Fraunhofer
CCPE

FRAUNHOFER CLUSTER OF EXCELLENCE CIRCULAR PLASTICS ECONOMOMY CCPE

PLASTIC-BASED REUSABLE SYSTEMS IN THE CIRCULAR ECONOMY

- A SYSTEM ANALYSIS

ON BEHALF OF THE INITIATIVE MEHRWEG FOUNDATION (SIM)

OBERHAUSEN/DORTMUND | APRIL 2022

PLASTIC-BASED REUSABLE SYSTEMS IN THE CIRCULAR ECONOMY- a system analysis

Authors: Jürgen Bertling, Kerstin Dobers, Stephan Kabasci, Anna Schulte

Contacts: **Fraunhofer Institute for Environmental, Safety and Energy Technology UMSICHTOsterfelder** Straße 3, 46047 Oberhausen, Germany
www.umsicht.fraunhofer.de

Jürgen Bertling
juergen.bertling@umsicht.fraunhofer.de

Fraunhofer Institute for Material Flow and Logistics IML
Joseph-von-Fraunhofer-Strasse 2-4, 44227 Dortmund, Germany
www.iml.fraunhofer.de

Dr. Kerstin Dobers
kerstin.dobers@iml.fraunhofer.de

Cover photo: Mario Iser, Jürgen Bertling © 2022

Client: **STIFTUNG INITIATIVE MEHRWEG**
Taubenstrasse 26, 10117 Berlin

Responsible:
Dr. Jens Oldenburg
j.oldenburg@stiftung-mehrweg.de

Issue: April 2022

Available on the Internet: https://publica.fraunhofer.de
DOI: 10.24406/publica-11

Citation: Bertling, J., Dobers, K., Kabasci, S. , Schulte, A.: Kunststoffbasierte Mehrwegsysteme in der Circular Economy - eine Systemanalyse, Oberhausen/Dortmund 2022.

Content

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

1 Summary

1.1 Why this study?

The waste hierarchy plays a special role in European and German waste legislation. It defines an order of priority in the generation and handling of waste. However, a waste hierarchy is only meaningful if the practices assigned to one level are associated with advantages over the practices of the lower levels. The waste hierarchy therefore prioritizes the options that are likely to be more useful over those that are less useful, thus providing a compass of sorts. To ensure compliance with the waste hierarchy, political action must be more strongly oriented to it than in the past, suitable incentive systems must be created, and their disregard must be sanctioned.

Economic action that represents a deviation from the waste hierarchy must be justified and may only be possible on the basis of clearly defined conditions, as required by Section 6 (2) of the Closed Substance Cycle Waste Management Act.[1] An appropriate example is the calorific value clause, which until 2017 allowed energy recovery as an alternative to mechanical recycling for high-calorific waste. The calorific value clause has since been abolished for good reasons; it has also hardly promoted the path to the circular economy.

From the point of view of the Closed Substance Cycle Waste Management Act and the European Waste Framework Directive, the multiple use of packaging represents an important strategy for waste prevention and therefore ranks at the top of the waste hierarchy. Recycling is downstream of this and only ranks on the third level. This is also understandable insofar as packaging that has been used several times can still be recycled at the end of its life, but not vice versa.

Despite the fact that multiple use should actually be given primacy, it is mentioned at best as an alternative in subordinate regulations, directives, and even standards and environmental labels. Frequently, this alternative is also limited to certain areas of application. Insofar as the primacy of reuse is addressed, for example, in quotas, the regulatory requirements have not yet been adequately implemented.

This report represents the beginning of a series of analyses and evaluations of plastic-based reusable systems compared to their single-use competitors. Initially, three reusable systems were analyzed and shown whether and under which conditions they have an advantage over single-use systems. Further reusable demonstrators are planned for the future. As far as possible, generalizable conclusions should be drawn from the individual case analyses based on a large number of evaluation categories.

In the view of the authors, the results already speak in favor of consistently implementing the waste hierarchy and thus the primacy of reusable systems,

1 These can be, for example, evidence of improved ecological performance or aspects of food safety.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

formulating conditions for deviating from the waste hierarchy and scrutinizing existing deviations. A corresponding approach could accelerate the implementation of a circular economy and reduce the environmental impact of packaging. In addition, existing optimization potentials for reuse systems could be activated through greater dissemination.

Green Deal and taxonomy clearly show the political will of the EU. It is also a matter of making sustainable reusable solutions economically attractive for the trading companies compared to single-use solutions. The redirection of capital flows by linking them to robust sustainability criteria, as envisaged in the taxonomy, is a suitable means of achieving this. The sensible coordination of recyclate use quotas (> 90 percent) in production and minimum circulation figures for reusable systems (> 10), as is currently being discussed in the expert committees on the Taxonomy Regulation, seems suitable for this purpose.

1.2 Three important reusable systems in view

The study analyzes the three application examples of crates, plant trays and coffee-to-go cups. While reusable crates are already established, reusable cups are in the introductory phase and reusable planter trays are in preparation for large-scale use. The crates are a packaging system for retailers, the cups are intended for distribution to the end consumer, and both are conceivable for the plant trays.

With the three demonstrators selected, the present study focuses exclusively on plastic systems for reusable packaging. From the point of view of the clients and authors, this made sense because the properties of the plastics - durable, inert and lightweight - make them particularly suitable for reusable systems.

Figure 1:
Reusable solutions for crates, cups and trays

1.3 Performance of plastic-based reusable systems[2]

The performance of plastic-based packaging systems can be evaluated using a variety of criteria. This set of criteria can hardly be exhaustive, as the selection should be application-specific and is also influenced by attitudes and beliefs of the

[2] Details, calculations as well as information on the sources used can be found in the chapters in which the individual categories and demonstrators are dealt with in detail. Here, for reasons of clarity, repetition has been omitted.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

evaluators. In the context of this study, we have focused primarily on those aspects that we consider to be particularly relevant for modern, sustainability-oriented and sovereign corporate management in line with regulatory developments on climate change and the circular economy.

We see aspects of circularity as an important enabler for positive performance in use and improved sustainability impacts for the environment and society. In the following, we summarize the results obtained for the three demonstrators in the analyzed categories and, as far as possible, draw general conclusions for the comparison of reusable to single-use packaging.

Circularity

The circulation **rate** is the most important parameter for describing the performance of reusable systems. Our research has shown that in established B2B systems, such as the plastic crates, circulation rates of over 100 are achieved. Corresponding values should also be possible for plant trays. Initial experience with reusable cups, including studies of their rinsability and the short turnaround times to be expected, suggests circulation figures of 85.

Reusable systems have a high **material efficiency.** Even with a circulation rate of 5, material consumption is significantly lower than with the competing single-use systems. At high circulation rates of over 50, which are achievable in practice, material consumption for packaging of less than one gram per liter of product and use can be realized. This is a value that is virtually unattainable for disposable systems. Future increases in the number of bottles in circulation will further increase the material efficiency of reusable systems.

The **return rate** determines how high the proportion is that can be recycled - regardless of whether it is reuse or recycling. Reusable systems easily achieve values of over 90 percent, established systems even over 99 percent.[3] Such high return rates are not achievable for single-use systems. Even cardboard crates, for which mechanical recycling via the waste paper route is established, achieve a value of 87 percent in the best case. Disposable plant trays achieve a return rate of 55 percent via partially existing industry-related return logistics. A maximum value of 57 percent is assumed for disposable paper cups, as a large proportion of this to-go packaging is sent for thermal recycling via public waste garbage cans and is therefore lost for material recycling.

In the case of packaging, **reparability is** not generally envisaged. Nevertheless, there is a permanent feedback of information about weaknesses in the packaging via the closed-loop management of the packaging system, which can also lead to a re-design in the medium term, which provides for exchangeable components and thus a repair. This is the case with reusable crates and is conceivable in the long term for reusable plant trays and reusable cups. Single-use systems, on the other hand, are always designed to be non-repairable.

---

3 Damaged and rejected boxes do not reduce the return rate, only the shrinkage rate, see chapter 5.3.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

The reusable systems considered in this study are made of very recyclable monomaterials, usually polyethylene or polypropylene. This applies both in terms of the **recyclability of** these thermoplastics in principle and in terms of their practical recyclability, since recycling technologies and infrastructure for reprocessing these plastics are state of the art in Germany and Europe. Single-use systems are generally made of the same plastics or paper, cardboard or paperboard and are therefore also readily recyclable. One exception is the disposable plant trays made of polystyrene, whose practical recyclability must be rated lower due to declining volumes in recent years.

Accordingly, reusable packaging that is discarded within the scope of the circulation systems due to damage or wear is generally also recycled. The **recycling rates** indicated for the examples considered are over 80 percent. Values above 80 percent are also achieved for the disposable systems made of paper, cardboard, and paperboard (disposable pens, disposable cups). In contrast, the disposable plant trays lag behind with a recycling rate of only about 50 percent.

When it comes to the use of recyclates in the manufacture of reusable packaging, the picture is currently differentiated: reusable plant trays are made almost entirely from recyclate, while recyclate **content for reusable** crates ranges from zero to seventy percent, with an average of just under twenty percent, and an even lower recyclate content is recorded for reusable cups. The reason given for the low recyclate use in crates and cups is the regulations on materials for food contact. In the case of disposable systems, the crates achieve recyclate percentages of over 83 percent; in the case of plant trays, the recyclate percentage depends on the manufacturer and will not exceed 50 percent on average, but can reach 100 percent in individual cases. Disposable cups are not made from secondary material for functional reasons.

Plastic emissions occur as a result of wear and abrasion as well as littering. Deposited systems generally experience little littering and are often quickly collected again to redeem the deposit. Nevertheless, reusable crates and reusable plant trays, which are subject to high mechanical stress, can experience wear and tear, resulting in minor emissions. Disposable trays are designed to be much less stable than reusable trays. Damage, breakage and wear, and consequently littering, are therefore more likely. With disposable cardboard trays, the cardboard itself is readily degradable, so littering and abrasion are not as critical. In many cases, however, the cartons have polymer inks, adhesives, tapes, or strings that must be counted as plastic emissions. Reusable cups are unlikely to be littered after their widespread introduction due to the deposit, and abrasion is also unlikely. From the perspective of avoiding plastic emissions, a return option would be important even if the cup is damaged. Disposable cups are a classic top litter item found in large quantities during clean-ups. Since the cups are at least coated with plastic, this leads to emissions.

Performance

Packaging systems must be as standardized as possible in their external dimensions and fit with storage and transport systems - they must have a high degree of

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

modularity. We see this modularity above all in reusable systems, which have generally developed in parallel with transport systems. Single-use systems generally perform worse here due to individualization and differentiation - not infrequently due to competitive pressure. In the case of cups, however, we do not yet see any advantages for reusable over disposable solutions in terms of modularity.

The **ability to reduce volume,** especially for empty transport and disposal, is of great importance for efficient storage and transport processes. Modern reusable systems have made significant gains here compared to the first variants used in the past thanks to slim designs, nestability or foldability. In the case of crates, therefore, disposable and reusable systems are already on an equal footing. In the case of plant trays and cups, where reusable solutions do not have such a long history and are not yet so widespread, single-use systems are still superior in terms of volume reducibility.

Product protection is one of the essential packaging functions. Due to the higher material usage, reusable systems allow for more robust designs that increase stackability and reduce breakage during transport and handling. These advantages are particularly evident in the case of crates and coffee-to-go cups. For these, the breakage rate of reusable packaging is about five to ten times lower than for disposable packaging. In the case of cups, product protection is also closely coupled with protection against scalding - an important aspect in favor of the reusable system. With regard to plant trays, we still see advantages in single-use systems today, which allow perfect adaptation to the plant or plant pot thanks to a high product variety. Correspondingly adaptive reusable systems are in development, but their introduction is still pending.

Whether a package has a high level of **digitizability depends** on the one hand on whether the costs for optical codes or radio labels are significant and on the other hand on whether lifecycle-wide information transfer is possible. The latter is particularly the case with non-destructive recycling. This is the case with all the reusable systems investigated. Optical codes (barcode, QR code) are also widespread today for disposable crates. More elaborate radio labels for bulk detection or even indicators to record the product condition, on the other hand, appear to be ruled out for all single-use systems. A sophisticated and at the same time environmentally compatible extension of the packaging functionalities can therefore be expected above all in the returnable system.

The **transport effort** is an important criterion for the comparative evaluation of packaging systems. In addition to packaging volume and weight, the transport distance is the central factor. Often, higher transport distances are attributed to reusable systems per se. However, our analysis shows that the situation is different for single-use packaging when the transport distance for production and disposal is taken into account. For both crates and plant trays, transport distances of 250 to 500 kilometers per use are significantly lower than for the competing single-use systems, which require transport distances of 500 to 1000 kilometers even when optimized. This does not yet take into account the fact that reusable systems may also fundamentally promote greater regionalization of the economy.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

Sustainability

The indicator **greenhouse gas emissions** is currently the most frequently discussed impact category for assessing environmental impacts. As this is an output-related impact category, the value for greenhouse gas emissions also results, among other things, from the performance and recycling of the individual packaging systems. The plastic-based reusable systems investigated show lower greenhouse gas emissions per service unit overall,[4] i.e. they perform better overall than the respective single-use systems made of different materials. In all cases, the decisive factors for the advantageousness of a reusable system were the number of units in circulation and the distribution structures. The higher the number of items in circulation and the lower the transport distances, e.g., through decentralized pool management, the better the reusable versus single-use variants.

The cumulative energy expenditure is an important life cycle inventory figure and represents the sum of the primary energy expended for a product or service. Analogous to greenhouse gas emissions, this category is also reported per service unit. Although a relevant part of the primary energy can be partially recovered at the end of life, particularly for single-use systems made of cardboard, the cumulative energy input for all the reusable systems investigated performs better on average than for single-use systems. Analogous to the greenhouse gas emissions, the result also depends on the circulation numbers and the transport distance per service unit. Since the production of reusable systems generally has a higher cumulative primary energy requirement per unit, this additional expense must be compensated for by a corresponding number of rotations. However, this was clearly achieved in all the cases investigated.

Reusable systems show improved **relative economic efficiency at** comparable transport costs to the competing single-use systems.[5] In all the applications investigated, the reusable systems were already competitive from 5 circulations and had a clear advantage at 50 circulations. For reusable systems with high circulation rates, such as those established for crates and expected for plant trays, specific life cycle costs of less than 1 cent per use and liter of fill (excluding transportation and storage costs) are obtained. For disposable systems such as crates and plant trays, these tend to be around 4 cents per use and liter of product, and for disposable cups even over 16 cents per use and liter of product.

The Corona pandemic and the Russia-Ukraine crisis have made it clear that raw material dependencies have drastic effects on the price development and availability of raw materials, materials and intermediate products. The concept of **technological sovereignty** is therefore becoming increasingly important in politics and business. From a national and corporate perspective, a technological system is all the more independent the fewer components have to be imported from the upstream chain. For this study, the import independence for the essential material for the packaging system was used as an indicator. For all reusable systems, this

4 In order to compare disposable and reusable systems, the service unit has been defined here as one circulation with 1000 liters filling volume of the packaged product

5 For the specific definition of relative economic efficiency in this study, see Sect. 6.3.3

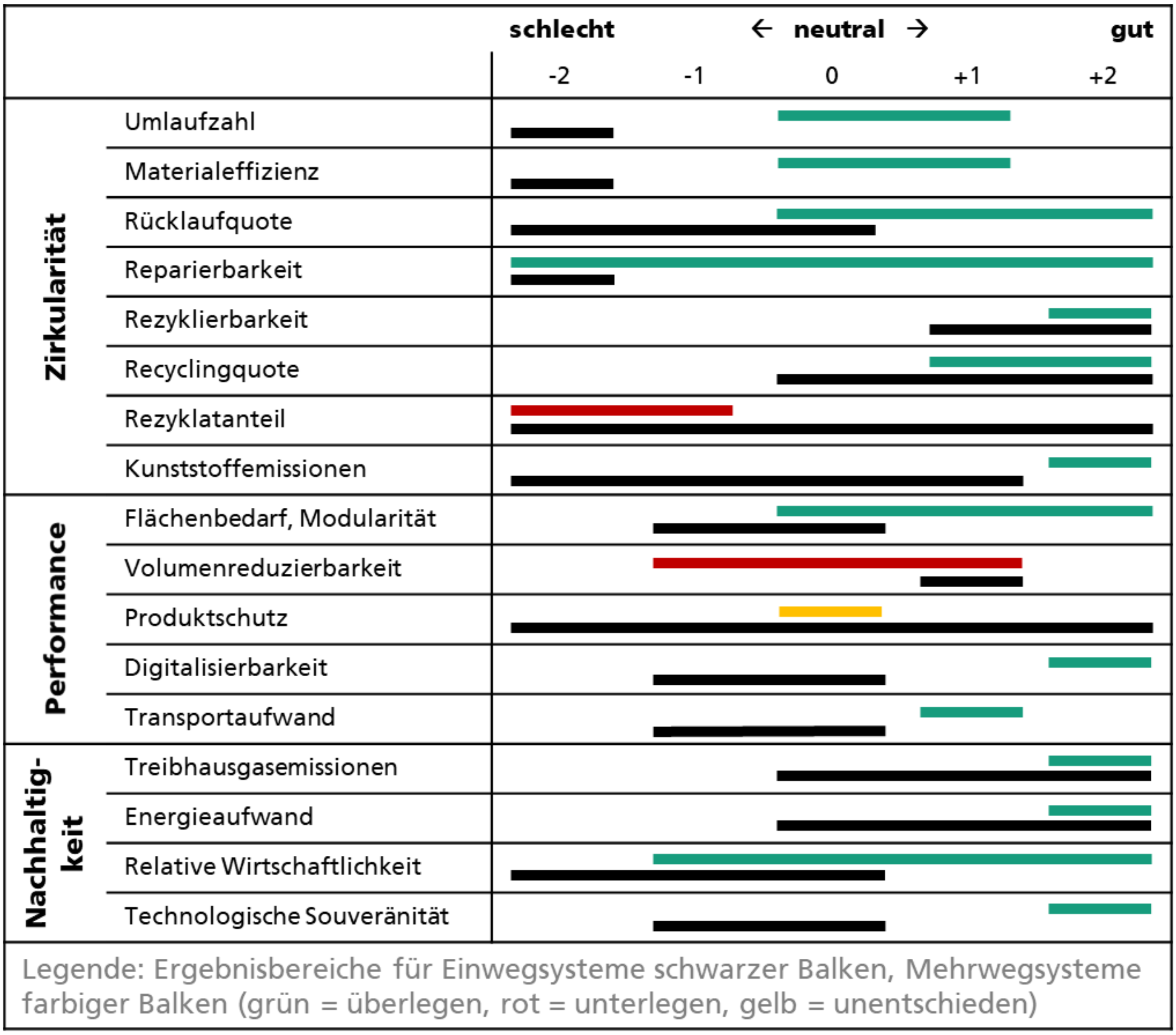
ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

reached values of over 95 percent, since only a small proportion has to be imported to cover the losses. This means that the plastic reusable systems even perform significantly better than paper and cardboard, even though the German paper industry carries a large proportion of the waste in its circle and thus achieves a high import independence of 80 to 90 percent for crates and coffee-to-go cups. We see the lowest import independence for disposable plant trays of only about 71 percent. Reusable systems therefore also make an important contribution to technological sovereignty.

In total, we considered 17 categories for the three demonstrators, evaluating available data from literature and expert interviews and performing our own calculations. In 14 of these categories, clear advantages emerged for the reusable systems studied. In two cases, the single-use systems have an advantage, and in one category the result is undecided. (Figure 2).

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

Figure 2: Comparison of evaluation results in 17 categories for the three reusable and single-use systems studied (crates, planter trays, coffee-to-go cups).



1.4 Recommendations

The results of this study show that reusable systems have advantages over single-use systems. However, this finding ultimately does no more than confirm the expectation already incorporated into the waste hierarchy that reuse through reusable systems is the top and priority level in dealing with waste. This makes it all the more surprising that reusable packaging is the niche rather than the norm. The following recommendations therefore have two main objectives:

1. Suggest ways to implement the waste hierarchy and thus a change to more reusable and

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

2. To identify optimization potential for reusable systems so that they can build on their existing advantages over single-use systems and eliminate the deficits that still exist in 2 of the 15 categories studied.

With this in mind, the authors of this study make the following recommendations:

... for associations and organizations of the reusable industry

- Associations should drive initiatives to create (European) industry solutions to avoid isolated solutions from individual providers.

- Wherever possible, reusable systems should be standardized nationally and internationally in order to optimize logistical processes. Round tables and standardization activities of all stakeholders involved in the life cycle of a reusable packaging can help. When standardizing, care must be taken to ensure that it is done in a way that is open to innovation.

- The associations of the reusable sector should support and coordinate the introduction of large-scale reusable systems, which require cooperation across companies and stages of the value chain.

- Reusable references should be defined for individual packaging applications and their sustainability performance determined. Alternative reusable systems and single-use packaging should have to be oriented to these references.

- Labels and eco-labels should enable a clear distinction to be made between reusable packaging and deposit and/or recyclate-based disposable packaging. The aim is to make the qualitative differences between reuse and recycling transparent to consumers.

- For comparative life cycle assessments of reusable and disposable packaging, standards and rules for life cycle assessment must be developed. ("Product Category Rules", PCR), which are already established in the construction industry, for example. The sustainability performance of the reusable reference could also be evaluated on the basis of these PCRs.

... for politics

- The focus on recycling quotas leads to downcycling, the invention of new applications for recyclates, and exerts little pressure on recycling-friendly product design. The targets for recycling quotas should therefore be abandoned and recyclate shares in production demanded. At the same time, the recyclate use achieved so far in plastics production (approx. 13.4 percent) shows very clearly that a circular economy of plastics is hardly feasible without a drastic expansion of reusable systems.[6]

6 The recycled content of single-use systems is roughly equivalent to the return rate for reusable systems. The latter is significantly higher.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

- A flat-rate incentive tax on single-use systems, as is also demanded for beverage packaging, would be an option for achieving ambitious reuse quotas. An incentive tax makes single-use packaging more expensive and works in favor of reusable packaging. However, the incentive tax could also result in a switch to cheaper single-use packaging or products. It would therefore probably not be sufficient on its own to bring about a change in the direction of reusable packaging for all conceivable packaging tasks. In particular, measures should be taken into consideration that more precisely evaluate the ecologically best solution for the specific packaging task.

- It is therefore necessary to extend the minimum standard for the recyclability of single-use packaging to include proof of its ecological advantage over a competing reusable reference system. This can be done on the basis of standardized life cycle assessments (ideally based on so-called Product Category Rules (PCR)) or, if these are not available, on the basis of simple categories such as those developed in the context of this study (material efficiency, recycled content, plastic emissions, sovereignty, etc.). For single-use packaging that is found to be disadvantageous compared to a reusable reference, a surcharge should be levied in addition to the existing license fee, which takes into account the additional environmental costs against a reusable system. This should be used for the benefit of further development and dissemination of ecologically advantageous reusable systems. The organization and control could be taken over by the Central Packaging Register Office. Analogous solutions should be developed for packaging systems that are not subject to the participation obligation.

- A specific plastic tax that addresses the non-circulated portion of a packaging would definitely have an effect in favor of the reusable system. In contrast, the currently practiced flat-rate national plastic tax to finance the EU budget is too unspecific. It ultimately leads to higher costs for all plastics and does not distinguish whether the specific applications are ecologically advantageous or disadvantageous. Moreover, in view of the current and expected long-term increase in the price of fossil raw materials and their possible shortage due to sanctions, it is questionable whether a tax is necessary and socially acceptable.

- Some reusable systems are also the more sustainable alternative to single-use packaging in international trade, e.g. between the EU and neighboring countries such as the UK, Switzerland and the Western Balkan states. The danger is that reusable plastic products will be burdened with plastic taxes already introduced or soon to be implemented for each individual circulation across borders of economic areas. Legislators in Brussels, in the EU member states and also in trading partners outside the EU must introduce regulations to prevent such tax payments that burden reusable systems.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

- It is necessary that the delegated regulation on the circular economy, which is necessary within the framework of the EU taxonomy and which is still in the preparatory phase, contains more far-reaching regulations for a successful circular economy.[7] This must also take into account making sustainable reusable solutions economically attractive for the trading companies compared to single-use solutions. The redirection of capital flows by linking them to robust sustainability criteria, as envisaged in the taxonomy, is a suitable means of achieving this. The sensible coordination of recyclate use quotas (> 90 percent) in production and minimum circulation figures for reusable systems (> 10), as is currently being discussed in the expert committees on the Taxonomy Regulation, should be implemented for this purpose.

...for the manufacturers of returnable packaging systems

- Optimization of the circulation figures should be one of the primary objectives in product and system development. The target value for reusable systems should be 100 on average. In order to increase the circulation figures, it makes sense, for example, to optimize the breaking strength of collapsible crates. New test procedures laid down in standards could help here. Improving communication with users or incentive systems to reduce shrinkage could also be the subject of optimization.

- Recycled content should be increased where permissible in terms of food safety by also using secondary raw materials from other applications in new or growing pools.

- Materials (plastics and additives) from different manufacturers should be recyclable together. Individualized materials should only be used for closed pools. When using additives, forward planning is necessary to ensure that recyclability is not jeopardized by any further tightening of environmental requirements in the future (cf. discussion on legacy additives such as brominated flame retardants in recyclates currently being produced).

- Where possible, monomaterial solutions should be used. Packaging made of several materials should be easily decomposable into monomaterial components in the course of the recycling process.

- Intensive efforts should be made to make reusable packaging compactable (through nestability, foldability, etc.). Anything that allows the reusable packaging to be lighter, smaller and more adaptable to the contents will have an advantage in many of the categories under consideration.

- The design of reusable packaging should be optimized to further increase cleaning efficiency. It should be examined whether non-destructive refreshing (e.g. by high-pressure impregnation) of reusable packaging is

7 Originally, publication was planned for 31.12.2021, but this has not yet taken place by the time of publication of this study. The entire taxonomy incl. the delegated regulation on the circular economy is to be put into force by 2023.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

possible in order to counteract aging or age-related phenomena such as fading or embrittlement of the materials and to increase the service life.

- The potential of digitization should be further exploited, especially for packaging in the B2C sector. Separating the communication function from the actual packaging offers great potential for new intelligent functions (product information, usage behavior, return locations, etc.).

...for the operators of pools

- For each multi-packaging system, a minimum circulation rate should be - estimated before it is started, above which an ecological advantage over single-use systems is achieved with a high degree of certainty. It should then be checked whether this circulation rate appears to be realistically achievable in the operation of the system.

- A monitoring system should be installed for each reuse system relevant in terms of volume, with regular and transparent reports on the average number of items in circulation achieved by a reuse system until it is discontinued due to shrinkage or breakage. A comparison of the actual circulation rate with the previously calculated minimum circulation rate should be presented transparently and, if necessary, can be used to regularly communicate the advantages of the reuse system.

- Cleaning technology and reusable packaging design should be coordinated. Where possible, their necessity should be checked before cleaning in order to save resources.

- The use of digitization options is intended to achieve a higher turnover rate for the systems. This will further increase the efficiency of the systems.

1.5 Fifteen questions and answers

Below we have compiled fifteen questions that are frequently asked about reusable solutions and what the authors believe to be the correct answers to these questions. These FAQs are intended to provide a quick overview and an easy introduction to the subject for those who are interested in the topic but do not wish to work through the full report.

1Scientific policy advice: Are studies on the environmental impacts of individual packaging solutions at all suitable as guidance?

No study can cover all possible use cases and thus clarify once and for all what needs to be done. This study is no exception. Nevertheless, it is necessary to provide general recommendations for political processes, corporate strategies or consumer behavior to guide action. This study shows that reusable packaging has advantages in many respects. In our opinion, they should therefore be the standard

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

solution. However, there will also be sensible areas of application for single-use solutions, but in our view, these would have to be legitimized on a case-by-case basis in accordance with political and legal requirements by providing evidence of their advantages.

2Circular Economy: How can it be better realized with recycling or reusable?

The question assumes that recycling and reuse are mutually exclusive alternatives. This view is well established, but in our view it is wrong. A Circular Economy worthy of the name requires a combination of both strategies. Only then can the need for virgin material and the associated negative environmental impacts be significantly reduced. However, this also means that, wherever it makes sense[8] , priority must be given to non-destructive multiple use, which is then followed by mechanical recycling. The reverse approach is understandably not possible. To date, however, the primacy of reusable solutions has not been implemented in the Packaging Act, despite being stipulated in the waste hierarchy in the Closed Substance Cycle Waste Management Act. Only for beverage packaging and service packaging are specifications made for a quota, but these are not very binding and must be considered ineffective without the necessary enforcement.

3New reusable systems: What are the challenges in introducing them?

The introduction of reusable systems is indeed costly. For them to work, they must reach a certain size. Sufficient storage areas, return points (possibly also deposit machines), cleaning capacities and logistical processes must be set up so that the system is attractive compared to the one-way competition. The establishment of this system is therefore generally a process that spans companies and value chains, and is also challenging in terms of competition and antitrust law. Associations and policymakers are therefore called upon here to create suitable framework conditions and organize processes that enable the systems to be set up. However, the realization that such complex systems cannot be realized by the market alone is increasingly gaining ground in politics and business. Active support through research programs and promotion of sustainable investments is therefore necessary.

4Return transport : Don't reusable systems lead to a high logistical effort?

