Study by the BVL E-Commerce Focus Group

Sustainable packaging in e-commerce

BVL

In cooperation with:

4FLOW

Contents

A study by the BVL E-Commerce Focus Group

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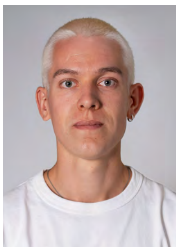

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Foreword

The BVL's volunteer focus groups are platforms for professional collaboration as well as sources of studies and publications. Through these focus groups, the BVL (Bundesvereinigung Logistik) strives to connect people with diverse backgrounds in supply chain and logistics, regardless of job title. In the e-commerce focus group, industry professionals meet to address logistics and supply chain management topics of special relevance to this market.

In this study, experts from across the e-commerce landscape have tackled an important yet under-examined topic: shipping packaging, specifically the costs and emissions associated with different packaging methods. Many thanks to the authors and all those who supported the completion of this study. We hope the findings serve as an inspiration for companies seeking to optimize their packaging processes and make them more sustainable.

Christoph Meyer
Managing Director, BVL

One symbol in particular is associated worldwide with e-commerce and online retail: the shopping cart, not the package, even though almost all mail-order shipments have one thing in common – they reach the recipient's doorstep in a delivery vehicle in a box, bag or paper envelope.

Despite the ubiquity of shipping packaging, there is surprisingly little data available for a comprehensive comparison of the environmental impact, supply chain costs and automation potential of different packaging methods. The recently adopted EU Packaging and Packaging Waste Regulation (PPWR) poses additional challenges for online retail companies and packaging manufacturers. In the past, regulations were often based on incomplete assessments of total emissions and total costs, which has led to increased interest in a comprehensive and industry-oriented approach to the issue.

In response, the BVL's e-commerce focus group undertook the following study in cooperation with 4flow. Our goal was to demonstrate to logistics and supply chain professionals the extent to which packaging impacts the costs and emissions of shipments, what role automation and reusable packaging methods play, and whether shipping products without additional packaging is ultimately the best solution. To accomplish this, we analyzed the entire life cycle of packaging from the perspective of a retail company.

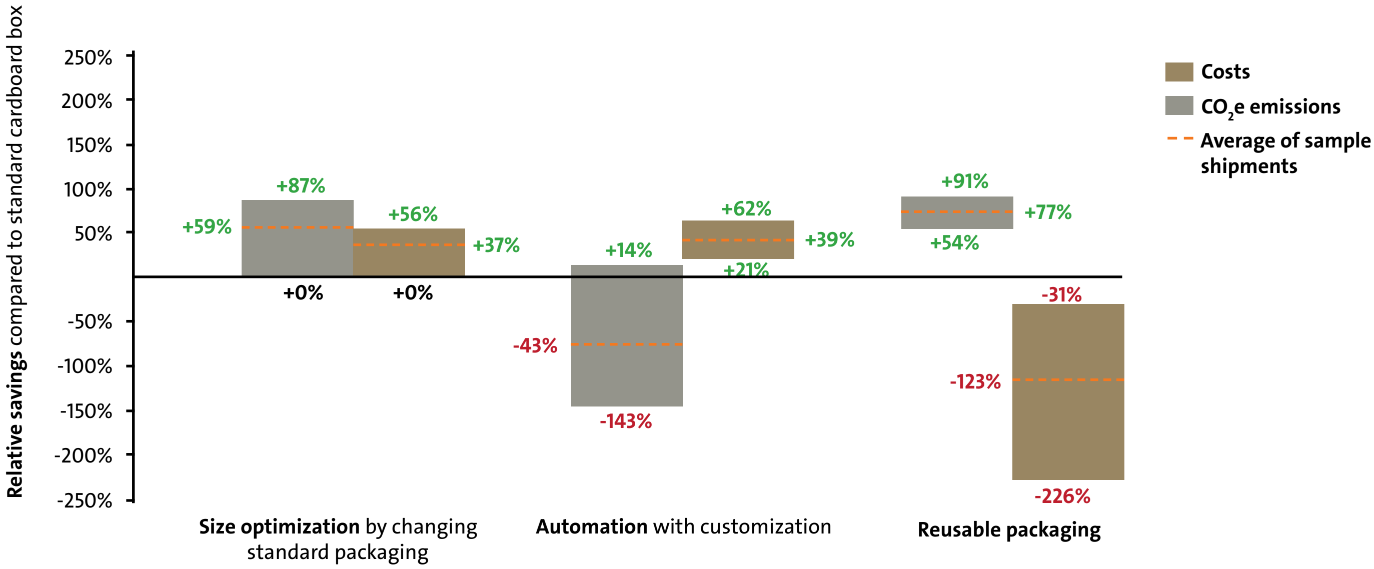
Lennart Brüggemann-von Ackern
Spokesperson of the BVL E-Commerce Focus Group and Partner, 4flow

We hope the results of our model-based study inspire discussion and show how incentives and control mechanisms can promote sustainability in e-commerce logistics.

Many thanks to everyone involved and happy reading!

Anne Suhling
Head of Event Content Strategy & Research, BVL

Executive summary



This study, initiated by the BVL e-commerce focus group and conducted under the direction of 4flow, examines the costs, environmental impact and feasibility of shipping packaging in online retail. The aim is to provide professionals in logistics and supply chain management (SCM) with a sound basis for more sustainable shipping processes.

Important takeaways, at a glance:

- Standard cardboard boxes are not always best: Classic cardboard boxes often incur higher costs, both financially and in terms of emissions. In comparison, paper shipping bags and plastic poly mailers can reduce packaging emissions by up to 80%.

- Size optimization is worthwhile: Empty space ratios (ESR) are currently 30-40% on average (depending on the product segment), which leads to unnecessary material and space consumption.

- Shipping in product packaging: This option greatly reduces packaging material but is only realistic for around 30% of products and requires close coordination with product manufacturers. This option is often impractical, particularly in the fashion segment (with a return rate of 44%) and for expensive goods.

- Automation for efficiency: Packing machines can reduce packaging costs by up to 50% and enable throughputs of 600-700 packages per hour. Emissions savings are greatest for medium-to-large shipments, e.g., a handbag or a toaster.

- Reusable packaging offers environmental advantages: Reusable boxes break even on emissions after just five shipping cycles, reusable bags after seven cycles. However, these kinds of packaging inevitably involve additional costs due to return logistics, which must be borne by customers or retailers.

Recommendations for action:

Optimize packaging sizes: Reducing the empty space ratio can reduce material and distribution costs. This is best achieved by using shipping bags or pouches, as long as they provide sufficient protection for the goods inside.

Prioritize material selection: Lightweight and efficient materials, such as thin-walled paper or plastic, are preferable. Increased use of recycled materials can significantly mitigate the environmental impact of plastic-based packaging.

Make targeted use of automation: Packing machines are particularly attractive for retailers with high shipment volumes and a homogeneous product portfolio.

Determine the best product-specific solution: Shipping without additional packaging is the most sustainable and cost-effective option for suitable products and should be used whenever possible.

Incentives and regulations for reducing packaging-based emissions can lead to inefficient results, as the impact of packaging is small compared to that of transport logistics. A better approach combines CO_2 pricing and holistic solutions implemented in collaboration with manufacturers, such as shippable product packaging.

This study shows that sustainable packaging solutions can offer both environmental and economic advantages. However, the suitability of any packaging depends heavily on individual factors like product portfolio, shipment volume and investment in new technologies. A holistic approach that accounts for materials, processes and distribution is key to long-term success and sustainability in e-commerce.

E-commerce packaging: what's on the horizon?

New challenges posed by consumers and policymakers are creating a complex decision-making situation for shippers seeking to optimize their packaging

Each of the more than 4 billion mail-order parcels delivered annually to private and commercial customers in Germany is packaged in some form before being shipped.[1] This results in over 1 million tons of shipping packaging for online retail in Germany alone, 96% of which is cardboard.[2] The challenge of optimizing packaging logistics arises from the multitude of choices available. These choices relate to materials, packaging processes, automation technologies, filling materials and distribution options. Reusable packaging is also increasingly available, but no standard has yet been established for design and distribution models.

Increasingly stringent legal requirements intend to reduce the resource and energy waste of packaging. In the coming years, the European Packaging and Packaging Waste Regulation (PPWR) will require all packaging to be recyclable. Waste management in Germany is well positioned to meet this requirement. Already today, over 90% of paper and cardboard waste and a good 65% of plastic waste are recycled. Most of the remaining waste is used to generate energy. In Germany, only 0.1% of paper, cardboard and plastic waste is sent to landfill.[3] However, composite packaging made of multiple different materials may not meet the guidelines for recyclability. Additionally, the EU directive requires a lower empty space ratio (ESR): At least 50% of the shipment volume must consist of either goods or filling material necessary to protect them.

In addition to considerations related to damage, theft and smooth logistics processes overall, customer emotions also play a decisive role in a shipper's choice of packaging. Shippers want to make the customer experience – the feeling a customer gets when receiving and unpacking goods – as positive as possible. Many customers evaluate shipping packaging based on value and individuality, as well as on perceived environmental sustainability.

Online retailers are therefore faced with the challenge of finding the right balance between costs, service and sustainability when it comes to choosing a packaging method. The sustainability assessment in this study focuses on climate-relevant greenhouse gases, measured in carbon dioxide equivalents (CO_2e), to ensure standardization and comparability across findings. Nevertheless, other environmental factors remain relevant in the packaging sector, such as materials (paper vs. plastic), water consumption, resource consumption and environmental impacts at both the beginning and end of the raw material extraction cycle (for instance, microplastics).

Our analysis considers average values for the German and European markets. Results may

[1] BPEX (2025): "Sustainability Study 2025"
[2] UBA (2021): "The Greening of Online Retail – Part II"
[3] UBA (2024): "Generation and recycling of packaging waste in Germany in 2022 – Final report"

vary depending on region-specific factors. Particularly relevant is the German electricity mix, with its relatively high CO_2e footprint, as well as recycling and recycled material usage rates, which are higher in Germany than in other countries. Distances traveled during distribution are also market-specific. More information about these values can be found in the appendix.

The packaging life cycle

A life-cycle analysis of emissions, costs and other criteria related to different types of packaging can support retailers in their choice of shipping packaging. To determine which packaging method is the most environmentally sustainable – and to calculate the associated costs – the entire packaging life cycle must be considered from start to finish (Figure 1).

