statement lies in the fact that these decisions not only have a direct impact on the greater or lesser consumption of materials (and any associated waste) but also an indirect impact on the efficiency of many logistics operations such as picking, packing, and, particularly, last-mile transport (Zimmermann & Bliklen, 2020).

Thus, the design topic seems to be located in a relevant research area, the importance of which is growing as e-commerce itself grows. Curiously, authors such as Pålsson, Pettersson and Hiselius (2017), García-Arca, Comesaña-Benavides, González-Portela-Garrido and Prado-Prado (2020), Escursell et al. (2021) or García-Arca et al. (2023) point out that this impact contrasts with the scant attention so far paid to the issue by the academic world.

In this context, the main aim of this article is to understand, illustrate and compare the diversity of solutions adopted in the packaging system for e-commerce, measuring their impact on the global efficiency and sustainability of the supply chain. To do this, a conceptual explanation is first given of the problems associated with this design process, and then a field study is developed using a sample of twelve orders for household goods that will analyse the efficiency and sustainability of the packaging system adopted for their sale through e-commerce.

The article is structured in five sections, starting with this introduction. Section 2 describes the general issues associated with design of the e-commerce packaging system, which is followed by a description of objectives and methodology used in analysis of packaging in household sector (section 3) and the results achieved in the field study (section 4). Finally, section 5 provides the discussion and conclusions.

2. The Packaging System for E-Commerce

Within the design of the e-commerce supply chain, the selection of its packaging system is one of the most relevant elements. This consideration is based on terms that are both economic (lower consumption of materials and greater efficiency of logistics operations; Pålsson et al., 2017; Brüel-Grönberg & Hulthén, 2022) and environmental (lower waste generation and better use of transport, among other impacts) and, therefore, this design is closely aligned with the deployment of sustainability in its three pillars (environmental, economic and, indirectly, social). Thus, as the market share of e-commerce grows, so does the proportional amount of packaging that is supplied to the market (Halldorsson & Wehner, 2020), with the subsequent negative impact on the environment (Fernández-Briseño, Chegut, Glennon, Scott & Yang, 2020; Zimmermann & Bliklen, 2020).

However, the e-commerce supply chain should not be considered in isolation but rather as having potential for integration and coordination with more traditional supply chains based on physical stores in a strategy called "omnichannel" (Hübner, Kuhn, Wollenburg, Towers & Kotzab, 2016), which provides it with significant synergies at an economic and also an environmental level (García-Arca et al., 2020, 2023).

However, at this point it should be asked what is understood by the packaging system for e-commerce and what it is that makes it different from the traditional three-level one (based on primary, secondary, and tertiary packaging). The main need associated with the packaging system lies in the requirement that e-commerce orders usually have for packaging that can group them and protect them in what is called the "package", "packet" or "express packaging"—formally a type of secondary packaging (Wang & Hu, 2016; Pålsson, 2018; García-Arca et al., 2024). Initially, the cardboard box has mainly come to be used as the outer packaging for e-commerce, but it is frequently being substituted (when the product allows this) by simpler formats that are more economical and sustainable such as flexible envelopes (particularly plastic-free ones).

Likewise, this outer packaging tends to be used for order returns (when necessary), although it is still not common in e-commerce to employ reusable packaging that is good for several deliveries or customers (González-Romero et al., 2024). However, the issue of reverse logistics and its packaging should be connected to design decisions associated with where and how returns are made (including, if an omnichannel strategy is appropriate, the use of a physical store network). Logically, the packaging for these groupings is far removed from the large-scale groupings typical of consumption through physical stores based mainly on palletized units (tertiary packaging) (Barnes, 2016).

Additionally, packaging system for an e-commerce order tends to need the use of complementary materials (filling materials), to improve the level of protection (but also the commercial presentation of the products themselves), filling up the space between the inside of the packaging and the various items (Regattieri, Santarelli, Gamberi & Mora, 2014). These filling materials have in many cases become the focus of environmental controversy as their excessive use has negative impacts that include the costs of the materials themselves (and their waste management), the increase in the weight and volume of outer packaging that affects both the cost and environmental impact of transport, and the increased complexity of picking and packing processes at the warehouse (Pålsson, 2018; Regattieri, Santarelli, & Piana, 2019; Lu, Yang, Liu & Jia, 2020; Escursell et al., 2021; García-Arca et al., 2024).

At the same time, another substantial change in the e-commerce packaging system is its new commercial role, as it is becoming the first contact (and impression) the customer has with the products and an inseparable part of the shopping experience (the unboxing experience; Barnes, 2016; Regattieri et al., 2019; Schnurr & Wetzels, 2020). Likewise, customers themselves are becoming more critical of online orders, which they perceive as inefficient from an environmental perspective, and this should condition the packaging solutions proposed by e-commerce retailers (Ignat & Chankov, 2020; Pålsson & Olsson, 2023).

In all events, e-commerce packaging system design should not be addressed in an isolated fashion, away from the product manufacturer's traditional packaging system (based on the primary, secondary, and tertiary levels), bearing in mind that after manufacture and packing, the products can be supplied to various commercialization channels (including e-commerce but in many cases to the store-based channel) (Pålsson et al., 2017; Freichel, Wollenburg & Wörtge, 2020). Given this situation, e-commerce "pure players" such as Amazon have promoted the Frustration Free Packaging strategy among its suppliers with the aim of designing product packaging that can go from the manufacturer to the end customer without additional handling or protective packaging (García-Arca et al., 2024).

Organizational coordination aspects, both internally (within each company) and externally (between companies on the supply chain such as packaging suppliers, product manufacturers, retailers, 3PLs and so on) are key when designing the traditional packaging system, and this is also true when it comes to addressing the design of the e-commerce packaging system (Pålsson & Hellström, 2016; Freichel et al., 2020; García-Arca et al., 2020, 2023). Thus, such a coordinated vision will facilitate the correct adoption of packaging solutions that not only take into consideration the various design requirements (including productive, commercial, logistical, environmental, legal, or ergonomic ones) but do so in a way that is integrated into the design of the products themselves and the supply chain (Olander-Roese & Nilsson, 2009), and also in a way that is dynamic and adaptable to changes in such things as product range, commercialisation channels, technology, or legislation.

Regarding the legal aspect, it should be pointed out that public administrations have been very active in incentivising policies in companies that promote the implementation of more sustainable packaging alternatives, encouraging aspects such as reuse, materials recycling, or prevention through eco-design (Pålsson & Olsson, 2023). In this sense, the European Union has been particularly belligerent over the last three decades, ranging from publication of the European Directive 94/62 (1994) leading to deployment of the "green dot", which has been since been further updated and regulated, to the most recent Regulation on packaging and packaging waste (2025). These European norms have to be transposed by the different countries in the Union into their respective national legislation. To illustrate the current importance of this legal framework, it can be pointed out that, for example, Spain's current Law 7/2022 on Waste and the Circular Economy attempts, among other aims, to limit the use of plastic in packaging materials, imposing an additional fee that depends on the level of recycled material used. The new European Regulation (Regulation (EU) 2025/40 of the European Parliament and of the Council of 19 December 2024 on packaging and packaging waste; published in the Official Journal of the European Union in 22 January 2025) further develops this restrictive use of plastic by establishing, for example, minimum percentages for recycled materials by as soon as 2030; additionally, regarding e-commerce, it establishes a minimum occupation for transport packaging of 50%.