Reusable systems must be returned for filling after a cleaning step. Assuming a circular economy, however, this also applies in full to single-use systems. Recyclates must also be cleaned and returned to the plastics processor. A disadvantage of reusable systems is the higher packaging weight and occasionally also the larger volume that has to be transported. With foldable or nestable as well as weight-optimized reusable packaging, significant optimizations have already been achieved here and even more are possible. In addition, reusable systems reinforce the trend towards regional business, so that the supply chains can even

8 Restrictive factors are, for example, hygiene requirements or transport distances.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

be shorter overall than with the single-use alternatives. Single-use systems also naturally lead to empty transports, especially for waste disposal. The often claimed transport advantage of single-use packaging is unfounded in its generality and not tenable.

5Pfand : Does it have to hurt for reusable systems to be beneficial?

The higher the deposit, the higher the return rate, which in turn has a positive impact on the environmental impact of packaging. Naturally, however, there are limits to the acceptance of high deposit fees, as these reduce the liquidity of users despite reimbursement. As an alternative to the deposit, there are other incentives or (technological) options to increase return rates. Examples of this are monitoring and tracking software, which can be used especially for high-value and long-life reusable systems. Well-functioning examples exist here in the B2B sector. In the consumer business, the first deposit-free reusable packaging already exists, where users can decide between the options of free use with return or purchase via digital tracking.

6 Innovation: What's new in reusable systems?

In the future, we can expect a variety of new reusable systems. Online retailing and the take-away sector in particular could come up with exciting new solutions. However, it will be necessary to create framework conditions and agree on standardization in order to exploit the ecological potential of reusable systems. Other exciting developments relate to solutions such as "refill on the go" and "refill at home," which are reusable systems in the broader sense. However, they require a significant change in consumer behavior. To date, they have been used primarily for cosmetics, detergents, cleaning agents and cleaning products. Thanks to the close integration of packaging systems and transport logistics, reusable systems offer a great deal of potential for optimization that is not apparent to the same extent with disposables.

7Plastic littering : Can reusable packaging reduce the amount of plastic waste in the environment?

The incentive systems for the return of reusable systems are a strong argument against littering. In contrast, there is no economic incentive to prevent littering in the case of participation fee-based return for single-use packaging. Disposal via dual systems or the environment is ultimately cost-neutral for the disposer. The levying of fines for littering and illegal waste disposal, while fully envisaged across the board, is hardly feasible. Of course, all disposable packaging, not just that of beverages, could also be subject to an additional deposit. However, the other advantages of reusable systems could not be exploited in this way. Reusable packaging is the clear way out of a throwaway society!

8 Living plastic-free: Is it necessary and sensible?

Doing without is a necessary component of sustainability strategies, even if its implementation is difficult. Of course, dispensing with plastic packaging is also

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

perfectly conceivable and sensible in some areas. But if plastic is substituted with other materials just for the sake of it, it is worth taking a closer look. Plastic is light, durable and chemically very inert. In many cases, these properties also result in an ecological advantage over other packaging materials. Reusable systems combine a partial avoidance of plastics with its ecological advantages. In particular, the low weight and durability make plastic especially attractive for reusable systems. Single-use systems, on the other hand, cannot exploit the ecological potential of plastic due to their short lifespan.

9 Repair culture: Is it worth repairing packaging?

Most packaging is not designed to be durable or repairable. They have thus clearly given fuel to the idea of a throwaway society. With reusable systems, on the other hand, there is an intrinsic interest on the part of the system operators in the robustness and replaceability of defective components. In the case of reusable packaging, which has been in use for a long time, repair is already well established. New technical solutions for healing cracks or rejuvenating the material are also conceivable in the future. More repairable reusable systems could therefore also help the idea of a repair culture to take off. This is a significant contribution to resource conservation.

10 Climate change: Do plastic-based reusable systems lead to lower greenhouse gas emissions than single-use systems?

Of course, not all reusable packaging is superior to single-use packaging in every application. Nevertheless, the large number of life cycle assessments in most of the application areas investigated so far, especially for lightweight plastic-based reusable systems, show advantages in terms of greenhouse gas emissions. It therefore makes sense, if both systems exist, to initially establish the use of lightweight reusable packaging as a guideline for action and only resort to the single-use system in justified individual cases. This would also be in line with the basic idea laid down in the waste hierarchy.

11 Hygiene: Are reusable packaging systems critical here?

The use of reusable cups, containers and tableware has been more in demand in the past. Nevertheless, there are also occasional doubts, currently intensified by the Corona pandemic, as to whether reusable systems are safe from a hygienic point of view. As with any packaging material, the food law conformity of reusable plastic packaging systems is ensured by regulations relating to safety and sensory aspects. To ensure that hygiene regulations are observed when handling reusable packaging, there are also guidelines, leaflets and instructional videos for all those involved in the circulation process chain. For these reasons, and because the plastic materials used have surfaces that are very easy to clean, the use of reusable packaging can basically be regarded as hygienically safe. In addition, the cycle and cleaning process for reusable packaging are significantly more defined and better traceable than the recycling of single-use systems.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

12 Goodbye individualism: Do reusable systems and large pool solutions lack pool solutions lack uniqueness?

Differentiation in the competitive environment constantly requires new individual designs and functions, also in the packaging sector. If this is attempted with reusable systems, it can lead to problems in return logistics and squander the advantages of reusable systems. This is currently being discussed in the beverage industry, for example, where special bottles have also been used in the reusable sector that have to be returned long distances for filling. However, the question arises as to whether individualization via packaging is still in keeping with the times. New possibilities of digitalization allow the virtual extension of the packaging with additional functions and benefits for the people using it. Here, reusable packaging, in which radio labels, sensor technology and user interfaces pay off ecologically and economically thanks to the high circulation rates and non-destructive circulation, has clear advantages over disposable packaging. New, exciting application examples could show what reusable packaging can achieve in the coming years.

13Extended producer responsibility: Are reusable systems the best answer?

Reusable systems, by definition, require take-back by the pool operator or distributor. Particularly with regard to illegal or unregulated end-of-life practices, the incentive systems used to ensure closed loop recycling (deposit, rental) are particularly powerful. Manufacturers and pool operators, out of self-interest, design their packaging and systems in such a way that they can maintain the cycle for a long time without losses. Cycles based on recycling, where recyclates are rarely returned to the same application and even more rarely to the same manufacturer, do not achieve such a high level of accountability. With single-use systems, there is more of a tendency toward "out of sight, out of mind."

14Dependence on crude oil: Don't plastic-based reusable packaging increase our dependence on fossil raw materials?

Reusable systems increase the stock of anthropogenically stored materials in resource-poor nations like Germany. They thus balance unevenly distributed natural resources toward demand, reducing dependence on imports and the risks of trade barriers. Ultimately, building anthropogenic stocks through reusable systems can lead to greater technological sovereignty in the packaging sector as well. Plant shutdowns ("force majeure") at plastics manufacturers, which are being reported with increasing frequency, would hardly affect reusable systems.

15 Circulation figures: How much single-use packaging replaces reusable systems?

An answer to this question depends in principle on the system used. For all three demonstrators examined in this study - reusable crates, reusable plant trays and reusable cups - 70 to 100 cycles are realistic. Thus, during one of their life cycles, they already replace the production of 70 to 100 single-use packages. At these circulation rates, reusable systems have a clear advantage over single-use systems

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

in almost all economic and ecological criteria. At the end of their life, they also score points for the excellent recyclability of their material. In the case of single-use systems, closed-loop recycling only takes place in exceptional cases (e.g., in the case of PET bottles for which a deposit has been paid). Instead, the plastic of most disposable packaging must be recycled from a largely undefined mixed waste fraction ("yellow bag") that is also contaminated with product residues. The recyclates produced from this are hardly suitable for the same use, especially in the food sector. In the case of reusable systems, a defined material exists at the end of an initial life cycle, for example, when reusable packaging has to be sorted out due to irreparable damage. Its use is well documented over the entire life cycle and its material composition is known. The recyclate produced from it is therefore the ideal starting point for further life cycles, each with a further 70 to 100 cycles.

2 Design and structure of this report

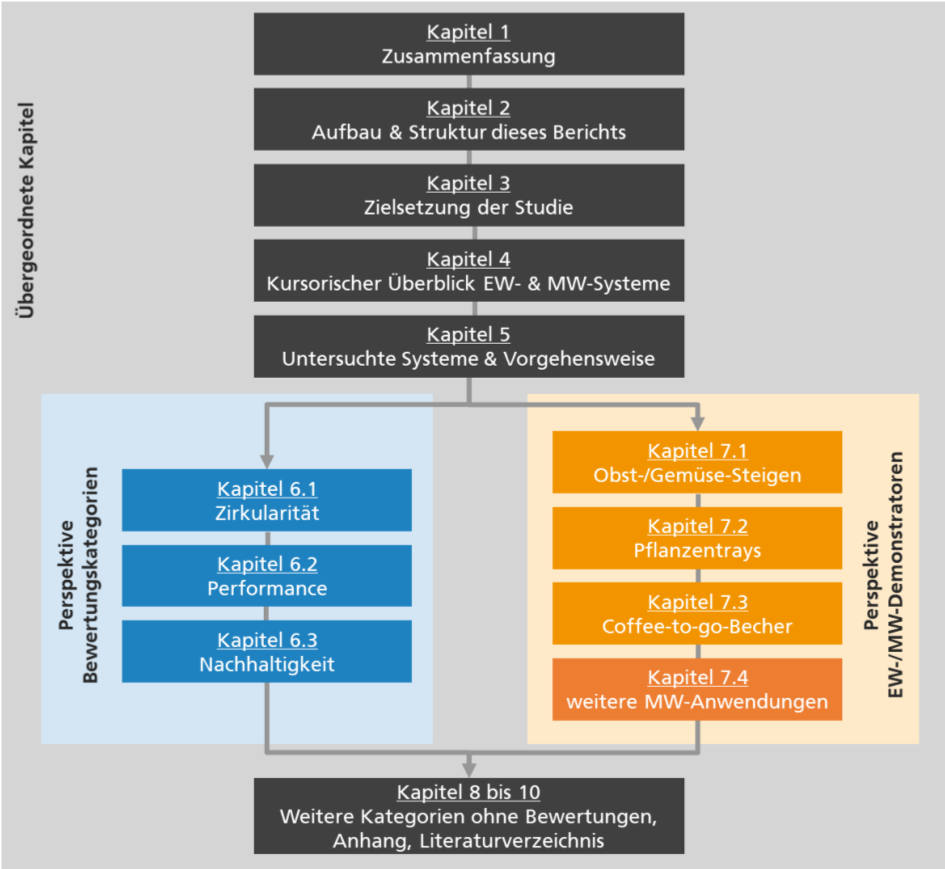
By way of introduction, overarching topics such as the objective of the study (chap. 2), a first cursory overview of single-use and reusable systems (Chapter 4) and the systems studied in particular (Chapter 5) are briefly discussed. This is followed by two parallel strands:

- The 17 **evaluation categories** chosen in the study are presented methodically in chap. 5.2 methodologically presented. The results of our evaluations of the three demonstrators selected-fruit and vegetable crates, plant trays, and coffee-to-go cups-are presented in chapters 6 presented.
- The results of the individual **disposable and reusable demonstrators** are shown in chap. 7 is presented. After a brief description of the application, the status of the respective single-use and reusable solution is outlined. Subsequently, the evaluation results are presented in summary for each demonstrator.

The chapters listed are preceded by a summary including a question-and-answer catalog (Chapter 1).

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

Figure 3:
Structure of the study



ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

3 Objective of the study

The aim of the study is to make a scientific contribution to the evaluation of plastic-based reusable packaging systems. Their characteristics (advantages and deficits), challenges and potential for improvement are investigated in a multi-criteria approach.

3.1 Subject and procedure

To this end, the study compares selected plastic-based reusable packaging systems with existing single-use alternatives in Germany[9] . This analysis is carried out with reference to categories from the subject areas of circularity, performance and sustainability. The three topics are each underpinned by a detailed set of categories, which enables differentiated analyses.

In the run-up to the project, three application examples were initially selected in a dialog with the client, the Stiftung Initiative Mehrweg, and the European members, as well as during a discussion event at the European Green Week 2021:

- Crates for fruit, vegetables, meat or industrial products
- Plant transport systems (plant trays)
- Coffee-to-go cup (C2G cup)

These reusable systems include solutions for business-to-business (B2B) (crates) and business-to-consumer (B2C) (C2G cups) as well as those that can be used across business and consumer traffic (B2B and B2C) (plant trays). The reusable systems have already been established on a larger scale for decades (Steigen) or a few years (C2G cups), or they are on the verge of widespread introduction after many years of use in smaller quantities (Pflanzentrays). The study is structured in such a way that further applications can be added in the future to provide an overall view of reusable systems in the long term.

The comparison of the selected reusable systems takes place with the established single-use systems in the respective application area, regardless of whether the latter are made of cardboard (crates), plastic (plant trays) or composites of plastic-coated paper (C2G cups). As far as the selection of applications and the data situation allow, generalizations for the comparison of plastic-based reusable systems with competing single-use systems are derived. A comparison to alternative materials for reusable systems is not the subject of the study.

Scientific literature, product information from manufacturers and pool operators of disposable and reusable packaging, and interviews with experts served as data sources. Simplified rough calculations were carried out on this basis. No in-depth calculations or life cycle assessments were carried out. The interviews were conducted primarily with members of the commissioning foundation Initiative

9 This does not mean that cross-border packaging systems are excluded.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

Mehrweg (SIM), supplemented by discussions with other stakeholders at European level to clarify specific issues.

Particular focus was placed on the classification of data availability and quality. The uncertainty of data from both literature sources and expert testimony was accounted for by a pedigree approach (cf. Sect. 9.3.1), which is used to assess and document the data quality in a comprehensible way.

3.2 Presentation of the results

To introduce the topic, some definitions of terms, systemic considerations, preliminary comparisons as well as the status in packaging consumption and the regulatory situation are first presented (Chapter 4). Subsequently (chap. 5), the investigated systems and the approach are described.

The results in the categories studied are presented as a pairwise comparison of the single-use and reusable systems in the applications studied (Chapter 6). Where possible, a classification of the pairwise comparisons was made with respect to an absolute reference. The results of all categories in which quantifiable values could be obtained (e.g., greenhouse gas emissions) were converted into index values of a five-point scale (-2,
-1, 0, +1, +2). Thus, comparative considerations with purely qualitatively assessable categories (e.g. recyclability) are possible. This classification resulted in a joint graphical and tabular presentation of the results per category.

The presentation by category is followed by one by demonstrator (chap. 7). It begins with a detailed description of the application and the status of reusable and single-use systems. Subsequently, the index values of all categories were presented graphically in summary form in the form of a harp for each reusable system considered and the competing single-use system. This presentation of results makes it possible to highlight advantages, deficits and potential for improvement. With regard to the existing technological and systemic status of the reuse systems in the evaluation categories examined (circularity, performance and sustainability), development potentials are identified and measures are recommended.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

4 Cursory overview of single-use and reusable systems n[10]

4.1 Single-use and reusable systems in public perception

The public debate about reusable systems - often referred to simplistically as "returnable" in the further course of this study - focuses almost exclusively on beverage bottles. In this context, the deposit and separate return of single-use beverage bottles contributes to consumer confusion because single-use and reusable packaging are increasingly less distinguishable for consumers. Although the littering of bottles has decreased (not least due to deposit collectors) and the recycling industry has gained access to largely separately collected material fractions, the ecologically relevant differentiation "recycling or reuse" can hardly be made by the consumer. (NABU 2021; Verbraucherzentrale 2020).

Labels established on the market also do not contribute to greater clarity. The symbol for single-use beverage containers with a deposit does not give any indication of the completely different type of recycling and recovery (Figure 4 - center) in this system.

Figure 4:
Reusable label, single-use deposit symbol and Blue Angel reusable label

Only recently has a Blue Angel been awarded for reusable to-go packaging, for which there are only three label holders so far. Other labels, especially for the B2B sector, do not yet exist in Germany.

4.2 Definitions and classifications

The demarcation of single-use and reusable systems is not trivial. In §3 of the Packaging Act, the following legal definitions can be found. (VerpackG 2021):

"(3) Reusable packaging is packaging that is designed and intended to be reused several times for the same purpose after use and whose actual return and reuse is made possible by adequate logistics and encouraged by appropriate incentive systems, usually a deposit.
(4) Single-use packaging means packaging that is not reusable packaging."

10 We would like to point out that the comments in this chapter are a scientific and technical evaluation and not a legal assessment of the legal classification.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

The European single-use plastics directive (EU 2019/904) consistently defines single-use plastic articles (i.e., not just packaging) as follows:

"Single-use plastic article means an article made wholly or partly of plastic that is not designed, developed, and placed on the market to undergo multiple product cycles during its lifetime by being returned to a manufacturer for refilling or reuse for its original intended use"

In the definition of the EU Packaging Directive (94/62/EC)as amended by (2018/852/EU) it is added that reusable packaging must be designed from the outset in such a way that multiple use is possible:

"Reusable packaging: Packaging that is designed and placed on the market in such a way that its nature allows for multiple cycles during its lifetime by being refilled or reused according to its original purpose."

According to the above legal definitions, reusable packaging is such,

- which are used several times for the same purpose after a first use while retaining their shape (i.e. have a minimum circulation of three),
- have a functional and robust design for multiple use,
- for which suitable logistics are available that allow multiple use with shape retention for the same purpose, and
- for which an incentive system exists that promotes precisely this type of recycling over (factory) material or energy recovery.

Only if these conditions are met can one speak of a reusable system. Single-use systems that only occasionally and not systematically lead to multiple use or for which neither incentive system nor reusable logistics exist do not meet these requirements. Containers that are sold directly to the consumer and are brought back multiple times for filling at retail also do not meet the requirements because neither incentive nor logistics are organized as a system. Therefore, these variants are not considered in this study.

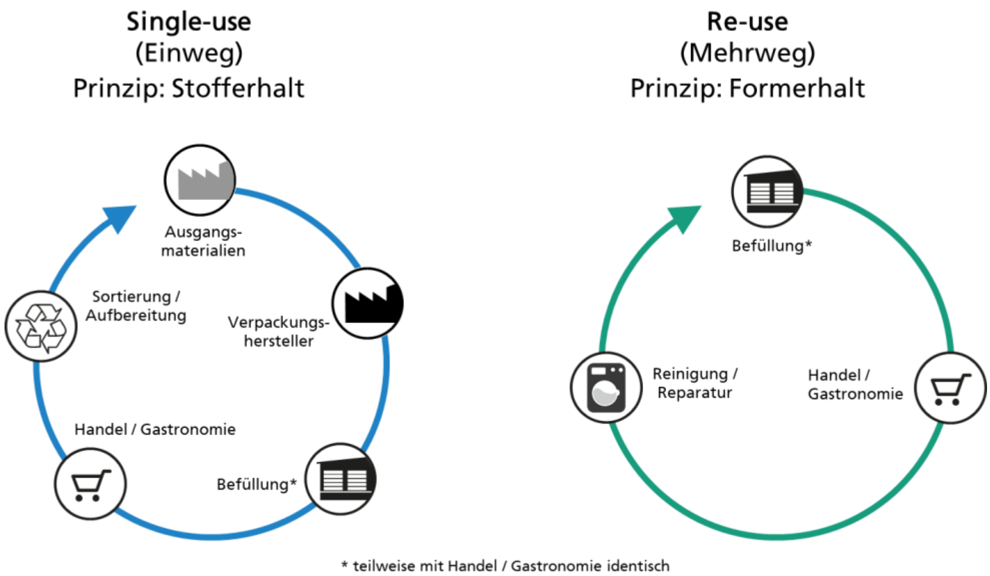
Expectations are associated with reusable systems, especially with regard to their ecological advantages over single-use systems. In this context, it is discussed whether it would be useful to specify the concept of reusable systems with the aid of targets, e.g. on the basis of the number of items in circulation. However, technical criteria such as a minimum circulation rate would make the introduction of new reusable systems more difficult and could vary greatly depending on the application. It would seem more sensible to specify the minimum circulation rates to be achieved after an introductory phase in labels such as the Blue Angel, for example, on an application-specific basis by means of a process that has yet to be defined. In contrast, a comprehensive mission statement process that addresses the values that one would like to see associated with reuse systems can only be initiated at the association level.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

4.3 System analysis of single-use and reusable systems

Apart from the problem of demarcation described above, the terms "disposable" and "reusable" only very inadequately describe the differences between the two systems. In principle, a closed loop can be implemented in both systems. If single-use systems are to be circulated, this is done by reusing the (materials). Reusable systems, on the other hand, focus on maintaining form and function throughout the entire cycle. Single-use systems require renewed production of the packaging material in each cycle, while reusable systems primarily require cleaning and possibly repair steps. The cycles are shown in a simplified, ideal-typical form in Figure 5 shown.

Figure 5Ideal typical cycles for Single-use (disposable) and re-use (reusable)



This illustration neglects the fact that materials fatigue, losses occur and the energy required to operate the cycle must also be covered by resource input. For an efficient circular economy, the following measures are therefore necessary (Figure 6):

1. First, measures must be taken to maximize efficiency (). To this end, efficiencies must be increased and losses reduced.
2. Where multiple use reaches its limits, it should be supplemented by recycling cycles. Products or packaging that are no longer usable due to damage are recycled in a closed loop (compensation within the technosphere).
3. Material losses and the necessary energy requirements are ideally covered by renewable raw materials. Closing the loop is then achieved by integrating natural cycles within their load limits (compensation by integrating the biosphere).
4. Material losses and energy requirements, to the extent that they cannot be represented from renewable resources, are ultimately met from non-renewable sources (compensation within the lithosphere).

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

A combination of reusable systems and recycling after an initial life cycle has the potential to reduce system losses and the resources required to close the loop (Figure 6).

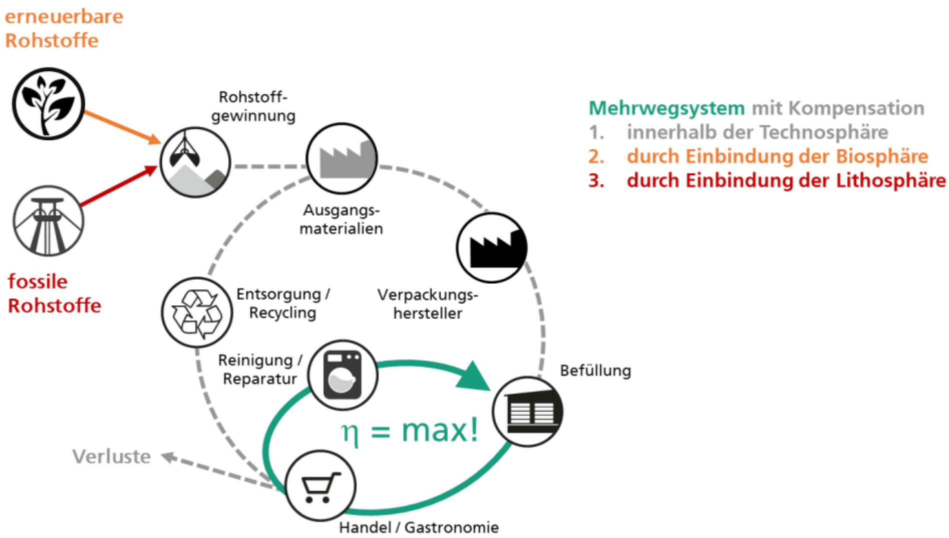


Figure 6: Combined cycle with re-use (reusable) and single-use (disposable) as second option as well as compensation of losses by renewable and fossil resources.

4.4 Preliminary comparison of the primary energy consumption of reusable to disposable containers

Reusable systems make ecological sense as long as resource requirements and emissions via a cycle are lower than those for a competing single-use cycle (cf. Figure 5). In simplified terms, the reusable cycle is ecologically beneficial if the effort required to manufacture, wash, repair and transport the reusable packaging is less than the effort required to transport and recycle the single-use packaging. The latter assumption makes sense for paper and used glass, since a virtually closed single-use cycle already exists here. For single-use plastic packaging, on the other hand, it is too optimistic, as recycling and reuse rates are still far from closed-loop today (cf. Section 4.5).

In the following, the primary energy consumption[11] of sub-processes will be used as an example to show that the result can be very different. Each of the systems, whether single-use or reusable, ultimately requires comprehensive optimization in order to be called a sustainable option.

The primary energy input for processing plastics by means of injection molding can be assumed to be about 1.8 to 3.6 kWh per kilogram (Kent 2009). The energy input for processing plastic packaging waste into secondary raw materials is likely to be determined primarily by the shredding effort and to be about 0.2 to 1.8 kWh per kilogram (Morris 1996) .

11 Primary energy factors used for electricity 1.8, diesel 1.2 and natural gas 1.1

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

An industrial belt washer requires approximately 0.11 kWh per kilogram of packaging weight (Meiko 2021).[12] However, it can be assumed that the washing effort required for recycling, especially for applications in the food sector, is at least as high. This is probably even higher, since the surface/mass ratio of shredded plastic waste, which determines the cleaning effort, is significantly greater than that of whole reusable packaging. The repair effort for reusable systems essentially takes the form of replacing parts which are also produced via injection molding.

In addition, the transports necessary between the individual processes of a cycle and the associated energy requirements must be taken into account. The frequently encountered opinion that the transport distances of reusable systems are higher per se due to the transport of empty packaging is incorrect. If the goal of a closed loop economy is also assumed for single-use packaging, it is initially disposed of as waste after use, which is transported and processed and later transported again as a secondary raw material to the place where the packaging was produced. The idea of a circular economy therefore requires that the entire material flow is transported through the cycle, even in the case of disposable packaging. Therefore, even in the case of single-use systems, the closed-loop system involves transport costs, including a large number of empty runs (e.g., in the case of waste transport), as well as energy costs. These must be determined in the specific application. It is not possible to make a general statement that one of the two alternatives, single-use or reusable, is favored in terms of the total transport distance (details in chapter 6.2.5).

The energy requirement of transport is determined in particular by the distance to be covered as well as the weight to be transported (distance [km] x weight [t] = transport performance [tkm]). Since the distances depend strongly on the respective area of application of the packaging solution, particular attention should be paid here to the weight: because reusable solutions are usually somewhat heavier than their single-use alternative. However, only in rare cases, e.g. in the case of very heavy packaging, is there a limitation on the loading quantity due to the permissible total weight being reached. Furthermore, a volume-related limitation can result from unfavorable size ratios of product to packaging. Both effects can occur with disposable and reusable packaging and are not considered further here. A large proportion of fuel consumption during transport is already caused by dead weight and air and rolling resistance; the load-related proportion is much lower. On the basis of the data in the manual for emission factors (Infras 2019) we have calculated Empty consumption: 2.9 kWh/km plus 0.09 kWh/tkm for loading.

In Figure 7 the calculation result of a comparison of the primary energy consumption of reusable to disposable is shown. The primary energy ratio is plotted on the y-axis as a function of the number of cycles (x-axis, logarithmically scaled) and the distance and mass ratios (plot parameters). Various assumptions were made for the transport distance ratios of returnables to disposables (SV) and the corresponding weight ratios (MV). The ratio of transport distances SV was set

12 This assumption was estimated with the aid of the data sheet provided. It was further assumed that a standard plastic plate has a weight of 125 grams and that the surface/mass ratio corresponds approximately to that of reusable packaging.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

to 1 in the basic calculation (solid lines) (SV id), i.e. the same transport distances are used for the calculation. Only half the transport distance (SV min = 0.5; dotted lines) and twice the transport distance (SV max = 2.0; dashed lines) are shown as variants. The ratio of the mass of the reusable packaging to the mass of the disposable packaging was assumed to be two values, the low, MV low = 2 (orange lines), and the high, MV high = 5 (blue lines).

Results: For the same transport distances (SV id), reusable packaging that is twice as heavy (MV low) is already superior from 3 circulations, while reusable packaging that is five times heavier (MV high) only reaches this point at around 6 circulations (logarithmic scaling of the x-axis of the diagram). At the same time, it can be seen from the figure that the transport distance ratios also have an influence. If the total distance of the multi-way system is twice as long (s max), significantly more circulations (35) are required for an advantage to be achieved. If the total distance is half as long (s min), on the other hand, the returnable system already has an advantage with a low number of circulations.

The informative value of the presentation is limited, as it only approximates the direct primary energy consumption. From the viewpoint of the reusable systems, however, it is to be regarded as rather conservative, since 100 percent recycling was assumed for the single-use system. Nevertheless, the illustration shows that at a relatively low mass ratio of 2, advantages can already be expected for circulation numbers in the range of 2 and above, even for long transport distances. With a high mass ratio of 5, these advantages are also achieved with lower and identical transport distances at circulation rates of 5 or more. Only at a significantly higher mass and longer transport distances does it become more difficult, but not impossible, for reusable systems to achieve competitiveness in terms of primary energy consumption. The transport distances are not only dependent on the quality of the logistical planning, but above all on the regionality of the economic cycle.