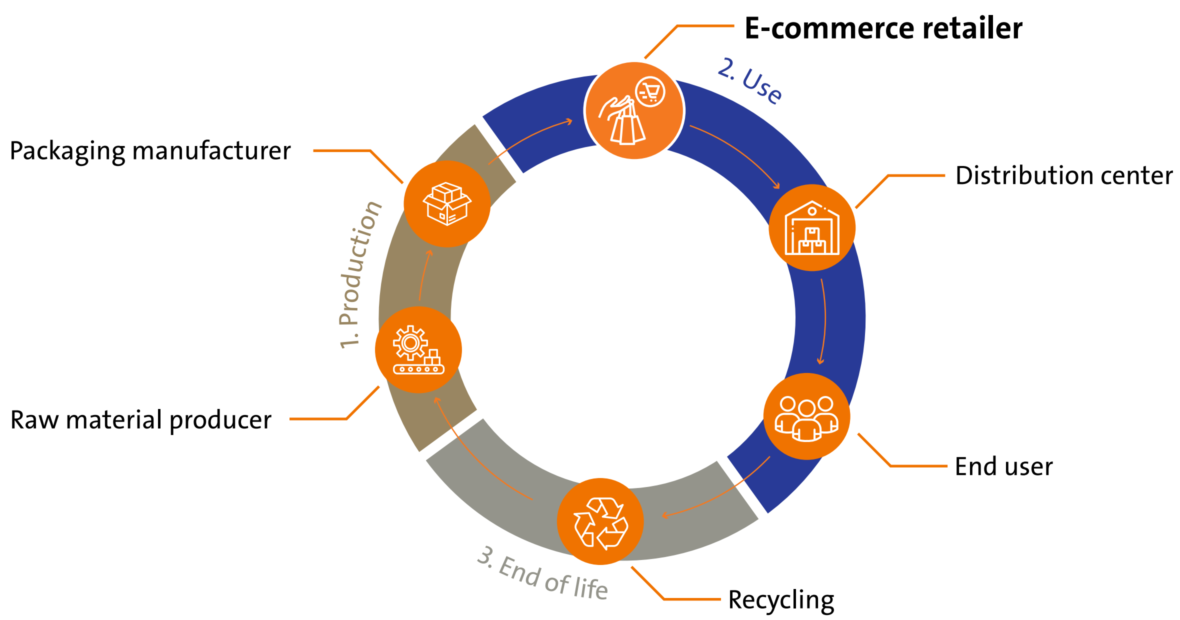
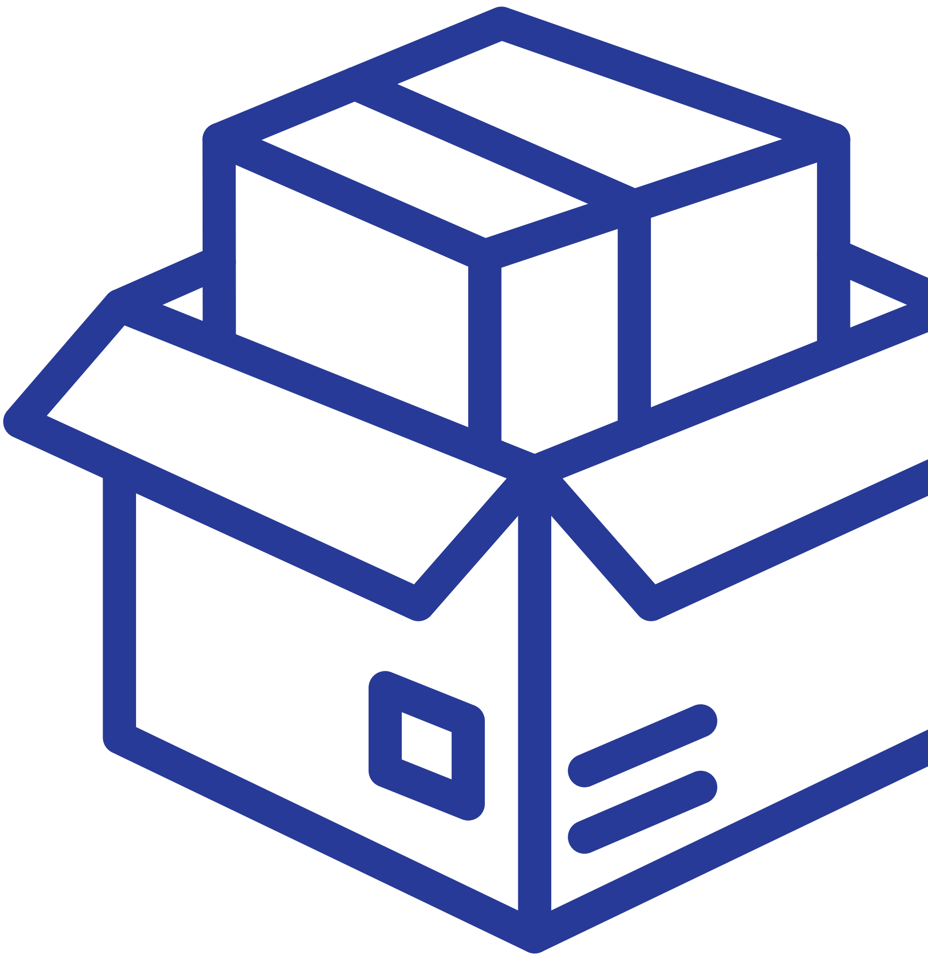


Figure 1: Stages in the life cycle of single-use packaging

This begins with the production of the packaging material. Regional factors already come into play at this stage: Material and energy consumption for production, and the associated costs and emissions, depend heavily on energy source, availability of raw materials, legal regulations and other local conditions.
In addition, before packaging materials can be used by a shipper, they must be transported and stored.

The next step in the process involves preparing packaging materials for use by folding, cutting and gluing, either by machine or manually. Once filled with goods and sealed, a package is then transported to the customer via a logistics service provider or with the shipper's own vehicles. The delivery process is usually divided into a main haul, making use of large trucks or rail transport, and the last mile, accomplished by small trucks, cargo bikes or, in the future, at least partially autonomous delivery vehicles. Returns of packaging materials must also be taken into account. With disposable packaging, this only occurs if a product is returned. Meanwhile, in the case of reusable packaging, the packaging material is always returned.
The final step in the cycle – the disposal or recycling of the packaging by the recipient and management of the subsequent waste – also has a decisive influence on emissions.



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Types of e-commerce packaging

Material, production and reusability define the options for optimal packaging

The wide variety of standardized shipping packaging available on the market illustrates the broad spectrum of goods that are packaged and shipped daily in today's e-commerce landscape. Some large online retailers have a range of up to 50 million items. Paper and cardboard are some of the most commonly used materials for shipping packaging, as are high- and low-density polyethylene (HDPE/ LDPE) and polypropylene (PP) plastics. For simplicity's sake, we distinguished six types of packaging based on three criteria: packaging material, production process and recyclability (Figure 2).

On one side are boxes made of cardboard or, in the case of reusable packaging, made of plastic. On the other are bags, which are also made of paper or plastic and can also be either single-use or reusable. Automation technology makes it possible to cut boxes and bags to fit their contents in one or more dimensions, thus expanding the range of packaging methods. The dimensions of package can vary as necessary within the scope of a parcel service provider's range of services.

Box, single-use, standard

- Standard box (FEFCO 0201) made of corrugated cardboard
- Suitable for all uses
- Can be padded, as needed

Box, single-use, optimized

- Box made of corrugated cardboard, mechanically cut to size
- Customized to each shipment
- Contents must adhere to min./ max. permissible volume

Box, reusable

- Standard box made of (recycled) plastic (PP)
- High reusability
- Can be padded, as needed

Shipping envelope

- Standard envelope
- Customizable material (corrugated cardboard, solid cardboard)
- Contents must adhere to max. permissible volume

Shipping bag

- Standard bag made of plastic (LDPE) or kraft paper
- Plastic poly mailer bags can be padded, as needed

Reusable bag

- Standard bag made of (recycled) plastic (PP)
- High reusability

Figure 2: Types of e-commerce packaging, divided into single-use and reusable

Overview of shipment emissions and costs

Transport logistics determine sustainability

We analyzed environmental impact and costs at every stage in the packaging life cycle. The first step in comparing different types of packaging is to consider the environmental impacts and costs of the packaging together with those of the goods being shipped. Most shipping-related emissions and costs are not due to packaging but to the goods themselves. When considering a whole shipment – both shipped goods and packaging – initial distribution accounts for around two-thirds of total emissions and costs.

It should be noted that the distribution of emissions across the different phases of the packaging life cycle varies depending on the product group. For a relatively small shipment, such as a book, smartphone or action figure, packaging accounts for around 10-15% of total emissions. This rises to 25-35% for products such as sweaters, handbags and toasters (see Figure 4). This is because emissions relate to varying degrees to a package's volume. While distribution emissions are largely independent

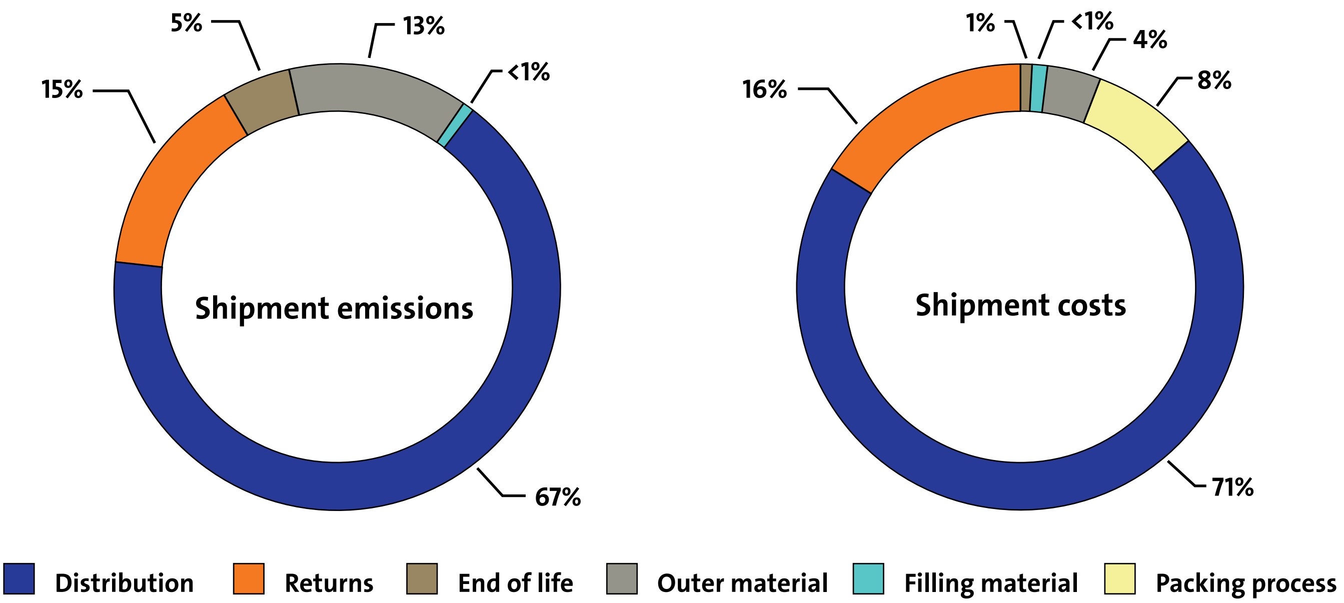

Figure 3: Distribution of shipment emissions and costs across the individual life-cycle phases (average of the products tested)

Returns, which also require transport, account for a further 15%, meaning that packaging material, filling material and end of life contribute on average less than 20% of total shipment emissions and costs across various sample items (see Figure 3).

of package size and volume, packaging emissions are highly dependent on item size.

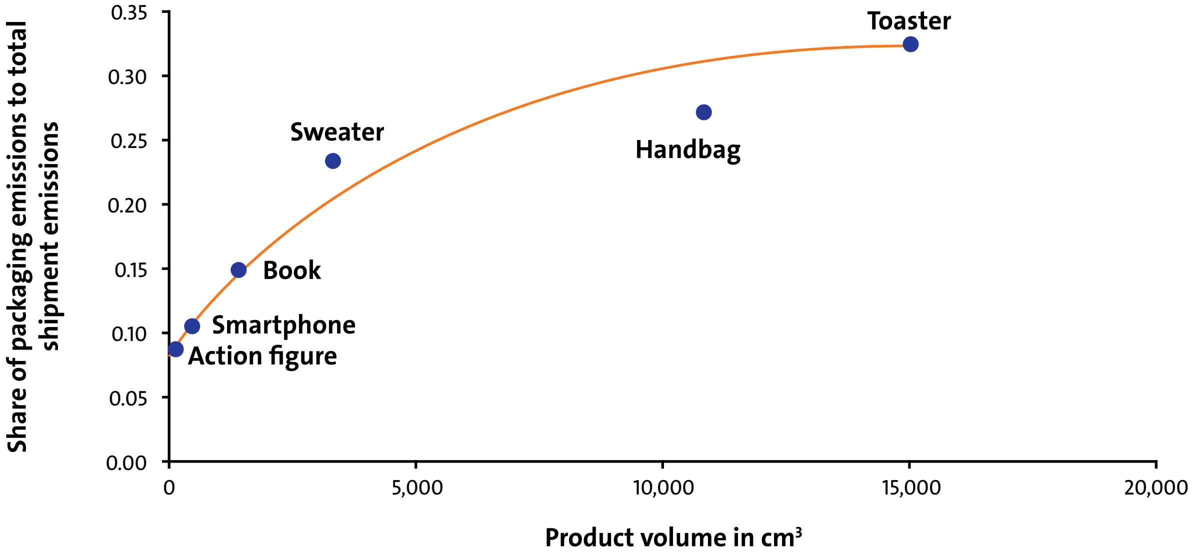

Figure 4: Packaging emissions as a percentage of total shipment emissions (excluding returns)

In distribution, the last mile accounts for a high share of total transport emissions. Empirical analyses of route data have shown that the number of shipments in a delivery vehicle usually depends on a route's duration and not on the volume of the packages. Moreover, payload only minimally affects vehicle emissions. A fully loaded van consumes only slightly more fuel in urban stop-and-go traffic than an empty one. The size of a package and the choice of packaging therefore have little influence on emissions in the last mile.