In this context, the two main strategies associated with packaging system design for e-commerce include, on the one hand, reductions in the environmental impact and the cost of materials employed, and on the other, reductions in packaging volume to improve transport efficiency (reducing logistics costs and the environmental impact of the delivery itself) (Regattieri et al., 2014, 2019; Wang & Hu, 2016; Pålsson et al., 2017; Rai, 2019; Lu et al., 2020; Kao, Sun, Tang, Luo & Zeng, 2020; Escursell et al., 2021; García-Arca et al., 2023, 2024). Logically, deployment of both strategies should also meet the basic premise of ensuring protection of the product and the retailer's commercial image.

But how much are these costs and environmental impacts? And how can they be measured? To illustrate the first question, for example, Zimmermann and Bliklen (2020) indicate that the packaging in an online order can account for between 10 and 30 percent of the total CO_2 emissions, while Fernández Briseño et al. (2020) comment that the carbon footprint of packaging can amount to 45% of the emissions for an e-commerce order. At an economic level, it should be noted that a study on e-commerce in Spain carried out by the Spanish Logistics Centre in 2023 ("III Estudio de la Logística del e-commerce"; https://cel-logistica.org/wp-content/uploads/2023/11/III-Estudio-de-la-Logistica-del-E-commerce.pdf) pointed out that within an e-commerce order's distribution costs (which include the picking and packing processes, packaging materials and transportation), the weight of the packaging materials can reach 20%; in fact, if the cost of transport (the main cost) is excluded from that analysis, the economic importance of the delivery materials with respect to all other processes and consumption carried out in the logistics platform can exceed 60%.

As for the second question concerning measurement, the range of metrics varies depending on the perspective or sustainability variable that takes centre stage (García-Arca et al., 2023). Thus, the range of metrics goes from the economic perspective (different costs affected by the packaging system design; Regattieri et al., 2014; Freichel et al. 2020) to the environmental perspective (applying techniques such as LCA or Life Cycle Assessment that assess the carbon footprint associated with packaging design; ISO 14040, 2006; Molina-Besch & Pålsson, 2020), and even to the commercial perspective (the impact on sales or a comparison of packaging systems among competitors by means of benchmarking techniques; Gelici-Zeko, Lutters, Klooster & Weijzen, 2012; Magnusson, Olander & Olsson, 2012).

In fact, given that packaging system design must meet a broad and diverse series of requirements, both the literature and praxis provide metrics that combine different qualitative and quantitative variables. Of note among the quantitative ones is the Packaging Scorecard method (Olsmats & Dominic, 2003), which has been used by major companies such as Ikea and Walmart.

Traditionally, packaging system design decisions have mainly been taken by the product manufacturing companies, although, as mentioned earlier, the desire is that this is done together with other parts of the supply chain; these traditional packaging system decisions are associated with selection of the material types to be used, the dimensions and formats, and the relationship between the structure levels (primary, secondary, and tertiary), aesthetic aspects (colours, texts, images, and so on) and, finally, the technology used in the various logistics processes (from packing to transport or handling).

However, with this manufacturer's packaging system in mind, in the e-commerce packaging system, design decisions relating to express packaging or filling materials to be used are mostly made by the distributor or retailer. This affects the range or number of packages needed and the filling materials and, therefore, once again includes design aspects such as formats, material type, dimensions, aesthetics, and technology. Linked to these technology aspects is the idea that packaging is increasingly considered to be an intelligent element that is able to monitor and trace the state of the product and the delivery ("smart packaging"; Zhang, Liu, Liu & Li, 2016; Ahmed, Lin, Zou, Li, Brody, Qazi et al., 2018; Lydekaityte & Tambo, 2020).

At this juncture, it should be pointed out that among all the decisions to be taken, it is likely that those concerning dimensions (seeking improved volumetric occupation) will be particularly complex and not easily resolved by simulations and rapid calculations (or NP-hard; Wu, Li, Goh & de Souza, 2010; García-Arca, Comesaña-Benavides, González-Portela-Garrido & Prado-Prado, 2021; García-Arca et al., 2023, 2024). This statement is based on the fact that in order to define the most interesting volumes (associated with the most suitable range of packaging and filling materials) it is necessary to find a balance between economies of scale in purchasing each format and the need to limit the complexity of the picking process (increase productivity) while not reducing the logistical efficiency of the transport. Moreover, all this must be addressed within a dynamic order framework and growing product range. Additionally, the various combinations of products in e-commerce orders (which are difficult to forecast anyway) increase the complexity of this decision-making process (Freichel et al., 2020).

In such a design scenario, a variety of interests, priorities, and needs emerge (often contradictory) that complicate decision making (Pålsson & Sandberg, 2020; García-Arca et al., 2020). From a conceptual or more academic point of view, design issues facing sustainable packaging systems for e-commerce have been covered in research approaches such as "Packaging Logistics" (Saghir, 2002) or, more recently, "Sustainable Packaging Logistics" (García-Arca, Prado-Prado & González-Portela-Garrido, 2014), which seek efficient and sustainable integration of product design, the packaging system, and the supply chain itself.

3. Objectives and Methodology

As mentioned in the introduction, this article has two aims: to illustrate the problems of e-commerce packaging system design, addressed in the previous section, and to analyse in an applied way the diversity of solutions adopted in that system within the household goods sector, measuring and comparing the impact on global efficiency and sustainability of its supply chain.

The main reason for selecting this sector lies in the important function that packaging has in ensuring protection and integrity of the (often highly fragile) products. However, this need for protection can also lead to the use of extra volume in packaging and the potential undesired side-effect of "overpackaging". This effect, paradoxically, can lead to diminished performance in logistics and sustainability. On the other hand, the household goods sector also has a significant presence in worldwide e-commerce, only surpassed by clothes, electronics, and toys ("III Estudio de la Logística del e-commerce", 2023; https://cel-logistica.org/wp-content/uploads/2023/11/III-Estudio-de-la-Logistica-del-E-commerce.pdf).

The article's practical research has been developed in a two-phase structure: an exploratory phase, to discover how the supply chain operates for online sales of household good, and a field-study phase that will allow comparison of the various alternatives in terms of efficiency and sustainability. Below is a description of both phases.