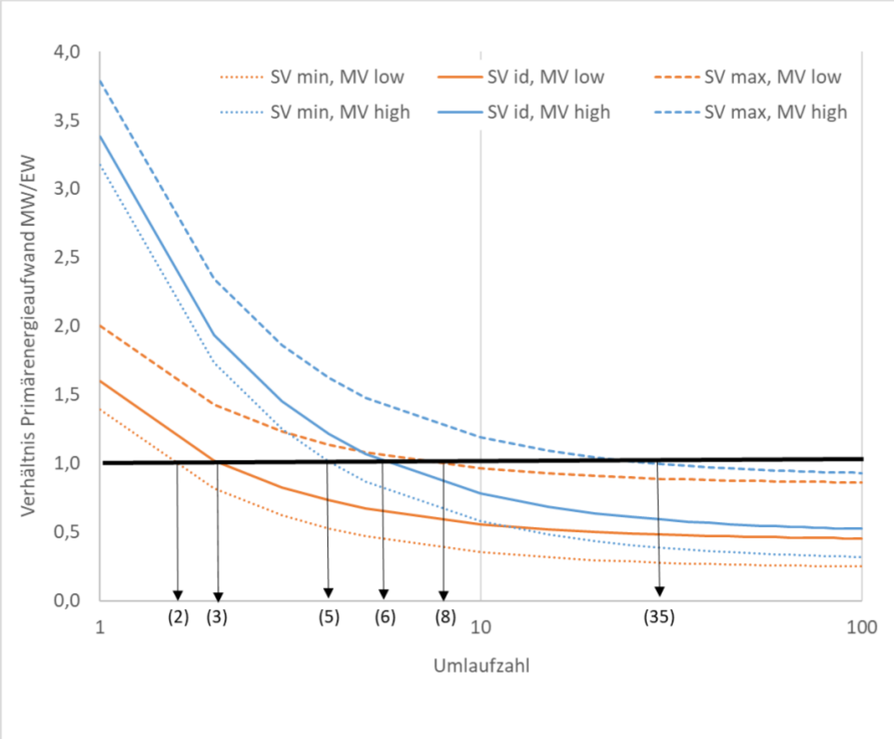
The calculation can be found in the appendix (chapter 9.1). A more detailed consideration of the cumulative energy input can be found in Chapter 6.3.2.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

Figure 7Comparison of primary energy consumption of returnable and non-returnable containers as a function of the number of cycles [Own calculation].

SV: Ratio of transport distances reusable to disposable;
SV min = 0.5
SV id = 1.0SV
max = 2.
0

MV: Ratio of mass returnable to non-returnable;
MV low = 2
MV high = 5



4.5 Status of packaging consumption in Germany

Despite the introduction of the Packaging Ordinance and the Closed Substance Cycle Waste Management Act in the 1990s, the amount of packaging consumed per person in Germany has increased continuously while the population has remained roughly the same (Federal Environment Agency 2018). Total consumption in Germany in 2016 was about 220 kilograms per person per year, of which about 190 kilograms per person per year in the four most important material groups of paper, plastic, glass and metal (Figure 8).

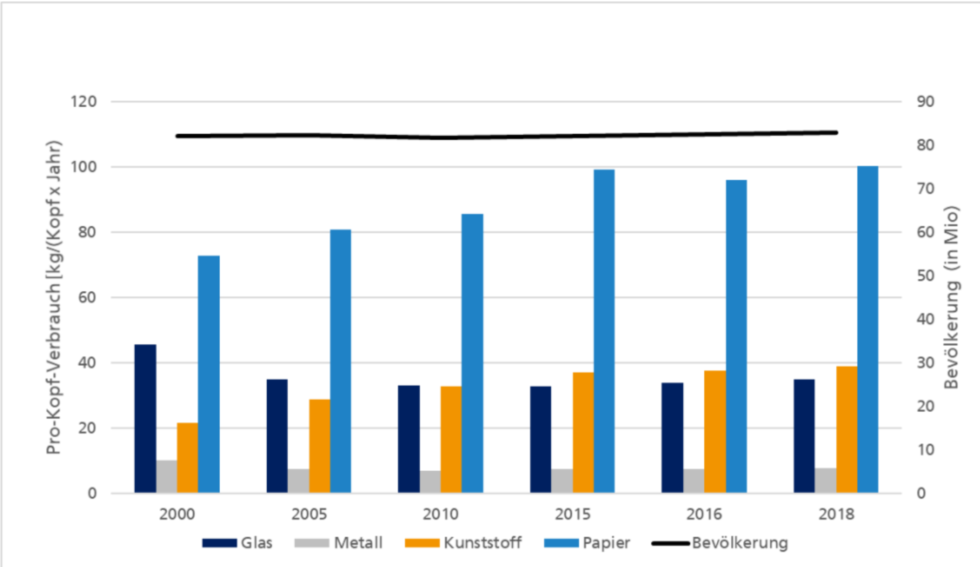
The highest growth in absolute terms is seen in paper packaging, with an increase of 27.5 kilograms per person per year, and plastics reach 17.3 kilograms per person per year. By contrast, the consumption of metals is stagnating, while glass has also been growing again since 2010 following a temporary reduction. In relative terms, plastics show the greatest growth over the 18-year period under consideration, with an annual average of 4.4 percent, ahead of paper at 2.1 percent.

The increases in plastics consumption are hardly accompanied by increased recycling. In 2019, the share of secondary materials was just 10.5 percent (Conversio 2020), while 44.4 percent of consumption corresponds to growth since 2000. That is, even assuming there were no plastic recyclates in the packaging sector in 2000, they cover less than a quarter (23.6 percent) of the growth. In contrast, the recyclate share in the paper and cardboard packaging sector has remained largely constant at around 90 percent since 2000. This means that about 90 percent of the growth in paper consumption, but not all of it, was also made

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

possible by recycling. (vdp 2015, 2021) .[13] De facto, therefore, there is no reduction in primary raw material consumption for paper and even less for plastics. The question therefore arises as to whether, in the case of plastic packaging in particular, an increased switch from single-use to reusable systems is not necessary, in addition to recycling, for an improvement in circularity and a reduction in raw material requirements.

Figure 8: Population development and consumption of packaging per person by material, Own representation based on data from the Federal Environment Agency. (Federal Environment Agency 2018)



4.6 Waste and substance legal situation

The following legislation and strategy papers from Germany and the EU are of high importance for the topic of (reusable) packaging:

- European Waste Framework Directive (WFD) (EU RL 2008/98)
- German Packaging Act (Packaging Act 2021)
- EU Packaging Directive (2018/852/EU)
- EU directive on single-use plastic articles (EU 2019/904)
- EU Action Plan for the Circular Economy (COM(2020) 98 final)
- EU Plastics Strategy (COM(2018) 28 final)
- 5-point plan of the Federal Ministry for the Environment (BMU 2018)

In it, the following measures for reducing packaging waste can be found, essentially in agreement:

- Prohibitions and quantity limits
- Recycling of used packaging
- Recycling-friendly design of packaging

13 However, since the recycled paper reuse ratio reported in the sources is not the actual recycled content in the product, it was corrected for the ratio for corrugated paper for all paper-based packaging types to allow comparison with the values for plastic recycled content.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

- Promotion of the recycled content
- Promotion of reusable
  (often also referred to as "reusable packaging").

In the German Packaging Act (Packaging Act 2021) in its initial version of 2017, §4 already called for "the reusability of packaging and the proportion of secondary raw materials in the packaging mass to be increased to the highest possible level." This is a clear signal for increasing the use of reusable packaging. This requirement is only restricted by a few exceptions, for example when it is "technically possible and economically reasonable, taking into account the guarantee of the necessary safety and hygiene of the goods to be packaged and consumer acceptance." An analogous restriction is found in the EU Packaging Directive. Here, too, it is required that "the increase in the proportion of reusable packaging placed on the market" be promoted, but "without compromising food hygiene or consumer safety." (EU 2019/904 2019). The EU directive on single-use plastic articles also wants "circular approaches that promote sustainable and non-toxic reusable articles and reuse systems over single-use articles."

According to the EU Circular Economy Action Plan, there is a call to strengthen the mandatory essential requirements for packaging on the EU market (COM(2020) 98 final). The focus is to be on, among other things, measures to reduce packaging and packaging waste and to promote design with a view to reuse and recyclability of packaging. The EU Plastics Strategy is a step towards creating a circular economy in which the design and manufacture of plastics and plastic products take full account of reuse, repair and recycling requirements and develop and promote more sustainable materials (COM(2018) 28 final). One component of the vision of a new plastics economy for Europe set out there is that by 2030 all plastic packaging placed on the EU market will be reusable or can be recycled cost-effectively. Even though it can thus be stated that reusable/reuse plays a central role in these two important EU strategy papers, it is placed on a par with recycling in them, in contradiction to the idea of the waste hierarchy.

At the end of 2018, the German Federal Ministry for the Environment presented the 5-point plan for less plastic and more recycling (BMU 2018). In it, the following priorities are formulated for Germany's path out of the throwaway society:

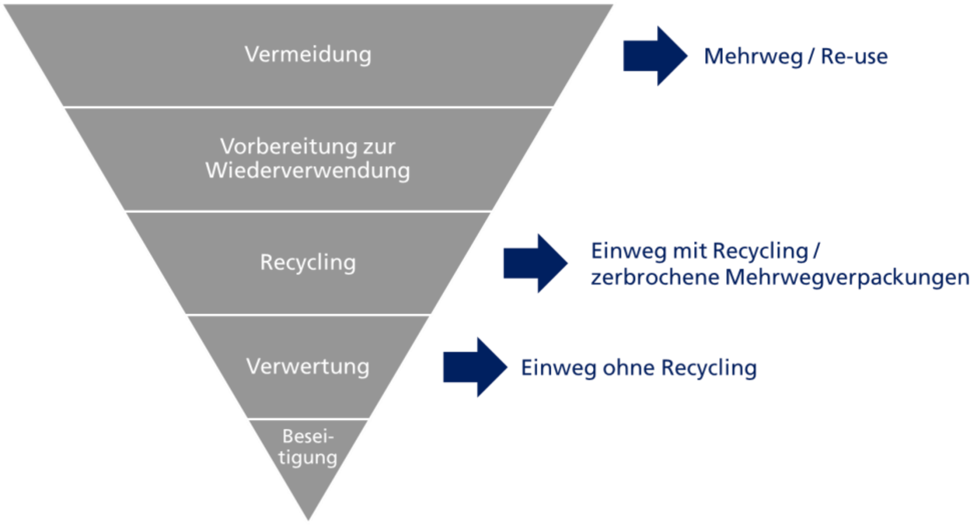
- Avoid superfluous products and packaging
- Making packaging more environmentally friendly, strengthening reusable packaging
- Promote environmentally friendly product design
- Closing material cycles through smart and high-quality recycling
- Drastically reduce inputs of plastic waste into the world's oceans

This list includes reusable packaging before recycling. In the detailed description of the focal points, however, the 5-point plan focuses solely on the applications beverage bottles and coffee-to-go cups. Other reusable systems are not mentioned.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

In summary, it can be stated that the promotion of reusable packaging is mentioned in all lists of measures for the prevention of packaging waste. It can be found in the strategy papers of the EU (on Circular Economy and on Plastics Strategy) and it can be found from there as a political objective in the German Packaging Act and the EU Packaging Directive. So far, however, there is only an example of this in the VerpackG (2021) a target quota for reusable packaging - but this is limited to beverage packaging/bottles, has only an appellative character and is not legally binding. It therefore still remains to be asked whether and how policymakers intend to promote the use of reusable packaging in the future with further concrete measures.

Figure 9: Classification of single-use and reusable materials in the waste hierarchy



Reusable packaging is not waste as long as the respective owner does not want to get rid of it. Furthermore, the reuse of products - i.e. also of packaging - counts as waste prevention. The use of reusable packaging is therefore on the highest level of the waste hierarchy and contributes directly to the conservation of resources. The subsequent stage, preparation for reuse, is linked to the beginning of waste generation. As long as the reusable packaging is cleaned or repaired by the owner himself, this stage has not yet been reached. Accordingly, the use of reusable systems, in accordance with the requirements set out in the European Waste Framework Directive (EU RL 2008/98) and the German Closed Substance Cycle (KrWG) the use of reusable systems has priority over single-use systems and their recycling or energy recovery. A deviation from the waste hierarchy is possible if this achieves the best result in terms of health and environmental protection. This concerns above all

- the emissions to be expected,
- the degree of conservation of natural resources,
- the energy to be used and
- the accumulation of pollutants.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

Technical feasibility, economic reasonableness and social consequences should also be taken into account.

The requirements for the waste hierarchy are laid down in the European Waste Framework Directive (EU RL 2008/98) and the German Closed Substance Cycle (KrWG) are formulated in the same way (KrWG 2012). If the waste hierarchy were implemented in practice, the use of reusable packaging would be the standard and deviations - especially the use of single-use packaging including its recycling - would have to be justified by appropriate evidence of improved environmental compatibility and improved health protection. However, such a strict application of the waste hierarchy does not take place today.

The concrete measures to strengthen waste prevention in the area of packaging have been sparse so far. Plastic carrier bags with a wall thickness of 15 to 50 micrometers and disposable service packaging made of polystyrene have been banned. At the same time, the waste avoidance program of the German Federal Ministry for the Environment refers to measures that are not at all to be assigned to the level of waste avoidance (Federal Ministry for the Environment (BMU) 2020). These include the obligation to take back electrical and electronic equipment, the extension of the mandatory deposit to more disposable beverage bottles and cans, and the obligation to use recycled materials for plastic beverage bottles. Also, the Packaging Act, which was amended in 2021, now requires (Packaging Act 2021) now stipulates that, from 2023, food and beverages for takeaway must also be offered in reusable packaging and that this must not be more expensive than disposable packaging. On the other hand, however, an exception is granted to smaller outlets. Here, there is only an obligation to fill reusable containers brought by consumers. If they do not have such containers with them, disposable plastic food packaging and disposable beverage cups can continue to be used. Even if the above-mentioned measures at the other levels of the waste hierarchy have their justification, they cannot disguise the poor state of incentives at the top level of the hierarchy, i.e. waste prevention.

With regard to waste prevention, reference is also made above all to extended producer responsibility. Even though this is a sensible instrument in principle, it fails to take into account the fact that reusable systems in particular require a closed-loop system across manufacturers and consumers, which would only be economically viable for a single manufacturer in exceptional cases.

Possible influence on the use of plastics in packaging and their recycling could come from the European Plastics Tax in the future. The European Union has introduced a "plastics tax" as the first step in the EU's own resources system, which has provided the Union with funds for the orderly development of its policy areas (EU, Euratom 2020/2053). This is primarily an own resource for the 2021-2027 EU budget and not a direct tax. Member States must pay contributions to the EU from their budgets based on the amount of non-recycled plastic packaging waste generated in each Member State.

From January 1, 2021, this contribution will be calculated at a uniform rate of 0.80 euros per kilogram. It will be based on Eurostat data that member states already

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

collect and transmit under existing reporting obligations - in particular the Packaging and Packaging Waste Directive and its implementing decision (EU 2019/665) - are collected and transmitted.

According to initial estimates, this new contribution for plastic packaging can provide the EU with additional revenue of 6 to 8 billion euros per year. In line with the European strategy, national contributions will be proportional to the amount of plastic packaging waste not recycled in each member state. According to initial estimates, Germany will account for around 1.3 billion euros per year. (KPMG 2021)

The plans of the new German government envisage that this European plastic tax will also be -passed on to packaging manufacturers or -distributors in Germany. (SPD, Bündnis 90/Die Grünen, FDP 2021). In other countries (Italy, Spain), the introduction of the national allocation of plastic taxes is already progressing rapidly and other EU countries are likely to follow suit. As a result, companies that manufacture or import packaging will be faced with additional costs. There is a risk that reusable systems, where packaging is transported across national borders or even across the EU internal market border in the course of individual circulations, will be burdened with these costs for each circulation. The legislators in Brussels, the EU member states and also trading partners such as Great Britain, which has also introduced a plastic tax, should make regulations here that exclude such tax payments that burden the reusable systems.

Another element to consider is EPR (Extended Producer Responsibility) fees, which could be increased to cover the plastic tax contribution. EPR fees are required to be paid by companies for the disposal of their packaging at the end of its life. The fees are used for the collection, sorting, treatment, management and recycling of packaging waste. Part of the EPR fees can be used to finance the EU plastic levy in some countries (e.g. France and Belgium). EPR fees in these, as well as other countries, could increase to finance national plastic levies. (EY 2021)

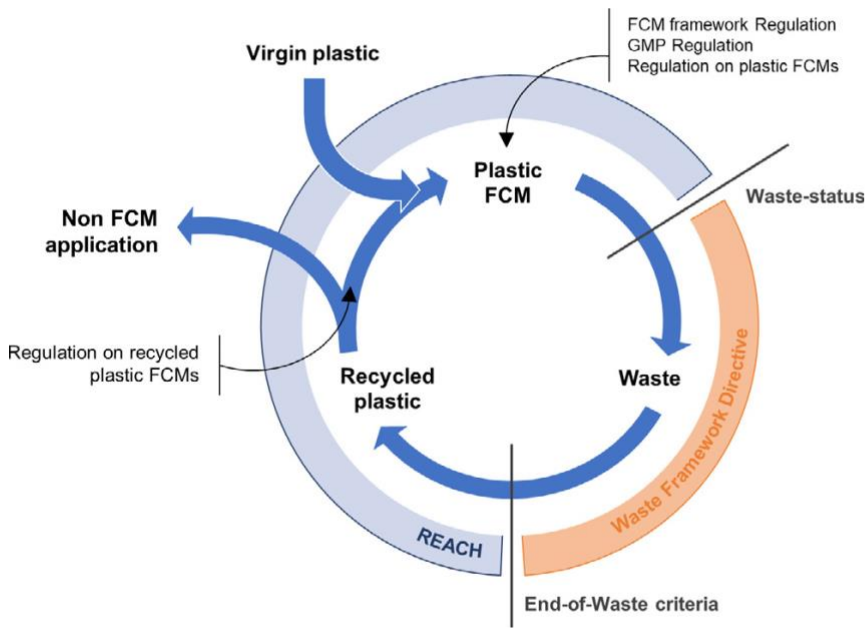
In connection with (reusable) packaging, the EU chemicals legislation (REACH - Registration, Evaluation, Authorisation and Restriction of Chemicals) must be observed with regard to the materials used, in addition to the general packaging and waste legislation (EC 1907/2006). In addition, for products that come into contact with food, regulations on food contact materials (FCM) in particular must be observed. (EC 1935/2004). This regulates the food law conformity of packaging systems of any material with regard to safety and sensory aspects. For plastic packaging, specific requirements are laid down in the European Plastics Regulation (EU). No. 10/2011 (EU) is laid down. Among other things, this contains detailed rules for determining total migration and specific migration, as well as time/temperature combinations that must be used for analytical migration tests. Low molecular weight chemicals, such as monomers and additives, have the potential to migrate from food contact articles. Migration of these must be assessed according to internationally accepted scientific principles for risk assessment (Article 19 of Regulation (EU) No. 10/2011 (EU)). Special requirements also apply in particular to recycled materials. The European Recycling Regulation

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

(EC) No. 282/2008 places great emphasis on packaging and food safety when new food contact materials are made from recycled post-consumer material.

The current status on the use of recycled plastics in FCM is presented in an article by a Belgian team (Tandt et al. 2021). The article provides an overview of the legal requirements for the use of post-consumer recycled plastics in articles placed on the EU market. It also discusses the interactions between REACH and the Waste Framework Directive (WFD - Waste Framework Directive, (EU RL 2008/98)) are discussed. A second part focuses on the use of recycled plastics as food contact materials. The scope of the various applicable EU FCM regulations is presented (see Figure 10) as well as the main related legal principles.

Figure 10:
Graphical representation of the applicability of the EU REACH and EU FCM regulations to (recycled) plastic-in-food contact materials (FCMs) throughout the value cycle (from Tandt et al. (2021))



Furthermore, the article addresses the discussion on the approval of recycling processes under the FCM Regulation and the practical challenges associated with the effective introduction of FCMs containing recycled plastics. Overall, it is found that the complexity of different regulatory perspectives, a lack of communication and transparency within the plastics value chain, and technical challenges related to recycling processes continue to severely hinder the effective uptake of FCMs made from recycled plastics (with the exception of PET bottles). The authors would like to see the development of targeted solutions for the entire value chain, taking into account the different perspectives related to legislation and health protection, economic growth and technical innovation. Only then, they say, can a circular economy for plastics, including recycled plastics for FCM, be realized. (Tandt et al. 2021)

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

4.7 Instruments for sustainable investments

The EU plans to transform the EU economy for sustainable development as part of the Green Deal agreed in 2019 (COM(2019) 640 final). A key element of this is the financing of this turnaround. To this end, new specifications have been drawn up that place sustainable investments and sustainability communication on a binding and data-based footing. Statements that are open to interpretation and greenwashing that leave it unclear whether an economic activity or investment is sustainable or not are thus to be avoided.

Three regulatory elements are of particular importance: the Sustainable Finance Disclosure Regulation (SFDR), the Corporate Sustainability Reporting Directive (CSRD), and the EU Taxonomy (ESG Enterprise)[14]. While SFDR and CSRD define the type, scope and form of disclosure and reporting obligations of financial market participants and companies, the Taxonomy Regulation provides a classification system for deciding whether and to what extent a financial activity may be described as environmentally sustainable. In addition to positive sustainability effects in a specific area (e.g. greenhouse gas reduction), a special focus is placed on the avoidance of adverse effects in other areas (e.g. freedom from pollutants). Through the EU taxonomy and the CSRD, the requirements for financial market participants and their financial products also reach the real economy. Only the real economy can develop, provide and apply the necessary technologies for which the "hard facts" are then measured or calculated, which ultimately enable a decision to be made on the sustainability performance of an investment and thus of a financial product.

The EU taxonomy (2018/852/EU) addresses the following environmental objectives:

a) Climate protection;
b) Adaptation to climate change;
(c) sustainable use and protection of water and marine resources;
d) Transition to a circular economy;
(e) pollution prevention and control;
f) Protection and restoration of biodiversity and ecosystems.

Article 13 of the EU taxonomy identifies various measures for a transition to the circular economy, such as recycling, life extension, reparability improvement, and reuse. However, the definition of the term "circular economy" in Article 2 is of particular interest for the present study (2018/852/EU):

"Circular economy [is an] economic system in which the value of products, materials, and other resources in the economy is maintained as long as possible and their efficient use in production and consumption is improved, thereby reducing the impact of their use on the environment and minimizing the

14 Explanations can be found here, for example: SFDR, NFRD, and CSRD: Guidance on EU Taxonomyhttps://www.esgenterprise.com/esg-reporting/eu-taxonomy-sfdr-nfrd-csrd/

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

generation of waste and the release of hazardous substances at all stages of their life cycle, including through the application of the waste hierarchy. "

In the last half-sentence in particular, explicit reference is made to the waste hierarchy. This is described in more detail in the present study in chap. 4.6 and it has been used as a basis for the combined model approach in chapter 4.3 as a basis.

The objectives of the Taxonomy Regulation are specified by the EU in delegated acts. So far, these have only been issued for the two criteria climate protection and adaptation to climate change. For the other environmental objectives, secondary criteria (DNSH criteria, "do no significant harm") are already taken into account in some places. The DNSH criteria are intended to ensure that a positive effect of an operational measure in one environmental objective (e.g. climate protection) is not associated with disadvantages in other environmental objectives (e.g. the transition to a circular economy). (EU 2020/852 (DV)).

An expert group on sustainable investments was established to prepare the content of the delegated acts. In particular, the recommendations for the production of plastics contained in the annex to the final report of the expert group are of interest for this study (EU Technical Expert Group on Sustainable Finance 2020). It was proposed that plastic-producing companies should ensure, as a secondary criterion, that 90 percent of the quantity produced of a type of plastic must either not be used in single-use applications or that this must be on the basis of recycled plastic. With a Germany-wide recycling rate of currently 13.7 percent and a packaging share of total consumption in Germany of approximately 26.6 percent, which can largely be regarded as single-use, this requirement would have provided a clear impetus for an increased reusable share or significantly improved recycling. Although many of the recommendations of the expert group are reflected in the delegated act on EU taxonomy that has been adopted and published in the meantime, this recommendation on the circular economy of plastics was deleted without replacement. (EU 2020/852 (DV)).

In addition to the DNSH criteria, "minimum safeguards" are specified as further secondary conditions, thus addressing minimum standards for human rights and social standards. It would be an interesting question, but not addressed in this study, whether there are differences between single-use and reusable systems.

It is necessary that the delegated regulation on the circular economy, which is still in the preparatory phase, contains more far-reaching regulations for a successful circular economy.[15] This must also take into account the fact that sustainable reusable solutions must be made economically attractive for the trading companies compared to single-use solutions. Redirecting capital flows by linking them to robust sustainability criteria, as envisaged in the taxonomy, is a suitable means of achieving this. The sensible coordination of recyclate use quotas (> 90 percent) in production and minimum circulation rates for reusable systems (> 10), as is

15 Originally, publication was planned for 31.12.2021, but this has not yet taken place by the time of publication of this study. The entire taxonomy incl. the delegated regulation on the circular economy is to be put into force by 2023.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

currently being discussed in the expert committees on the Taxonomy Regulation, seems suitable for this purpose.

5 Systems investigated and procedure

5.1 The demonstrators in this study

As a working basis for the investigations of the present study, the client, the Stiftung Initiative Mehrweg, supported by its European members, initially selected three demonstrators in consultation with the contractors on the basis of which the analyses were to take place (Figure 11). These are. [16]

- **Crate** (reusable transport crate for fruit, vegetables, bakery products, etc.)
- **Trays** for transport and handling of plants in pots
- Coffee-to-go cup (**C2G**)

While both single-use and reusable systems are established for crates, the market for plant trays has so far been the domain of single-use products. However, there are already far-reaching plans to introduce a reusable system across the board in the coming years. Both systems belong to the B2B sector, but in the case of the trays, an expansion to the B2C sector is being discussed. Reusable systems for coffee-to-go cups have been on the market for several years and are currently spreading rapidly - supported by legal requirements. They represent a pure B2C solution.

Only plastic-based variants are considered for the three reusable solutions. They are contrasted with disposable solutions, e.g., made of PPK, plastic or wood (disposable tray), plastic (disposable tray) and paper-plastic composites (disposable cups). If other material solutions are relevant for the disposable systems and a sufficient data basis exists, these were also considered. Further details on the demonstrators can be found in the subsections in Chapter 7.

16 The terms in bold are also used as abbreviations in the following.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

Figure 11: Demonstrators used in this study

5.2 Procedure - from the categories to the demonstrator profile

As already described in the preliminary remarks on the structure of the report, our analysis is presented in two dimensions. First, the selected demonstrators are each analyzed together using different evaluation categories (chap. 6). Then, the ratings for each demonstrator are combined (Chapter 7).

For the evaluation within a category, a five-level evaluation system is used. The best level in relation to the criterion is given the value +2 and color-coded dark green, the worst level is given the value -2 and color-coded dark red. Intermediate levels are coded +1 (light green), 0 (yellow) and -1 (orange). Positive values are always chosen to describe a state that the authors believe is desirable for achieving the ideal of a sustainable economy (e.g. low greenhouse gas emissions or a high recycled content).

The evaluation within a category is done with qualitative or quantitative indicators. In the case of qualitative indicators, a description is provided for each of the five levels, which allows the demonstrators to be assigned. For quantitative indicators, a specific metric is named and how the data was obtained and, if necessary, calculated is presented. Indicator values are then calculated and presented for the selected single- and multiple-use demonstrators.

There are two options for assigning indicator values to an assessment level:

a) Reference values are available which can be used to classify the levels. These can be statistical average values from industry surveys, values from analogy observations, etc. Ideally, several reference values that can be plausibly assigned to quality levels are available for a meaningful level classification.

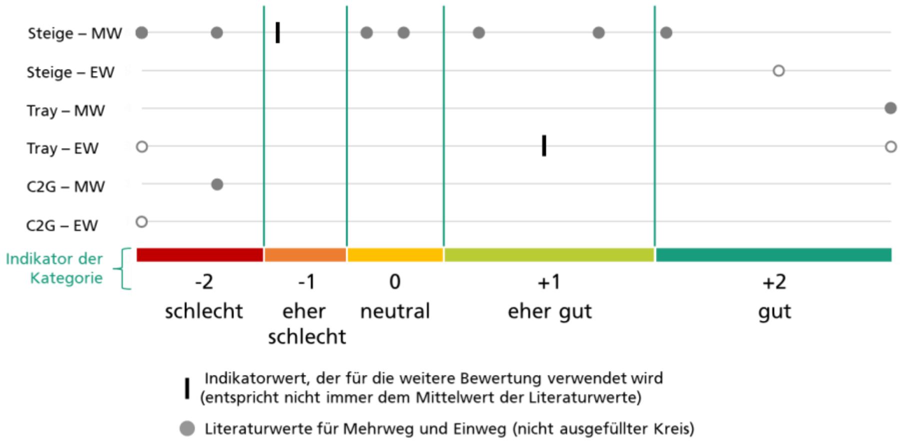
ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

b) If no or too few reference values are available, the classification of the stages is based on the range of values calculated for the demonstrators.

Case b) leads to a subjective evaluation based on value measures determined by the author team based on the range of values obtained by the selected demonstrators. Analysis of additional demonstrators could lead to changes in the future. Wherever possible, the author team has therefore given preference to method a).

The evaluation of the demonstrators within a category is summarized in a diagram (Figure 12). In the case of qualitative assessments, the levels are shown on the x-axis (as a color scale); in the case of quantitative assessments, the absolute value range of the levels is also shown. On the y-axis the demonstrators are named, as far as data were available for them. In the case of several data sets per demonstrator, these are then found in the lines belonging to the demonstrators in the diagram. If the different data sets for an individual demonstrator can be explained by known parameters, these values are additionally indicated in the diagram. If an indicator value is used for the summary evaluation of the respective demonstrator, which is not already listed as a data point, this is entered as a vertical line in addition.

Figure 12: Exemplary representation of the evaluation within a category



Compiling the results for the different demonstrators in a single diagram also allows a comparison between the very different applications. To make this comparison meaningful, we used packaging volume as a reference for material efficiency, economic efficiency, greenhouse gas emissions and cumulative energy input.[17] Unlike the mass of the product, the packaging volume leads to more robust results, since the mass of the product as a reference variable depends on the density of the product. Nevertheless, it should be taken into account that, depending on the category, there may also be good reasons for very different results between the demonstrators, which make a direct comparison difficult. For

17 For the plant trays, the volume of the plant pots to be set was used.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

example, high- and low-priced goods may be packed very differently, irrespective of the volume of the filling material.