Nevertheless, optimizing shipment volume by optimizing packaging does make a difference on main hauls to a distribution center. Due to volume restrictions on these runs, reducing volume per shipment allows for a higher number of shipments per vehicle and thus leads to lower relative emissions per shipment. However, because emissions on the main haul typically account for less than 10% of transport emissions, such a reduction has only a minor overall impact.

Another product-specific emissions factor is return rate. In the fashion sector, approximately 44% of shipments are returned on average, requiring additional transport. This figure is only around 10% for printed products and consumer electronics.[4] Transport-related emissions are therefore higher for shipments containing clothing and other fashion products, especially since average return distances tend to be significantly higher, while packaging-related emissions remain comparably lower. These factors were taken into consideration when modeling the sample shipments; further details can be found in the appendix.

A more detailed analysis of packaging's environmental impact and costs helps to identify optimization potential for the 10-30% of shipment emissions that can be directly attributed to packaging. Of course, optimizing transport-related emissions by adjusting routes or switching vehicle types, for instance, remains important, especially for shippers with their own vehicle fleets. This study, however, focuses on the costs and emissions directly related to packaging, which are examined in more detail in the following section.

[4] University of Bamberg (2025): "Statistics on Returns in Germany – Definition"

Packaging emissions

Choice of material is the biggest factor for packaging emissions

Allocating costs and emissions is not an issue during the manufacturing, packing and end-of-life stages of the packaging life cycle. However, at first glance, determining which costs and emissions are caused by packaging and which by the packaged goods is not as clear for life-cycle stages involving transport, namely distribution and returns. This might not be clear at first glance. Once an order has been packaged, a clear distinction between the costs and emissions related to the shipped goods and those related to the packaging is done following the “polluter pays” principle. This step is particularly critical when allocating fixed vehicle emissions, which are generated solely by a vehicle’s weight, whether or not it is carrying a load. To accurately demonstrate the difference between different packaging methods, we have allocated these fixed emissions to the goods being transported, which in turn allows us to calculate those additional emissions that are attributable to the added load created by the weight of the packaging itself (see appendix for details).

From a perspective that focuses solely on emissions caused directly by packaging, the greatest emissions are generated by material production and end-of-life processes, which together account for over 90% of total packaging emissions (Figure 5). Despite high recycling rates, the production of paper and plastic remains emission-intensive, due to both the energy and chemical processes required. Distribution plays a minor role, primarily due to the low weight of the packaging compared to the goods being transported and to the fact that transport to a customer’s location is required in the first place. Emissions from filling materials are lower than those from outer materials, as not all shipments require filling. Since our sample scenario assumes a purely manual packing process, no emissions are generated here. Total emissions therefore depend almost exclusively on the amount of material used and on the size of the package. A comparison of different packaging methods shows that standard cardboard boxes create the most emissions regardless of the goods

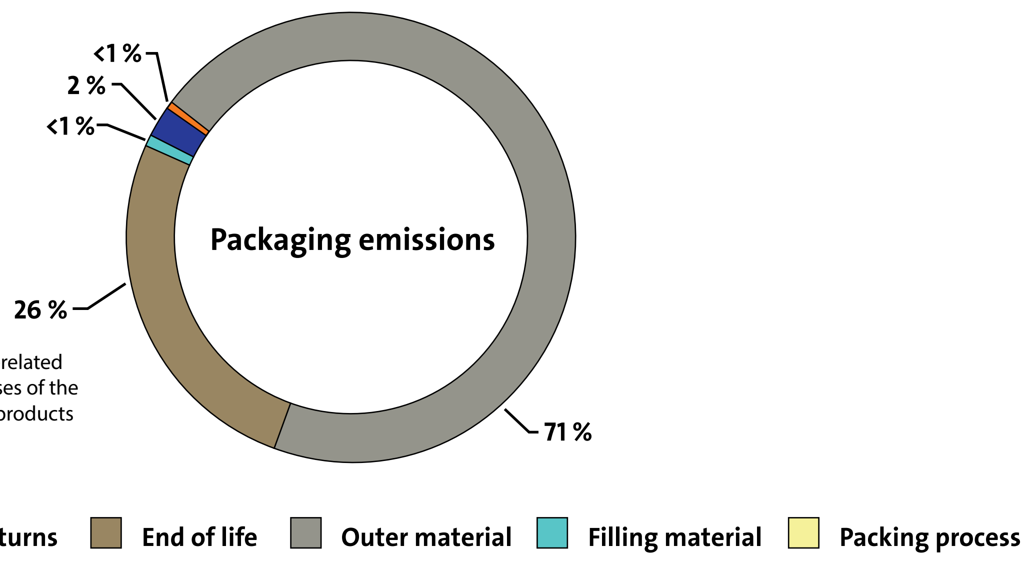

Figure 5: Distribution of packaging-related emissions across the individualphases of the shipment life cycle (average of the products tested)

being shipped, followed by cardboard shipping envelopes (Figure 6). This is mainly due to the substantially higher material consumption of corrugated cardboard compared to plastic or paper, thus demonstrating the significant influence that choice of packaging material has on packaging emissions. If the same amount of material were used, paper packaging would always be preferable to plastic, but this is rarely the case in practice, especially given the popularity of multi-layer paper materials like corrugated cardboard. In contrast, paper-based shipping bags offer some advantages over plastic ones, further illustrating that the quantity of material used to make different kinds of packaging can be as important as the material itself. As long as goods are shipped safely, the use of material-saving bags can reduce emissions by over 80% compared to standard cardboard boxes.

Plastic packaging is at a considerable disadvantage to corrugated cardboard and paper in terms of recyclate use. Plastic packaging in Germany contains around 15% recycled material, far lower than the 88% that makes up corrugated cardboard. Although a weakness, this also represents a good opportunity for optimization. For LDPE, emissions from material production can be reduced by around 19%, and by as much as 49% for PP.

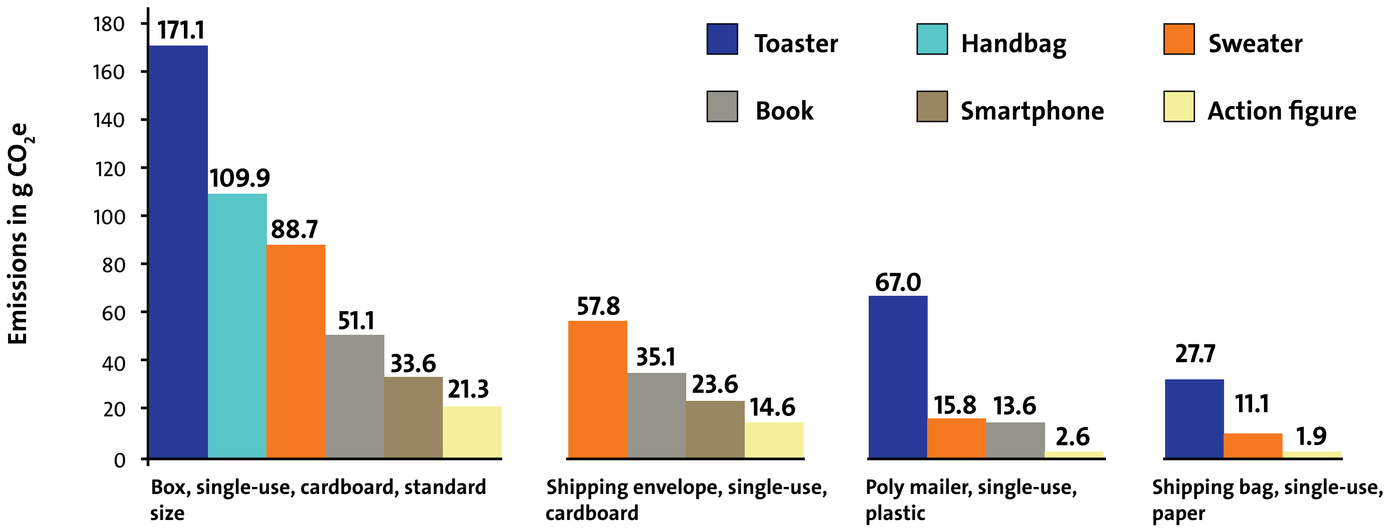

Figure 6: Absolute emissions of different packaging types, by product (missing values indicate that shipping an item in this packaging is not practical)

"The frequently used standard corrugated cardboard box performs particularly poorly due to its comparatively high material consumption. However, environmental impact beyond pure CO_2e emissions must always be taken into account for plastic-based packaging."

Lennart Brüggemann-von Ackern
Spokesperson of the BVL E-Commerce Focus Group and Partner, 4flow

Packaging costs

Process costs are decisive for the economic efficiency of different packaging methods

In the packaging life cycle, cost structure differs greatly from emissions allocation, as the packing process accounts for the largest share of costs (Figure 7). Relative packing costs are particularly high for smaller products with lower material costs, because packing costs do not decrease proportionally. Decisive drivers of packing costs include speed of the packing process and the number of staff required, both of which are affected by more factors than just the size of a product being shipped. The complexity of the packaging method is also relevant – for example, does a cardboard box first have to be assembled and sealed with adhesive tape, or can a bag be filled directly and sealed with an adhesive strip that is already attached? Orders consisting of more than one item also take more time to process and thus increase costs per shipment. It should be noted here that packing several items together is significantly faster than shipping each item in its own individual package. Although the direct costs of filling materials are relatively low, filling a package with protective materials can slow down the packing process and result in a significant increase in costs.

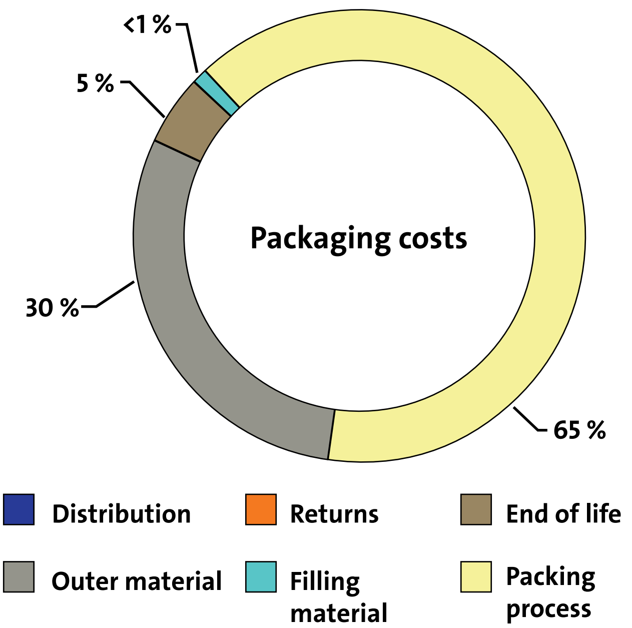

Figure 7: Distribution of packaging-related costs across the life cycle of single-use packaging

From a purely packaging perspective, transportation in the course of distribution and returns has virtually no impact on costs. Of course, when the focus is expanded to the entire shipment including goods, shipping-specific costs contribute significantly to total costs, just as shipping-specific emissions contribute significantly to total emissions. When taking such a broad view, the choice of packaging method has only a very small impact.

In our analysis, the costs associated with end-of-life processes are driven by the fees paid in Germany for the collection and recycling of packaging waste. However, these costs account for only a small portion of total costs. CO_2 emissions trading also influences end-of-life costs. Waste incineration has been included in Germany's national emissions trading scheme since early 2024. Starting in 2026, emissions certificate prices will be determined, within a specified range, by the market.[5] Furthermore, there are ongoing discussions about including energy recovery in the European Emissions Trading System (EU

[5] DEHSt (2025): "Understanding National Emissions Trading"

ETS). Operators of waste incineration plants have been subject to reporting requirements since 2024.[6] Both current and expected certificate prices have only a minor impact on overall costs.