3.1. Exploratory Analysis of the Supply Chain

The aim of this initial phase is to explore how the different stages on the household goods e-commerce supply chain function (including processes, criteria, resources, and infrastructure). To do this, interviews were held with operations and logistics managers in the most relevant organizations on this chain, which included visits to their logistics facilities. In this way, information was gleaned from within the supply chain of the following organizations:

- Two online retailers. The first is a major multinational specialized in household and home furniture products that also has an extensive physical store network; however, although the company operates in an omnichannel environment, the logistics platform visited is aimed exclusively at servicing the company's e-commerce activity in Spain, employing over 200 people.

  The second trader analysed is a small company specialized in online sales. It has a wide product range, which included both household goods and "gourmet" type food products; its logistics platform is a small warehouse where online orders are prepared, employing a workforce of fewer than ten people.

- Two packaging materials and packing equipment suppliers, who supply their products to the household goods sector and other sectors (including the two previous retailers). The range of packaging materials on offer is wide and goes from cardboard boxes (in many formats, qualities, and dimensions) to envelopes (paper and plastic) and filling materials for protection and improved aesthetics (paper and plastic). Some of the materials are manufactured by the companies themselves but they also act as suppliers of those manufactured by other producers.

- A logistics operator for parcel deliveries in Spain, with a strong presence in e-commerce orders (including the two previous retailers). The transport services include activities such as parcel collection from origin, route consolidation to forward parcels to their destinations and, finally, last-mile delivery to the destination (end customers' homes, delivery points, or lockers). When instructed by the retailers, this logistics operator also takes care of customer returns. This analysis also included a visit to one its logistics centres for order consolidation and crossdocking.

The above analysis has improved understanding of the production and logistics problems of these organizations. The following processes have been reviewed in more detail: procurement, reception and storage; picking; packing; distribution transport; returns collection; and, finally, management of packaging materials waste. These processes are briefly discussed below:

- Procurement, reception and storage on the retailer's platform. Product procurement is done from the suppliers' factories or warehouses; in addition to the suppliers providing the products to be sold, other suppliers are relevant such as those for packaging material.

  In this process, the main resources consumed are associated with transport for the supply, which has an environmental impact and cost that are conditioned, among other things, by the quantity of a product in the shipment, the distance from the supplier, and how full the truck is; the supplier's own packaging system design plays an important role in the efficiency of this transport. At the same time, rationalisation of the resources in the retailer's logistics platform is affected by the design and the location criteria for the storage and handling system (again, affected by the supplier's packaging system). Logically, in the two retailers analysed, the diversity of the range, the suppliers of the selected products (including their original packaging system), the logistics resources, and the number of orders to prepare are very different.

- Picking at the retailer's logistics platform. This process aims to adapt the quantities received from suppliers to those requested in the various customer orders. The main resource used in this process is the workforce associated with moving, handling, and searching within the facility (this process is typically carried out manually on logistics platforms, including the two analysed ones). The cost and environmental impact of picking is associated with minimizing breakages and waste, and also with the productivity of the pickers.

  Regarding this last point, it should be noted that productivity depends, among other aspects, on the warehouse layout, the method employed, the supporting information system, the criteria for locating products in the warehouse, or the picking batch, i.e., the number of orders prepared simultaneously. All these aspects are very different at the two analysed retailers although one thing they have in common is that they are highly labour intensive.

- Packing and shipping of orders on the retailer's logistics platform. This process consists of gathering the units for each order that have come from the picking process while at the same time choosing the most suitable packaging (from the available range). This process also includes the protection of products and enhancement of their commercial presentation. Likewise, the documentation and labels needed for dispatch and distribution transport are generated

  The packing process is also typically carried out manually and productivity is affected by the design of the workstation (including the supporting information system), the variety of packaging formats available, and, related to the latter, the ergonomics in handling the products and packaging (including the quantity and type of filling and aesthetics material to be used). Unlike the previous processes, packing tasks are similar at both the analysed retailers, with the real difference lying precisely in the range of packaging materials available at the workstation, which conditions packaging agility, logistics efficiency, and sustainability (due to the volume employed in the external packaging and the quantity of materials used in each order).

- Distribution transport from the retailer's logistics centre to the delivery point (customer's home, locker, collecting point, etc.), using the courier services of a specialized company. This transport is not homogeneous, but actually has several steps that include, at least, collection from the retailer's logistics centre to a nearby order handling centre of the transport company (typically a crossdocking centre), transport from this centre at the start of the logistics flow to another of the transport company's centres at the destination (near the delivery point), and, finally, from this handling centre to the final delivery point (last mile).

  Each of these steps means additional handling of the parcels in the orders and the use of different vehicle types (trucks, vans), with different types of capacity in terms of load volume and weight. However, in the orders commonly taken by parcel services (which include online orders), the most critical restriction for vehicles tends to be volume rather than weight. In this sense, different studies (Braekers, Ramaekers & Van Nieuwenhuyse, 2016; Aljohani & Thompson, 2020) highlight the low occupation of such transport given that aspects linked to speed take priority in customer deliveries. Thus, occupied volume is not usually greater than 50%, and is less in last-mile deliveries and pickups, which clearly has additional negative impacts in economic terms but also environmental terms (as more vehicles are used with a lower occupation rate).

- Customer returns pick-up transport. As the e-commerce customer's first contact with the product is on delivery, some orders may not be to their liking or taste (alternatively, they may receive the wrong product or—more likely with household goods—one that is broken). For these reasons, the customer can decide to return all or part of the order. This opens up an additional process of reverse logistics (the first mile) that includes transport to a point specified by the retailer. In this process, as mentioned previously, the availability and condition of the original packaging is critical to facilitate the return for the customer, but also to ensure the integrity of the returned product.

- Finally, once the (accepted) order reaches the customer, the packaging and its associated material becomes waste (unless returnable packaging has been chosen, which is an unusual alternative in e-commerce). Traditionally, this packaging system waste ends up in specific supply chains linked to integrated management systems for recycling or recovery. In many markets (like Europe), this management means the payment of a green fee (the green dot) which depends on the weight and type of material according to legal framework in force. As mentioned previously, this legislation in Europe has been recently updated (European regulation 2025/40 on packaging and packaging waste) in order to promote, as far as possible, prevention, reuse, and an increased use of recycled materials.

Thanks to the analysis made of the supply chain in the sector, it has been possible to share the problems of each process with each company, collecting primary information in terms of costs, but also validating or establishing consensus on hypotheses and criteria in order to interpret those costs and the environmental impacts, which will be useful in the second part of the research, the field study.

In this sense, there has also been consensus with the analysed companies about how critical the processes are in relation to the specific design of the e-commerce packaging system. Thus, for these companies, the processes associated with packing, distribution and returns transport, and waste management of the system itself are the most critical of all the processes in the chain.