All categories are combined into a profile for each demonstrator, which can be found in chapter 7 and is shown here as an example in Figure 13 shown here as an example. The plot provides an overview of performance in three areas: circularity, performance and sustainability. The more index values are in the green area, the better the demonstrator is. The indices of the reusable demonstrator are marked by colored cuboids, the disposable alternative is additionally drawn as a line. In this way, weaknesses and optimization potentials of the reusable solution become visible at a glance.

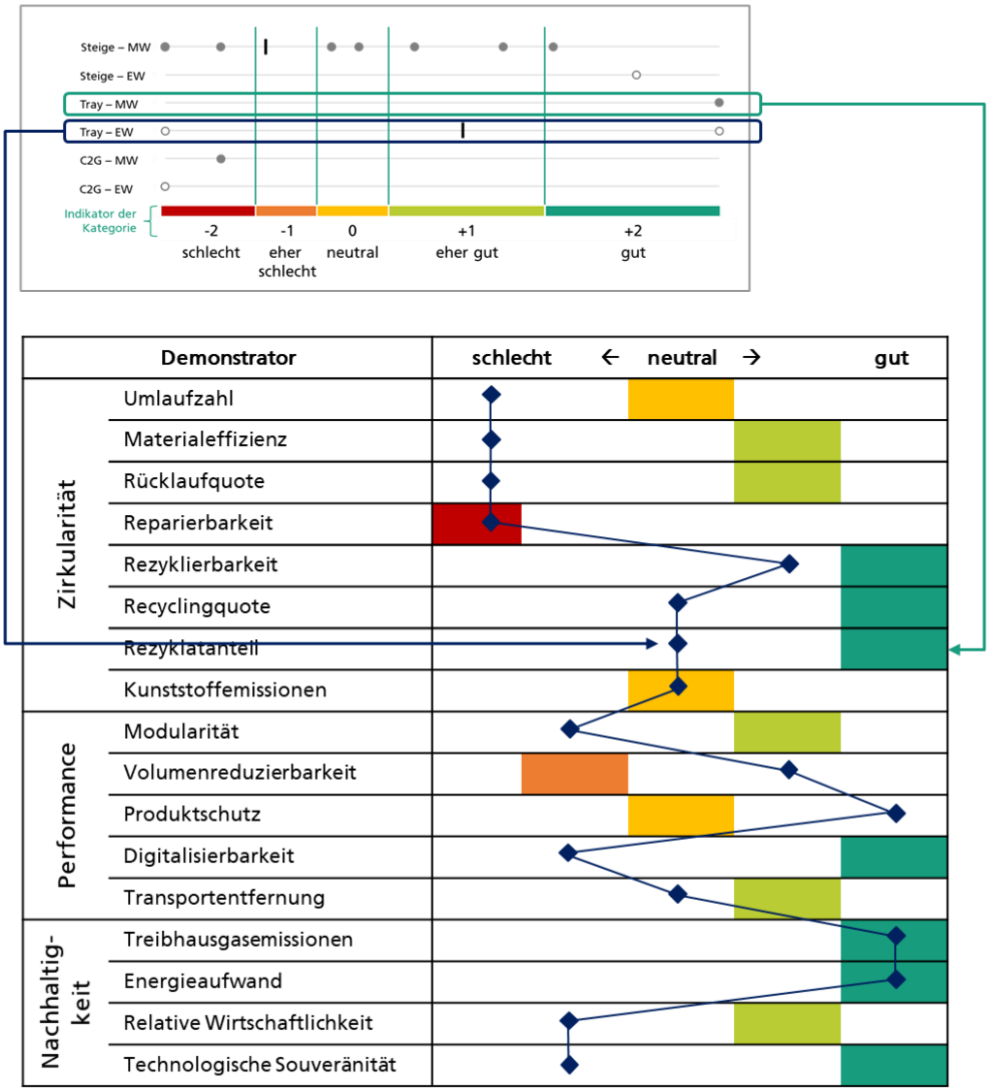


Figure 13: Evaluation principle - from the categories to the demonstrator profile

5.3 Definition of parameters: Circulation rate, loss rate, breakage rate, shrinkage.

The definition of the **circulation number** with "average[r] number of use phases of a reusable packaging material" (Detzel et al. 2016, p. 248) appears simple. Its

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

practical determination, on the other hand, is fraught with difficulties. First limitation is that it can only be specified for systems that are in a state of equilibrium. This means that there is a fixed number of packaging materials circulating in the reusable cycle.

In these established MW systems, which have reached market saturation, the amount of packaging material added corresponds to the amount of losses. The **losses are** caused by rejection and shrinkage of packaging materials. In the case of packaging materials that can no longer be repaired, they are usually **rejected and** then fed into a recycling system during inspection prior to refilling by pool operators or users. **Shrinkage is** mainly caused by removal from the cycle for final external use, theft or littering. The shrinkage that results in the loss of material from the circulation system can also be expressed by the return rate:
Shrinkage rate = 1 - return rate.

The total loss of packaging materials due to shrinkage and rejection must be compensated by newly manufactured products. From a number balance of packaging materials it follows that the number in circulation and the loss ratio per circulation are related to each other: **Number in circulation = 1/loss ratio**. If one percent of the packaging materials cannot be refilled after a circulation, regardless of whether this is due to the fact that they were not returned due to shrinkage or were rejected, the average number of packaging materials in circulation is 100. If two percent are lost, the number in circulation is 50. The number in circulation can thus be easily determined by the quantity of fresh packaging materials to be supplied to a system. As already mentioned, however, this only applies to a system which is in equilibrium, i.e. which operates with a constant number of packaging materials.

If reusable systems are still being set up or are expanding, the number of new packaging materials introduced into the system is higher than the compensation for losses. In this case - and this is the case with most returnable systems based on plastic packaging today - the number of items in circulation cannot be derived from the number of packaging materials introduced into the system. Instead, the circulation figures that can be expected in the subsequent equilibrium must be estimated from knowledge of the rejection and shrinkage rates, since their sum results in the loss rate. It should be borne in mind, however, that the values for segregation and shrinkage in systems that are still being set up are unlikely to be the same as those in established systems. Thus, on the one hand, rejection will be lower for packaging materials that are still comparatively young than after many years of operation of the reusable system. On the other hand, shrinkage due to removal for other uses will decrease over time.

The determination of the circulation figures in the context of this study was based on a comprehensive literature review and interviews with experienced persons from the operation of the example systems considered (see chap. 6.1.1).

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

5.4 Dealing with uncertainties

The statements made in this study are based on specific case studies, literature data, expert surveys and our own calculations. Where the results generalize in terms of the study's objective, namely to draw up a general comparison between plastic-based reuse systems and their single-use competitors, they must therefore be understood as provisional and subject to uncertainties. It is hardly possible for a meta-study such as this to be otherwise. To date, only a few life cycle assessments of single-use and reusable systems are available whose data basis would be suitable for metastudies. The complex and sophisticated methods used in available LCA studies should not obscure the fact that the calculations are based to a considerable extent on industry averages, expert estimates, simplifications or analogy considerations. In addition, the system boundaries and allocation rules are chosen very differently. For some of the categories we considered, we were unable to draw on any prior studies, so we conducted our own simplifying analyses. We assume that these analyses and the results obtained have been presented in a sufficiently plausible manner for readers, and as the author team we are happy to answer any questions about our approach. The uncertainties arising from the chosen approach should always be taken into account when making generalizations and drawing conclusions based on the results reported here.

We evaluated the sources for the analysis of the categories in terms of their quality, using the pedigree approach (Chapter 9.3.1). This allows literature sources and expert opinions to be subjected to a qualitative evaluation. We have thus made the uncertainties transparent. Nevertheless, in most cases, we refrain from specifying ranges when evaluating the categories, as this information would also only represent estimated values and could suggest a false sense of security.

Political decisions and frameworks are usually not legitimized for each individual case. Instead, the issue is to set the direction that is likely to make the most sense. A good example of this is the hierarchy of treatment measures laid down in the waste pyramid, which does not make sense for every application. Nor has its adherence been verified for every use case. Instead, it primarily represents a reasonable preliminary estimate worked out by the experts. Despite the uncertainties, we therefore believe that the attempt made here to provide an overall view and to derive generalized recommendations is necessary. They can be an important element in political debates on reusable and single-use packaging. Nevertheless, the data basis should be improved in the future in order to be able to make case-by-case decisions based on facts and also to enable continuous readjustment of the political framework conditions.

6 Evaluation of single-use and reusable alternatives based on selected categories

The categories used to describe the advantages and disadvantages of single-use and reusable solutions can be divided into three groups (main categories):

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

- Circularity categories,
- Performance categories and
- Sustainability categories.

The circularity categories address the cross-company aspects of a circular economy. We start from the fundamental assumption, shared by many stakeholders, that an efficient circular economy is desirable in terms of both economic efficiency and environmental sustainability and has an advantage over a linear economy. However, this assumption must ultimately translate into advantages in performance and environmental categories. The Circular Economy is therefore above all a promising solution approach, but must not be an end in itself. However, since linear economic activity in its current form is clearly not sustainable without threatening human existence, efficiency improvements are only possible to a limited extent, and comprehensive sacrifice strategies (sufficiency) are hardly feasible, the Circular Economy is probably also largely without alternative.

By performance categories, we mean above all those categories that relate to the direct impact that packaging has on the business processes of the companies using it. The sustainability categories address the effects of packaging systems in relation to the environment, society and the economy.

The selection of categories (Figure 14) was made according to relevance from the authors' point of view and data availability. It makes no claim to completeness or freedom from overlap. Nevertheless, we assume that they reflect a good section of the functions and properties that are usually associated with packaging.

Figure 14 : Categories considered in this study

The analyses within the individual categories are based on the following structure

1. Brief description of the category and its relevance
2. Proposal for an evaluation standard/indicator
3. Determination of the values for the investigated systems

In the evaluation measures and indicators used, we use both known quantities and those that are new and based on our own considerations. To enable an overall

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

assessment based on different categories, the absolute indicator values are converted into index points on a five-point scale from -2 to +2. Where possible, we have applied absolute references for indexing. In other cases, we used the values for single-use systems as the reference. A compilation of the categories per demonstrator can be found in chap. 7.

In the appendix (chapter 9.4) contains the numerical values in tables for the examined categories, supplemented by an evaluation of the data quality according to the pedigree approach (cf. chapter 9.3.1).

6.1 Circularity Categories

The circularity categories analyzed below are intended to provide information on how well a packaging material can be recycled. It is important not to equate circularity categories across the board with positive sustainability impacts. Nevertheless, in a survey conducted by the world's largest classification society for ships, see (DNV 2021), 57.5 percent of 793 companies see opportunities for improved sustainability performance in implementing a circular economy. 65.7 percent hope to achieve cost savings from a high level of circularity. In addition, implementing circular economy (CE) strategies is expected to increase brand value as well as better address customer, stakeholder and investor interests. The most important strategies for a CE are considered to be the circularization of products, the extension of product life cycles, the sharing of products (sharing), the recycling of resources, and the implementation of product-service-system concepts.

75 percent of the companies surveyed analyze the opportunities of a circular economy for their company, 33 percent want to implement at least one strategic approach to a circular economy in the next few years, 26 percent have already integrated the concept of a CE into their sustainability strategy, and 12.4 percent already see it as the core of their business model. However, the key finding of the survey is that a circular economy requires more cross-company cooperation along the supply chain, across the life cycle and even with supposed competitors than has been the case in the past.

Against this background, the Circular Economy can be seen as an important enabler for sustainable development. It will therefore be differentiated and analyzed in more detail in the following chapters in relation to the subject of this study.

6.1.1 Re-use/circulation and service life

The reuse of packaging solutions is one of the central strategies in a circular economy. It increases the useful life and frequency of products or selected individual components (Potting et al. 2017). Re-use is when the product is used again for the same purpose while retaining its design. If the product is used again for a different purpose, it is referred to as reuse. The preservation of the shape (form) distinguishes reuse and further use from recycling, in which only a new use of the (material) takes place.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

Reuse should be taken into account in the design of the packaging solution, since the closed-loop recycling of the reusable variant poses additional requirements and opportunities complementary to the actual packaging task, such as volume reduction (cf. Sect. 6.2.2) or reparability (section 6.1.4) to extend the service life. Standards developed by the industry can help here in the future.

Evaluation measure/indicator

The frequency of reuse of a packaging solution is measured with the rotations, represented as the number of rotations. In a methodological report on life cycle assessments of beverage packaging for the German Federal Environment Agency, summarize Detzel et al. (2016) summarize that "circulation figures [...] have always been a point of discussion in life cycle assessments [because] there is no binding procedure for determining them and usually no empirically supported determination of circulation figures is carried out. " (Detzel et al. 2016, S. 33)

The definition of Detzel et al. (2016), according to which the **number in circulation** is the "average number of phases of use of a reusable packaging material," as well as other related indicators, was explained in Chapter 5.3 explained.

Since reuse/repurposing is a central strategy for realizing a Circular Economy and, in addition to recycling, represents a second option for closing the loops, it is nevertheless sensible to report the number of cycles for both systems, even if the single-use systems generally perform worse here. The circulation figures for the reusable systems were determined on the basis of a comprehensive literature research and interviews with experienced persons from the operation of the demonstrators under consideration.

The following scale is used for the use of the "circulation number" indicator (Table 1). When defining the value ranges, the MW systems considered were classified as "neutral" to "good"; only those with circulation numbers of over 150 are classified as "very good". This makes it possible to reserve the scale "up" for demonstrators with higher circulations as well as for future further developments of the MW systems considered.

Table 1: Evaluation of the indicator circulation number

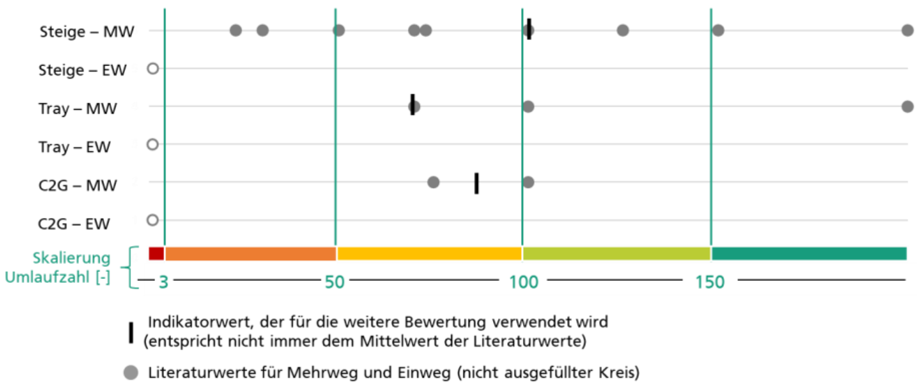
Indicator	-2 (bad)	-1 (rather bad)	0 (neutral)	+1 (rather good)	+2 (good)
Circulation number	< 3	3 to < 50	50 to < 100	100 to < 150	≥ 150

Determination of the values for the investigated systems

The following graph shows the results for the investigated reusable systems (MW) and the corresponding single-use alternatives (EW). Notes on how the values were determined are given in the text below the figure. Tables with the data used can be found in chap. 9.4.1.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

Figure 15: Comparison of circulation figures for single-use and reusable systems



Based on the circulation figures listed in chapter 9.4.1 the following indicator values for **fruit and vegetable crates** were derived. The most frequently researched/mentioned circulation figures were between 100 and 150 for MW crates. However, practical experience in recent years has shown that the maximum number of fruit and vegetable crates in circulation is 100. An indicator value of +1 is assigned here.

For **plant trays,** the value range for reusable was somewhat narrower and lower at 70 to 100. However, it must be taken into account that the reusable solution is even less established than that in the vegetable and fruit sector. A circulation rate of 70 (indicator value 0) is used for further comparison.

The market for **coffee-to-go cups is** also still under development; for example, the current RECUP cups have been in circulation since May 2017 at the earliest (Pachaly 2021). With 15 circulations per year for about 5 years, this means that 75 circulations have already been achieved. In test cycles in industrial washing machines, no defects were found in the cups after 1000 washes. A value range of 70 to 100 rotations (on average 85 rotations, indicator value 0) can therefore be regarded as realistic for the MW cups and is used in this study for further comparison. For PET returnable bottles, circulation figures of only 15 to 20 are currently achieved. (Deutsche Umwelthilfe e.V. 2020). In the future, it will have to be seen whether the high expectations for the circulation of returnable cups are justified.

6.1.2 Material efficiency and material intensity

The material requirements for packaging vary greatly. In the case of single-use systems, efforts are made to reduce the material input as much as possible in order to save costs for materials and waste disposal. Reusable packaging, on the other hand, is usually realized with a significantly higher material input in a robust design to enable many uses and a long service life. Ultimately, a fundamental objective for ecologically and economically advantageous packaging must be to minimize the material input in relation to the volume of contents per use. This tends to have a

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

favorable effect on costs, extracted resources or even the release of carbon dioxide during thermal disposal.

When evaluating material efficiency, it must be taken into account whether savings in the area of primary packaging have been achieved, if necessary, at the expense of increasing material use in secondary and tertiary packaging. For example, non-stackable primary packaging requires sufficiently stable transport packaging to ensure efficient use of transport and storage space capacities.

Evaluation measure/indicator

The material intensity, defined as the mass of the packaging in relation to the volume of the filling material and the number of uses, is used as a measure of material efficiency in this study. The lower the material intensity, the higher the material efficiency. Klooster et al. (2017) have investigated the ratio of packaging weight to product weight for a wide range of products in the food packaging sector. The range was from about 1 gram to 100 grams of packaging per kilogram of product, with only a few exceptions below or above this. The authors were unable to confirm the expectation that the ratio of packaging mass to product mass would reduce as the product mass increased. One of the reasons they gave for this was the increased stability requirements for larger packaging. Assuming that the filling goods have a density of about 1 kilogram per liter, a classification was determined for the evaluation of the material intensity according to Table 2 was defined. Even if this generic classification enables a comparison of packaging across applications, it must be pointed out that there are specific applications that require significantly different material intensities (e.g. for reasons of product protection). More detailed analyses are then required in individual cases.

Table 2: Evaluation of the indicator material intensity

Indicator	-2 (bad)	-1 (rather bad)	0 (neutral)	+1 (rather good)	+2 (good)
Material intensity [g/(L x use)]	≥ 10	3.2 to < 10	1 to < 3.2	0.32 to < 1	< 0,32

Determination of the values for the investigated systems

The following graph shows the results for the investigated reusable systems (MW) and the corresponding single-use alternatives (EW). Notes on how the values were determined are given in the text below the figure. Tables with the data used can be found in chap. 9.4.2.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

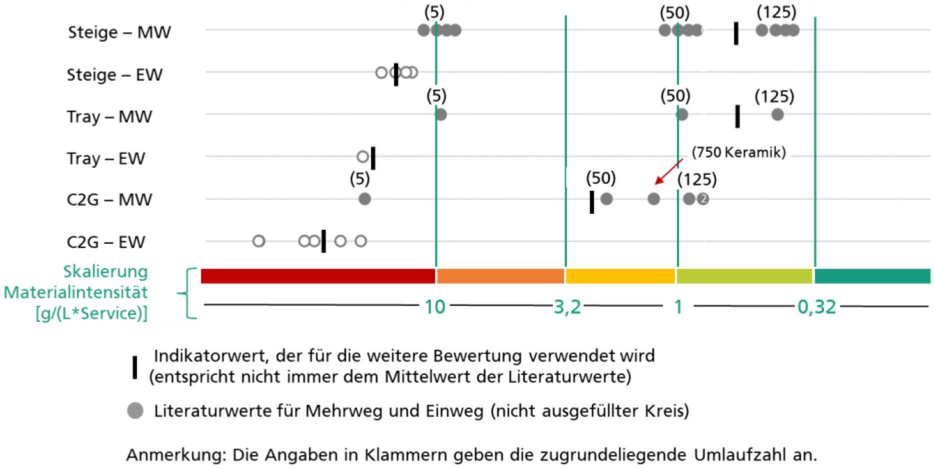


Figure 16:
Material efficiency and intensity of single-use and reusable systems in comparison

The advantages in terms of material efficiency are clearly in favor of the reusable systems in all three demonstrators. This is already evident with a low total number of items in circulation of 5. With an increase in the number of items in circulation, the material intensity drops significantly, so that reusable systems achieve a material efficiency that will hardly be achievable with single-use packaging, even if future savings potentials are exploited (thinner films, avoidance of so-called "cheating packaging").

For **multi-way** crates for O/G in B2B use, circulation rates of over 50 are common. This results in material intensities of less than 1 gram per use and liter of product (indicator value +1). **Single-use** crates, on the other hand, are well over 10 grams per use and liter of product (indicator value -2). The supposedly high weight of reusable packaging is therefore more than compensated for by the large number of uses. In addition, the material intensity of reusable packaging can be reduced not only by material savings on the packaging itself, but also by increasing the number of items in circulation (e.g. by minimizing losses, shortening the handling time, etc.).

Disposable plastic **plant trays** have been in use for a long time. Due to their better mechanical properties, they achieve a somewhat lower material intensity than disposable cardboard trays (indicator value -2). Nevertheless, they cannot compete with the (expected) material efficiency for **reusable plant trays** (assuming that at least 50 rotations are achieved, indicator value +1). Experience with existing solutions as well as design studies for future reusable systems suggest similar or even higher material intensities as for reusable trays, since there are no moving parts.

In contrast to crates and trays, coffee-to-go cups address the B2C market. Disposable solutions in particular have established themselves here in recent decades. In the future, paper cups will be the main option for disposable **coffee-to-go** cups. Due to the fact that these are increasingly double-walled and ribbed, the material intensity is comparatively high and the material efficiency low. The "vending machine cup" made of polystyrene has a somewhat lower material

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

intensity. In principle, however, the material intensity for all variants remains above 10 grams per use and liter of product (indicator value -2). Cups made of foamed polystyrene are less material-intensive due to the implementation of regulations of the EU Single-Use Plastics Directive. EU 2019/904 (2019) in the VerpackG (2021) banned since July 2021.

In the case of **coffee-to-go reusable cups,** the current suppliers rely almost without exception on polypropylene cups. The material efficiency compared to the disposable solution is given from 5 uses. Rinsing machine tests have shown that the cups can be used significantly more often; for a conservative estimate, we assume at least 50 rotations here (cf. Section 6.1.1). This results in an indicator value of 0. For very frequent use (750 times), even heavy ceramic cups exhibit good material efficiency. To date, however, there is no evidence that correspondingly frequent use is realistic.

Material intensities of 0.32 grams per package and use and thus an indicator value of +2 would be achievable for all reusable applications at significantly higher circulation rates (approx. 500). However, these do not seem feasible in practice at present.

6.1.3 Returns and material losses

Material losses hinder an efficient circular economy. The losses are not available for high-quality recycling and have to be compensated by virgin material. Material losses from a recycling system can have various causes:

- Disposal as residual waste or supply for recycling outside the closed-loop system - this includes the export of waste for recycling outside the region under consideration, in this case Germany
- Non-return due to final third-party use (collection object, building material, etc.)

In addition, littering or abrasion can also be reasons for material losses, but these are usually much smaller and are discussed separately in section 6.1.8 dealt with separately. Packaging materials that are not lost are collected and reused or recycled.

Evaluation measure/indicator

The return rate serves as an evaluation benchmark for material losses. In the case of reusable systems, the return rate is often recorded directly. For single-use systems, it is calculated from the amount of waste collected for recycling in relation to the total amount of waste awaiting disposal:

$$Rücklaufquote = \frac{Abfallmenge\ zur\ Verwertung}{Abfallmenge\ zur\ Entsorgung}$$

The amount of waste awaiting disposal can thereby be determined from the consumption quantity, corrected for export/import surpluses, production waste

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

quantities and changes, in stock. Reference values can be derived from the GVM study on packaging waste generation, which can be used to classify the ordinal scale for evaluation purposes (Pupil 2020). For this purpose, individual waste groups are analyzed below.

Consumption of plastic packaging in Germany, adjusted for imports and exports as well as production waste, amounted to 3.24 million tons in 2018. Of this quantity, 2.46 million tons are currently collected for recycling by system providers, industry solutions, single-use deposit systems, etc. (excluding energy recovery in waste incineration plants). This results in an average return rate of plastic packaging for Germany of:

$$Rücklaufquote_{Kunststoff,2018} = \frac{2{,}46\ Mt}{3{,}24\ Mt} \approx 76\ \%$$

If the proportion exported abroad (0.20 million metric tons) were deducted from the volume collected for recycling, the plastics return rate would fall to 69.8 percent. However, it is unclear whether and how much secondary materials are re-imported from abroad for plastics consumption in Germany. To simplify matters, it is assumed that these material flows are identical, so that a correction can be dispensed with.

For paper, cardboard and paperboard (PPK), the return rate amounts to (VDP - Association of German Paper Mills 2021).[18]

$$Rücklaufquote_{PPK,2018} = \frac{7{,}28\ Mt}{8{,}34\ Mt} \approx 87\ \%$$

Based on the values for plastic, response rates of below 80 percent are classified as rather low and below 70 percent as low. An acceptable response rate is derived from the current value for paper and is between 80 and 90 percent, rather high response rates are 90 to 95 percent, and we set high response rates at over 95 percent (Table 3).

Table 3: Gradation of the indicator response rate

Indicator	-2 (bad)	-1 (rather bad)	0 (neutral)	+1 (rather good)	+2 (good)
Response rate	< 70 %	70 to < 80 %	80 to < 90%	90 to < 95 %	≥ 95 %

Determination of the values for the investigated systems

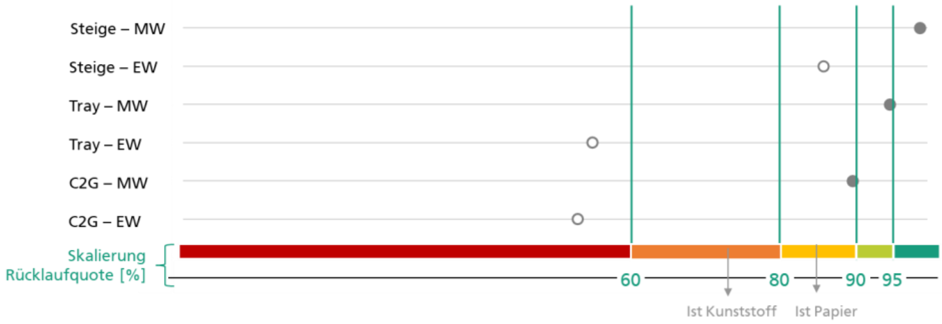
The following graph shows the results for the investigated reusable systems (MW) and the corresponding single-use alternatives (EW). Notes on how the values were

18 For PPK as a whole, the Association of German Paper Mills gives lower figures of 78%.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

determined are given in the text below the figure. Tables with the data used can be found in chap. 9.4.3.

Figure 17: Return rate of single-use and reusable systems in comparison



Multidirectional trolleys in B2B use achieve response rates of 99.2 percent (Muske 2021). This corresponds to an indicator value of +2. It is unclear where the 0.8 percent drop comes from. This is presumably due to uses outside the intended purpose, which may also only lead to longer return times.

The recycling of PPK transport packaging in the retail sector is very heterogeneous. It takes place through a large number of different companies and along very different paths. It is therefore difficult to quantify both the volume of waste generated and the quantities awaiting recycling. (Pupil 2020). The average value of 87 percent for the PPK material group is therefore assumed to be realistic for the return rate for **disposable cardboard packaging** (indicator value 0).

For **disposable trays for plant transport,** the recycling rate (tray-to-tray) is 50 percent, according to a market leader (Normpack 2021). Due to the fact that there are no mandatory collection systems for commercial waste and no explicit industry initiative has been identified for the collection of plant trays, it can be assumed that the return rate is around 55 percent (recycling share plus 5 percent rejects) and the remainder is sent for thermal waste recycling (indicator value -2).

For **reusable plant trays,** the feasible return rate also depends on whether the system is opened up to the end consumer (takeaway and return of the tray by the consumer). In this case, experience shows that high return rates can only be expected if a deposit is charged. However, experts expect that no more than 5 percent of the trays will be taken away by end consumers (Muske 2021; Oldenburg 2021).. As a result, a return rate of over 95 percent can therefore be expected (indicator value +2).

Return rates of up to 90 percent were determined for the **coffee-to-go reusable cup as** part of a study conducted at a service station operator (Pachaly 2021). As the reusable systems are still being set up and the stock volume is currently increasing significantly, return rates are not yet available at the pool operator level (indicator value 0).

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

Disposable packaging is used to 81 percent for immediate and out-of-home consumption. It can hardly be assumed that large quantities are collected separately and sent for recycling via the dual systems. In particular, a large proportion of **disposable cups** disposed of in public waste containers are probably disposed of as residual waste and are therefore no longer available for recycling. This also means that, in addition to the fee resulting from the obligation to participate in the dual systems, the disposable cups generate additional costs, since disposal as residual waste in public waste bins is financed through the waste charges (Städte-Gemeindebund Nordrhein-Westfalen 2003). Around 43 percent of disposable cups are used in the to-go sector (Kauertz et al. 2019). For the sake of simplicity, it is assumed that this proportion is not recycled via the dual systems, but is thermally disposed of as residual waste via public paper bins. If cups used for out-of-home consumption were to be disposed of in the yellow garbage can after use, the proportion of recycled disposable cups could be higher, but at the same time, disposable cups used at events and disposed of in public wastebaskets could significantly increase the non-recycled quantity. The return rate to the recycling systems for disposable cups is therefore assumed to be 57 percent (indicator value -2).