A comparison of packaging methods in terms of cost shows a similar picture overall to that of emissions: Using packaging that is less material-intensive, like shipping bags made of paper, cardboard or plastic, can reduce costs if the chosen packaging facilitates an efficient packing process (Figure 8). However, discrepancies are not quite as pronounced as with emissions.

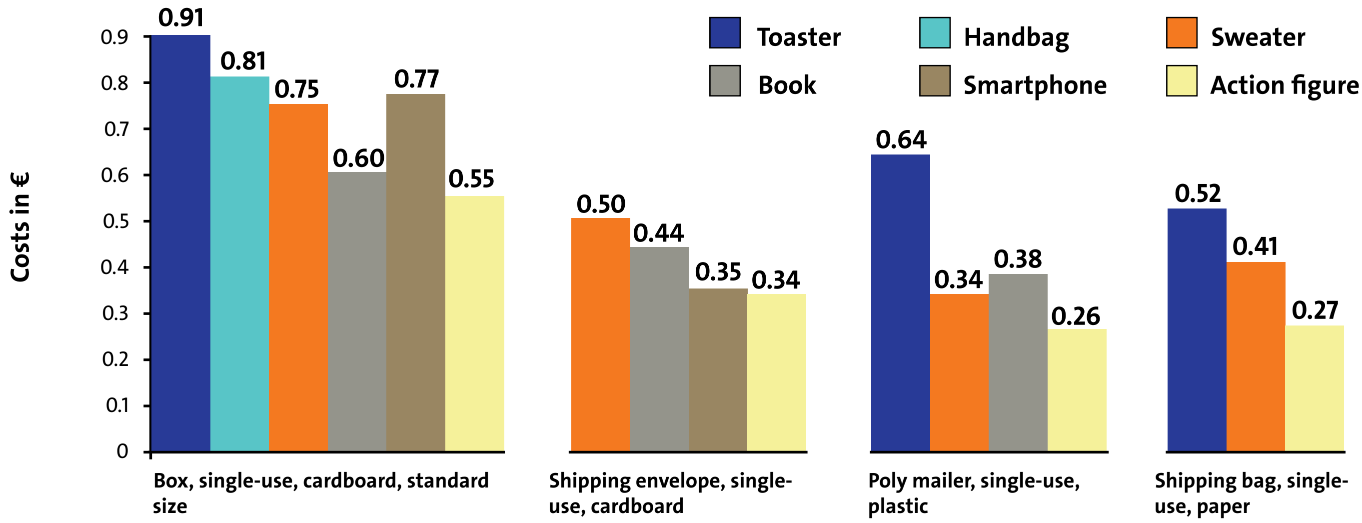

Figure 8: Absolute costs of different packaging methods, by product (missing values indicate that shipping an item in this packaging is not practical)

> "Packaging costs can only be influenced to a limited extent by the type of packaging. There are other, bigger levers here, especially in the packing process."
>
> Jens Veltel
> Director Warehouse Automation, FIEGE

[6] DEHSt (2025): "Reporting Requirements for Waste Incineration Plants"

Potential of automation in the packing process

Further cost savings through automation with consistently high throughput

The required amount of a given material plays a prominent role in a packaging method's environmental impact. This confirms that oversized packaging should be avoided as much as possible. Two key indicators are the fill ratio and the empty space ratio (ESR, see info box). Both measure the ratio between the volume of a package and the volume of the goods inside.

Reducing the number of oversized packages has multiple advantages. On the one hand, it reduces the amount of material used in packaging production. It also reduces the amount of filling material needed to ship goods safely in an oversized package. On the other hand, CEP service providers also benefit, as the reduction in volume means that more shipments can be transported at once, especially during the main haul. The extent to which a CEP service provider's savings are passed on to the online retailer must be established through rate negotiations. Only in exceptional cases will a smaller box allow for a switch to a cheaper shipping category.

Custom packaging has become increasingly popular in recent years. Package customization is achieved through technical solutions with varying degrees of automation (see info box on page 18).

Empty space ratio

With the Packaging and Packaging Waste Regulation (PPWR) adopted at the end of 2024, the European Parliament has specified a target ESR value (<50%) for the first time, which goes into effect in 2030. It is important to note that the PPWR considers filling materials as empty space if they are not directly required to protect a product. More complex product shapes that inherently create empty space when packaged in rectangular boxes are considered separately.[7]

Various studies exist on current practical consequences of ESR. ESR varies greatly in accordance with a retailer's size and product portfolio. The more homogeneous a retailer's product portfolio, the more homogeneous the typical package dimensions, and therefore the easier it is to adopt standardized packaging. At the same time, larger retailers with higher shipment volumes are more likely to acquire a broad portfolio of standard packaging methods than smaller retailers with fewer shipments. A 2018 study by Forbes Insights in collaboration with packaging manufacturer DS Smith examined 190 orders comprising 498 products from 44 retailers. The study found average ESRs ranging from 18% (fashion) to 64% (glassware), depending on the product category.[8] In 2019, DHL reported an average ESR of 24% for all shipments, with ESRs up to 40% in some product categories.[9] Postnord, a Swedish CEP service provider, reports that an average of 30% of its packages are oversized, while Packsize, an American manufacturer of automated packaging machines, reports 40% oversized packages.[10,11]

[7] European Parliament (2024): "Regulation (EU) 2025/40 of the European Parliament and of the Council of December 19, 2024, on packaging and packaging waste"
[8] Forbes Insights (2018): "The Empty Space Economy"
[9] DHL Trend Research (2019): "Rethinking Packaging"
[10] Postnord (2021): "Swedish consumers react negatively to unnecessary air in parcels"
[11] Packsize (2024): "Why a Right-Sized Box is the Perfect Protective Packaging"

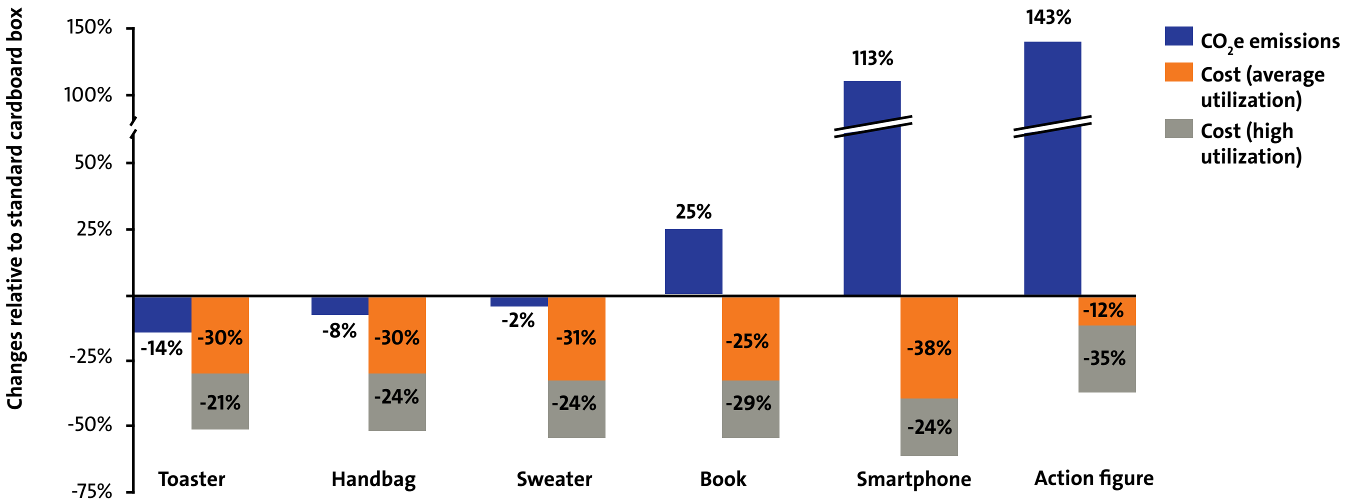

Figure 9: Change in costs and emissions by switching to automated 3D cutting, from a packaging perspective

Packing machines offer other advantages beyond savings in materials and reduced package volumes. They also enable significant savings in process costs. Packing machines realistically enable throughputs of 600 to 700 packages per hour, compared to around 120 packages per hour per worker in the case of completely manual processes. Such machines can lead to significant cost advantages, taking into account the depreciation of the acquisition costs over seven years (Figure 9).

On the emissions side, automation is not advisable in every case. Various product-related factors come into play, particularly with regard to shipment sizes and ESR. When accommodating small shipments, packing machines quickly reach the limits of the minimum box size that they can produce, meaning that little or no material is saved compared to small standard boxes. Meanwhile, large and bulky shipments may not be able to be packed automatically, reducing the efficacy of the machine and negatively impacting the energy-related emissions of individual shipments. In general, the use of machines requires greater energy consumption than purely manual processes. Real savings can therefore only be achieved where material can actually be saved. This applies in particular to medium- to large-sized shipments, which would previously require a lot of filling material.

The cost-effectiveness of automation solutions and their potential for reducing emissions are largely determined by the specific requirements of the shipper. A company's product range, particularly the range of products suitable for automated packing, is the most important factor. Only an individual analysis ensures optimal alignment in the packing process, while order volume will determine whether a shipper can actually make the most of a packing machine.

"Automation solutions offer economic advantages in the packing process for many types of products with high throughputs. When assessing the environmental benefits, the retailer's specific requirements must be taken into account. This allows for a wide range of options to be considered and to determine the best technical solution for the target system."

Andreas Hennig
Director Fulfillment, Thalia

Packing automation

The most basic level of automation involves providing packing station workers with size suggestions based on article master data. Recommendations might not always be followed, for example when a specific packaging solution is either unavailable or difficult to reach at the packing station.

For shipping bags, machines like the Sealed Air Autobag Brand 850S help reach the next level of automation. These machines automatically open bags and seal them after filling but offer no options for adapting bag sizes to goods. For boxes, machines like the Form'it! from Ranpak can help with automatic assembly. Meanwhile, the E-com Packer Gen. 2 from Varo goes even further by scanning an order, selecting the appropriate size from a standard portfolio of packaging solutions, and then automatically packing the goods.

These types of automation rely on an established portfolio of standardized packaging solutions and merely attempt to select the most suitable standard size. Machines such as the E-CO FLEX from IMA or the Cut'it! EVO from Ranpak can adapt packaging even further by, for example, reducing the height of a cardboard box so that it corresponds to the goods packed inside, which furthermore helps secure goods and eliminate the need for filling material. However, these solutions usually enable only minimal reductions in overall material consumption, as excess material is simply folded into the box. Only a package's volume is reduced, which mainly affects distribution, where packaging contributes comparatively little to total emissions.

Packing machines such as the CartonWrap Series from CMC, the Opera System from WestRock and the CVP Impack and CVP Everest from Sparck go the furthest, producing custom boxes that are tailored to an order in all three dimensions. Here, standard portfolios are eliminated in favor of maximum customization. Even these machines have limitations, however, particularly with regard to the minimum and maximum packaging sizes that they can produce; with regard to shipments containing more than one item; and with regard to items with spherical or cylindrical shapes. While some machines are already designed to handle such shipments, others, such as the CMC CartonWrap, require the order to be fixed in advance for certain products. Additionally, it is difficult to determine the exact amount of material saved, as waste depends largely on the type of material used, the specificities of the shipment and the machine being implemented. A product portfolio with fluctuating shipment sizes will lead to more waste.

Shipping in product packaging

The best packaging is no packaging

Another option is to ship a product in its own packaging. This option simply omits shipping packaging like boxes and bags and leads to maximum material savings, making it the preferable method whenever possible. In this case, processing and labeling generate only minimal packaging-related emissions. However, the greatest driver of overall shipment emissions and costs remains largely unaffected: distribution (Figure 10).

This option is only practical for a limited range of products. Products must come pre-packaged, which is rarely the case in the fashion segment – the largest sector in German e-commerce in terms of sales[12] – and also rare for books. Moreover, certain types of packaging are necessary to ensure that the goods are protected, particularly in the consumer electronics sector.