The justification for excluding the processes of procurement, reception, storage, and picking is based on the fact that these are precisely where the supplier's traditional packaging has most impact on the system, and this is highly variable depending on the selection of suppliers and the product range chosen by each retailer. Additionally, the critical impact of the packaging system on the generation of returns (through breakages or damage) can be mitigated in the analysis if it is ensured that the products arrive in perfect condition (and, logically, without errors); thus, if customer returns were produced, they would be motivated more by commercial issues that by the packaging itself.

With these considerations in mind, and with the working hypothesis that no product returns are made due to breakages, the field study will pay special attention to the impact of the packaging used in e-commerce (that designed by the retailer) in the processes of packing, distribution transport, and waste management, where, as indicated, certain design decisions play an important role: materials, quantities used, range of packaging, and associated volumes.

3.2. Field Study Design

In order to develop the field study that forms the subject of this second phase, the authors made a prior study of the Spanish market of household goods retailers operating online. That analysis led to the selection of a sample of 12 companies with various characteristics in terms of size, sales channels, geographical area for activity, or product range on offer (see Table 1).

Code for the company	Company size	Preferred geographical market	Sales channels	Specific range of products (if range only includes household goods)
Retailer 1	Multinational	World	E-commerce	NO
Retailer 2	Small	Spain	Omnichannel	YES
Retailer 3	Small	Spain	E-commerce	NO
Retailer 4	Large	Europe	Omnichannel	YES
Retailer 5	Multinational	World	Omnichannel	YES
Retailer 6	Small	Spain	E-commerce	YES
Retailer 7	Small	Spain	Omnichannel	YES
Retailer 8	Small	Spain	Omnichannel	YES
Retailer 9	Large	Europe	Omnichannel	YES
Retailer 10	Multinational	World	Omnichannel	YES
Retailer 11	Small	Spain	Omnichannel	YES
Retailer 12	Multinational	Europe	Omnichannel	NO

Table 1. Characterization of the sample of companies in the field study

At the same time, in order to configure the order to be placed with each of the 12 companies, four common household products were selected that vary in terms of fragility, shape, and volume. In each order, it was decided to include a single unit of each product in order to reduce distortion in the results that could be generated by the variety of packaging furnished by the supplier to the retailer and that, logically, could be different depending on the supplier chosen.

The two e-retailers analyzed in detail in section 3.1 are also included in the sample of companies discussed in Table 2 (retailer 3, small, and retailer 5, large and multinational). On the other hand, as already mentioned, each of the two suppliers analyzed (packaging materials and packing equipments) correspond to the main suppliers of the retailers 3 and 5. Finally, the logistics operator analyzed is the transport supplier for 6 of the 12 orders (including those of retailers 3 and 5). This overview of the supply chain gives an approximate idea of the possible problems encountered during the preparation and shipment of each order.

Likewise, the individual product approach would increase, a priori, the logistical complexity of the packing in terms of protection materials and packaging volumes used, which could provide a greater diversity and richness in the solutions offered by the retailers in the orders. In this context, the following products were selected (see Figure 1):

- A wine glass of approximately 33 centilitres.
- A glass tumbler of approximately 9 cm in diameter and 10 cm tall.
- A ceramic plate of approximately 26 cm diameter.
- A ceramic bowl of approximately 15 cm in diameter and 8 cm tall.

However, although an attempt has been made to select products of similar weight and volume, as they came from different retailers (and associated suppliers), complete homogeneity is not possible. For this reason, the analysis of results includes a double perspective in terms of weight and volume (the critical variables for comparing economic and environmental impact); the results are given in absolute terms, but also in relative terms (i.e., depending on the weight and volume of the products). In the analysis the concept of theoretical volume of the product is applied (a theoretical cylinder that would enclose externally each product in order to get its diameter and height).

The orders at the various retailers were placed and received in the same 15-day period, outside special sales periods to avoid distortions of a commercial nature. The detailed results from the field study are given in the following section: preliminary results were presented by the authors at the 18th International Conference on Industrial Engineering and Industrial Management (ICIEIM), held in Madrid (2024).

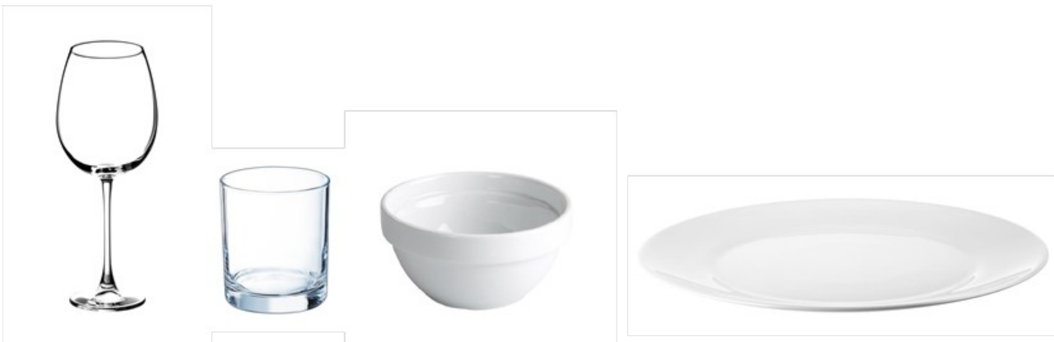

Figure 1. Products selected in a sample of orders in e-commerce

4. Field Study Results

Once each order has been received, a thorough analysis of the materials, weights and dimensions of both the packaging system elements and the products themselves is carried out. In this regard, Table 2 contains detailed information of the products.

The packaging configurations adopted for all 12 deliveries share a common element in having a cardboard box as outer packaging, although, logically, with differing dimensions and weights. Inside each outer box is where the most significant conceptual differences begin, as some orders include inner cardboard boxes for one or several of the products (these are the retailers' own packaging), and some use various types of material (paper-card and/or flexible plastic) as packaging filler (as both a protective and aesthetic element).