6.1.4 Repairability

Product repair is an option in reusable systems to extend service life. It is usually an option for products that consist of multiple components. Whether to consider repair is ultimately a decision between the cost of repair versus the value of the product when new. Components replaced during a repair include, for example, moving parts on risers that enable folding and thus volume reduction (e.g., levers, side panels) or codes/tags for product identification that are currently still partially affixed.

Evaluation measure/indicator

In order to be able to qualitatively assess the reparability of the packaging considered, the following scaling is used (Table 4).

Table 4: Assessment of repairability

Indicator	-2 (bad)	-1 (rather bad)	0 (neutral)	+1 (rather good)	+2 (good)
Repairability	The repair is not provided and does not take place.	The repair is scheduled, but does not take place.	Repair is not primarily provided, but takes place individually.	Repair is provided for, but rarely takes place.	The repair is standard.

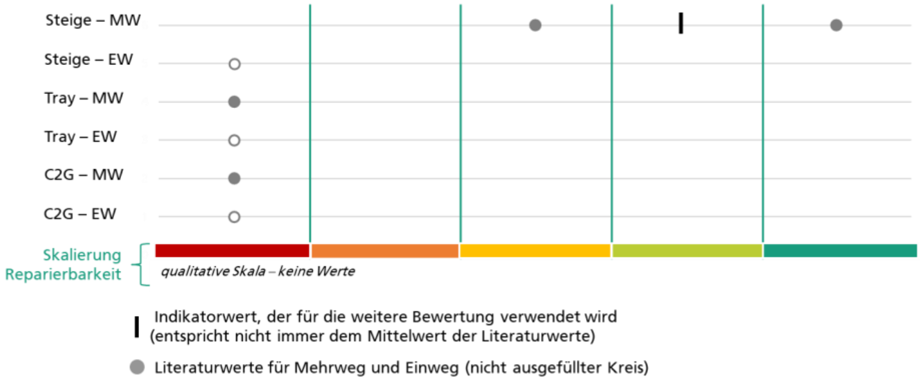
Determination of the values for the investigated systems

The following graph shows the results for the investigated reusable systems (MW) and the corresponding single-use alternatives (EW). Notes on how the values were

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

determined are given in the text below the figure. Tables with the data used can be found in chap. 9.4.4.

Figure 18:
Reparability of single-use and reusable systems in comparison



Since foldable/foldable fruit and vegetable crates require moving parts (e.g. levers, side parts), their replacement and thus repair of the crate is conceivable in principle, but is carried out differently in the respective pools, which is why both a "neutral" and "very good" reparability in Figure 18 was assigned. On average, this results in an indicator value of +1 (green dot). The reparability of disposable crates is neither intended nor given as a disposable packaging material. Therefore, the reparability is classified as "poor" (indicator value -2).

Plant trays are made of mono-material, identification options are printed/fused on and have no movable components. From today's perspective, reparability is neither envisaged nor given for both the disposable and the reusable variants ("poor", indicator value -2).

Coffee-to-go cups are made of mono-material, future identification options are planned to be printed/fused on. The cup itself has no moving components, the optional decker is a separate component purchased by the customer. Reparability is neither planned nor given today for both the disposable and reusable variants ("poor", indicator value -2).

6.1.5 Recyclability

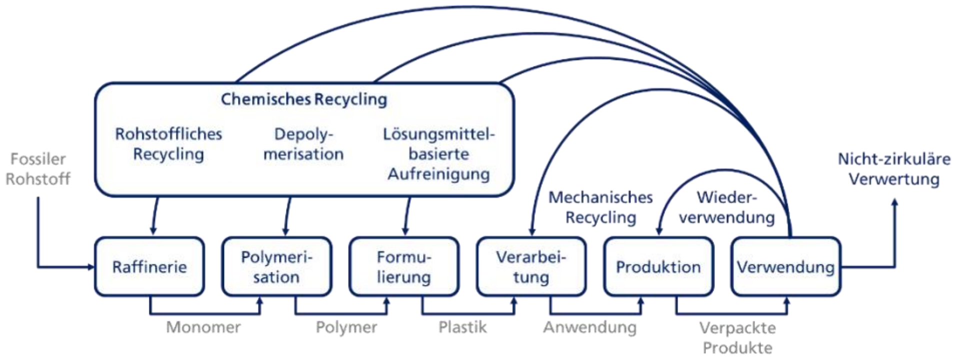
Plastics are materials that contain organic macromolecules as their main constituent. In most cases, the latter consist of a sequence of repeating basic building blocks, the monomers, and are referred to as polymers. The properties of plastics depend essentially on the structure of the polymers (linear or branched), their chain length/molecule size and the molecular attractive forces acting between the polymers. The wide variety of plastics available today is based on the large number of possible monomers, the many ways of polymerizing them and the numerous ways of mixing the polymers together. The range of material properties is further extended by the use of additives (see section 8.2). Plastics can range from soft-elastic (e.g. rubber rings) and soft-flexible (e.g. plastic bags) to hard and rigid materials (e.g. telephone housings).

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

Plastics are usually divided into two main groups depending on their behavior when heated. Those that initially soften when heated and then form a flowable polymer melt are referred to as thermoplastics. Their cohesion at lower temperatures is based on the comparatively loose interactions between the macromolecules. Duromers (also known as thermosets), on the other hand, do not soften when heated, but decompose chemically. Their cohesion is based on a crosslinking process that takes place during the manufacture of the plastic component, during which a three-dimensional network linked by covalent bonds is formed. In terms of processing and recycling, the two groups differ fundamentally: the molding of a thermoplastic is a reversible process. The material can be melted and processed again. A thermoset, on the other hand, cannot be remelted or reshaped after the component has been manufactured; when heated, the material decomposes, usually into a large number of different fragments.

Based on the manufacturing process of a plastic component or product, various recycling options are available for the reuse of its ingredients, as outlined in the figure below.

Figure 19:
Overview of different cycles for plastics in a circular economy. Modified according to IN4climate.NRW (2020).



All plastics can be used to generate energy by incineration at the end of the useful life of a component or product made from them (far right in Figure 19, "non-circular recycling"). Reuse, e.g. of reusable packaging, represents the next option, which is also applicable to all plastics. The following mechanical (or material or mechanical) recycling, i.e. the reuse of already processed or used plastics by remelting, can only be carried out with thermoplastic materials. Chemically cross-linked - i.e. thermoset or elastic - secondary materials can, in the best case, be added to a small proportion during new production. The same applies to solvent-based purification, which involves dissolving the polymers in low-molecular solvents so that they can be separated from each other and also from additives and reused. This physical dissolution process only works for non-chemically crosslinked polymers. In addition to thermoset and elastomeric polymers, electron-beam crosslinked thermoplastics, for example, cannot be completely recycled. The depolymerization of plastics to the basic building blocks is usually carried out by heating and/or the addition of chemical reagents. The process is particularly applicable to polymers linked by functional chemical groups such as polyesters, polyamides or polyurethanes. Polymethyl methacrylate (PMMA, known as Plexiglas) and polystyrene (PS) can also be used. Depolymerization is not possible for the other polyolefins (mainly PE, PP and PVC). Feedstock recycling is the recovery of low-molecular, liquid or gaseous chemicals. The decomposition process

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

required for this is caused by strong heating of the plastics and can be applied to all duromers and thermoplastics.

Thermoplastics in particular are, in principle, recyclable materials because of the basic possibility that they can be used to manufacture new products after remelting, just like metals or glass. In a comparison of recycling methods, this process is the best because of its simplicity and nearly 100 percent recovery (Meys 2020). However, the quality of the material to be remelted is of great importance. According to Pfaender (2016) mechanical recycling is "the most energy-efficient and environmentally preferred recycling method, provided there is a relatively unmixed and clean material stream. The benefits of mechanical recycling diminish as sorting and cleaning efforts increase. The ultimate goal of mechanical recycling is the replacement of virgin material with the same functionality, i.e. a closed loop should be achieved ('closed-loop')." It should be noted, however, that there are limits to repetitive use and recycling cycles (Shamsuyeva and Endres 2021). The reason for this is the influences on the polymers that lead to chemical changes due to light, UV radiation and water (use phase), oxygen (use phase and recycling) and high temperatures (especially in recycling). These changes are not reversible, but they can be - and are - controlled in the manufacture of plastics, see section 8.2 - be delayed by the use of stabilizing additives. For sufficient recyclate quality with required processing and long-term stability for the intended application, reformulation with suitable additives is often necessary. For this purpose, the entire additive field is basically available as for virgin material. Even PP from waste collections can compete with virgin material in terms of processing and thermal stability, provided such post-stabilization is carried out. The same applies to PE, e.g. bottle crates. (Pfaender 2016). The extent to which multiple recycling has an effect on material qualities (expressed, for example, in terms of tensile strength, bending stiffness and impact strength of the material) despite the addition of additives cannot be stated in general terms according to the current state of knowledge. (Shamsuyeva and Endres 2021).

Evaluation measures/indicators (Table 5)

Basic recyclability: In this study, basic recyclability is understood to mean the fundamental suitability of the plastics used in the products under consideration for the highest possible quality as well as energy- and material-efficient recycling. The assessment is evaluated using the methods available for the material at the end of its useful life. The best level of recyclability in principle (+2) is mechanical recycling, starting with largely unmixed and clean plastic products. This is followed in the downward gradation by mechanical recycling starting from mixed and/or contaminated plastic products (+1) and solvent-based recycling (0). Depolymerization (-1) and feedstock recycling (-2) are the worse recycling processes, as they involve higher energy input and material losses.

Practical recyclability: Practical recyclability assesses whether the technology required for the recycling of the materials of the demonstrator products is available for collection, sorting and processing. For the best level of practical recyclability (+2) in the context of this study, it is assumed that industrially used plants with operating experience exist and are operated in Germany. This is followed in the

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

gradation by plants used in Europe (+1) and those located outside Europe (0). If the plant technology for recycling is in industrial testing, the level (-1) is assigned and, if it is currently only being researched or has not yet been dealt with at all, (-2) is assigned.

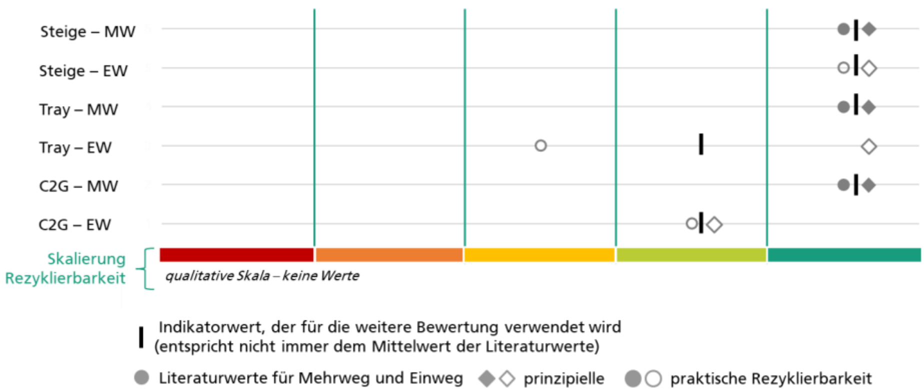
Table 5: Indicator and evaluation of basic and practical recyclability

Indicator	-2 (bad)	-1 (rather bad)	0 (neutral)	+1 (rather good)	+2 (good)
Basic recyclability (PriRe)	Duromers, elastomers, crosslinked thermoplastics contaminated thermoplastic mixtures	Polyester, Polyamide, Polyurethane, PMMA, PS	Thermoplastics, contaminated, mixed or containing undesirable additives	Thermoplastics, mixed or contaminated	Thermoplastics, largely unmixed and slightly contaminated
Practical recyclability (PraRe)	Technology is still being researched or has not even been tested yet	Technology is undergoing industrial testing	Technology is operated outside the EU on an industrial scale	Technology is operated on an industrial scale in the EU	Technology is operated on an industrial scale in DE

Determination of the values for the investigated systems

The following graph shows the results for the investigated reusable systems (MW) and the corresponding single-use alternatives (EW). Notes on how the values were determined are given in the text below the figure. Tables with the data used can be found in chap. 9.4.5.

Figure 20: Recyclability of single-use and reusable systems in comparison



All literature reviewed and also the interview partners stated that **multiway crates** for fruits and vegetables are usually made of polypropylene (PP) o high density polyethylene (HDPE). In some designs, e.g., closure systems, polymers with good slip and durability, such as polyoxymethylene (POM), are also used (Haidlmair

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

2021). Only colorants, UV and oxidation stabilizers are added to PP or HDPE; mineral fillers are hardly ever used. (Haidlmair 2021). Therefore, these plastics are very well separated from POM or other foreign materials such as polyesters or polyamides during the standard float/sink separation used in the processing of crushed crates. PP and HDPE, on the other hand, can be well separated from each other by optical sorting, usually in the infrared range (IR sorter) - if this has not already been done before shredding, e.g. by separation according to manufacturers, types or colors.

In summary, it can be stated that after reprocessing, the materials of the multiway web end up as largely unmixed and slightly contaminated thermoplastics (PP and HDPE). They are therefore readily recyclable in principle. The indicator value for "recyclability in principle" of the multiway web is +2.

All processes for crushing, cleaning, separation of impurities and remelting of the fruit and vegetable crates prepared in this way are state of the art in Germany. The indicator value for "Practical recyclability" of the multiway crates is also +2.

The material of the **disposable comparison product**, a **transport carton, can** also be recycled very well. This is due to the fact that, as a rule, the cardboard packaging from the food retail trade is collected clean and sorted by type and fed into the paper recycling process. The indicator value for "Principle recyclability" of the transport carton is +2. The process of recycling waste paper is state of the art in Germany. The indicator for "Practical recyclability" of the cartons is therefore also given the value +2.

The literature reviewed and the interviewee indicated that **reusable plant trays** are usually made of polypropylene (PP) or high-density polyethylene (HDPE). As shown above for the fruit and vegetable trays, these plastics are well recyclable in principle and they can be recycled without problems according to the state of the art in Germany. The indicator values for "Recyclability in principle" and "Practical recyclability" for reusable plant trays are +2.

The material of the **disposable plant tray** is usually polystyrene (PS). In principle, this thermoplastic is easily recyclable. However, its use in the packaging sector has been declining sharply in Germany in recent years, so that in the meantime the revision of the minimum standard for measuring the recyclability of packaging subject to system participation pursuant to Section 21 (3) of the German Packaging Act (VerpackG) only indicates a limited recycling infrastructure for PS packaging in Germany. The indicator value for "Principle recyclability" of disposable plant trays is therefore also +2. The "Practical recyclability" of disposable plant trays, on the other hand, is assessed as neutral, 0.

In the literature, polyethylene terephthalate (PET) and the bio-based plastic polylactic acid (PLA) are once mentioned as materials for **coffee-to-go returnable cups in** addition to polypropylene (PP), which is always mentioned. The interviewee, a representative of the deposit system reCup, which is widespread in Germany (Pachaly 2021), states that PP is used for the cups of this system. This material is therefore assumed to be the standard. It can be recycled well in

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

principle and can be recycled well according to the state of the art in Germany. The indicator values for "Principle recyclability" and "Practical recyclability" of the coffee-to-go returnable cups are +2.

The material of **disposable coffee-to-go cups** is usually coated cardboard. The paper fibers of this composite material can in principle be recycled. However, since the plastic coating makes paper recycling more difficult and this plastic component cannot be recycled, the indicator value for the "principle recyclability" of disposable coffee-to-go cups is slightly devalued to +1. The value for the "practical recyclability" of these cups is also set at +1. Although paper recycling is well established in Germany, many of the disposable coffee-to-go cups end up in residual waste, where they are only recycled for energy.

6.1.6 Recycling rate

Recycling rate is a category that looks at the end-of-life of products. It indicates the percentage of materials recycled at the end of the product's useful life via one of the recycling processes - mechanical or chemical recycling (cf. Figure 19, chap. 6.1.5) - remain in the material cycle. For the transfer to a five-point ordinal scale, the current situation in packaging recycling in Germany is used for classification, as described in the study "Aufkommen und Verwertung von Verpackungsabfällen in Deutschland im Jahr 2019" by the Federal Environment Agency (Burger et al. 2021). The data based on the German Packaging Act, described in Chapter 7 of the aforementioned study, is used. The mass-related share of material recycling of plastics in Germany is 51.5 percent according to (UBA 2021, Table 84). This recycling rate plus/minus about 20 percent of the value, i.e., the range from 41 to 62 percent, is set as 0 (neutral) in the scale. Down to half of the value (26 percent) is classified as -1 (rather poor), up to the recycling rate of "paper, cardboard, carton" (88 percent) as +1 (rather high). Below and above this, the levels -2 (poor) and +2 (good) follow (Table 6).

Table 6: Indicator and evaluation of the recycling rate of the demonstrator products.

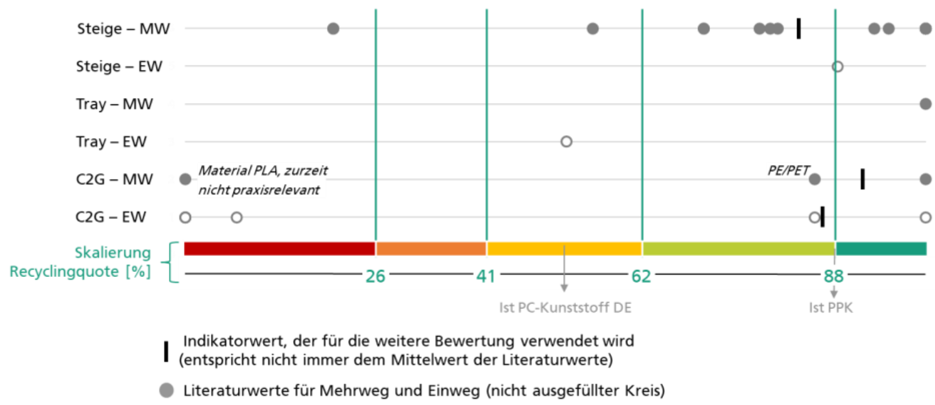
Indicator	-2 (bad)	-1 (rather bad)	0 (neutral)	+1 (rather good)	+2 (good)
Recycling rate	< 26 %	26 to < 41 %	41 to < 62 %	62 to < 88 %	≥ 88 %

Determination of the values for the investigated systems

The following graph shows the results for the investigated reusable systems (MW) and the corresponding single-use alternatives (EW). Notes on how the values were determined are given in the text below the figure. Tables with the data used can be found in chap. 9.4.6.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

Figure 21:
Recycling rate of single-use and reusable systems in comparison



The data for recycling rates in the production of **multiway crates** for fruit and vegetables from the literature and the interviews show a wide range. In contrast to the use of recycled material, data at the upper end predominate here, with a total of seven times a 100 percent recycling rate is given. The lowest value given in the literature, albeit in a 20-year-old source, is 20 percent (ADEME 2000). On average, the recycling rate is around 80 percent in the multiway stations. Thus, their indicator value for the "recycling rate" is +1.

The recycling rate of the **single-use comparative system for transport cartons** is the value for the material recycling of packaging "paper, cardboard, carton" from (UBA 2021, Table 84). It is 89 percent. This results in an indicator value for the "recycling rate" of the single-use transport carton of +2.

There is no information in the literature on the recycling rate of **reusable plant trays**, which are generally also made of polypropylene (PP) or high-density polyethylene (HDPE). In the assessment, therefore, the information from the expert interview conducted with a manufacturer is used here. (Breukers 2021)is used. According to this, the recycling rate of reusable plant trays that are no longer fit for use is 100 percent. Their "recycling rate" indicator value is therefore +2.

There is little information on the recycling rate of **disposable plant trays**. The manufacturer Normpack states the closed loop proportion as 50%. (Normpack 2022). Assuming that the used products in Germany are fed into the recycling of lightweight packaging via the dual systems, the value for the recycling of plastics of 51.5 percent can be assumed as the recycling rate (UBA 2021, Table 84). Both assumptions result in a "recycling rate" indicator value for disposable plant trays of 0.

Only one literature reference provides information on the recycling rate of **coffee-to-go reusable cups** (Cottafava et al. 2021). For the materials PE and PET, 85 percent are mentioned. For PLA, it is assumed that used cups are sent for composting, i.e. 0 percent recycling rate. According to the expert interview, the recycling rate is 100 percent. Since the information for PLA from the literature refers to a case that is not (yet) relevant in practice, it is not taken into account in the averaging. On average, therefore, a recycling rate of 92.5 percent is determined

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

for coffee-to-go returnable cups. Their indicator value "recycling rate" is therefore +2.

The material of disposable **coffee-to-go cups** is usually coated cardboard. As a first approximation, the recycling rate for these disposable cups could be assumed to be the value for the recycling of "paper, cardboard, paperboard" (PPK) of 88 percent according to (UBA 2021, Table 84). However, it should be borne in mind that presumably significantly fewer coffee-to-go cups than other PPK packaging are placed in the waste paper collection but in residual waste garbage cans. Therefore, the indicator value "recycling rate" for the C2G disposable cups is devalued by one level to +1.

6.1.7 Recycled content

The recyclate content is measured by the mass-related proportion of recyclate used in the manufacture of the demonstrator products under consideration. For the transfer to a five-level ordinal scale, a closed-loop recycling system currently regarded as particularly good[19] , that of disposable PET bottles, is used for classification. In the study "Aufkommen und Verwertung von PET-Getränkeflaschen in Deutschland 2019" (Volume and Recycling of PET Beverage Bottles in Germany 2019) by Gesellschaft für Verpackungsmarktforschung mbH, the mass-based share of recycled PET in German bottle production is 34.4 percent (Pupils 2020). This recyclate share plus/minus about 20 percent of the value, i.e., the range from 28 to 41 percent, is set as 0 (neutral) in the scale. Up to half of the value (17 percent) is classified as -1 (rather poor), and up to twice this value (69 percent) as +1 (rather good). Below and above this, the levels -2 (poor) and +2 (good) follow (Table 7).

Table 7: Indicator and evaluation of the recyclate content in the demonstrator products.

Indicator	-2 (bad)	-1 (rather bad)	0 (neutral)	+1 (rather good)	+2 (good)
Recycled content	< 17 %	17 to < 28 %	20 to < 41 %	41 to < 69%	≥ 69%

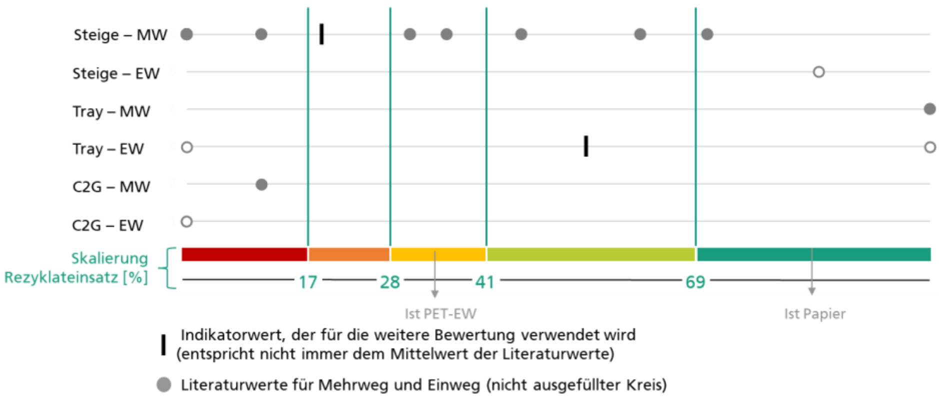
Determination of the values for the investigated systems

The following graph shows the results for the investigated reusable systems (MW) and the corresponding single-use alternatives (EW). Notes on how the values were determined are given in the text below the figure. Tables with the data used can be found in chap. 9.4.7.

19 In the sense of closing the cycle of the material to the same application with the same quality

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

Figure 22:
Comparison of recyclate content of single-use and reusable systems



All of the literature reviewed, as well as the **interviewees, indicated that multiway crates** for fruits and vegetables are usually made of polypropylene (PP) or high-density polyethylene (HDPE). The data for their recycled content show a wide range in the literature and interview data. In the literature and in the interviews, up to 70 percent recycled material is reported, but it is also often described that only virgin material is used. The latter in particular, i.e. the avoidance of any recycled material, is usually justified by the need for the products to be approved for contact with foodstuffs. On average, due to the high weighting of the zero recyclate use mentioned eight times in total, the recyclate content of the returnables is around 19 percent. This means that the indicator value for "recycled content" of the returnable crates is -1.

According to the data set "corrugated board, mixed fiber, double wall, at plant" of the LCA database Ecoinvent, the recycled content of the single-use **comparative transport carton** is 83 percent. This means that the indicator value for the recycled content of the single-use transport carton is +2.

For the recycled content of **reusable plant trays**, which are also usually made of polypropylene (PP) or high-density polyethylene (HDPE), both a value of 100 percent and a value of 0 percent are given in the literature, albeit for purely theoretical life cycle considerations (van Paassen and Scholten 2020). In the assessment, therefore, the information from the expert interview conducted with a manufacturer is used here. (Breukers 2021)is used. According to this, 100 percent recyclate is used for the production of reusable plant trays. This very high use of recyclate is favored by the fact that these products do not require approval for contact with food. The indicator value for "recycled content" of reusable plant trays is therefore +2.

The recycled content of **disposable plant trays** is given in the literature as 0 percent. However, this value should also be regarded as an assumption of an LCA calculation. In practice, disposable planter trays can be found today from individual manufacturers that already consist of 90 to 100 percent post-consumer recyclate (Pöppelmann 2021; Normpack 2022).. Nothing has been published about the share of products made from PCR in the overall market. Thus, it is not possible to obtain

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

an indication of the average recyclate use for single-use plant trays from generally available data. The indicator value for "recycled content" of disposable plant trays is therefore set as neutral (0).

The literature does not provide any information on the proportion of recycled material in **coffee-to-go returnable cups.** The assessment is therefore based on the information from the expert interview of less than 10 percent recyclate use. The indicator value for "recycled content" of coffee-to-go returnable cups is therefore -2.

The material of **disposable coffee-to-go cups** is usually coated cardboard. The paper fibers of this composite material are usually made exclusively from virgin pulp due to the required strengths and because of the food contact. The second reason is also causal for the fact that virgin material is also used for the plastic coatings. The indicator value for "recycled content" of disposable coffee-to-go cups is therefore also -2.

6.1.8 Plastic emissions

Plastic emissions in the form of littering and microplastics have been the subject of intense debate and scientific investigation for several years. Even if the effects of plastic emissions are still unclear, there is a social consensus that they should be reduced as far as possible in line with the precautionary principle. It remains questionable why the focus on emissions has so far been almost exclusively on plastics and does not also include glass, metals and modified natural materials such as impregnated wood or paper. In addition, unmodified natural substances can also be assessed as emissions, provided they enter an environmental compartment where they were not originally present or not present to this extent. It remains to be seen to what extent the debate will extend to other material groups in the future. However, the present study deals exclusively with plastic emissions in order to be compatible with the current debate.

The quantitative aspects of material losses, for example through external use or disposal as residual waste, have already been dealt with in section 6.1.3 discussed above. In addition to these "properly" occurring material losses from the reuse systems, there are also those which enter the environment as plastic emissions. However, these are likely to account for a much smaller proportion. Furthermore, it is obvious that the maximum possible plastic emissions are significantly lower in reusable systems compared to single-use systems, since material losses are already significantly lower. The causes of plastic emissions are littering (the deliberate or negligent illegal disposal of waste[20]), abrasion or fragmentation.

No empirical surveys by specific product groups are available for littering. Out-of-home products, products in environmentally open applications and products without a deposit tend to be littered more frequently. This also includes the fact that smaller packaging parts (lids or other small closure parts, etc.) can be lost, for

[20] Occasionally, littering is also separated from illegal waste disposal and classified as careless disposal of waste. However, since littering is already an administrative offense subject to a fine, we see no need for a distinction.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

example, when the packaging is opened. Littering occurs in both private and professional use. Quantifying improperly collected waste is inherently difficult. Bertling et al. (2021) give typical values of 0.03 to 1.02 percent and 0.105 percent as the most likely values, based on plastic consumption. Specific values for packaging or even by packaging type are hardly available. However, top 10 litter item lists are often published as part of clean-ups.

Abrasion and fragmentation occur both during transport and during use. To date, no empirically collected data are available on abrasion and fragmentation of disposable and reusable packaging. Fraunhofer UMSICHT has determined wear rates of 0.012 percent per year within the framework of a wear investigation of playground equipment made of plastics, which are also subject to high mechanical stress.[21] Abrasion and fragmentation are favored by material embrittlement. This takes place primarily in outdoor applications due to light exposure and frequent temperature changes (weathering).

Losses to the environment are largely unproblematic if rapid degradation can be assumed. This is generally the case for natural polymers such as paper and wood, but not so for plastics. The latter also applies to bioplastics such as polylactide, which can be composted in an industrial plant at sufficiently high temperatures and residence times, but usually do not achieve sufficient degradation rates in the environment. Composite materials made of paper and plastic should also tend to be classified as non-degradable until appropriate evidence is provided for the relevant environmental compartments (soils, freshwater, oceans, sediments).

Evaluation measure/indicator

The evaluation of the category plastic emissions takes place qualitatively. Initially, the prevention of littering and the prevention of abrasion and fragmentation are used as indicators and evaluated separately.

Littering is avoided if the packaging system is labeled, has no packaging parts that can be detached for opening, and the packaging is not used for to-go application. Abrasion and fragmentation can be reduced by low environmental toxicity (permanent outdoor use), absence of embrittlement and low mechanical stress. Degradable materials also have a favorable effect. The concrete classification of the indicator values can be Table 8 can be taken from the table below. Here, the indicator values tend to be good if plastic emissions are avoided.