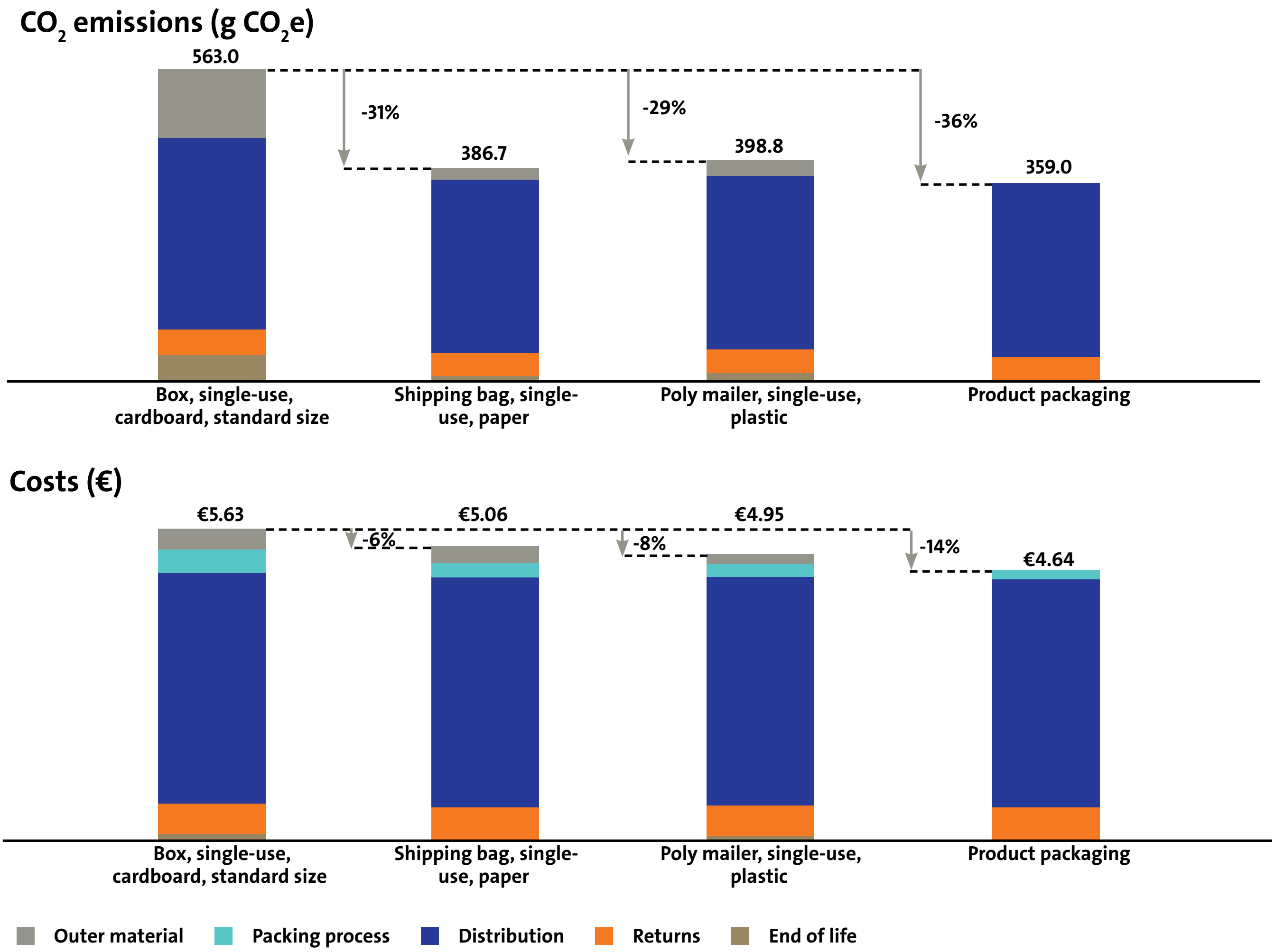

Figure 10: Emissions and costs of shipping a toaster in product packaging compared to other standard packaging methods, from a shipment perspective

[12] BEVH (2024): "Interactive retail in Germany – results for 2023"

Outer packaging also provides privacy, which plays a role across all product segments. Certain products, such as medication, can reveal sensitive information about the person who ordered them, whereas expensive and luxury goods are at risk of theft. In the high-end segment in particular, unpacking the product is also an important part of the customer experience, and unique and elaborately designed product packaging makes for poor shipping packaging.[13]

In the case of multi-item orders, dispensing with shipping packaging eliminates the bundling effect, adding extra handling steps and increasing distribution costs and emissions. Nevertheless, there are already many products, such as toasters and other small electronic devices, that can easily be shipped in their product packaging.

"Product manufacturers know best whether their packaging already meets protection requirements and customer expectations. A corresponding label, 'Recommended for shipping in product packaging,' would make it much easier to quickly and comprehensively eliminate unnecessary transport packaging, as long as the shipper's logistics processes do not impose any additional requirements."

Markus Mehrtens
Head of Logistics Sourcing & Partners
MediaMarktSaturn

[13] UBA (2021): "The Greening of Online Retail – Part II"

Reusable packaging in e-commerce

Reusable packaging has the potential to reduce emissions – at an additional cost

Reusable packaging is currently still a marginal phenomenon in e-commerce, but it has been gaining attention due to regulatory incentives. For example, reusable packaging is exempt from the EU requirements for ESR coming into effect in 2030.[14] In Europe and Germany, there are now several providers of reusable packaging, divisible into three categories:

- In-house projects by online shops focused on sustainability, such as Memo Box and FoxBox
- Independent start-ups such as RePack, heycircle, Hipli, Rhinopaq and Ravioli
- Spin-offs from established logistics players, such as the newly founded joint venture Multiloop from FIEGE and the Schoeller Group

While solutions like the FoxBox and Memo Box tend to be heavy, rigid plastic boxes, almost all start-ups rely on significantly lighter and often foldable boxes that facilitate return shipping. Many start-ups also offer reusable bags alongside boxes. Much reusable packaging is made of polypropylene (PP), which scores higher in terms of durability compared to the LDPE often used to make disposable poly mailers. Depending on the complexity of the reusable packaging, PET may also be used for zipper and Velcro fasteners, although most suppliers state they want to move toward single-material packaging in the future to increase recyclability. It should also be noted that many suppliers already use an above-average proportion of recycled material to counteract plastic's poor image among consumers.

Cycle count is crucial

The decisive metric for reusable packaging is the number of shipping cycles it can withstand. The more often a packaging method can be used, the greater the return on its manufacturing and disposal costs, which are higher than those of single-use solutions. The cycle count is determined first by the packaging itself, i.e., how durable or dirt-resistant it is designed to be. Second, the count depends on end customers and the likelihood that they will actually return the packaging. Manufacturers have a direct influence on durability but only an indirect influence on consumer behavior. For example, design measures can simplify the return process, as in the case of foldable packaging, which can be dropped in a mailbox. Further incentives can be created through the shipping process, either with a deposit system or coupons.

[14] European Parliament (2024): "Regulation (EU) 2025/40 of the European Parliament and of the Council of December 19, 2024, on packaging and packaging waste"

All in all, offsetting the high emissions generated by production and end of life is not enough to make reusable packaging environmentally friendly. Each shipping cycle incurs additional emissions and costs because reusable packaging must be returned to the manufacturer or retailer, which is not the case with single-use packaging. From a packaging perspective in particular, return transport plays an important role, as a higher share of packaging's distribution emissions are attributable to the producer. This makes reusable packaging particularly attractive in market segments with high return rates, such as clothing rental or regular food deliveries, where return shipping is built into the business model. On top of additional return shipping,

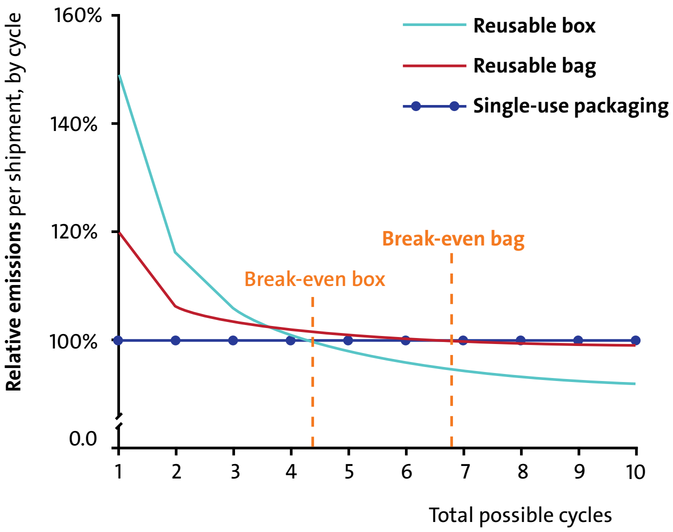

Figure 11: Break-even analysis of emissions for shipping a sweater with single-use cardboard and reusable solutions

reusable packaging methods necessitate additional handling to remove old shipping labels and clean the packaging. Also, if filling material has been used, it will likely need to be replaced.

In terms of emissions, reusable boxes typically beat disposable cardboard ones after just five cycles, while reusable bags beat disposable poly mailers after around seven cycles (see Figure 11). This cycle count can be achieved with all packaging analyzed; heycircle promises 50 cycles, RePack between 20 and 40, and Multiloop around 30.

Additional costs due to return transport

This picture changes when it comes to costs. In none of the sample shipments examined did reusable packaging offer any advantages over single-use equivalents (see Figure 12). Interestingly, this is not due to higher purchase costs but primarily to the high return-shipping costs that are incurred with each individual use cycle, which are costs that do not decrease over time. Different rates could be negotiated for large-scale use. For retailers who do not rely on external delivery service providers, costs can be significantly lower. Multiloop, for example, plans to set up its own network of 15,000 return points to manage returns itself, at scale. This will reduce costs and enable the use of more user-friendly packaging designs that would not be feasible with traditional letterboxes. Nevertheless, it should be noted that, under the current circumstances, a broad switch in the e-commerce industry to reusable packaging will involve additional costs.

Given the dynamic developments in reusable packaging, it is not yet clear which products, pricing models and logistics configurations will prevail or whether single-use packaging will remain the industry standard (see info box).

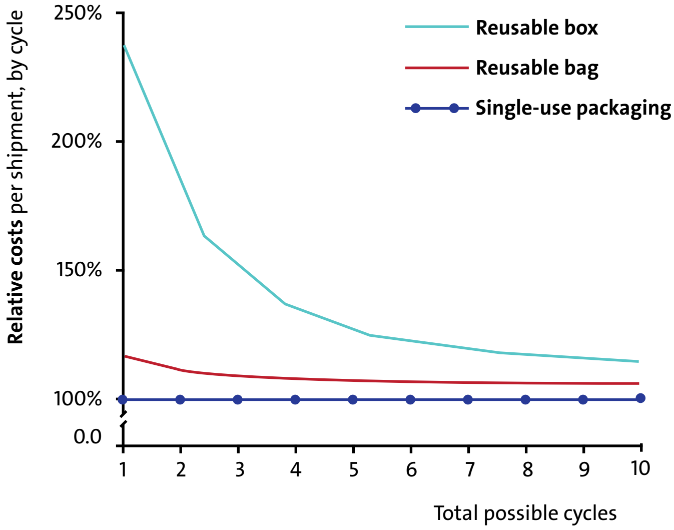

Figure 12: Break-even analysis of costs for shipping a sweater with single-use cardboard and reusable solutions

Additional costs incurred now and in the near future will have to be borne by one party or another. Ultimately, retailers have the choice either to absorb these costs themselves or pass them on to consumers. It is doubtful that consumers would be willing to pay even more for shipping than they do now, especially if they must also make the effort to return reusable packaging. It is also conceivable that retailers that operate both online and offline might allow packaging to be returned to their brick-and-mortar locations, thereby financing part of the additional costs of reusable packaging through potential follow-up sales in stores.

In any case, the additional transport required for customers to reach a return point is potentially problematic from an emissions perspective. Transporting a single piece of reusable packaging can generate relatively high emissions, in turn possibly reducing the likelihood that the packaging will be returned at all, all of which should be top concerns from both an environmental and a cost perspective.

"From an environmental point of view, switching to reusable packaging already makes sense today. From an economic point of view, an extensive return network and widespread consumer acceptance are decisive for the success of reusable solutions – this is the only way to achieve efficient return logistics."

Daniela Bleimaier
Head of Public Affairs Germany & Regional, bevh (Bundesverband E-Commerce und Versandhandel Deutschland e.V.)