	Type of Product	Weight (Kg)	Diameter (cm)	Height (cm)	Theoretical cylinder volume (dm^3)
Retailer 1	Wine Glass	0.206	8	22	1.106
	Glass tumbler	0.098	8.5	10	0.567
	Ceramic plate	0.794	25.5	2.5	1.277
	Ceramic bowl	0.362	14.5	8	1.321
		1.460			**4.271**
Retailer 2	Wine Glass	0.185	8	24	1.206
	Glass tumbler	0.171	8.5	9	0.511
	Ceramic plate	0.357	25	2.5	1.227
	Ceramic bowl	0.295	15.5	6.5	1.226
		1.008			**4.171**
Retailer 3	Wine Glass	0.553	10.5	18	1.559
	Glass tumbler	0.325	8	9.5	0.478
	Ceramic plate	0.685	25.5	3	1.532
	Ceramic bowl	0.060	13.5	8	1.145
		2.123			**4.713**
Retailer 4	Wine Glass	0.154	6	26	0.735
	Glass tumbler	0.302	7.5	10.5	0.464
	Ceramic plate	0.693	30	2.5	1.767
	Ceramic bowl	0.354	15	7	1.237
		1.503			**4.203**
Retailer 5	Wine Glass	0.183	8	21.5	1.081
	Glass tumbler	0.396	9	13.5	0.859
	Ceramic plate	0.633	27	3	1.718
	Ceramic bowl	0.425	15	8	1.414
		1.637			**5.071**
Retailer 6	Wine Glass	0.248	6.5	17.5	0.581
	Glass tumbler	0.206	9	10	0.636
	Ceramic plate	0.646	28	4	2.463
	Ceramic bowl	0.114	11.5	4	0.415
		1.214			**4.095**
Retailer 7	Wine Glass	0.187	8.5	24	1.362
	Glass tumbler	0.226	8.5	9	0.511
	Ceramic plate	0.464	27	2	1.145
	Ceramic bowl	0.251	15.5	4	0.755
		1.128			**3.772**
Retailer 8	Wine Glass	0.365	9	20	1.272
	Glass tumbler	0.320	8	10	0.503
	Ceramic plate	0.726	26	2.5	1.327

	Type of Product	Weight (Kg)	Diameter (cm)	Height (cm)	Theoretical cylinder volume (dm^3)
	Ceramic bowl	0.359	13	7	0.929
		1.770			**4.031**
Retailer 9	Wine Glass	0.396	8.5	23	1.305
	Glass tumbler	0.487	9	9.5	0.604
	Ceramic plate	0.692	27	2.5	1.431
	Ceramic bowl	0.295	13	6	0.796
		1.870			**4.137**
Retailer 10	Wine Glass	0.209	9	23	1.463
	Glass tumbler	0.376	8.5	13.5	0.766
	Ceramic plate	0.634	26	2	1.062
	Ceramic bowl	0.346	14.5	6.5	1.073
		1.565			**4.364**
Retailer 11	Wine Glass	0.280	11	12	1.140
	Glass tumbler	0.112	5.5	9.5	0.226
	Ceramic plate	0.717	25.5	3	1.532
	Ceramic bowl	0.185	13.5	4	0.573
		1.294			**3.471**
Retailer 12	Wine Glass	0.305	9	21.5	1.368
	Glass tumbler	0.319	9.5	9	0.638
	Ceramic plate	0.625	28	2	1.232
	Ceramic bowl	0.334	14.5	8	1.321
		1.583			**4.558**

Table 2. Data compilation of products in orders (weight, dimensions and volume)

The outer boxes are mainly of the "American" type with overlapping flaps; only one order was made using a lidded box. None of the outer boxes are reusable beyond possibly serving for customer returns. In this sense, in terms of delivery quality, it should be noted that none of the deliveries showed any signs of product breakage or deterioration, which justified not assessing reverse logistics for returns in the analysis of economic and environmental impacts.

At the same time, of the 12 orders, only two do not include plastic in their filling material, while in another three the filling material is only flexible plastic; the seven remaining orders combine card with flexible plastic as filler (low-density polyethylene or LDPE). Tables 3 and 4 show the basic analysis of dimensions, weights, materials, and volume corresponding both to the packaging system and the products themselves, where the broad dispersion of quantitative parameters offered by the retailers in their orders can be observed.

In this sense, the weight of the packaging system with respect to the weight of the whole order (packaging material weight plus product weight) varies between 18% and 50%; in fact, the outer box alone accounts for between 42% and 75% of total packaging material weight. On the other hand, the volume occupied by the products (theoretical) with regard to the total outer volume of the main box varies between 7% and 23%, which empirically validates what has been mentioned in the literature regarding the low level of filling in e-commerce packaging.

From these basic data, operational indicators (OPIs) can be obtained regarding the weight and volume of the packaging system with respect to theoretical volume and weight of the products themselves in each of the 12 deliveries (see Table 5). In this way, in terms of packaging materials weight with respect to theoretical volume of the products, the best packaging alternatives (retailers 1, 2, and 3) only employ 25% of the weight required by the worst deliveries (retailers 12, 11, and 10). At the same time, in terms of outer box volume with respect to theoretical product volume, the best packaging alternatives (retailers 3, 2, and 5) only employ 30% of the volume required by the worst deliveries (retailers 8, 12, and 11).

	Theoretical product volumes (dm^3)	External dimensions in outer box (Length* width* height) (mm)	External box volume (dm^3)	External dimensions in inner box(es) (Length* width* height) (mm)
Retailer 1	4.271	400*315*215	27.090	Box 1: 90*90*225
Retailer 2	4.171	300*295*210	18.585	–
Retailer 3	4.713	350*295*195	20.134	–
Retailer 4	4.203	460*300*300	41.400	–
Retailer 5	5.071	320*295*245	23.128	–
Retailer 6	4.095	550*350*150	28.875	–
Retailer 7	3.772	350*350*150	18.375	–
Retailer 8	4.031	400*300*475	57.000	–
Retailer 9	4.137	390*385*285	42.793	Box 1: 280*280*90 Box 2: 110*115*150 Box 3: 100*105*270
Retailer 10	4.364	510*410*195	40.775	–
Retailer 11	3.471	405*330*300	40.095	Box 1: 280*275*35 Box 2: 70*70*155 Box 3: 145*145*50 Box 4: 110*110*150
Retailer 12	4.558	400*365*430	62.780	Box 1: 260*355*385

Table 3. Volumes of packaging and products in the deliveries

	Products weight (kg)	Empty outer box weight (Kg)	Inner box(es) weight (Kg)	Filling material (paper) weight (kg)	Filling material (plastic) weight (kg)	Pack. materials weight (kg)	Order weight (products and pack.) (kg)	Volumetric weight in the order (Kg)
Retailer 1	1.46	0.25	0.047		0.096	0.393	1.853	4.515
Retailer 2	1.008	0.286	–		0.144	0.43	1.438	3.098
Retailer 3	2.123	0.372	–		0.120	0.492	2.615	3.356
Retailer 4	1.503	0.469	–	0.020	0.208	0.697	2.200	6.900
Retailer 5	1.637	0.429	–	0.421		0.85	2.490	3.855
Retailer 6	1.214	0.529	–	0.017	0.192	0.738	1.952	4.813
Retailer 7	1.128	0.426	–	0.244	0.031	0.701	1.829	3.063
Retailer 8	1.77	0.76	–	0.122	0.221	1.103	2.873	9.500
Retailer 9	1.87	0.722	0.303	0.042	0.110	1.177	3.047	7.132
Retailer 10	1.57	0.671	–	0.619		1.29	2.860	6.796
Retailer 11	1.294	0.528	0.258	0.219	0.056	1.061	2.355	6.683
Retailer 12	1.583	0.684	0.439	0.301	0.180	1.604	3.187	10.463