Table 8 :Indicator and evaluation for the prevention of abrasion as well as the prevention of littering

Indicator	-2 (bad)	1 (rather bad)	0 (neutral)	+1 (rather good)	+2 (good)
Litter prevention	No deposit, To-go application,	No deposit, to-go application	No deposit	Deposit, off-site use/environmentally friendly	Deposit, B2B use

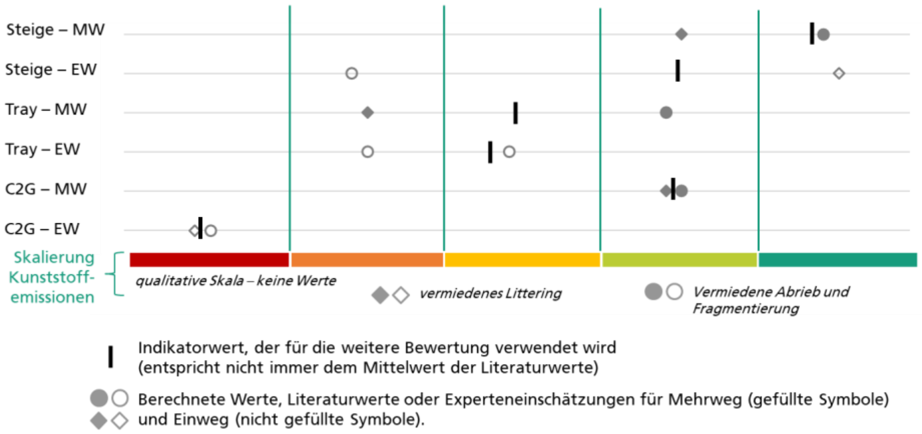
21 Internal report, unpublished.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

Indicator	-2 (bad)	1 (rather bad)	0 (neutral)	+1 (rather good)	+2 (good)
	separate packaging parts				
Avoidance of abrasion and fragmentatio n	environmentall y unfriendly, embrittlement probable, high mechanical load	(partially) environmentally friendly, with mechanical load	(partially) environmental ly friendly	Hardly environmentall y friendly application, but high mechanical load	No environmentall y friendly application, low mechanical stress

The following graphic shows the results for the reusable systems investigated and the corresponding single-use alternatives. A mean value (vertical lines) was derived from the two individual criteria, which is used for further evaluation. Detailed justifications for the evaluations are given in the text below the figure.

Figure 23: Reducing plastic emissions by avoiding littering, abrasion and fragmentation.



Multi-way crates are pawned or rented and are only used for a very short time, e.g., for off-site filling. As they are purely a B2B application, third-party use is also rather unlikely. The indicator value for avoided littering is therefore set at +2. The mechanical load of the crates is likely to be rather high, but usually does not take place environmentally openly or only occasionally. The release of microplastics through abrasion can therefore be avoided quite well (indicator value +1). Since, in the authors' view, greater weight is to be attached to littering, the indicator value was set at +2.

The **one-way** cardboard crate is non-deposited and is occasionally used externally by end consumers as transport packaging (indicator value -1). As the packaging is made of cardboard, it can be classified as very readily degradable (indicator value +2). However, it can be assumed that plastic adhesive tapes or labels are used for many disposable crates. Here, too, greater weight was attached to littering and the indicator value was set at +1.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

Reusable trays are pawned, so littering is unlikely. Occasional out-of-home use is likely for the trays. Here, damaged trays could be littered (indicator value +1). The mechanical stress on the plant trays can be assessed as particularly high due to the rather high weights of the plants, and brittleness is favored by moisture and UV radiation in outdoor applications (indicator value -1). The indicator value used further on was set to 0.

The **disposable trays**, like the reusable trays, are subject to high mechanical stresses; due to the lack of labelling, environmentally open use or storage over longer periods is possible and losses are more likely (indicator value 0). Embrittlement is also favored by the possible environmentally open uses (indicator value -1). The indicator value used in the following was set to 0.

Reusable cups have a deposit, but are used off-site, so littering cannot be completely ruled out, especially as long as the reusable cups are not recognized as such by everyone (indicator value +1), embrittlement and abrasion are unlikely to play a role, occasional fragmentation due to breakage is likely in to-go applications (indicator value +1).

As to-go packaging, unlittered **disposable cups** are a typical top-litter object that is collected in large quantities during clean-ups. The fact that the cups are usually dirty also makes it rather unlikely that they will be collected (indicator value -2). As the cups are usually made of plastic or coated with plastic, they are assessed as non-degradable but easily fragmentable (indicator value- 2).

6.2 Performance Categories

Reusable packaging is often discussed primarily in terms of its ecological advantages over single-use solutions. However, a comprehensive evaluation should also take into account the performance of packaging solutions from the perspective of the users or companies.

Significant differences result from the longer useful life of reusable packaging and its closed-loop recycling. This results in both limitations and potentials. In particular, it should be emphasized that today's product world is primarily adapted to the flexibility and variety of single-use packaging. If product designers were to adapt their product development more closely to existing or yet-to-be-developed reusable systems, further gains in performance could be achieved.

In connection with the industrial use of disposable or reusable packaging, a large number of processes take place: the filling of the packaging at the producer of the filling material, transport processes for full containers and empties, conditioning in ripening facilities if necessary, storage and sales processes in wholesale and retail, and especially in the case of reusable packaging, its washing and sanitizing, and storage at a pool operator if necessary. All these processes must be carried out as optimally as possible in terms of costs, social and ecological effects. The extent to which corresponding optimization is possible also depends on the packaging system itself.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

6.2.1 Space requirements and modularity

For producers and caterers, it is relevant how much storage/buffer space they have to keep available for clean empty containers. On the one hand, this is determined by the need-based delivery (just in time) of reusable containers or the purchase of disposable containers, and on the other hand by their space requirements and demands. The space requirements of empty containers can be significantly reduced by their foldability (collapsibility) or nestability (i.e. the ability to stack them inside one another by means of a conical shape).

The more standardized (and thus the less individual) a transport packaging is in terms of the logistics chain, i.e. compatibility with load carriers such as the Euro pallet or the CC container, nesting/stacking or folding/folding of empty and full containers, identification of individual containers, etc., the better logistics service providers can design their partly automated processes. the better logistics service providers can design their partly automated processes. The same applies to washing and hygiene centers, sorting and inventory management between customers within a reusable pool and, in some cases, for filling with goods to be transported.

Standardized transport packaging also supports retail processes, including picking for the final retail stage, by reducing repackaging operations, or when placed in retail outlets on tables, on shelves, or in separate displays ("shelf-ready packaging").

During product development of the transport containers (e.g. fruit and vegetable trays, plant trays), the partly specific requirements of the goods to be packaged must also be taken into account for optimized processes. This includes, for example, the ripening process of fruits and vegetables and the air circulation during transport and in ripening chambers (slots/recesses in the outer walls/edges, distance between stacked containers) to be ensured by intelligent product design. Furthermore, the size of the product influences the dimensions of the transport containers, which can be adjusted, for example, by using different heights for the same base area (crates) or by intelligently and robustly fixing different plant pots. In the case of coffee-to-go cups, heat transport through the cup wall and tight sealing with a lid, which may be purchased separately, at the filling location are of great importance.

Assessment indicator modularity

The compatibility of transport packaging with load carriers such as the Euro pallet or the CC container is represented by their modularity. The basic dimension, the so-called area module, of a Euro pallet is 600 mm x 400 mm. The multi-modules or sub-modules derived from this are shown in the following table. Table 9 shown below (Behrens et al. 2018).

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

Table 9: Modularity of Euro pallets (Behrens et al. 2018) S. 256

Modulus of area [mm]	600 x 400
Multimodule [mm]	1200 x 800, 800 x 600
Undersizes [mm]	400 x 300, 300 x 200, 400 x 200, 400 x 150, 300 x 100

If a high degree of modularity of the respective transport packaging has become established in the market, its stackability on the respective load carrier is also improved. This is because the more homogeneously modular units are positioned on top of one another, the more stable and ultimately safer their subsequent handling and transport and the lower the breakage rate of the transport packaging (see also explanations on product protection in section 6.2.3). (Lange et al. 2013)

In order to be able to qualitatively assess the modularity of the transport packaging considered, the following scaling (Table 10) is used.

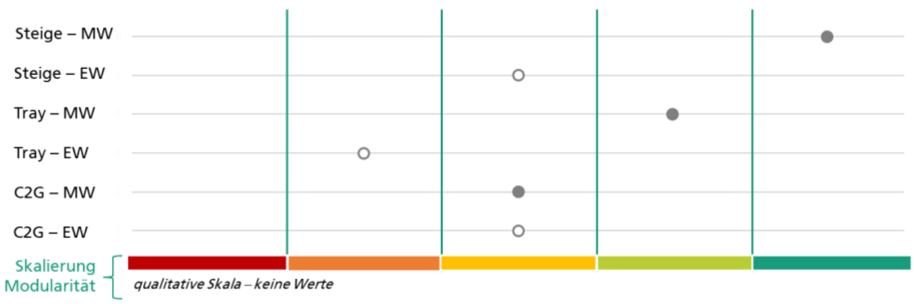
Table 10: Evaluation of modularity for business process optimization.

Indicator	-2 (bad)	-1 (rather bad)	0 (neutral)	+1 (rather good)	+2 (good)
Modularity	mainly individual dimensions	little uniform dimensions	Modularity irrelevant or relevance recognized, but not present	Standard modules introduced, business process optimization possible based on them	Recognized standard modules widely used, TV based on them in use

Determination of the values for the investigated systems

The following graph shows the results for the investigated reusable systems (MW) and the corresponding single-use alternatives (EW). Notes on how the values were determined are given in the text below the figure. Tables with the data used can be found in chap. 9.4.8.

Figure 24: Modularity of single-use and reusable systems in comparison



ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

Fruit and vegetable crates: Fruits and vegetables in EW and MW transport containers are mainly transported on Euro pallets (1200 mm x 800 mm) in the first distribution stage (growers to the central retail warehouse); industrial pallets (1200 mm x 1000 mm) are also used to a small extent, e.g. in sea freight. In the second distribution stage to the store, the transport containers are further stacked on Euro or half pallets, roll containers or roll carts (dolly) (815 mm x 670 mm).

While the automotive industry has an industry standard for small load carriers (KLT) (German Association of the Automotive Industry (VDA) 2018) exists, there are currently no standards or norms for fruit and vegetable crates that would specify area dimensions (Lammers 2021). Rather, the current surface dimensions of MW solutions have evolved as a result of the market itself (Kellerer 2021). For the main players IFCO, EPS and WBG Pooling the surface dimensions of the crates are mostly 600 mm x 400 mm or 400 mm x 300 mm (see also Table 19), which are sub-modules of the Euro pallet size. Overall, the indicator value for multiway crates can be rated as "good" (+2).

In the disposable transport crate market, uniform area dimensions have also developed over time. These are, for example, the previously mentioned area measure of 600 mm x 400 mm, which is used in various studies on environmental impacts (cf. (Albrecht et al. 2013; Del Borghi et al. 2020; Franklin Associates 2016)) or the 400 mm x 500 mm surface area of the banana crate, which is based on the industrial pallet. However, there are also many individual solutions which have different surface dimensions. (Franklin Associates 2016). Unfortunately, the authors of the study do not have any statistical data on the dimensions of disposable solutions. For this reason, the indicator value "neutral" is used for the modularity of one-way crates.

In the plant supply chain with **reusable plant trays,** CC containers are used in addition to the Euro pallet. While food retailers tend to favor pallets, garden centers and DIY stores prefer CC containers for plant distribution. A CC board has the area dimension of 1270 mm x 545 mm (inside) (Container Centralen GmbH 2018)which will lead to different area modules for a future MW solution compared to the Euro pallet (1200 mm x 800 mm). From the point of view of a uniform area dimension, it is disadvantageous to stick to the parallel distribution paths for plant trays by means of pallets and CC containers.

A modularity comparable to the Euro pallet for CC container boards could only be identified during the research for the MW solution "Palettino". (Breukers 2021): Here, the area dimension 390 x 275 mm (Euro pallet) as well as 530 mm x 300 to 315 mm (CC board, so-called Dane dimension) is listed (HAWITA Technoplant 2021).

As part of the "Flowertray" project, a European reusable solution for a plant tray is to be developed (Weschnowsky 2021). The decision as to whether the surface module of a future standardized plant tray will be based on the Euro pallet or the CC container board seems to have been made in the "Flowertray" project in favor of the CC container (Oldenburg 2021). For this reason, modularity was rated "rather good" (+1). In the disposable segment, according to BaumarktManager

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

(2021) currently around 55 different tray sizes (surface dimensions), which is why modularity was assessed as "rather poor" (-1).

Modularity is used as an evaluation criterion in this study, particularly for transport packaging. Since coffee-to-go cups are product packaging, their standardization may be relevant for the filler (e.g. with regard to compatibility in the dishwasher), but not for the logistics chain. For this reason, the "modularity" indicator for the coffee-to-go cup in MW and EW versions is set to 0 (i.e. irrelevant).

6.2.2 Volume reducibility

The reduction of empty capacities, whether during transport or storage, enables greater economic efficiency as well as a reduction in energy requirements and the associated environmental impacts, for example greenhouse gas emissions. Even though the latter aspects are discussed in separate chapters below, the authors have decided to elaborate this category separately and to evaluate the possibilities of volume reduction of single-use as well as reusable solutions in a differentiated manner.

Volume reduction can take place at different points in the utilization cycle:

(a) Foldability/foldability of the packaging: When empty, the packaging can be folded or unfolded and prepared for filling by means of at best simple handles (e.g. crates). In this case, the volume reduction is non-destructive.
(b) Nestability of the packaging: As empties, it is possible to stack the packaging inside each other due to its conical shape (e.g. cups, pots, rigid boxes, plant trays). Volume reduction in this case is also non-destructive.
(c) Compressibility during the disposal phase: If rejected packaging is to be sent for disposal/recycling, its material can be compressed by waste pressing. In this case, the volume reduction is not non-destructive. Alternatively, the foldability/foldability of rejected crates also plays a role here.

Evaluation indicator Volume reduction factor

The volume reduction factor, which represents the ratio of the volume of the full packaging (unfolded, not nested, not compressed) to the volume of the compressed empty packaging (Table 11).

Table 11: Evaluation of volume reducibility for business process optimization.

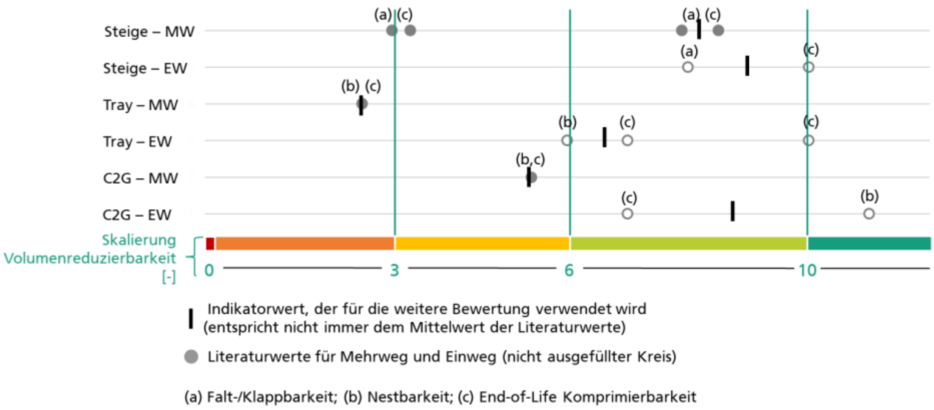
Indicator	-2 (bad)	-1 (rather bad)	0 (neutral)	+1 (rather good)	+2 (good)
Volume reducibility [-]	0	< 3	3 to < 6	6 to < 10	≥ 10

Determination of the values for the investigated systems

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

The following graph shows the results for the investigated reusable systems (MW) and the corresponding single-use alternatives (EW). Notes on how the values were determined are given in the text below the figure. Tables with the data used can be found in chap. 9.4.9.

Figure 25: Volume reducibility of single-use and reusable systems in comparison



For the **fruit and vegetable crates,** foldability is a relevant performance category. The fruit boxes, for example, are delivered flat, which was estimated by a factor of 8 for the banana crate. Only at the grower or packing stations are they unfolded and glued immediately before filling. After use, they can again be compressed to an even higher reduction level by means of PPK waste presses. The indicator value +1 is assigned.

In the reusable version, the side panels can usually be folded in. Volume reduction factors of approx. 3 to 8 can be achieved. The range results from the different heights of the folded-up crates, but the same height when folded. For the comparison with a disposable banana crate, the larger value is selected for a high multi-way crate and thus the indicator value +1 is assigned.

Plant trays can be stacked inside each other when empty. The nestability varies depending on the design of the trays. Since no detailed figures are published on this, the volume reduction factor was estimated: For EW trays, the stack height was measured on the basis of photos and a volume reduction factor of approx. 6 was determined. Furthermore, photos with stacked MW trays on a CC container have been evaluated. 80 stacked trays had a height of approx. 1900 millimeters, i.e. 23.75 millimeters per nested tray. According to internet data, TEKU® trays have a height of 62 mm, resulting in a volume reduction factor of approx. 2.6 (62 mm / 23.75 mm = 2.6). (Pöppelmann 2021).

After use, plant trays can also be compacted, although no published data could be researched on this. Therefore, a similarly good compaction of EW trays as cardboard crates was assumed. Since presses are not available at all trade levels, but trays are collected loose, a range of 4 to 10 is used. Since MW trays are more stable than the EW variant, it is assumed that their degree of volume reduction is significantly lower. This is conservatively equated with nestability and also

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

estimated at 2.6 for the disposal phase. In summary, the indicator value +1 is used for disposable plant trays and the indicator value -1 for reusable plant trays.

The volume reduction factor for **coffee-to-go cups** was again measured using two specimens. The 0.3 liter RECUP cup has a height of 100 millimeters, and each nested cup contributes 15 millimeters to a stack. The cups are usually supplied in boxes in a stack of 25, so in a stack of 25, each cup contributes an average of 18.4 millimeters. With a cup height of 100 millimeters, this results in a volume reduction factor of 5.4. For a disposable cup, it is assumed that the rim is smaller (assumption: 5 millimeters per nested cup). With the same cup height of 100 millimeters, the average nested cup height (stack of 25) is 8.8 millimeters, resulting in a volume reduction factor of 11.4.

In the disposal phase, the same volume reduction factor of 5.4 is again assumed for the reusable cup, since at the filling site the discarded cups are returned stacked one inside the other. At best, the EW cups end up in the household waste or public wastebaskets, where they are usually collected loose, pressed together manually. In the disposal vehicle, they can then be compacted again as mixed waste. Here, a volume reduction factor of approx. 4 is used for comparison.

Thus, mean indicator values of 0 (reusable) and +1 (disposable) are assigned for coffee-to-go cups.

6.2.3 Product protection

One of the essential tasks of packaging is to protect the product it contains. To this end, the packaging must be robustly designed to withstand the stresses of handling, storage and transport, while at the same time taking into account the specific requirements on the part of the product by means of an adapted design.

In the case of certain packaging, such as coffee-to-go cups, it is not only product protection that must be taken into account, but also the safety of users with regard to scalding.

Evaluation measure breakage rate

The breakage rate of packaging during transport and handling is suitable as an assessment criterion for product protection or protection of the persons using the packaging. It should be borne in mind here that damaged packaging is not associated 1:1 with product loss; the latter may be lower, see the explanations on fruit and vegetable crates later in the text. It should also be noted at this point that, with regard to product protection, only the breakage rate during full container transport and handling is relevant.
and- handling is relevant. The breakage rates (Table 12) listed here therefore do not refer to the empties processes during distribution, cleaning and redistribution, for example.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

Table 12: Evaluation of product protection using the breakage rate indicator

Indicator	-2 (bad)	-1 (rather bad)	0 (neutral)	+1 (rather good)	+2 (good)
Breakage rate	> 3 %	3 to > 1 %	1 to > 0.1 %	0.1 to < 0.01 %	≤ 0,01 %

The classification in the table is based on studies of breakage rates of (Lange et al. 2013) on crates (see below). No data are available for the plant tray and coffee-to-go cup demonstrators, which is why the following presentation is qualitative for all three demonstrators.

Determination of the values for the investigated systems

The following graph shows the results for the investigated reusable systems (MW) and the corresponding single-use alternatives (EW). Notes on how the values were determined are given in the text below the figure. Tables with the data used can be found in chap. 9.4.10.

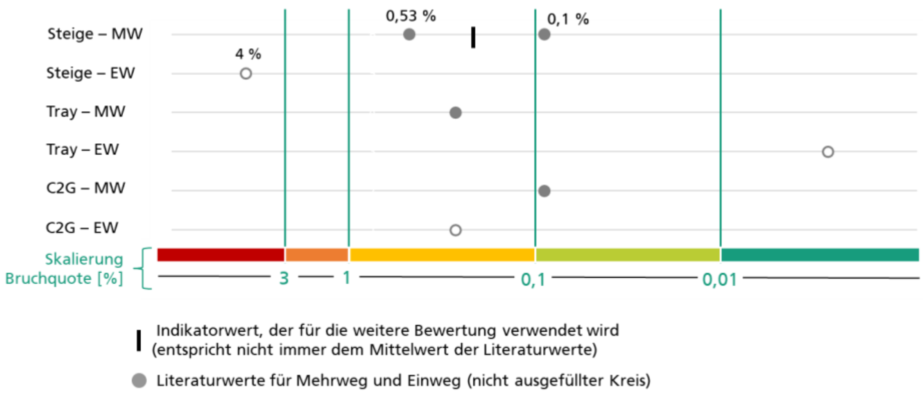
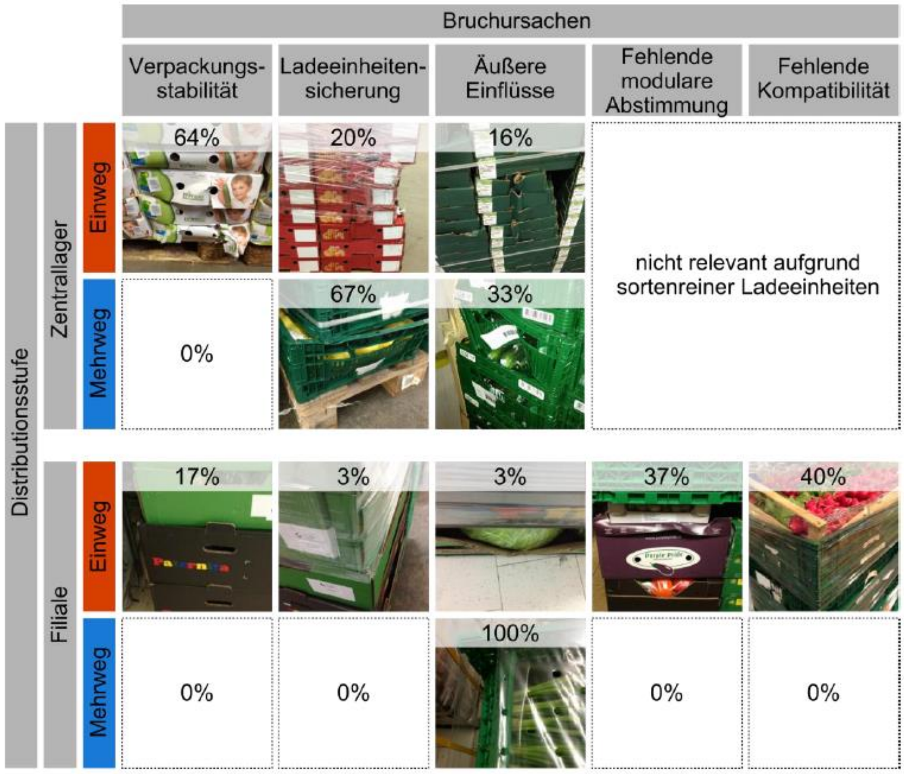


Figure 26: Breakage rate of single-use and reusable systems in comparison

In the case of fruit and vegetable sticks, five main causes of packaging damage are identified in the literature (Lange et al. 2013). One is the lack of stability of the respective transport packaging. The strength of cardboard/cardboard, for example, is adversely affected by moisture entering during transport and handling (Lange et al. 2013). In addition, the stability depends on the stacking height of the crates on the pallet. Another factor is inadequate securing of the load unit, which is generally ensured by shrink-wrap film or strapping bands on the pallet. During handling, additional external influences can cause damage to the packaging and thus to the products, e.g. by forklift trucks when loading and unloading the pallets. (Lange et al. 2013). Finally, the lack of modular coordination of the packaging and a lack of compatibility are cited as causes of damage, which have already been discussed in section 6.2.1 section. The following are results of the study by Lange et al. (2013) which have estimated the proportion to which the various causes contribute to packaging breakages at the respective distribution stages.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

Figure 27: Comparison of the causes of breakage from the "Safefood" study. (Lange et al. 2013)



Concrete figures on breakage rates and resulting product losses have hardly been published. Qualitatively, the breakage rates of reusable solutions are considered to be lower compared to single-use solutions. For example, it was stated that the rigid walls of the MW crates enable better stackability and offer better protection in the event of impacts. (Lange et al. 2013)

According to the "Safefood" study by Fraunhofer IML, the average breakage rate of multi-way crates (approx. 0.1 percent) is not attributable to the packaging solution itself, but to the (possibly inadequately selected or executed) load unit securing and external influences. In the case of one-way crates, on the other hand, the material (in combination with moisture ingress) as well as the variety and, at the same time, low modular coordination/compatibility are responsible for a large proportion of the breakage events. The data were collected separately at the respective distribution levels of central warehouse and store. (Lange et al. 2013)

A Fraunhofer IBP study on fruit and vegetable crates uses a higher breakage rate of 0.53 percent per rotation on average, which is based on primary data collections from Euro Pool Systems and IFCO (Krieg et al. 2018).

Not every breakage of a fruit or vegetable crate is accompanied by a complete loss of product, but requires additional handling steps such as breaking up the original pallet, removing the damaged crate, sorting out the spoiled product, and repacking the remaining goods and the undamaged crates. The extent to which these additional product preservation steps are performed in the central warehouses and

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

stores is not reported in the available studies. The "Safefood" study quantifies the percentage of impaired product quality in the damaged crates as approximately 40 percent (EW) or 22 percent (MW) in the central warehouse and 20 percent (EW) or 0 percent (MW) in the stores. (Lange et al. 2013)

For this study, the indicator values are assigned to "neutral" (0) for the multi-use paths and "poor" (-2) for the one-way paths.

In the case of plant trays, product protection relates in particular to the safe standing (stability) of the plant pots in the trays along the supply chain from plant producer to retailer to store (possibly to end customer). Information in this regard could not be found in the literature. However, it was emphasized in the interviews that future reusable solutions must also achieve the very good stability that is realized today in the individual solutions for disposable trays. (Breukers 2021)

To enable a uniform visualization for all three demonstrators, a separate estimate was made for a first indicator value. Here, the best indicator value "good" (+2) was assigned for disposables, which is also to be seen as the target mark for reusables. However, as this is not yet considered to have been achieved today, it is assessed with the indicator value "neutral" (0) in the study.

Coffee-to-go cups: For business-to-consumer packaging, there is the methodological problem that the "breakage rate" indicator for reusable cups refers to the (proportionate) successful closure of the loop, although the data situation is not yet satisfactory. Thus published Pladerer et al. (2008) for example, for the use of reusable cups in German soccer stadiums (Bundesliga operations) breakage rates averaging 0.93 percent (with a minimum of 0.46 percent at Werder Bremen and a maximum of 1.68 percent at VfB Stuttgart).

The "breakage rate" indicator refers less to the proportion of cups which, after filling with the product, lead to product loss or endanger consumers until consumption. With this demon strator, the "breakage rate" would thus be understood more in a broader sense as the proportion of "safe consumption": influenced, for example, by the rigidity and thus safer portability of the cup as well as (optionally) closability of the cup with a lid or heat transfer through the cup wall.

Data usable for this study could not be identified for coffee-to-go cups either. Therefore, an own estimation was made for a first indicator value, in which reusable is rated slightly better than disposable ("neutral") with "rather good" (+1).

6.2.4 Digitization rability

Digitalization does not stop at the packaging industry either (Valtokari 2021). At the packaging level, barcodes (visual codes such as barcodes, QR codes, Data Matrix codes, etc.) and recycling codes are already in universal use. The codes are read via camera scanners and allow the identification of packaging and item types down to individual objects. Combined with cloud data, any properties can be temporarily or permanently assigned to the products and packaging. Furthermore, tracking of packaging along the transport routes and over the entire life cycle is also possible.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

In addition to visible QR and barcodes, digital watermarks are also currently being developed. The corresponding project is called "Holy Grail 2.0". (Schröer 2020). These digital watermarks are to be realized as largely invisible printed or embossed markings. They are applied over the entire packaging so that even packaging parts or fragments remain clearly identifiable. They should enable improved sortability and thus achieve an innovative leap in recycling. Ultimately, however, practical recyclability depends on a whole range of variables, including impurities, separability of composites, the achievement of critical volume flows and also the presence of the necessary plant technology. This is taken into account, for example, in the minimum standard for recyclability (see also section 6.1.5) (Federal Environment Agency 2021).

In addition to QR and barcodes, radio technologies such as RFID (radio-frequency identification, radio tags with chip) are also used. In addition to RFID, there are also alternative technologies based on Wi-Fi, Bluetooth (ibeacon) or ultra-wide band (UWB), but so far they have only limited relevance. In RFID systems, there are passive and active solutions (with battery). They consist of a transponder on the object to be tracked and permanently installed readers along the transport route to enable reading and tracking. Chips of the transponders are single or multiple writable. The advantages of radio tags over barcode technology are that data can be recorded without visual contact due to the wireless radio technology, the good resistance to environmental influences provided by embedding in the packaging material, and the fast and simultaneous recording of several objects ("bulk recording").