Pricing models in reusable packaging

Some providers, such as heycircle, sell their reusable packaging solutions, which shifts responsibility for returning and reprocessing to the retailer.

RePack and Hipli, among others, offer a leasing model that allows retailers to rent a fixed number of packaging units for a monthly fee. The retailer is responsible for returning and cleaning the packaging, but packaging that is no longer suitable for shipment is replaced.

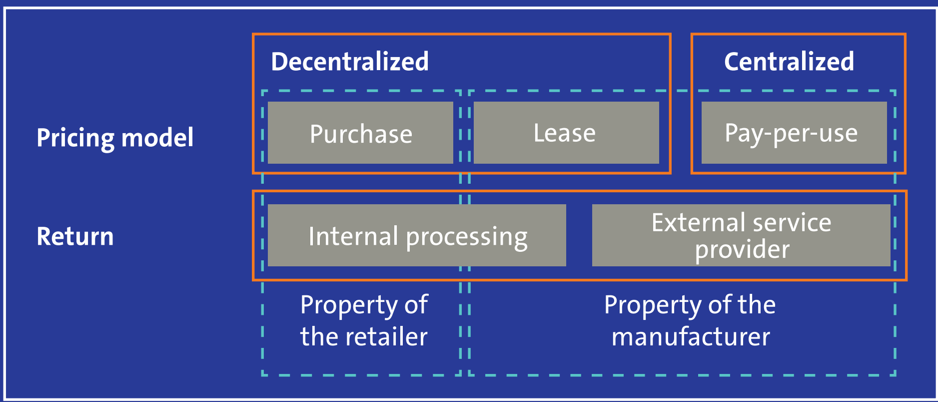

Figure 13: Pricing models and operating concepts in the reusable market

The more common arrangement is a pay-per-use system, in which a single piece of packaging is rented for a single shipment. Customers then return the packaging to the manufacturer, who cleans and recycles it and sends it back to the retailer upon payment. This system is also offered by RePack and Hipli, as well as Multiloop and others.

Pricing models for reusable packaging can also be divided into centralized and decentralized systems. Purchase and leasing are examples of a decentralized system, in which packaging is returned to one of a retailer's locations. Pay-per-use is a centralized system in which all reusable packaging from different retailers is returned to the same manufacturer.

Purchase allows for greater customization of packaging and reduces the distances required for return shipping. However, the initial investment and ongoing costs are higher than with pay-per-use. Purchasing reusable packaging methods is therefore more suitable for large retailers that can shoulder the costs and benefit from their comparably more developed networks. For small online shops, the pay-per-use model is the best option to start with.

Guidelines for packaging strategies

There is currently untapped sustainability potential in the e-commerce space. Measures to increase sustainability by reducing packaging and CO_2e emissions should always be compared with alternatives and validated in specific individual cases. At the same time, online retailers will always have to consider other key packaging requirements in addition to sustainability.

From both an emissions and a cost perspective, the top priority in packaging should be to avoid unnecessary material consumption. This means focusing on the optimal choice of packaging method and reducing packaging to the smallest possible size. Modeling results show that switching from classic cardboard boxes to material-saving solutions like shipping bags or envelopes can, on average, reduce emissions by 71% and costs by 45% for representative sample products.

Consumers should be informed about the advantages and disadvantages of different materials and what measures may be taken to neutralize any drawbacks. Most packaging emissions are material-dependent, mainly because of energy consumption. The use of environmentally friendly energy sources, such as sustainably supplied biomass power plants, can significantly improve the CO_2e balance of cardboard boxes, for instance. Despite its bad reputation, plastic packaging has relatively low material-intensity and therefore can have environmental benefits as long as it is properly recycled or disposed of at the end of its life cycle. Using higher shares of recycled material in particular offers potential for optimizing the environmental impact of packaging in the future.

The most direct way to reduce packaging materials and thus packaging-related emissions is to ship products without additional packaging. This should be the preferred option whenever feasible and approved of by customers. For retailers, there are ways to gradually change customer habits: Customers can be invited to opt out of packaging, either by choosing an option actively to opt out or by being given the choice to deselect a preselected packaging method; or they can be discouraged from requesting additional packaging by charging them an opt-in fee. To further promote this method, manufacturers may design their product packaging accordingly and label it as suitable for shipping, thus saving retailers from having to carry out tests.

Various forms of automation can be advantageous, but not in every case. In terms of costs, automation offers considerable savings, provided that a consistently high throughput is achieved. No general conclusion can be drawn regarding emissions, however, as results vary depending on the products being packaged and on the given automation solution. The high potential of automation nevertheless invites detailed, case-by-case analyses.

Reusable packaging remains niche. Analysis shows environmental benefits, even given the most realistic cycle counts. But either widespread adoption by consumers or government subsidies will be necessary to offset this method's considerable cost disadvantages. Empty packaging will have to be returned to sender as cost- and emission-efficiently as possible. Because postal delivery is expensive and individual collection is time-consuming, this method is, for the time being, most practical when employing a network of collection points. Reusable packaging is a dynamic market with high potential that is worth monitoring.

With such a large range of available packaging methods, retailers face complex decisions. Comparison of different solutions must include all life-cycle stages, which is why we developed a model for the holistic assessment of CO_2e emissions and costs as part of this study. Even though costs and emissions depend on a large number of variables, such a model can still serve as a starting point for further individual analyses. For instance, the model may be adapted to account for variables related to automation solutions and distribution networks, the latter being especially important for reusable packaging. The kinds of vehicles used in distribution are also a variable, which suggests that retailers should analyze different scenarios with a view to their share of total shipment emissions. This way, they can identify the greatest levers for cost and emission savings in each specific case and make more effective decisions.

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Appendix

In modeling the life cycles of different types of packaging, a range of variables were taken into account at each stage:

	Packaging production	Packing process	(Re-)distribution	End of life
CO_2e	• Material production & requirements • Share of recycled material • Filling material, when required	• Energy consumption of automated solutions	• Main haul and last-mile (especially capacity) • Returns	• Recycling • Energy recovery and disposal
Costs	• Purchasing costs of different packaging and filling materials	• Cost of labor • Energy, maintenance, financing and depreciation of automated solutions	• Shipping • Savings through capacity optimization • Returns and redistribution of reusable packaging	• Material-based participation fees in Germany's dual recycling system

Figure 14: Cost and emission sources considered in individual life-cycle phases for all packaging

Packaging production:

To determine size, the external dimensions of sample consumer goods were used and extended by a constant factor to achieve a realistic oversize (ESR). This was estimated at 40%. For size-optimized packaging, a buffer of 2% was also calculated in all three dimensions. The potentially higher amount of scraps and trimmings generated by automated packing machines, in comparison to the production of packaging in fixed standard sizes, was disregarded due to high dependence on retailer-specific product portfolios.

Material-intensity was based on package dimensions. The surface area of a given packaging method was multiplied by material/packaging-specific grammages (Table 1).

Table 1: Grammage of various packaging methods (materials) based on the average of various suppliers

Packaging (material)	Grammage
Disposable cardboard (corrugated cardboard)	350-505 g/m² (depending on product requirements)
Shipping box (corrugated cardboard)	350-505 g/m² (depending on product requirements)
Disposable bags (kraft paper)	100 g/m²
Disposable poly mailers (LDPE)	60 g/m²
Reusable box (PP)	829 g/m²
Reusable bag (PP)	259 g/m²

The resulting material requirements for the various sample shipments clearly follow the geometric area/volume ratio, which describes the relationship between the surface area and volume of a body. The A/V ratio decreases as volume increases, since surface area increases quadratically while volume increases cubically.

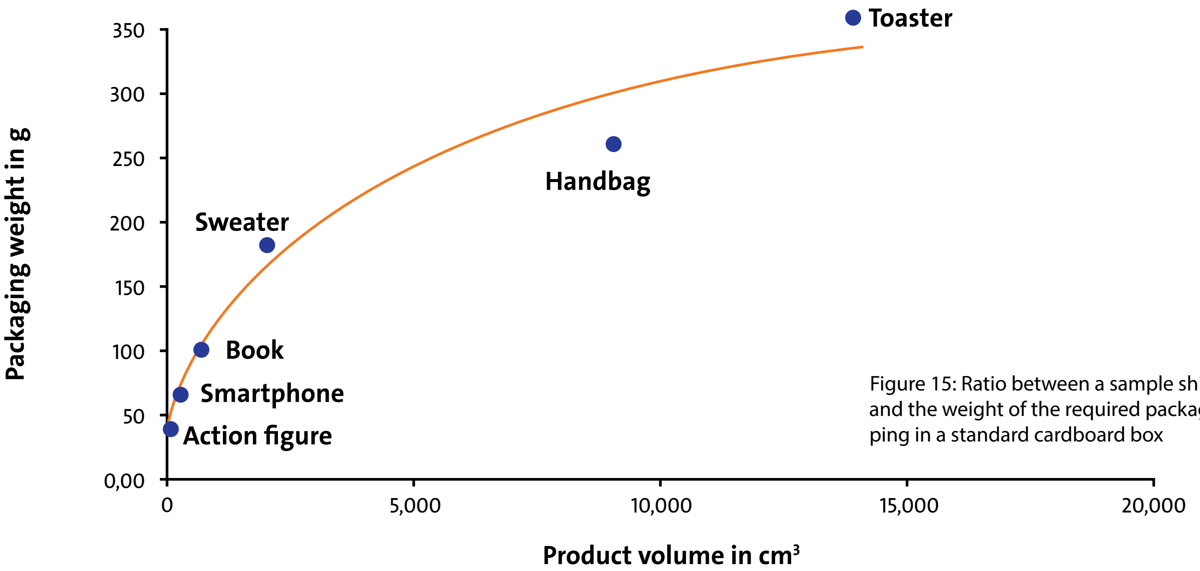

Figure 15: Ratio between a sample shipment's volume and the weight of the required packaging, when shipping in a standard cardboard box

As can be seen in Figure 15, this decreasing ratio is also evident in the model. Deviations can be explained by the fact that the packaging's weight does not depend solely on its surface area but also on the grammage used. Grammage varies in the model to meet the protection requirements of different product categories.

In addition to the material consumption of outer packaging, the model also set out to determine the material consumption of filling. Since filling material has to fill space, density instead of grammage was used as the main metric, which equated to approximately 7.167 kg/m³ for the packaging paper used in the sample shipments.

After calculating material consumption, CO_2e emissions were determined using material-specific emissions factors. A distinction was made between unrecycled and recycled materials. The standard recycled material quotas are:

- Plastics: 15%
- Corrugated cardboard: 88%
- Kraft paper: 0%

The following emissions factors were used (Table 2).

Table 2: Emissions factors of various packaging materials

Material	Emissions factor	Source
Corrugated cardboard	0.361 g CO_2e/g (for 88% recycled content)	FEFCO (2022): "The carbon footprint of corrugated packaging 2021" (excluding end of life)
Kraft paper	0.421 g CO_2e/g	CEPI Eurokraft (2024): "Carbon footprint of paper sacks: Infographic and fact sheet, 2021 figures"
LDPE (unrecycled)	0.943 g CO_2e/g	EU (2021): "Environmental effects of plastic waste recycling"
LDPE (recycled)	0.763 g CO_2e/g	EU (2021): "Environmental effects of plastic waste recycling"
PP (unrecycled)	1.185 g CO_2e/g	EU (2021): "Environmental effects of plastic waste recycling"
PP (recycled)	0.6 g CO_2e/g	EU (2021): "Environmental effects of plastic waste recycling"

To calculate costs, spends of various retailers were analyzed and different price ranges were calculated for each type of packaging, following their respective material consumption. The following cost factors were used (Table 3).

Table 3: Cost factors for various packaging methods based on the average of different suppliers

Packaging	Cost factor
Disposable cardboard box/shipping bag (corrugated cardboard)	€0.32-0.70/m² (depending on size)
Optimized box (continuous cardboard)	€0.32/m² (depending on size)
Disposable bag (kraft paper)	€0.32-0.82/m² (depending on size)
Disposable poly mailer (LDPE)	€0.29-0.55/m² (depending on size)
Reusable box (PP)	€0.55-1.66/m² (depending on size)
Reusable bag (PP)	€0.17-0.32/m² (depending on size)

The cost of filling material was calculated using a weight-based factor, as there is no correlation with surface area in this case. A factor of €2.15/kg was determined through market analysis.