Table 4. Weights of packaging and products in the deliveries

	Operational Indicators (OPIs)			
	Weight of packaging materials (Kg) relative to theoretical product volumes (dm^3) (OPI1)	Volume of outer box (dm^3) relative to product volumes (dm^3) (OPI2)	Weight of packaging materials (Kg.) relative to weight of products (Kg) (OPI3)	Volume of outer box (dm^3) relative to volume of products (Kg) (OPI4)
Retailer 1	0.092	6.343	0.269	18.555
Retailer 2	0.103	4.456	0.427	18.438
Retailer 3	0.104	4.272	0.232	9.484
Retailer 4	0.166	9.850	0.464	27.545
Retailer 5	0.168	4.561	0.518	14.102
Retailer 6	0.180	7.051	0.608	23.785
Retailer 7	0.186	4.871	0.621	16.290
Retailer 8	0.274	14.140	0.623	32.203
Retailer 9	0.285	10.344	0.629	22.884
Retailer 10	0.296	9.343	0.822	25.971
Retailer 11	0.306	11.551	0.820	30.985
Retailer 12	0.352	13.774	1.013	39.659

Table 5. Results in operational indicators (OPIs). Relative indicators of volume and weight for the packaging system in the sample of orders (colour range: green – most efficient solution and red – least efficient solution in each indicator)

Shifting the focus of analysis to the relative indicator for weight (packaging materials weight with respect to product weight), the best packaging alternatives (retailers 3 and 1) only employ 22% of the weight required by the worst orders (retailers 12, 10, and 11). Likewise, in terms of outer box volume with respect to theoretical product volume, the best packaging alternative (retailer 3) only uses 23% of the volume required by the worst deliveries (retailers 12, 8, and 11).

Regarding sustainability's economic pillar, from the above indicators it is possible to estimate the cost of each packaging material and the different supply chain processes affected by its design (including waste management). The following calculation criteria have been used to perform this economic estimate:

- Packaging costs. In both of the retailers' logistics platforms, time measurements were taken for 50 different orders that were similar in references and numbers to those in the field study; the times obtained have been displayed in a linear function that is related to the outer volume of the box (the greater the volume, the worse the ergonomics and the greater the quantity of filling used). With this function, the packing time for each order can be estimated. This time is then multiplied by the hourly cost for a typical worker (8.9 €/hour). The final reference value for the packing process is 0.008 €/dm^3.
- Cost of packaging materials. A market price has been agreed with the packaging materials suppliers for each kilo of material used: cardboard/paper (1.36 €/kg in the box and 0.8 €/kg in the filling material); flexible plastic (5 €/kg). This simplification was agreed upon even though these costs are clearly influenced by the box format chosen (inner or outer) and, particularly, by the quality of the materials used (including the percentage of recycled materials they may have).
- Transport cost. To estimate this cost, the logistics operator's tariff has been taken for a wholesaler delivery with a Spanish origin and destination (home delivery with no associated returns). This tariff varies in bands according to the weight of the shipment. However, to apply this weight banding, the maximum is used between the real weight and the volumetric weight. The volumetric weight is a commonly used variable in courier services that adjusts the real weight of the shipment to its density or volumetry; for the analysed logistics operator, a reference density of 6,000 cm^3 is used for each kilogram (also commonplace in other courier services), which makes it possible to calculate the volumetric weight using the Formula 1.

$$\text{Volumetric weight} = [\text{Length (cm)} * \text{Breadth (cm)} * \text{Height (cm.)}]/[6{,}000\ \text{cm}^3/\text{Kg}] \tag{1}$$

  As can be observed in the sample of orders (see Table 4), the cost of the transport tariff for all of them is conditioned by the volumetric weight and not by the real weight of the shipment.

- Waste management costs for packaging materials. To estimate these costs, use has been made of the tariff per kilo and the material type taken from the most widely used Integrated Management System in Spain, Ecoembes (https://ecoembesempresas.com). Thus, the tariffs applied (valid for 2025) are 0.117 €/kg for cardboard and 1.368 €/kg for flexible plastic.

Using this economic basis, and the primary data gathered from the shipments for volume and weight, detailed values are obtained for each cost in each delivery (see Table 6). Thus, by studying these costs, it can be seen how the importance of the packaging materials cost varies, depending on the shipment, between 18% and 29%. At the same time, the cost of packing varies between 3% and 5%, and the cost of waste management has a relative importance in terms of the total cost of between 1% and 4.5%. In all events, the most important cost associated with the delivery is that for transport, which varies in importance between 62% and 75%.

Shifting the focus of the analysis from sustainability's economic pillar to its environmental pillar, it should be noted that equivalent kilograms of CO_2 emissions have been used as the reference for all the activities, materials used, or waste generated. In this sense, the impact of the packing process has been disregarded due to its manual nature in the logistics platforms of the two retailers considered. Specifically, in terms of packaging materials and waste in each shipment, the reference values provided by Ecoinvent (2022; https://ecoinvent.org) have been used, with differentiation between materials production (1.24 kg/card-paper and 1.98 kg/flexible plastic) and waste management (2.52 kg/card-paper and 2.53 kg/flexible plastic).

	Outer box theoret. cost	Inner box(es) theoret. cost	Filling material cost (paper)	Filling material cost (plastic)	Packing cost for shipment	Shipment transp. cost	Waste manag. cost (card/ paper)	Waste manag. cost (plastic)
Retailer 1	0.339	0.064	0.000	0.480	0.229	3.620	0.000	0.131
Retailer 2	0.388	0.000	0.000	0.720	0.157	3.380	0.000	0.197
Retailer 3	0.505	0.000	0.000	0.600	0.170	3.380	0.000	0.164
Retailer 4	0.636	0.000	0.016	1.040	0.350	4.835	0.002	0.285
Retailer 5	0.582	0.000	0.337	0.000	0196	3.380	0.049	0.000
Retailer 6	0.718	0.000	0.014	0.960	0.244	3.620	0.002	0.263
Retailer 7	0.578	0.000	0.195	0.155	0.155	3.380	0.029	0.042
Retailer 8	1.031	0.000	0.098	1.105	0.482	7.000	0.014	0.302
Retailer 9	0.979	0.411	0.034	0.550	0.362	4.835	0.005	0.150
Retailer 10	0.910	0.000	0.495	0.000	0.345	4.835	0.072	0.000
Retailer 11	0.716	0.350	0.175	0.280	0.340	4.835	0.026	0.077
Retailer 12	0.928	0.596	0.241	0.900	0.531	7.535	0.035	0.246

Table 6. Results. Details of the costs associated with the shipments

In terms of the transport's environmental impact, the strategy used is an average radius for deliveries of 600 km (reasonable for Spain's centre-periphery axis), which includes the "first-mile" collection transport, the mid distance transport, and the "last mile" for home delivery (with no return). According to the logistics operator analysed, the vehicle chosen was a diesel van with a capacity of 18,000 dm^3 and an average occupation level of 50%. With this working hypothesis, information from the European Environmental Agency (2023; https://www.osti.gov/etdeweb/biblio/22128042) was used that puts this vehicle's environmental impact figure at 0.33 equivalent CO_2 Kg per kilometre, which, with the distance and occupation hypotheses, gives a study value of 0.022 Kg CO_2 per dm^3.