In addition to optical markings and radio tags, which are primarily used for identification and tracking, there are numerous other elements with which packaging can be equipped. This starts with simple active elements such as suction inserts (e.g. in meat packaging), desiccant bags, packaging under protective gas or the integration of oxygen absorbers, e.g. in bottle caps, to prevent oxidation of the product. Moreover, intelligent elements in packaging systems do not act exclusively on the product, but also provide information for the outside world, from which an additional benefit results. The technical basis for intelligent equipment is provided by sensors for temperature, position, humidity and pulse, coupled with radio technologies to relay the data collected. The sensors can be used to ensure monitoring of condition, proper transport and storage. Loudspeakers, LEDs and displays are used as interfaces. The latter compete with multi-purpose terminals such as cell phones, tablets, smartwatches or individual mobile computers (handhelds), which serve as readers in the sense of "extended packaging" while providing access to external data sources in clouds. The external content can include product information (specifications, batch number), status information (shelf life, location) as well as other information such as operating instructions, recipes, supplementary offers, pollutant content, ecological footprints, etc.

The price of the components is often decisive for the type and scope of the digital equipment of a package. While barcodes, for example, cost less than 1 cent per unit, the prices for passive RFID tags start at 5 cents per unit and for active RFID at

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

25 euros per unit, possibly considerably more for particularly durable types. (RFID journal o. J.)

RFID tags and sensors applied to packaging have a negative impact on recycling according to current knowledge. To avoid contamination of the secondary material and dissipative losses of metallic raw materials, the RFID tags would ideally have to be recoverable. Even if it were possible to produce purely organic and polymer RFID tags, it is questionable whether their retention in secondary raw materials would be acceptable, since polymer melts are sensitive to even minor impurities. Basically, sensors and RFID tags can be expected to have either a negative effect on the quality of secondary raw materials or an increased recycling effort.

Evaluation measure/indicator: Costs for digitization

A number of features speak for a high digitizability of a packaging :

- The implementation of digital equipment is easy due to the design of the packaging system and can be standardized.
- Information about packaging and contents is available over a complete or even several life cycles, so that a high benefit is achieved through tracking and information assignment to the packaging.
  is achieved.
- In addition, there is the option to disconnect/replace the digital equipment before end-of-life or in case of damage, or to circle it non-destructively.

In principle, the advantages of digitization strategies in the area of single-use systems are lower than for reusable systems, since non-destructive closed-loop recycling is not the goal. Even when using marking technologies, as discussed and developed under the catchword "Holy Grail 2.0", cloud-based product and material information can indeed be attributed to the packaging and larger fragments up to the sorting stage. But rather it seems excluded that this information can be uniquely attributed to a secondary product after the process of mechanical or chemical recycling. Information on how a package has been additivated, with which ingredients it has come into contact, is therefore not available for disposable systems after recycling in a package-specific form, but at best as averaged values.

A suitable quantitative indicator for determining the digitizability results from the costs for digitization (transponder), related to the costs of the packaging. The costs for digitization are apportioned to the costs of the packaging based on the number of items in circulation. The cost of a transponder of 10 cents per unit is taken as the basis for calculation. More complex sensor technology or even interfaces applied directly to the packaging would result in significantly higher costs. Infrastructure costs are likely to be similar for single-use and reusable systems and are therefore neglected. However, due to greater standardization of reusable systems or fewer changes in packaging design over time, it is also conceivable that the infrastructure for reusable systems could be simpler and more cost-effective.

In the considerations in this study, the lower the cost share, the greater the digitizability. The latter is calculated as follows (IP = circulation):

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

$$Kostenanteil\ f\text{ü}r\ Digitalisierung = \frac{Kosten\ Digitalisierung}{UZ * (\,Kosten\ Verpackung + Kosten\ Digitalisierung)}$$

For the evaluation of the different packaging systems, the aspect of non-destructive recycling and the cost share for digitization were combined and a gradation according to Table 13 was chosen.

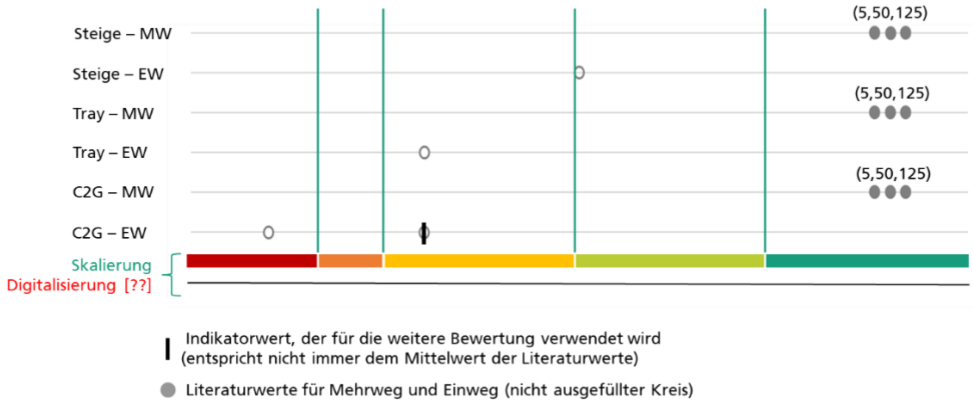
Table 13: Gradation of the indicator digitizability

Indicator	-2 (bad)	-1 (rather bad)	0 (neutral)	+1 (rather good)	+2 (good)
Digitizability	≥ 50 %	Cost share 10 to < 50	Cost share < 10 %	Cost share < 10 % and non-destructive recycling	Cost share < 5 % and non-destructive recycling

Determination of the values for the investigated systems

The following graph shows the results for the investigated reusable systems (MW) and the corresponding single-use alternatives (EW). Notes on how the values were determined are given in the text below the figure. Tables with the data used can be found in chap. 9.4.11.

Figure 28: Digitizability of single-use and reusable systems in comparison



Multiway crates for fruit and vegetables are already identified by a GRAI code (Global Returnable Asset Identifier). It consists of a base number, container type and check digit and allows the packaging system to be uniquely identified. Furthermore, the code can be supplemented by a serial component, which allows identification at the level of the individual container. In Europe, the GRAI code is usually implemented in the form of a bar code as an in-mold label. RFID tags are

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

already being used in the USA. Even low circulation figures result in a low cost share for digitization. The indicator was set at +2.

In the case of **one-way** carton **crates** and many other packaging units, unique identification of a shipping unit to the recipient by means of the shipping unit number (NVE, international: Serial Shipping Container Code) is common practice. It is applied by label, direct printing (inkjet) or RFID, but does not always cover the individual crate, but the shipping unit (e.g. a pallet with several cardboard crates). After the shipping unit is dissolved, the information is lost. The carton type is additionally identified with the FECO-EBSO code. For carton crates, the cost share for a passive RDID technology would still be quite low at 11 percent (indicator value 0).

Reusable trays and **cups** are circulated non-destructively. Despite the relatively inexpensive trays and cups, the costs for an RFID transponder are not significant even at low circulation rates and amount to well below 5 percent. Even significantly more expensive transponders including sensors would be conceivable (indicator +2). The introduction of RFID technology for returnable cups has been tested on a pilot scale since 2020. (RFID card 2020).

In the case of **disposable trays,** the costs for digitization represent a significant proportion of the total costs (indicator value -1). In the case of inexpensive **disposable cups, digitization** with RFID technology is hardly conceivable, as digitization would account for almost 80 percent of the total costs. Even in the case of high-quality cups, which are chosen here as a point of comparison because they are more likely to be able to compete with reusable cups in terms of performance, the cost share is still rather high (indicator value -1).

6.2.5 Transport effort

Transport effort is measured as transport performance (in ton kilometers) and is directly influenced by both the weight to be transported and the distance to be covered. Logistics actors along the life cycles of both single-use and reusable systems are continuously improving and optimizing their transports and thus the transport effort. Strategies lie, for example, in increasing utilization (the volume reduction/foldability of empty goods plays a role here, see also chapter 6.2.2) or avoiding empty transports (approx. 42 percent of the fuel consumption of a fully loaded truck is caused by the payload weight, 58 percent is caused by the empty vehicle (Infras 2019)[22]). Whether and to what extent empty transports are necessary is less a question of the packaging system than primarily of the size and network of the logistics service provider, the existence of freight exchanges, and the pairing of regions[23] . These points determine the number of pick-up and drop-off points in a logistics network, enable bundling, route optimization, and thus reduce empty runs (Dörfelt 2018).

22 According to Manual for Emission Factors HBEFA version 4.1: Vehicle class LZ/SZ >34-40t (diesel) with weighted pollutant class mix for the year 2020.

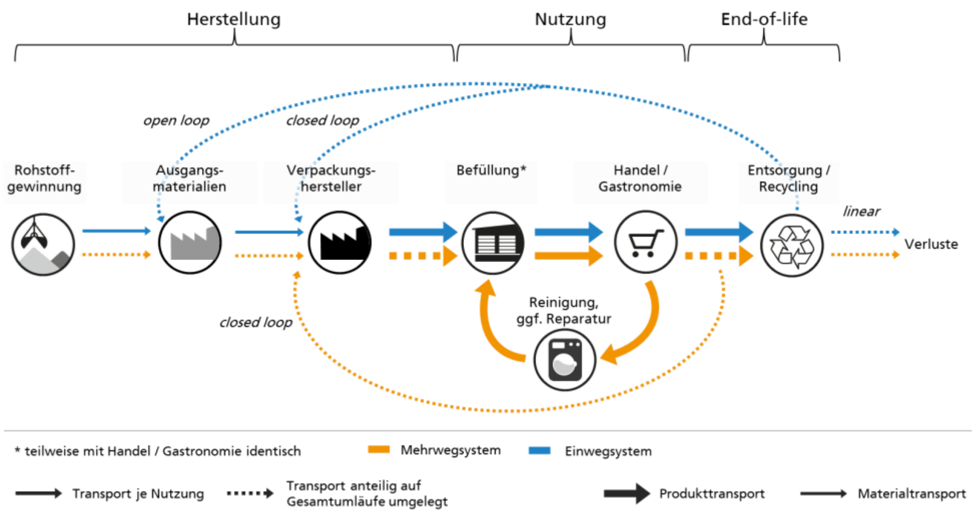
23 That is, when the regions' freight volumes are comparable in both transport directions.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

In addition to volume reduction through foldability and nestability of the packaging systems, the tare weight of the packaging - for both disposable and reusable systems - is also optimized (see also Section 6.2.2), which also affects the transport effort. Varying transport effort is in turn reflected in varying fuel consumption and thus energy expenditure (see section 6.3.2) and greenhouse gas emissions (carbon footprint, see section 6.3.1).

Transport effort is thus a performance category that is determined on the one hand by underlying parameters such as volume reducibility and deadweight, and at the same time influences higher-level sustainability categories. Since the weight aspect has already been discussed in chap. 6.1.2 it will now be put aside in this chapter and attention will continue to be paid to the transport distance that the single-use or reusable system typically has to bridge as a separate parameter. The relevant transports are outlined in the following figure.

Figure 29
Relevant transports in the single-use and reusable system[24]



Manufacturing phase: In the case of both disposable and reusable systems, packaging production and distribution can be realized regionally or supraregionally. In the case of plastic packaging, the first step is to transport the raw material to the manufacturer of the polymer, which is then transported to the packaging manufacturer via the compounder. Then the finished packaging is delivered to the place of filling (e.g. fruit/vegetable producer, plant producer, restaurant). These initial transports occur for each application in single-use systems (therefore shown in the figure with bold arrow). For reusable systems, the transportation expenses of the manufacturing phase are apportioned to the number of uses and are shown with thin dashed arrow in the figure.

Use phase: Detached from the regionality of the manufacturing processes of the packaging systems, their use is also associated with transport, which, however,

24 The term "closed loop" here refers to the loop closure of the material into the same application with the same quality (ideally without admixture of primary material), while the term "open loop" describes the loop closure of the material with possibly different (lower) quality and application.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

depends on the regionality of the products to be transported and should not be attributed causally to a single-use or reusable system. Transport from the point of filling to the point of sale or already use takes place in the same way for both systems. While single-use as well as reusable systems are used worldwide in supra-regional distribution structures (e.g. within Europe, the USA or Australia), single-use systems are currently more commonly used in global supply chains (Muske 2021). After use, reusable packaging usually requires transport back to the place of cleaning and from there to the place of refilling (redistribution).

End-of-life phase: The disposable packaging is sent for recycling after a single cycle, the reusable packaging after several cycles. In this step, single-use packaging has advantages because it can be destroyed more easily and compacted (e.g., by means of waste compactors), thus significantly reducing the transport volume (cf. Section 6.2.2). Recycling requires transportation from the point of ejection of the packaging systems to be disposed of to the respective recycling steps. In the case of reusable packaging, the packaging is usually diverted from the pool operators and transported by type to closed-loop recycling.[24] transported. In the case of single-use packaging, the EoL packaging mostly accumulates in retail or, in the case of B2C packaging, households or waste collection points in public areas. Depending on the realized loop closure, the collection of disposable packaging is followed by transport to the landfill/incineration plant (linear product life cycle) or to recycling (incl. sorting, pre-treatment, compounding).

As an evaluation standard for the transport effort (Table 14) in this study is the fictitious transport distance of an application in which the transports during production, distribution of the new crates and disposal are apportioned to the total possible circulations (dashed arrows in the figure). All other transports, shown in the figure with solid arrows, are included 1:1 in the notional transport distance.

Table 14: Transport distance of an application for the evaluation of transport effort

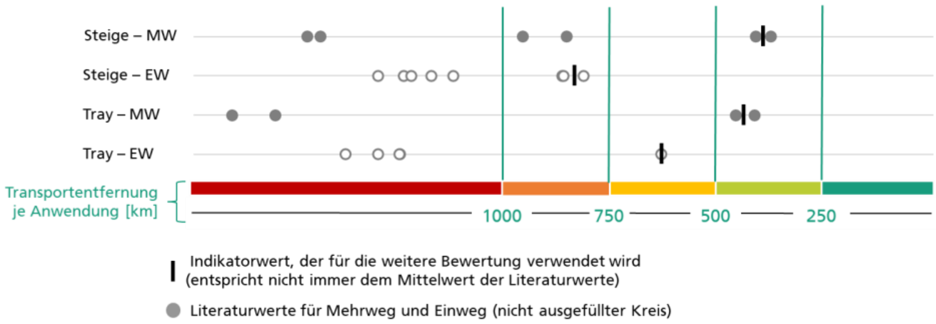
Indicator	-2 (bad)	-1 (rather bad)	0 (neutral)	+1 (rather good)	+2 (good)
Transport distance per application [km]	> 1000	1000 to > 750	750 to > 500	500 to > 250	≤ 250

Determination of the values for the investigated systems

The following graph shows the results for the investigated reusable systems (MW) and the corresponding single-use alternatives (EW). Notes on how the values were determined are given in the text below the figure. Tables with the data used can be found in chap. 9.4.12.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

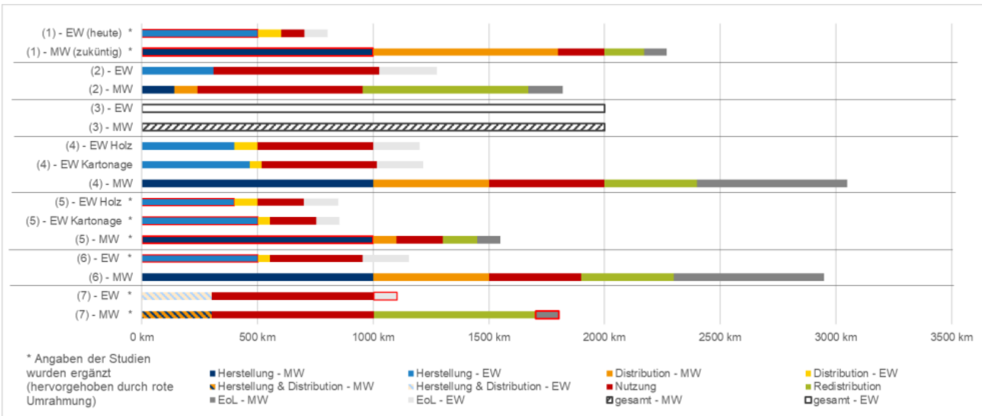
Figure 30: Transport distance per application of single-use and reusable systems in comparison



The separate consideration of the transport distance makes it clear that the distances upstream and downstream of use are negligible compared to the area of use. Therefore, MW solutions for regional application are evaluated favorably compared to one-way solutions. The procedure is described in detail below for the O/G risers as an example.

Fruit and vegetable crates: The respective transport effort of a EW or MW crate depends, as described before, on the respective manufacturing distance as well as individual application (product to be transported). Therefore, existing publications were analyzed with regard to the transport distance used and, if possible, these were included separately for production, distribution, redistribution and end-of-life. If secondary materials (regranulate) are used in packaging production, their transport is usually considered during production and not in the EoL (cut-off or recycled content approach). The following figure summarizes these transport distances.

Figure 31: Transport distances along the life cycle of fruit and vegetable sticks.[25]



In general, it should be noted that the documentation of the distances used as a basis in the studies varied greatly in detail, and the assignment to the respective stages in the transportation system had to be based in part on assumptions. For

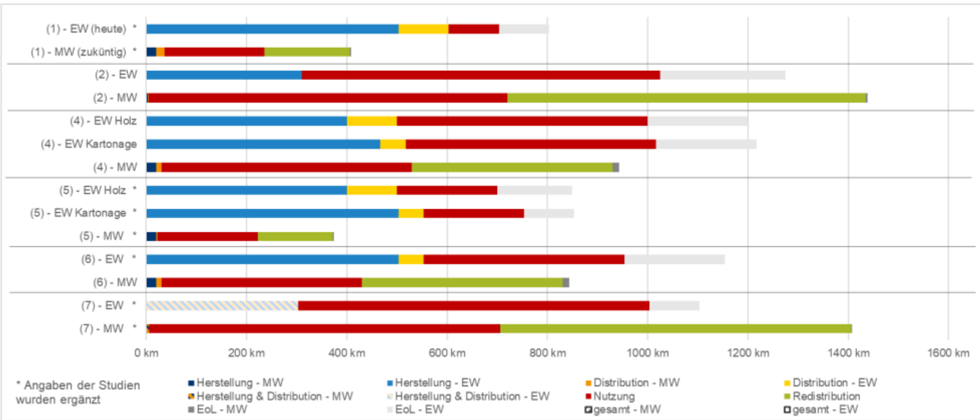
[25] With (1) Accorsi et al. 2014 (2) Koskela et al. 2014 (3) Levi et al. 2011; López-Gálvez et al. 2021; (5) Del Borghi et al. 2020; (7) Albrecht et al. 2013.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

the study of Levi et al. (2011) for example, the subdivision of the transport steps was not possible. In the study from Albrecht et al. (2013) no distance was given for the EoL and therefore the minimum distance of the other studies (i.e. 100 kilometers) was included (highlighted with the red border in the diagram). Furthermore, in the studies from Abejón et al. (2020) showed a transport distance of the plastic granulate for the MW riser, but no transport distance for the cardboard raw material of the EW solution[26] . For this reason, a distance of approx. 500 kilometers on average was added for the diagram shown above (FEFCO 2018). Only has Abejón et al. (2020) published a transport distance for the plastic granulate, the study of López-Gálvez et al. (2021) refers to this secondary source. Unpublished studies of Fraunhofer IML on O/G risers confirm this value, so that this also applies to the studies of Del Borghi et al. (2020) and Accorsi et al. (2014) was assumed.

These total distances were then applied to a uniform number of turns of the single-use (by definition, 1 use) and multi-use (a conservative number of 50 turns for all MW platforms) platforms, i.e., the transportation distances of manufacturing, distribution, and EoL of the MW platforms are divided by 50. Since a breakdown of the data from Levi et al. (2011) is not possible, this information has been removed from the presentation.

Figure 32: Transport distances for a fruit and vegetable crate application[27]



This illustration highlights that the distance of application of fruit and vegetable crates, in particular, influences the total transport distances and the comparison between single-use and reusable solutions. However, even with a redistribution distance of 400 to 500 kilometers. (Abejón et al. 2020; López-Gálvez et al. 2021)., reusable crates have a shorter total transport distance for an application than the single-use option considered.

In summary, fruit and vegetable crates are rated "rather good" (+1) for reusable and "rather poor" (-1) for disposable in terms of transport effort in this study.

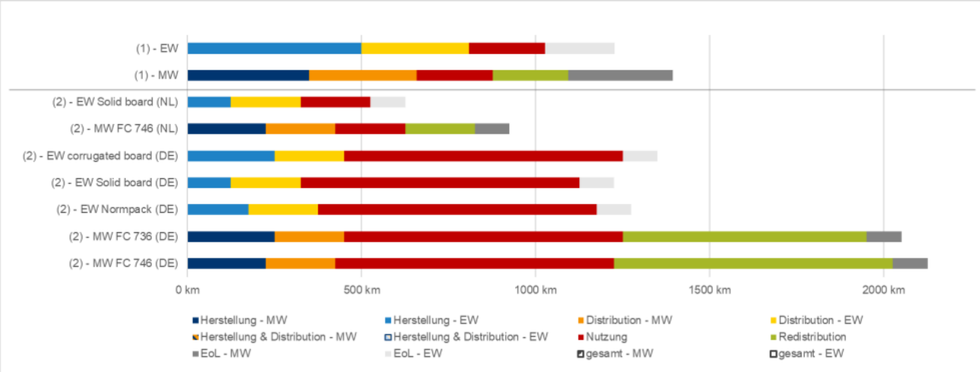
26 The accounting of these transports is included in the LCA modules used (GaBi). The study only does not show the distance separately.

27 With (1) Accorsi et al. 2014 (2) Koskela et al. 2014 (3) Levi et al. 2011; López-Gálvez et al. 2021; (5) Del Borghi et al. 2020; (7) Albrecht et al. 2013.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

For the plant trays, the same approach could be applied based on two literature reviews. Thereby the study of van Paassen and Scholten (2020) on the one hand, the application scenarios in Germany (DE), and on the other hand, the comparatively small application area of the Netherlands (NL) with the EW scenario with the shortest distance (EW Solid board) and the MW scenario with the longest distance (MW FC 756).

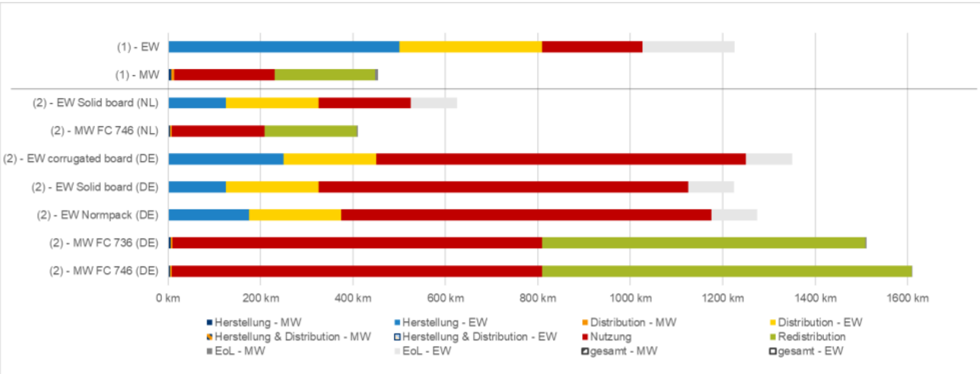
Figure 33: Transport distances along the life cycle of plant trays.[28]



These total distances were again related to a uniform number of circulations (EW=1 use; MW= 50 circulations). Again, it can be seen that for reusable trays, the distances upstream and downstream of use are negligible compared to the area of use. The decisive factor is the distance of application of the plant trays, which is shown by the investigations of van Paassen and Scholten (2020) on Germany and the Netherlands illustrates this.

In summary, plant trays are rated "rather good" (+1) for reusable and "neutral" (0) for disposable in terms of transport effort in this study.

Figure 34: Transport distances for a plant tray application.[29]



In the case of coffee-to-go cups, the literature evaluation based on the process steps along the life cycle was difficult (Ligthart 2007; Cottafava et al. 2021; Kauertz et al. 2019; Melbinger 2018) and therefore is not further graphically listed here.

28 With (1) Dobers and Lammers 2017; (2) van Paassen and Scholten 2020.
29 With (1) Dobers and Lammers 2017; (2) van Paassen and Scholten 2020.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

However, there is a difference to the previous demonstrators in the case of these B2C solutions: Depending on the area of application of the coffee-to-go cups, the use currently takes place within a city (e.g., municipal association) to within Germany (e.g., a retail chain, gas station association). Municipal solutions will thus have short distances for use, eliminating redistribution - provided the cups are returned to the same dispensing point. For nationwide pools, on the other hand, the distance is strongly dependent on the centralized (e.g. RECUP with today one location in Leverkusen (Pachaly 2021)) vs. decentralized organization and volume fluctuations. However, data on this have not yet been published. An evaluation with regard to the indicator value was therefore not carried out.

6.3 Sustainability categories

In accordance with the "three-pillar model", sustainability can only be achieved through the equally weighted and equally prioritized implementation of environmental, economic and social objectives. The provision and use of packaging systems is associated with impacts on the environment, the economy and society. Where these impacts are of a negative nature, it is important to minimize them and to share the burden fairly between people living today and future generations. To achieve this, Sustainable Development Goals (SDGs) were agreed at the global level. These goals, set in 2015 under the auspices of the United Nations, are to be implemented by 2030. They address more political objectives and are less guidelines for assessing the sustainability of individual products and processes.

Making sustainability measurable and comparable for individual products and processes is a major challenge. One possibility is to examine selected categories that address relevant aspects. However, a generally applicable set of indicators is not very useful, as very specific sustainability aspects are often particularly relevant and prioritized for concrete products, processes and industries. This is usually also reflected in public debates. In the apparel sector, for example, social aspects such as occupational health and safety and fair employment play a major role in public perception. Environmental impacts, on the other hand, have received less attention, although this has also been increasing in recent years.

For packaging systems, aspects of the Circular Economy, climate impacts, energy consumption, economic efficiency and sovereignty are currently of particular importance. Aspects of the Circular Economy are dealt with separately in section 6.1 dealt with separately. The other topics follow in this chapter.

Greenhouse gas emissions and cumulative energy expenditure are analyzed as important ecological criteria - also called environmental impact. Environmental impact is a generic term for all types of positive and negative impacts on the environment, which are analyzed in so-called impact categories in an environmental impact assessment as part of LCA. Principles and the guidelines for an LCA are standardized in the international standards of the ISO 14040 series (ISO 14040:2006; ISO 14044:2006). The comparison of single-use and reusable systems carried out here on the basis of environmental impact using various studies is not the result of our own life cycle assessment surveys and calculations. Instead, it is a classification of packaging systems based on literature data. The results are

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

therefore subject to uncertainties due to the dependence on the assumptions made and the boundary conditions of the respective studies. 9.3.2 as limitations of the meta-study. In addition to the two environmental impact categories analyzed, the contribution to abiotic resource depletion was also investigated as an environmental impact, but was not included in the evaluation (see Chapter 8.3). It was found that the study and data basis for these and other environmental impact categories were in line with the environmental impact categories recommended in the PEF 3.0 standard [30](Fazio et al. 2018; Zampori L. 2019) recommended environmental impact categories for the packaging systems investigated here is insufficient to date. Therefore, these were not evaluated.

The estimation on the relative economic efficiency of individual cost items and technological sovereignty are thus to be understood as rather economically or socially relevant sustainability categories. All sustainability categories examined in the context are described in detail below and evaluated in relation to the demonstrators.

6.3.1 Greenhouse gas emissions

The influence of humans on the climate is considered proven in science. The cause is greenhouse gas emissions, which are mainly generated in the energy sector, industry, private consumption, transport and agriculture. According to IPCC[31] , the an-thropogenic emissions of greenhouse gases (GHG) are the greatest threat in the history of mankind. The climate crisis includes both global warming caused by human-induced emissions of GHGs and the resulting changes in local weather patterns. All regions of the world are predicted to be affected in some way by the impacts of global warming, although the extent of each may vary. Climate changes have far-reaching impacts on natural and dependent technological systems. The best-known impacts are the melting of the polar ice caps and the associated rise in sea levels, as well as extreme weather events. For example, local droughts, heavy rain events and storms are attributed to the global climate crisis. The consequences that are already apparent today and the increasingly closing window of opportunity for necessary countermeasures have led to GHG emissions currently being the most frequently discussed and considered environmental impact in life cycle assessments. (IPCC 2014; European Commission 2021; Wincentsen 2013).

An important parameter in calculating the contribution of emissions to climate change is the global warming potential (GWP). The global warming potential of a gas is used to compare the influences of different greenhouse gases on global warming. It is a measure of how much climate-damaging emissions of a substance contribute to global warming in a given period of time (e.g. 100 years). Climate-damaging emissions absorb energy in the atmosphere over this time and partially radiate it back to the Earth's surface. The resulting effect is called the greenhouse effect. (IPCC 2014)

30 Product Environmental Footprint 3.0 (PEF 3.0) is a standard for the implementation of product life cycle assessments, which was initiated by the European Commission.