Packing process:

This study did not take into consideration emissions related to manual packing processes. Only in the case of automated packing was electricity consumption per package accounted for and calculated. Both manual and automated processes incur labor costs. Automated packing machines incur additional fixed and variable costs. The respective performance metrics of manual and automated packing processes are relevant when calculating costs and emissions (Table 4).

Table 4: Manual packing throughputs

Packing process	Throughput	Source
Manual – bag, no filling material, single-item order	120 packages/hour	Expert estimate
Manual – bag, no filling material, multi-item order	80 packages/hour	Expert estimate
Manual – box, no filling material, single-item order	72 packages/hour	Expert estimate
Manual – box, no filling material, multi-item order	48 packages/hour	Expert estimate
Manual – box, with filling material, single-item order	48 packages/hour	Expert estimate
Manual – box, with filling material, multi-item order	32 packages/hour	Expert estimate

Additional parameters related to packing machines impact cost modeling of automated packing processes (Table 5).

Table 5: Parameters for modeling the automated packing process

Parameter	Value	Source
Acquisition costs (AC)	€1,017,500	Expert estimate
Maintenance rate	15% AC/year	Expert estimate
Lifespan	7 years	Expert estimate
Operating time	7 hours/day or 14 hours/day (1 or 2 shift operation)	Expert estimate
Power consumption	26 kW	Expert estimate
Throughput	650 packages/hour	Expert estimate
Hourly wage (HW)	€18.49	Federal Employment Agency (2023): "Skilled worker – warehouse logistics"
Employer surcharge	24.5% HW	Eurostat (2025): "Labor cost levels by NACE Rev. 2 activity"
Electricity costs (industrial electricity price)	€0.17/kWh	BDEW (2025): "Electricity price analysis May 2025"
Emissions factor (German electricity mix)	445 g CO_2e/kWh	UBA (2024): "Development of specific greenhouse gas emissions from the German electricity mix in the years 1990-2023"

Labor costs are relevant in both manual and automated processes. When calculating the costs of manual processes, throughputs are determined per worker. In automated processes, a second worker is required to pre-bundle many orders containing multiple items. Further variable costs and emissions are attributable to the electricity that a packing machine consumes.

Distribution:

Modeling distribution emissions and costs was the biggest challenge. Conventional calculations use weight-based emissions factors like g CO_2e/tkm. Such factors do not adequately reflect the effects that volume has with respect to different packaging methods. For example, switching from standard-sized boxes to size-optimized boxes, or shipping goods in envelopes and bags, reduces not only weight but also volume, therefore increasing the number of packages that a delivery vehicle might potentially transport. To take this second effect into account, distribution had to be modeled from the ground up. Total emissions for different vehicle types were calculated by taking into account volume restrictions and weight utilization. Emissions were then broken down into individual packages and then allocated on a causal basis to determine packaging emissions.

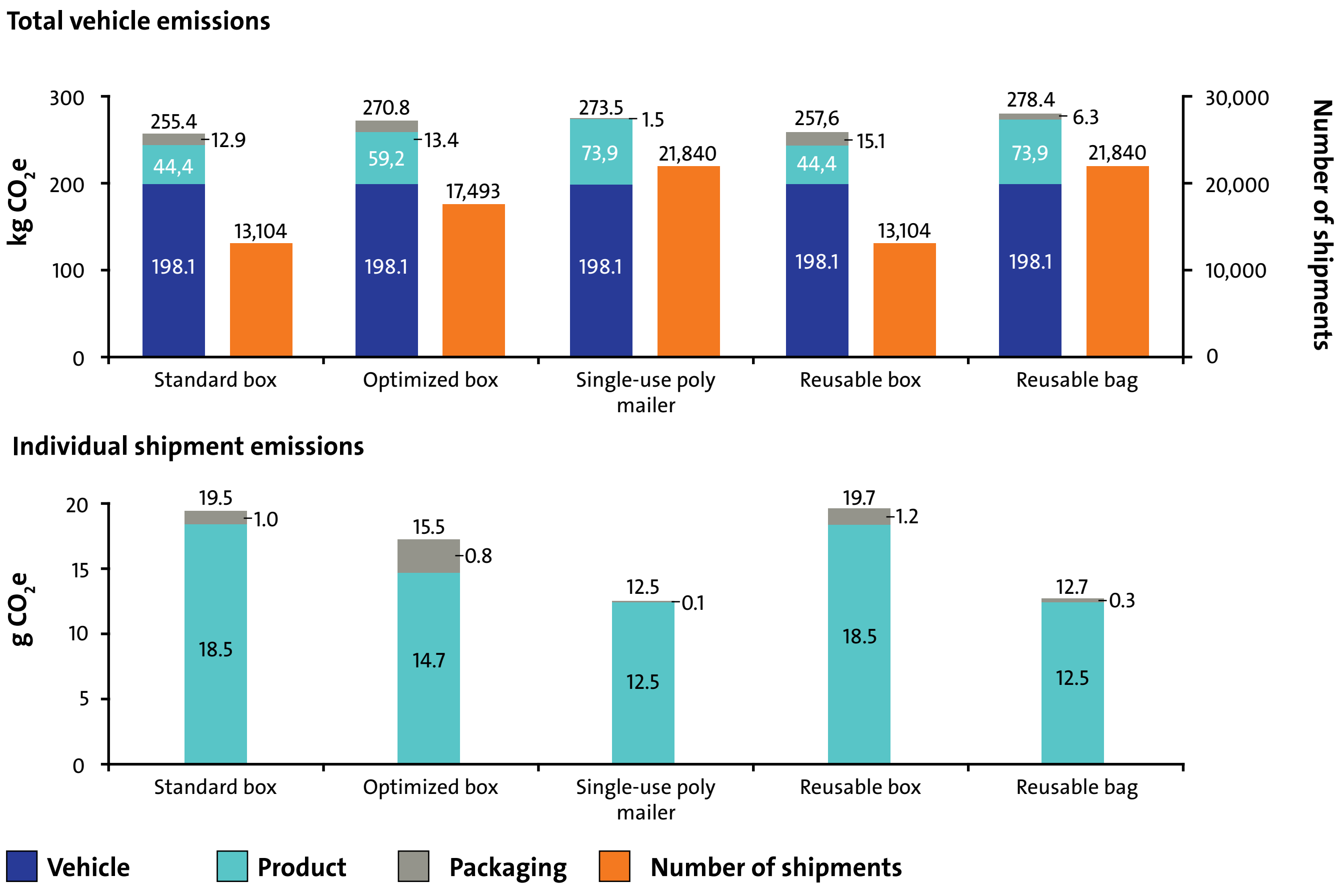

Figure 16: Allocation of main-haul CO_2e emissions based on a sample sweater shipment

Table 6: Parameters for modeling distribution emissions

Parameter	Value	Source
Distance	**Main haul:** 220 km **Last mile:** 127.5 km	4flow
Utilization (shipments)	**Main haul:** variable **Last mile:** 180 shipments	4flow
Vehicles	**Main haul:** standard trailer, 34-40t GVW **Last mile:** van, <3.5t	4flow
Emissions	**Main haul:** 101 g CO_2e/tkm (based on 49.8% utilization, varied in the model) **Last mile:** 842 g CO_2e/tkm (based on 37% utilization, varied in the model)	GLEC (2025): "Global Logistics Emissions Council Framework for Logistics Emissions Accounting and Reporting; V3.1 edition, revised and updated"

In terms of costs, as well, allocating between shipment content and packaging poses a challenge. This is compounded by the rigid price structures of CEP service providers, which make it difficult to model prices with a constant variable comparable to emissions. The emphasis placed on shipment weight and the large differences between weight categories mean that packaging rarely makes a practical difference in distribution costs. Nevertheless, CEP service providers achieve real savings when they can transport more shipments in the same vehicle, especially on the main haul. These potential main haul savings were modeled by calculating real transport costs – consisting of fixed vehicle costs, labor costs and variable utilization-based consumption – and comparing these costs to the packaging method with the lowest utilization.

Table 7: Parameters for modeling distribution costs

Parameter	Value	Source
Fixed costs (total vehicle and labor)	€0.6156/km	Expert estimate
Variable costs (consumption)	€0.4848–0.7438/km	Expert estimate

Lastly, this study employed a factor of 0.5 to represent the share of savings that might potentially be passed on to retailers in future negotiations with CEPs. For shipping costs, these savings were subtracted from CEP prices. Using a cause-based approach, it was assumed that packaging created no direct distribution costs, so the savings were reported as negative.

Redistribution:

There are two kinds of redistribution. For single-use packaging, redistribution occurs in the case of product returns. For reusable packaging, redistribution applies both in the case of product returns and when a customer chooses to keep a product. The same emissions and costs were used for both returns and initial deliveries.

Table 8: Return rates for various market segments

Sector	Return rate	Source
Fashion	44%	University of Bamberg (2025): “Statistics on returns in Germany – definition”
Consumer electronics	13%	University of Bamberg (2025): "Statistics on returns in Germany – definition"
Books	8%	University of Bamberg (2025): “Statistics on returns in Germany – definition”

For reusable packaging, initial distribution and redistribution of empty containers were assumed to occur over the same distance. Volume was deemed unimportant as reusable packaging is usually returned in a folded state. Accordingly, the general emissions factors from Table 6 were also used to calculate emissions from redistribution of reusable packaging. The costs were calculated based on transport as goods shipment with waybill, as reported by manufacturers such as heycircle.

End of life:

Packaging disposal occurs in three significant ways: material recycling, energy recovery or waste incineration, and landfill. Following the cut-off approach, no additional environmental impacts are considered in the case of recycling, as these impacts have already been attributed to the recycled materials used in production. This study did not take landfill disposal into consideration either, as it no longer plays a significant role in Germany: Only around 0.1% of paper/cardboard and plastic waste ends up in a landfill. In contrast, around 34% of plastic and 8.7% of paper/cardboard waste is recovered for energy. Emissions were calculated for these cases.

Table 9: Emission factors for energy recovery of various materials

Material	Emissions factor	Source
Paper/cardboard	0.13 g CO_2e/g	FEFCO (2022): "The carbon footprint of corrugated packaging 2021" (End of Life share)
LDPE	1.201 g CO_2e/g	EU (2021): "Environmental effects of plastic waste recycling"
PP	1.211 g CO_2e/g	EU (2021): “Environmental effects of plastic waste recycling”

Packaging waste is collected and recycled in dual systems in Germany. These are financed in one part by revenues from material and energy recovery, and in the other by fees paid by packaging distributors as part of extended producer responsibility. Since these are end-of-life costs incurred by retailers, they were factored into total end-of-life costs.

Table 10: Fees charged for different types of waste, based on the average of various providers

Material	Fee
Paper/cardboard	€0.22/kg
Plastics	€1.00/kg

Sample items and suitable packaging methods:

Online retailers now sell almost everything imaginable. Different products have different packaging requirements in terms of size, stability, protection, safety and privacy.

This study examined a portfolio of six products from the most relevant online retail sectors in Germany: fashion, consumer electronics and printed products.

Table 11: Properties of the sample products analyzed

Product	Dimensions	Flexibility	Weight	Value	Fragility
Book	0.20 x 0.15 x 0.04 m	Rigid	1.01 kg	Low	Medium
Sweater	0.25 x 0.25 x 0.05 m	Flexible	0.60 kg	Medium	Low
Smartphone	0.17 x 0.09 x 0.03 m	Rigid	0.35 kg	High	High
Action figure	0.10 x 0.05 x 0.05 m	Rigid	0.10 kg	Low	Medium
Handbag	0.33 x 0.21 x 0.14 m	Flexible	0.50 kg	High	Low
Toaster	0.30 x 0.25 x 0.20 m	Fixed	1.10 kg	Low	High

For various reasons, not all packaging methods available on the market are suitable for all products.