Detailed data for equivalent CO_2 emissions are given in Table 7. Thus, the importance of emissions form card-paper materials manufacture over all emissions for the shipment varied between 16% and 28%, while this relative importance for plastic materials manufacture over the total varied between 2% and 13%. On the other hand, the importance of waste management emissions for card-paper varied between 13% and 27%, while the importance of plastic waste management emissions varied between 2.5% and 17% (logically, in shipments using plastic partially or totally for filling).

More generally, Table 8 summarises the aggregates for costs and emissions, relativised, furthermore, by product weights and volumes, supporting economic indicators (ECIs) and environmental indicators (ENIs). Thus, the overall costs in the most economical orders (retailers 7, 5, and 3) come to roughly 41% of the costliest orders (retailers 12 and 8). Relativising these order costs by dm^3 of product, the relative cost of the best orders (retailers 5 and 3) comes to roughly 36% of the relative cost of the worst orders (retailers 8 and 12). Likewise, by relativising these costs per kilo of product, the relative cost of the best orders (retailers 3 and 5) comes to roughly 32% of the relative cost of the worst orders (retailers 12, 8, and 11).

At the same time, overall CO2 emissions for the most efficient orders (retailers 1, 2, and 3) come to roughly 28% of the emissions in the order with the worst environmental impact (retailer 12). Relativising these environmental impacts by dm3 of product, the relative impact of the best orders (retailers 1, 3, and 2) comes to roughly 30% of the impact of the worst orders (retailers 12 and 11). Likewise, by relativising these environmental impacts per kilo of product, the relative impact of the best orders (retailers 3 and 1) comes to roughly 23% of the relative impact of the worst orders (retailers 12, 11, and 10).

	Kg CO_2 Production of packaging paper-card in shipment	Kg CO_2 Production of plastic in shipment	Kg CO_2 Transport in shipment	Kg CO_2 paper-card waste in shipment	Kg CO_2 waste plastic in shipment
Retailer 1	0.368	0.190	0.596	0.748	0.243
Retailer 2	0.355	0.285	0.409	0.721	0.364
Retailer 3	0.461	0.238	0.443	0.937	0.304
Retailer 4	0.606	0.412	0.911	1.232	0.526
Retailer 5	1.054	0.000	0.509	2.142	0.000
Retailer 6	0.677	0.380	0.635	1.376	0.486
Retailer 7	0.831	0.061	0.404	1.688	0.078
Retailer 8	1.094	0.438	1.254	2.223	0.559
Retailer 9	1.323	0.218	0.941	2.689	0.278
Retailer 10	1.600	0.000	0.897	3.251	0.000
Retailer 11	1.246	0.111	0.882	2.533	0.142
Retailer 12	1.766	0.356	1.381	3.588	0.455

Table 7. Results. Detail of the environmental impact in the shipments

As can be seen in the “colour map” in Tables 5 and 8, there is some variability in the ranking of the best and worst companies depending on the parameters being considered, although some homogeneity is observable for orders in the green area and in the red area. In this sense, order 3 could be chosen as the one found most frequently in the ranking for the best orders in all the variables considered, whereas order 12 is within the ranking of the worst orders in all the variables considered.

	Economic indicators (ECIs)			Environmental indicators (ENIs)		
	Total order cost (€) (ECI1)	Order cost (€) / theoretical product volume (dm^3) (ECI2)	Order cost (€) / Kg product (ECI3)	Total Kg CO_2 Shipment (ENI1)	Total Kg CO_2/ theoretical product volume (dm^3) (ENI2)	Total Kg CO_2/ Kg product (ENI3)
Retailer 1	4.863	1.139	3.331	2.146	0.502	1.470
Retailer 2	4.842	1.161	4.804	2.134	0.512	2.117
Retailer 3	4.819	1.023	2.270	2.383	0.506	1.122
Retailer 4	7.164	1.705	4.767	3.688	0.877	2.453
Retailer 5	4.544	0.896	2.771	3.705	0.731	2.259
Retailer 6	5.820	1.421	4.794	3.554	0.868	2.928
Retailer 7	4.534	1.202	4.020	3.063	0.812	2.716
Retailer 8	10.032	2.489	5.668	5.567	1.381	3.145
Retailer 9	7.326	1.771	3.918	5.449	1.317	2.914
Retailer 10	6.658	1.526	4.241	5.747	1.317	3.661
Retailer 11	6.798	1.958	5.253	4.913	1.416	3.797
Retailer 12	11.012	2.416	6.956	7.547	1.656	4.768

Table 8. Results of economic and environmental indicators. Total and relative indicators (volume and weight) for the packaging system in the sample of orders in economic and environmental terms (colour range: green – most efficient solution and red – least efficient solution in each analysed area)

To provide a more global view of the results, each of the 10 indicators (4 OPIs, 3 ECIs and 3 ENIs) has been relativized to the best score, as shown in Table 9. This also makes it easier to see the proportion of the gap between the best and worst retailers for each indicator. From these relative values (where 1 corresponds to the best retailer for each parameter), the global average of all values was calculated and the retailers were ranked accordingly to this global average indicator (from lowest to highest; see Table 9).

Thus (see Table 9), the previous statement regarding the best and worst retailer (retailer 3 and retailer 12, respectively) is confirmed. Likewise, a group of 5 companies with particularly advanced results (retailers 3, 1, 2, 5 and 7), an intermediate group of 2 companies in terms of overall results (retailers 6 and 4) and a group of 5 companies with the worst results (retailers 8, 9, 10, 11 and 12) are qualitatively identified.

At this point, what characterizes the best retailers? A preliminary analysis does not identify any significant pattern for the variables in Table 1, "Preferred geographical market", "Company size" and "specific range of products". Thus, large and small retailers, operating in global or local markets and with a specific product range or not, are found in all groups of worst or best companies (see Tables 1 and 9).

However, despite the small size of the sample, it can be observed that in the group of worst retailers (9, 10, 11, 8 and 12) there are none that operate exclusively in the e-commerce channel. The above situation seems to indicate that companies operating exclusively in the online channel (retailers 1, 3 and 6) are more sensitive or predisposed (although not exclusively) to redesign their packaging system for e-commerce in order to reduce their costs and environmental impacts (and all this, regardless of company size, geographical area of operation and specificity in the range of products).

In order to further characterize the group of best retailers, we have proceeded to review the public information provided by their websites regarding their packaging systems. This information complements the information obtained directly from retailers 3 and 5. In this sense, most of the retailers in the sample (regardless of their position in the ranking in Table 9) declare a strategy of using recycled materials in their packaging systems for e-commerce, also promoting the theoretical reduction of the waste they generate. In this sense, it is also common for retailers to declare a strategy to reduce the use of plastic, although curiously only two companies do not use plastic in their filling materials (see Tables 4 and 9; retailers 5, among the best companies and retailer 10, among the worst companies).

	Operational indicators (OPIs)				Economic Indicators (ECIs)			Environmental indicators (ENIs)			Posición global (Average Indicator and ranking)	
	OPI1	OPI2	OPI3	OPI4	ECI1	ECI2	ECI3	ENI1	ENI2	ENI3	Ave. Ind.	Rank
Retailer 3	1.13	1.00	1.00	1.00	1.06	1.14	1.00	1.12	1.01	1.00	1.05	1º
Retailer 1	1.00	1.48	1.16	1.96	1.07	1.27	1.47	1.01	1.00	1.31	1.27	2º
Retailer 2	1.12	1.04	1.84	1.94	1.07	1.30	2.12	1.00	1.02	1.89	1.43	3º
Retailer 5	1.82	1.07	2.24	1.49	1.00	1.00	1.22	1.74	1.45	2.01	1.50	4º
Retailer 7	2.02	1.14	2.68	1.72	1.00	1.34	1.77	1.44	1.62	2.42	1.71	5º
Retailer 6	1.96	1.65	2.62	2.51	1.28	1.59	2.11	1.67	1.73	2.61	1.97	6º
Retailer 4	1.80	2.31	2.00	2.90	1.58	1.90	2.10	1.73	1.75	2.19	2.03	7º
Retailer 9	3.09	2.42	2.72	2.41	1.62	1.98	1.73	2.55	2.62	2.60	2.37	8º
Retailer 10	3.21	2.19	3.55	2.74	1.47	1.70	1.87	2.69	2.62	3.26	2.53	9º
Retailer 11	3.32	2.70	3.54	3.27	1.50	2.19	2.31	2.30	2.82	3.38	2.73	10º
Retailer 8	2.97	3.31	2.69	3.40	2.21	2.78	2.50	2.61	2.75	2.80	2.80	11º
Retailer 12	3.82	3.22	4.37	4.18	2.43	2.70	3.06	3.54	3.30	4.25	3.49	12º

Table 9. Global results and ranking (colour range: green – most efficient solution and red – least efficient solution in each analysed area)

However, if the commitment to material reduction and recyclability is not a differentiating factor for classifying the best and worst companies, what could this differentiating factor be? From the analysis of the public information of retailer 1 and the information collected "in situ" at retailers 3 and 5, it can be concluded that at least 3 of the 5 best retailers have undertaken specific projects or initiatives to rationalize the volume of their e-commerce packages. These projects or initiatives include both the study of the best range of packaging formats adapted to the dimensional and protective characteristics of the products, as well as specific training at the packing stations for a correct implementation that allows the selection of the best packaging format for each order. Curiously, although the packing process has a very low direct impact, its indirect impact due to a poor implementation of the whole system can be very high. In this way, material consumption and waste generation (with their associated costs and environmental impacts) could be reduced, and at the same time the cost and environmental impact of delivery transportation could also be reduced.

In contrast, none of the retailers with intermediate or poor results publicly state that they are working on these volumetric rationalization initiatives, with some of these retailers even contemplating an intensive use of individual boxes within outer packaging (e.g. retailers 9 and 11). In this context, as it was commented previously, in the sample of orders (see Table 4), the cost of the transport tariff for all of them is conditioned by the volumetric weight and not by the real weight of the shipment, although best retailers have a lower volumetric weight.

All of this, moreover, should be in line with more restrictive new legislation (at least in Europe; see European regulation 2025/40 on packaging and packaging waste) that will even condition minimum filling level for e-commerce parcels. By way of illustration, a priori the 50% objective of this new legislation is far from what was obtained by any of the 12 shipments analysed. In any case, it has not yet been established exactly how the law will be applied in terms of how this filling level will be measured.

5. Discussion and Conclusions

Throughout this paper, we have explored, from the retailer's point of view, the impact of packaging system design decisions in e-commerce on the logistics efficiency and sustainability of the supply chain. In this way, the analysis performed has made it possible to connect the academic context (literature review) with an applied one (field study and e-commerce supply chain analysis in the household goods sector), and meet the objective proposed at the outset.

Particularly, the field study carried out on the 12 sample orders in the household goods sector has shown not just the diversity of alternatives in the packaging systems adopted by the e-retailers, but also, and especially, their inefficiencies and opportunities for improvement from a broad perspective, measuring absolute and relative parameters linked to shipment weights and volumes and to costs and CO_2 emissions.

Thus, the results of comparing these orders show the potential impact of redesigning this packaging system for companies from any of the aspects and variables considered, given that the best shipments employ resources, generate costs, and make CO_2 emissions that only come to between 22% and 41% of those assigned to the worst shipments. In fact, this potential impact could be greater if the possibility of stacking many of the products on top of each other were considered, which would make the theoretical volume used even smaller. Likewise, a certain consistency can be observed when ranking the shipments from best to worst, regardless of the variables considered for analysis. It can therefore be concluded that the economic and environmental pillars of sustainability, far from being independent, can be linked and related in the context of packaging system design.

Therefore, the results reinforce the need for practitioners and academics to delve more deeply into how to provide support for more efficient and sustainable design strategies, not just in the household goods sector. In fact, the analysis reveals emerging lines of work that are associated with the use of returnable packaging, the search for balance between packaging standardisation and packaging format diversity (to reduce the impact of transport but without penalising the procurement and packing processes), simplification of filling materials—including using a greater percentage of recycled materials and/or a reduced use of plastic materials.

Finally, it should be pointed out that the small sample of orders (this paper's main limitation) would suggest a better characterization of the design process for the system, using a broader framework of products and companies.

Likewise, it would be interesting to study a larger number of orders in the sample from each company in order to validate the homogeneity of criteria in the packing and the shipments made, depending, for instance, on the time of year or the person doing the work. Additionally, a more varied range of sectors could be covered with field studies that include product categories with significant market share in the e-commerce channel such as clothing, food, or electronics. On the other hand, the paper has applied a sustainability approach on the basis of its economic and environmental pillars, while generally sidestepping the social pillar. In this sense, inclusion in the field study of variables related with this third pillar of sustainability (such as ergonomics, communication, the unboxing experience and so on) would provide a more complete (and novel) perspective to the results and conclusions. All these aspects will be taken into consideration by the authors in future research.

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