Table 12: Suitability of packaging, by sample product

Product	Box, single-use, standard	Box, single-use, optimized	Envelope, single-use, cardboard	Bag, single-use, paper	Poly mailer, single-use, plastic	Bag, reusable, plastic	Box, reusable, plastic	Shipping in product packaging
Book	✓	✓	✓	-	✓	✓	✓	-
Sweater	✓	✓	✓	✓	✓	✓	✓	-
Smart-phone	✓	✓	✓	-	-	-	✓	-
Action figure	✓	✓	✓	✓	✓	✓	✓	-
Handbag	✓	✓	-	-	-	-	✓	-
Toaster	✓	✓	-	✓	✓	✓	✓	✓

Model results

The following tables list the complete results of the emissions and cost modeling for the different types of packaging and products examined in this study, broken down by individual life-cycle phases.

Table 13: Model results for packaging emissions (global warming potential [GWP], g CO_2e) and costs (€)

		Toaster		Handbag		Sweater		Book		Smartphone		Action figure	
		GWP	Cost	GWP	Cost	GWP	Cost	GWP	Cost	GWP	Cost	GWP	Cost
Box, single-use, cardboard, standard size	Production	122.66	0.42	78.26	0.36	63.17	0.30	36.72	0.17	24.12	0.14	15.27	0
	Packing process	0	0	0	0.41	0	0.41	0.00	0.41	0.00	0.61	0	0.41
	Distribution	3.73	0	2.38	0.00	1.92	0.00	1.12	0	0.73	0	0.46	0
	Returns	0.51	0	1.05	0	0.85	0	0.09	0.00	0.10	0	0.06	0
	End of life	44.17	0.07	28.18	0.05	22.75	0.04	13.22	0.02	8.64	0.01	5.50	0.01
	Total	**171.07**	**0.91**	**109.87**	**0.81**	**88.69**	**0.75**	**51.14**	**0.60**	**33.59**	**0.77**	**21.29**	**0.55**
Box, single-use, cardboard, size-optimized	Production	92.25	0.19	59.03	0.15	49.02	0.12	33.25	0.07	38.53	0.07	26.70	0.07
	Packing process	17.80	0.36	17.80	0.36	17.80	0.36	17.80	0.36	17.80	0.36	17.80	0.36
	Distribution	2.81	-0.02	1.80	-0.01	1.49	0.00	1.01	0.00	1.17	0.00	0.81	0.00
	Returns	0.38	0.00	0.79	0.00	0.66	0.00	0.08	0.00	0.16	0.00	0.11	0.00
	End of life	33.22	0.06	21.26	0.04	17.65	0.03	11.97	0.02	13.87	0.02	9.62	0.02
	Total	**146.46**	**0.58**	**100.68**	**0.52**	**86.62**	**0.50**	**64.11**	**0.44**	**71.53**	**0.45**	**55.04**	**0.44**
Envelope, single-use, cardboard	Production	-	-	-	-	41.20	0.23	25.23	0.17	16.99	0.10	10.49	0.09
	Packing process	-	-	-	-	0.00	0.25	0.00	0.25	0.00	0.25	0.00	0.25
	Distribution	-	-	-	-	1.25	0.00	0.77	0.00	0.51	0.00	0.32	0.00
	Returns	-	-	-	-	0.55	0.00	0.06	0.00	0.07	0.00	0.04	0.00
	End of life	-	-	-	-	14.84	0.03	9.08	0.02	6.07	0.01	3.78	0.01
	Total	**-**	**-**	**-**	**-**	**57.84**	**0.50**	**35.14**	**0.44**	**23.65**	**0.35**	**14.63**	**0.34**
Bag, single-use, paper	Production	20.70	0.28	-	-	8.28	0.16	-	-	-	-	1.38	0.03
	Packing process	0.00	0.25	-	-	0.00	0.25	-	-	-	-	0.00	0.25
	Distribution	0.54	-0.02	-	-	0.22	0.00	-	-	-	-	0.04	0.00
	Returns	0.07	0.00	-	-	0.10	0.00	-	-	-	-	0.00	0.00
	End of life	6.39	0.01	-	-	2.56	0.00	-	-	-	-	0.43	0.00
	Total	**27.70**	**0.52**	**-**	**-**	**11.15**	**0.41**	**-**	**-**	**-**	**-**	**1.85**	**0.27**
Poly mailer, single-use, plastic (LDPE)	Production	54.15	0.38	-	-	10.83	0.09	10.97	0.13	-	-	1.80	0.02
	Packing process	0.00	0.25	-	-	0.00	0.25	0.00	0.25	-	-	0.00	0.25
	Distribution	0.65	-0.02	-	-	0.13	0.00	0.13	0.00	-	-	0.02	0.00
	Returns	0.09	0.00	-	-	0.06	0.00	0.01	0.00	-	-	0.00	0.00
	End of life	12.07	0.04	-	-	4.83	0.01	2.45	0.01	-	-	0.80	0.00
	Total	**66.96**	**0.64**	**-**	**-**	**15.84**	**0.34**	**13.56**	**0.38**	**-**	**-**	**2.63**	**0.26**
Bag, reusable, plastic (PP)	Production	13.99	0.10	-	-	5.60	0.06	2.84	0.03	-	-	0.93	0.01
	Packing process	0.00	0.25	-	-	0.00	0.25	0.00	0.25	-	-	0.00	0.25
	Distribution	1.40	-0.02	-	-	0.56	0.00	0.28	0.00	-	-	0.09	0.00
	Returns	14.45	1.00	-	-	3.94	0.65	3.10	1.07	-	-	0.96	1.00
	End of life	5.25	0.01	-	-	2.10	0.01	1.06	0.00	-	-	0.35	0.00
	Total	**35.10**	**1.34**	**-**	**-**	**12.20**	**0.96**	**7.28**	**1.35**	**-**	**-**	**2.34**	**1.26**
Box, reusable, plastic (PP)	Production	18.93	0.38	14.83	0.34	8.95	0.30	4.50	0.21	3.41	0.12	2.32	0.11
	Packing process	0.00	0.41	0.00	0.41	0.00	0.41	0.00	0.41	0.00	0.61	0.00	0.41
	Distribution	4.73	0.00	3.71	0.00	2.24	0.00	1.13	0.00	0.63	0.00	0.58	0.00
	Returns	48.89	1.61	26.10	1.05	15.76	1.05	12.31	1.72	6.25	1.61	6.00	1.61
	End of life	7.10	0.02	5.56	0.01	3.36	0.01	1.69	0.00	0.92	0.00	0.87	0.00
	Total	**79.65**	**2.42**	**50.20**	**1.81**	**30.31**	**1.76**	**19.63**	**2.34**	**11.22**	**2.34**	**9.77**	**2.13**

Table 14: Model results for shipping emissions (global warming potential [GWP], g CO_2e) and costs (€)

		Toaster		Handbag		Sweater		Book		Smartphone		Action figure	
		GWP	Cost	GWP	Cost	GWP	Cost	GWP	Cost	GWP	Cost	GWP	Cost
Box, single-use, cardboard, standard size	Production	122.66	0.42	78.26	0.36	63.17	0.28	36.72	0.17	24.12	0.14	15.27	0.13
	Packing process	0.00	0.41	0.00	0.41	0.00	0.41	0.00	0.41	0.00	0.61	0.00	0,41
	Distribution	348.53	3.99	314.96	3.99	283.77	3.99	281.52	3.99	268.15	3.99	265.64	3.99
	Returns	47.68	0.55	138.90	1.76	125.14	1.76	22.75	0.32	36.68	0.55	36.34	0.55
	End of life	44.17	0.07	28.18	0.05	22.75	0.04	13.22	0.02	8.64	0.01	5.50	0.01
	Total	**563.03**	**5.44**	**560.30**	**6.56**	**494.83**	**6.48**	**354.21**	**4.92**	**337.59**	**5.30**	**322.74**	**5.08**
Box, single-use, cardboard, size-optimized	Production	92.25	0.19	59.03	0.15	49.02	0.12	33.25	0.07	38.53	0.07	26.70	0.07
	Packing process	17.80	0.36	17.80	0.36	17.80	0.18	17.80	0.36	17.80	0.36	17.80	0.36
	Distribution	321.24	3.97	297.32	3.98	279.55	3.99	281.34	3.99	271.43	3.99	269.42	3.99
	Returns	43.95	0.54	131.12	1.75	123.28	1.76	22.73	0.32	37.13	0.55	36.86	0.55
	End of life	33.22	0.06	21.26	0.04	17.65	0.03	11.97	0.02	13.87	0.02	9.62	0.02
	Total	**508.46**	**5.12**	**526.53**	**6.27**	**487.29**	**6.08**	**367.09**	**4.76**	**378.76**	**4,98**	**360.39**	**4.97**
Envelope, single-use, cardboard	Production	-	-	-	-	41.20	0.21	25.23	0.17	16.99	0.10	10.49	0.09
	Packing process	-	-	-	-	0.00	0.25	0.00	0.25	0.00	0.25	0.00	0.25
	Distribution	-	-	-	-	283.10	3.99	280.91	3.99	267.77	3.99	265.49	3.99
	Returns	-	-	-	-	124.85	1.76	22.70	0.32	36.63	0.55	36.32	0.55
	End of life	-	-	-	-	14.84	0.03	9.08	0.02	6.07	0.01	3.78	0.01
	Total	**-**	**-**	**-**	**-**	**463.98**	**6.23**	**337.92**	**4.75**	**327.46**	**4.89**	**316.09**	**4.87**
Bag, single-use, paper	Production	20.70	0.28	-	-	8.28	0.16	-	-	-	-	1.38	0.03
	Packing process	0.00	0.25	-	-	0.00	0.25	-	-	-	-	0.00	0.25
	Distribution	316.31	3.97	-	-	276.02	3.99	-	-	-	-	264.05	3.99
	Returns	43.27	0.54	-	-	121.72	1.76	-	-	-	-	36.12	0.55
	End of life	6.39	0.01	-	-	2.56	0.00	-	-	-	-	0.43	0.00
	Total	**386.66**	**5.06**	**-**	**-**	**408.57**	**6.16**	**-**	**-**	**-**	**-**	**301.98**	**4.81**
Poly mailer, single-use, plastic (LDPE)	Production	54.15	0.38	-	-	10.83	0.09	10.97	0.13	-	-	1.80	0.02
	Packing process	0.00	0.25	-	-	0.00	0.25	0.00	0.25	-	-	0.00	0.25
	Distribution	316.41	3.97	-	-	275.93	3.99	279.80	3.99	-	-	264.02	3.99
	Returns	43.29	0.54	-	-	121.68	1.76	22.61	0.32	-	-	36.12	0.55
	End of life	12.07	0.04	-	-	4.83	0.01	2.45	0.01	-	-	0.80	0.00
	Total	**425.92**	**5.18**	**-**	**-**	**413.27**	**6.09**	**315.83**	**4.69**	**-**	**-**	**302.75**	**4.80**
Bag, reusable, plastic (PP)	Production	13.99	0.10	-	-	5.60	0.06	2.84	0.03	-	-	0.93	0.01
	Packing process	0.00	0.25	-	-	0.00	0.25	0.00	0.25	-	-	0.00	0.25
	Distribution	317.17	3.97	-	-	276.36	3.99	280.06	3.99	-	-	264.15	3.99
	Returns	57.65	1.54	-	-	125.57	2.41	25.71	1.39	-	-	37.09	1.55
	End of life	5.25	0.01	-	-	2.10	0.01	1.06	0.00	-	-	0.35	0.00
	Total	**394.06**	**5.88**	**-**	**-**	**409.63**	**6.71**	**309,67**	**5.66**	**-**	**-**	**302.52**	**5.79**
Box, reusable, plastic (PP)	Production	18.93	0.38	14.83	0.34	8.95	0.30	4.50	0.21	3.41	0.12	2.32	0.11
	Packing process	0.00	0.41	0.00	0.41	0.00	0.41	0.00	0.41	0.00	0.61	0.00	0.41
	Distribution	349.53	3.99	316.29	3.99	284.09	3.99	281.54	3.99	267.98	3.99	265.76	3.99
	Returns	96.05	2.16	163.95	2.80	140.06	2.80	34.97	2.04	42.83	2.16	42.27	2.16
	End of life	7.10	0.02	5.56	0.01	3.36	0.01	1.69	0.00	0.92	0.00	0.87	0.00
	Total	**471.62**	**6.96**	**500.63**	**7.56**	**436.46**	**7.51**	**322.70**	**6.65**	**315.14**	**6.88**	**311.23**	**6.67**

Imprint

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