31 Intergovernmental Panel on Climate Change

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

Carbon dioxide (CO_2) is the most abundant GHG. Therefore, it is used as a reference gas and benchmark, so gases emitted by a product or process are converted to CO_2 equivalents using a conversion factor. The conversion factor, known as the relative global warming potential, indicates how much a given mass of a GHG contributes to global warming compared to the same mass of CO_2 . The conversion factors can be found in the most recent IPCC report. Nitrous oxide (N_2 O), for example, is produced in agriculture and, according to the IPCC's Fifth Assessment Report, has a relative global warming potential about 300 times that of the same mass of CO_2 . To calculate CO_2 equi valents, the masses of all individual emissions for an activity or over a product life cycle are multiplied by the characterization factors and expressed as the sum of emitted CO_2 equivalents per functional unit. The calculated CO_2 equivalents are also often referred to as CO_2 footprint pressure, although usually not only the emitted amount of CO_2 , but the total amount of climate-damaging gases converted into CO_2 equi valents are given. This conversion makes the effect of different products or activities on climate change comparable in an aggregated single value. (IPCC 2014)

Evaluation measure/indicator

The greenhouse gas emissions for the demonstrators considered in this study are given in kilograms of CO_2 equivalent per circulation and 1000 liter filling volume. Literature values for the packaging systems studied here were converted to this unit in each case if otherwise stated. Studies in which a conversion was not possible, e.g. because the information on the packaging volume was missing, could not be taken into account in the analysis. For the fruit and vegetable trays and for the coffee-to-go cup, the volume refers to the respective packaged product or, unless otherwise stated, to the volume of the packaging system itself. Ange notes that the volume of the plant trays refers to the calculated volume of all plant pots that fit into the respective tray and not to the volume of the plant trays themselves. The reason for this is that the trays studied have different shapes and sizes and, as secondary packaging, fulfill the function of transporting a certain number of plant pots with a defined volume. The volume of the plant pots as a reference size is therefore more suitable than the volume of the plant trays, as these sometimes only have an opening into which the plant pots are placed, and the tray itself does not have a comparable volume. However, since the plants are usually not completely packed and protrude from the plant pot, the respective height of the plant has an impact on some process flows and thus also on the environmental effects. For example, depending on the height of the plants, different numbers of trays can be transported on top of each other. For reasons of comparability with the other packaging systems and the classification of the indicator chosen here, no other unit was used. The values and packaging systems from the literature used for the demonstrators are listed in chapter 9.4.13 listed.

For the classification of the indicator "CO_2 equivalents" in kilograms of CO_2 equivalent per circulation and 1000 liters of filling volume of the different packaging systems into a scale, a study by the ifeu Institute from 2018 was used as a reference. This life cycle assessment study examined 11 beverage packaging systems in the juice/nectar, UHT milk and fresh milk segments (Kauertz et al. 2018). It looked at a representative average of the beverage packaging systems available

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

in Germany in the reference period 2015 to 2017, including distribution distances, collection, sorting and recycling rates. The 11 packaging systems studied there represent four composite beverage cartons with and without an aluminum layer, five non-refillable PET bottles (mono and multilayer) and two returnable glass bottles. A classification of the indicator values of the packaging systems studied was derived from the CO_2 equivalents (see Table 15). This means that the classification of the indicator values places the packaging systems investigated here in a comparison with beverage packaging typically available on the market as reference packaging. The two extreme values (maximum and minimum) of the 11 beverage packaging systems form the low and the high threshold value (-2 "poor" and +2 "good"). The measure of dispersion between the extreme values and the lower and upper quartiles respectively forms the range for the indicator values -1 "rather poor" and +1 "rather good". Neutral values (indicator value 0) result from the distance between the two quartiles. [32]

Table 15: Evaluation of GHG emissions in CO_2 equivalents

Indicator	-2 (bad)	-1 (rather bad)	0 (neutral)	+1 (rather good)	+2 (good)
GHG emissions [kg CO_2 -eq. per circulation and 1000 L fill-volume]	> 177	177 to > 132	132 to > 45	45 to > 22	≤ 22

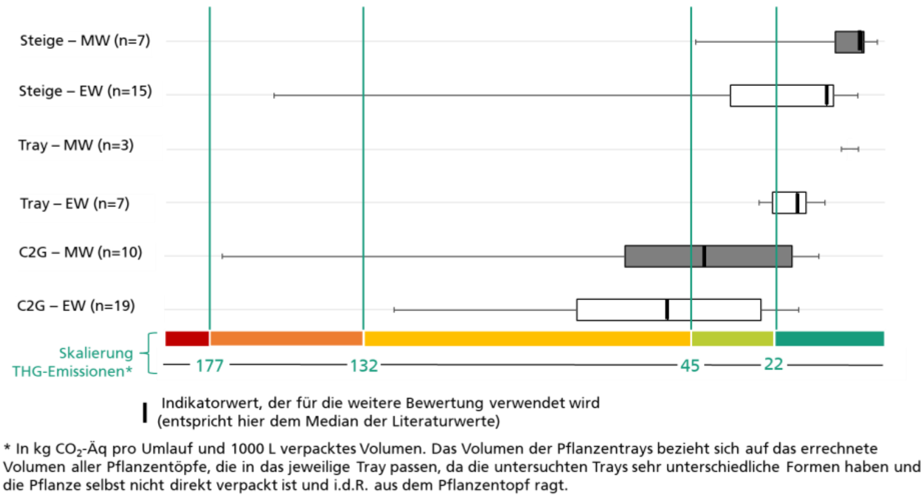
Determination of the values for the investigated systems

Building on the specific GHG emissions in CO_2 equivalents considered for beverage packaging to classify the indicator value, the single-use (EW) and reusable (MW) systems examined here were transferred from a literature study to this classification and plotted in a boxplot diagram (see Figure 35). In total, 42 single-use variants and 21 reusable variants of different materials from a total of 14 studies were considered. Notes on how the values were determined are given in the text below the figure. Tables with the data used can be found in chap. 9.4.13.

32 For quartiles and boxplot, see for example: Bettermarks 2022.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

Figure 35: GHG emissions of single-use and reusable systems in comparison



Fruit and vegetable crates: All of the multi-use crates studied are made of plastic, whereas the single-use versions are made of cardboard, wood, or plastic. Although the studies show great uncertainties with regard to the comparability of the assumptions and boundary conditions, six of the eight studies analyzed with a total of 24 packaging variants show the same tendency in a direct comparison: plastic multi-way crates are advantageous with regard to the specific CO_2 equivalents compared to the single-use crates analyzed. Furthermore, the comparison of all studies in Figure 35shows that the range of results of the one-way risers is higher than that of the multi-way risers. The values of the one-way climbers span the index ranges from "rather poor" (indicator value -1) to "good" (indicator value +2). One study in which a one-way crate made of PPK performs better than the multi-way crate made of plastic examines the delivery of bread (Koskela et al. 2014) and not fruit and vegetables. Another study shows in the basic scenario that one-way crates made of PPK are advantageous over plastic multiway crates (Levi et al. 2011). However, the base scenario chosen in this study assumes a long transport distance of 2000 km over the entire life cycle per round trip. In a later sensitivity analysis, however, it was shown that for a distance covered of 1200 km, the reusable systems perform better than the single-use systems.

Key boundary conditions influencing GHG emissions are the assumptions on transport distances and number of circulations. For the latter, values between 30 and 200 circulations are given in the studies reviewed. Assumptions on transport distances make comparability between the studies difficult, since in some cases products are transported within a country or globally, but within a study one-way and multi-way platforms always transport the same products (cf. also Chapter 6.2.5). However, it can be seen that the transport processes have a greater influence on multi-way boarding than on single-use boarding, i.e. the relative contribution to the total value is higher. If, in the future, emissions in the transport sector per kilometer traveled decrease, e.g., due to the electrification of means of transport in connection with the expansion of renewable energies, there would be a greater benefit for the multi-way variants than for the one-way variants. The

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

major share of GHG emissions from multi-use staircases is caused in the use phase; especially by necessary transports. Above all, short transport distances increase the benefits of reusable packaging. (Accorsi et al. 2014). Decentralized distribution structures and weight reductions promote the advantages of reusable crates. Plastic returnable crates have an advantage over wood due to their ability to be reduced in volume and their relatively light transport weight (cf. chapter 6.2.2).

In the LCA studies investigated, the number of circulations is generally the decisive factor for comparing a multi-way boarding bridge with a one-way boarding bridge. A sensitivity analysis based on the circulation numbers showed that a plastic multi-way platform can be advantageous compared to a one-way platform after only about 15 circulations (López-Gálvez et al. 2021). This can be regarded as realistic according to the information on the circulation figures determined from the expert interviews or is already exceeded in practice (cf. chapter 6.2.1). Studies based on a circulation figure of more than 100 circulations may need to be examined, as this does not correspond to practical experience (compare chapter 6.1.1 Page 43).

Plant trays: For the comparison of GHG emissions of disposable and reusable plant trays, only two studies could be evaluated, in which a total of three reusable and seven disposable variants are considered. Again, the three reusable trays studied are in the good range (indicator value +2) and have lower GHG emissio ns compared to the single-use trays. In both studies, the most important drivers of the results of reusable trays are the transport processes and - if necessary after use - the cleaning processes. (Dobers and Lammers 2017; van Paassen and Scholten 2020).. In relative terms, the transport processes - similar to those for fruit and vegetable trays - are also more important for reusable plant trays than for disposable plant trays. Accordingly, analogous to the explanation for the crates, the CO_2 footprint of the reusable trays would also decrease proportionately more here if the emissions in the transport sector per kilometer driven decrease overall in the future, e.g. through the electrification of the transport sector. It follows that through greenhouse emission savings in transport, reusable trays achieve higher savings than single-use potentials.

For single-use trays, the largest driver of GHG emissions is the provision of materials in the manufacture of a tray (van Paassen and Scholten 2020; Dobers and Lammers 2017). However, the study by van Paassen and Scholten (2020) also shows that the environmental impacts of single-use trays can be reduced if more recycled materials are used that are recycled again at the end of life. Furthermore, the CO_2 equivalent emissions of single-use trays compared to reusable trays are more dependent on the energy credits awarded through end-of-life incineration of the trays. (van Paassen and Scholten 2020). For Germany, the credits from providing electricity through end-of-life incineration are higher than in other European countries. (Blümm 2021). Reasons are the comparatively high electrical efficiency of waste incineration in Germany and the German electricity mix with comparatively high GHG emissions due to many fossil energy sources . (Blümm 2021). The more renewables provide electricity in Germany, the lower the credit per kWh of electricity provided from waste incineration will be in the future. An increasing share of renewable energy also has a positive effect on the already advantageous ratio of GHG emissions from reusable to disposable trays.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

Coffee-to-go cups: Most variants were investigated for the comparison between disposable and reusable cups. A total of four different studies with 19 reusable and 10 disposable variants were evaluated. Different disposable plastic cups (PS, PP, PLA, PET) as well as disposable paper cups with and without PE plastic coating and also single-walled and double-walled paper cups were investigated. Analyzed returnable cups are made of plastic, glass, clay or porcelain. Further, some of the cups were considered with and without lids. Three of the four studies explicitly addressed coffee-to-go cups, whereas one study analyzed beverage cups in general without explicit application. The results of the coffee-to-go disposable and reusable cups show the worst results per circulation and 1000 L of packaged product compared to the other demonstrators. Both variants show the largest range within the scaling for the indicator value of GHG emissions.

Even though different circulation rates and materials were considered in the studies, reusable cups perform slightly better on median than disposable cups. Ultimately, however, the studies indicate that the environmental impact depends primarily on handling during use, as well as pool management, if any. Returnable cups are only advantageous after a certain number of cups have been in circulation (break-even). For plastic reusable cups (PP, PET and PLA), the break-even compared to plastic or paper disposable cups in terms of CO_2 equivalents is between 5 and 54 circulations, depending on the comparison of the variants. (Cottafava et al. 2021). This was also confirmed in a German study commissioned by the Federal Environment Agency. (Kauertz et al., 2019). This showed that reusable plastic cups generally have lower GHG emissions when they:

- achieve at least a circulation rate greater than 10, or better still a circulation rate greater than 25, through adequate reverse logistics or responsible consumer behavior,
- not be equipped with disposable components such as lids and
- cleaned via a flushing process using green electricity.

However, another study showed that porcelain and clay cups, for example, performed significantly worse than disposable plastic cups, and that the reusable variants proved relatively insensitive to changes in service life and thus also in the number of circulations achieved (Ligthart 2007).

6.3.2 Cumulative energy expenditure

The packaging sector faces the challenge of finding energy-saving processes and packaging solutions. Solutions that should ultimately lead to lower energy requirements per package concern both upstream processes for sourcing materials, selecting energy sources, lightweight packaging and energy-efficient production, as well as downstream processes related to ecological and energy-efficient end-of-life use and recycling. The ongoing energy transition and global commitments to implement a circular economy create potentials for the packaging sector, such as the switch to renewable energy sources and the application of reusable packaging systems, as well as the recycling of packaging, which can lead to energy savings.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

The KEA is an indicator for the assessment of products along their life cycle or individual services and activities, which is used as an input-related impact category in life cycle assessments, but also as a common life cycle inventory parameter in material and energy balances. It is used to determine final energy use by converting the efficiency of energy conversion into primary energy expenditure (Klöpffer and Grahl 2009).

Despite its popularity, there is not yet a harmonized approach to assessing products using CED. Standards or guidelines define it differently (Frischknecht et al. 2015).. In this study, the CED is defined as the sum of all primary energy expenditures that occur during the life cycle of a packaging system. This includes all energy expenditures within the system boundaries considered, i.e. for the provision of the packaging, for distribution and for use until disposal at the end of life of the packaging system (cradle-to-grave system boundary).

The use of renewable energies can have positive effects on other environmental impact categories, such as greenhouse gas emissions, and thus also on the sustainability of packaging. However, the use of renewable energy does not fundamentally reduce the cumulative energy input (CED), as this is the sum of all primary energy inputs. This means that even when switching to renewable energy, the CED remains constant. In contrast to GHG emissions, which depend on the respective CO_2 equivalents of the energy sources, the KEA can be improved if, in principle, the primary energy input is reduced. While switching to renewable energy generally has positive effects on GHG emissions, the KEA is improved by reducing primary energy sources, addressing another strategy of sustainability and circular economy. Therefore, KEA is used alongside GHG emissions as a category to determine environmental performance.

Evaluation measure/indicator

For good comparability, the KEA in this study is related to the same functional unit as for GHG emissions, so that single-use and reusable systems become as comparable as possible. This means that the CED is given per rotation of a packaging system and per 1000 L of packaged product. The volume of the plant trays refers to the calculated volume of all plant pots that fit into the respective tray, since the trays studied have very different shapes, the plant itself is not directly packaged, and it protrudes from the plant pot at different heights depending on the variety. In practice, the latter has a significant impact on the quantity of products transported in a standard volume (CC container) and can thus influence distribution processes and energy consumption.

As a data basis, life cycle assessment studies on the corresponding packaging systems were evaluated, which show this life cycle inventory parameter as an impact category. It should be noted here that there are different impact assessment methods which take into account different energy sources and in some cases subdivide the CED into further categories.

In this report, to determine the cumulative energy expenditures, the total cumulative energy for the production and use of the products and services is used

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

as the overarching assessment metric (KEAtotal). In some cases, the studies also reported the KEA of fossil and renewable energy sources individually (KEAfossil and KEArenewable), e.g., in Cottafava et al. (2021). For ease of comparison, only studies that report the CEDtotal were considered here. However, it should be noted that the increased use of renewables leads to other positive environmental effects, such as lower GHG emissions compared to fossil fuels. The classification of the indicator values into a corresponding scaling (Table 16) was done analogously to the procedure for GHG emissions on the basis of the results for the CEDtotal of beverage packaging systems from (Kauertz et al. 2018).

Table 16: Evaluation of the cumulative energy expenditure (CED)

Indicator	-2 (bad)	-1 (rather bad)	0 (neutral)	+1 (rather good)	+2 (good)
KEAtotal [MJ per circulation and 1000 L filling volume].	> 3670	3670 to < 3040	3040 to < 1450	1450 till < 1240	≤ 1240

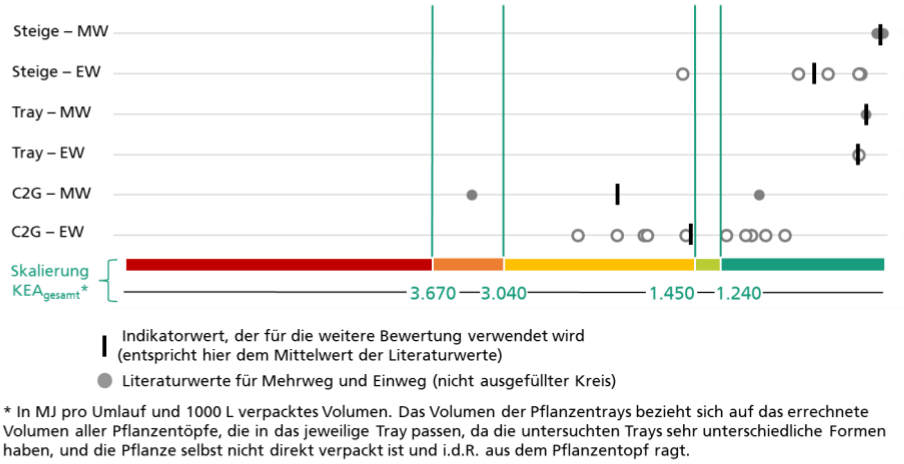
Determination of the values for the investigated systems

Compared to GHG emissions, significantly fewer studies identify CED as an impact category. In total, five studies were analyzed for all three packaging systems with six reusable variants and 17 single-use variants. Compared to GHG emissions, the results are less meaningful because fewer studies could be analyzed. The main drivers for single-use and reusable packaging systems are the same here as for GHG emissions. While the KEA for reusable systems is primarily dependent on redistribution logistics and general transport distances, as well as the cleaning process where applicable, for single-use variants it is determined more by the manufacture of the product and the provision of the materials.

The following graph shows the results for the investigated reusable systems (MW) and the corresponding single-use alternatives (EW). Notes on how the values were determined are given in the text below the figure. Tables with the data used can be found in chap. 9.4.14.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

Figure 36: Cumulative energy consumption of single-use and reusable systems in comparison



Fruit and vegetable crates: A total of six single-use crates made of wood and cardboard were analyzed, showing a median of 346.6 megajoules per circulation and 1000 liters of packaged product ("good", indicator value +2). In contrast, three multiway crates were analyzed, which have an average value of 85.6 megajoules per circulation and 1000 liters of packaged product ("good", indicator value +2). The three values on multiway crates from different studies are very close to each other, although the circulation numbers vary between 50 and 150 and also the volume ranges between 28.8 liters and 57.6 liters per crate. The study with the highest circulation number of a plastic multiway crate of 150 shows the lowest result of 34.6 megajoules per circulation and 1000 liters of packaged product ("good", indicator value +2) (López-Gálvez et al. 2021). The trend is in line with the assumption that the number of cycles is also decisive for the advantageousness of plastic multi-way crates in this impact category. The disposable crates made of wood and cardboard have a range of KEAs between 209.4 and 1589.6 megajoules per circulation and 1000 liters of packaged product (indicator values from 0 to +2). Thus, all disposable variants are above the results of the KEA for reusable plastic crates. Even though the total energy demand was analyzed here, one study, for example, indicates that the ratio of renewable to non-renewable primary energy demand is better for cartonboard than for plastic systems, i.e., the analyzed cartonboard system already uses proportionally more renewable energy (Albrecht et al. 2013). While the increased use of renewable energy has a positive effect on the reduction of GHG emissions, this does not exert any influence on the cumulative primary energy demand (KEA_{ges}). It further states that cardboard box risers recover about one-third of the total primary energy at end-of-life, which is credited to the system over a life cycle (Albrecht et al. 2013). This is mainly due to the higher calorific value of cardboard compared to plastic. The overall CED result for cardboard risers is therefore strongly dependent on the energy recovery at the end of life.

Plant trays: For the comparison in the case of plant trays, only one study could be evaluated in this category, each with one variant for disposable and reusable. This comparison shows that both variants perform "well" compared to the reference unit selected here (indicator value +2). Nevertheless, in the present case, the

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

reusable variant has a better value of 168.6 megajoules per circulation and 1000 liters of packaged product. In comparison, the single-use variant, with 226.1 megajoules per circulation and 1000 liters of packaged product, is associated with approximately 25 percent higher energy expenditures than the reusable product.

Coffee-to-go cups: Although the lower and upper values of the KEA for the coffee-to-go cups of the reusable variants are roughly the same as the values for the disposable cups, the disposable cups perform slightly better on average. The disposable and reusable systems are both rated "neutral" here (indicator value 0). For the comparison, the KEA of two reusable cups and ten disposable cups was evaluated. Similar to the GHG emissions, single-walled and double-walled coffee-to-go cups as well as cups with and without lids were again examined as paper disposable variants. The two reusable variants are 180 milliliter cups made of polypropylene (PP) with and without lids (indicator values -1 and +2 result in an average value of 0). The reusable PP cup without lid performs better than eight of the disposable variants studied, assuming 50 circulations with 1000 megajoules per circulation and 1000 liters of packaged product. Only the single-wall paper cup without lid with 200 and 300 milliliter volumes performs more favorably than the 180 milliliter plastic cup with 800 and 950 megajoules per circulation and 1000 liters of packaged product, respectively. As can be seen from the comparison of the 200 and 300 milliliter disposable cups, volume is a critical factor in the results. It should be noted that the volume of the plastic cup here is less than that of the disposable variants. Since with larger reusable cups, for example, cleaning processes with their energy requirements take place less frequently per 1000 liter filling volume, it is possible that a larger reusable cup would perform better.

6.3.3 Relative profitability

Packaging incurs direct costs during procurement, use, and its disposal or recycling at the end of its life. The cost structure of reusable and single-use systems is very different. In the case of single-use systems, it is primarily the production and the recycling or disposal at the end of life that are relevant. For reusable systems, the costs of production are allocated over a large number of uses. This also applies to recycling or disposal of the packaging materials. In addition, there are costs for cleaning after each use in the case of reusable systems.

Since the cost structure cannot be broken down in detail, approximate market prices were determined for the packaging systems studied. Subsequently, for the single-use systems, surcharges for recycling/disposal were estimated from the usual license fees. The relevant costs for cleaning in the case of reusable systems were determined from data for industrial belt washers. Losses due to shrinkage and breakage are taken into account for the reusable systems by the circulation number.

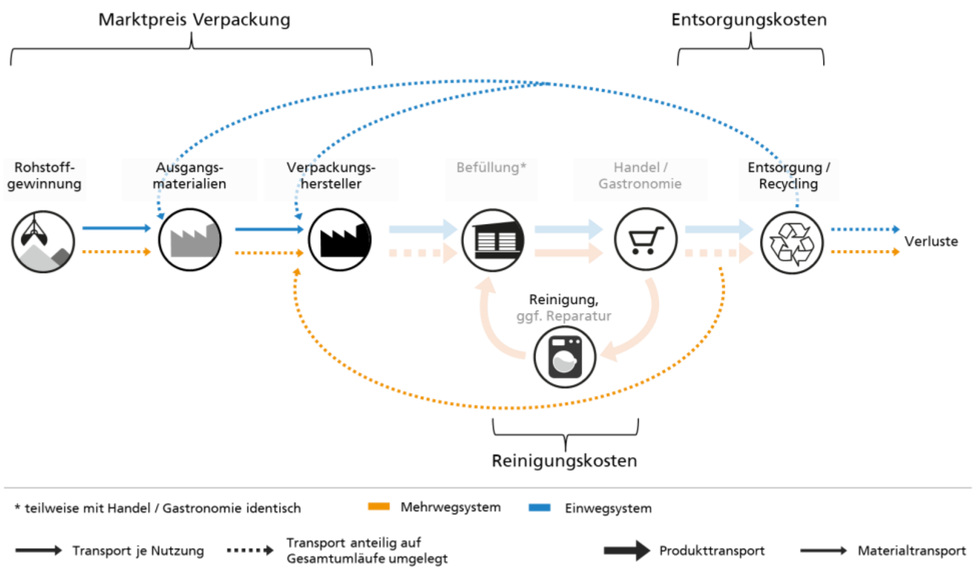
Transport, storage and handling costs (e.g. pressing) are particularly relevant in the absolute costs of a packaging system. However, they can differ significantly for single-use and reusable systems depending on the specific application. Despite their relevance, transport costs are therefore not considered here. However, a

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

detailed analysis of the transport costs of the two systems has already been carried out in section 6.2.5 took place.

A graphical representation of the relevant costs when considering the relative economics of the two systems can be found Figure 37. It should be noted that this chapter is neither a full cost calculation nor an absolute profitability analysis that takes into account achievable profits, etc. The focus is only on a comparison of the two systems on the basis of selected cost items. The focus is only on a comparison of the two systems on the basis of selected cost items.

Figure 37:
Cost items considered in the comparison of relative profitability (the grayed-out process steps and transport efforts are not considered).



Evaluation measure/indicator

To enable the comparison of different packaging systems, the costs per use are converted to one liter of filling material[33] . From data of the Federal Environment Agency, the packaging costs for food and beverages can be estimated at approx. 61 euros per person and year. This means that approx. 1500 liters of food and beverages are packaged. (Statista 2022; Federal Environment Agency 2020).[34] Assuming a predominantly one-time use of the packaging units, specific packaging costs of 4.0 cents per liter of filling material and use result as a reference value. No participation fees were taken into account. Since the current state of packaging consumption is generally considered to be less than satisfactory, this value is defined as a threshold value between rather low and neutral. (Federal Government 2018). The cardboard crate as a packaging material with generally attributed high efficiency is evaluated as neutral with the selected classification. The other ranges

33 The use of the product volume neglects the volume utilization factor. This is particularly relevant for large products (cabbages or similar). However, since we considered the comparison across packaging materials to be important, we nevertheless decided to use the more robust product volume instead of the filling mass.

34 The total consumption of packaging in Germany is 18.9 million t/a, the share for private end consumers is 8.8 million t/a, of which 62.3% for food and beverages, corresponding to 5.5 million t/a; the total turnover of the packaging industry in Germany is approx. 17.5 billion €; assuming proportionality of mass and costs, this results in 5.1 billion €/a or 61 €/(cap a) for the food packaging sector; with a food consumption of 719 kg/(cap a) corresponding to approx. 1000 L(cap a) and a beverage consumption of 530 L/(cap a), this results in a total of approx. 1500 L/(cap a).

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

were selected on the basis of the values determined for the three demonstrators (Table 17).

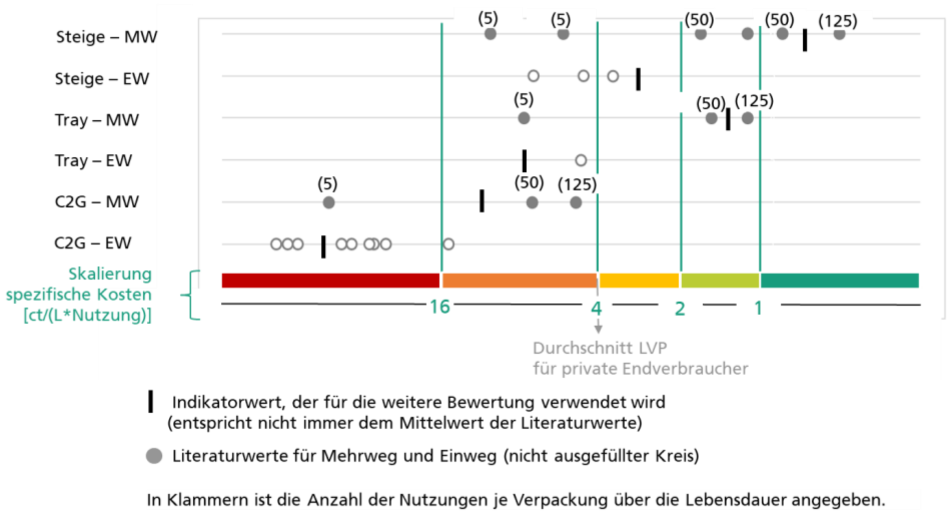
Table 17: Evaluation of economic efficiency

Indicator	-2 (bad)	-1 (rather bad)	0 (neutral)	+1 (rather good)	+2 (good)
Direct costs [ct/(L x usage)]	> 16	16 to > 4	4 to > 2	2 to > 1	≤ 1

Determination of the values for the investigated systems

The following graph shows the results for the investigated reusable systems (MW) and the corresponding single-use alternatives (EW). Notes on how the values were determined are given in the text below the figure. Tables with the data used can be found in chap. 9.4.15.

Figure 38: Relative cost-effectiveness of single-use and reusable systems (excluding transport effort, see text).



As expected, the specific costs of reusable systems depend significantly on the achievable circulation rate. On the one hand, the procurement costs are apportioned over the total number in circulation during the service life, while on the other hand the cleaning costs are comparatively low. Values of 5, 50 and 125 were assumed as the total number in circulation (corresponding to loss rates of 20 percent, 2 percent and 0.8 percent respectively). In all the applications investigated, the reusable systems were already competitive from 5 circulations and had a clear advantage at 50 circulations. Although the costs were related to the product volume, it is noticeable that larger packages nevertheless have lower specific costs. One reason for this could be that as packaging units become smaller, material and machine costs rise disproportionately compared to labor costs. When compared with the reference value determined above, it is noticeable that in the systems investigated, cost savings can be realized compared with the average

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

specific packaging costs of end consumer packaging, above all through efficient reusable systems with high circulation rates.

Multiway crates are established for meat, bread and bakery products as well as fruit and vegetables. As early as 2015, it was assumed that around 1.5 billion crates were in use for these three application areas in Europe alone. The number is likely to have increased further since then, so no further potential savings can be expected in terms of prices. The cost of simple boxes is less than 3 euros per unit. Foldable multi-way crates are in the range of 5 to 8 euros per piece. For cleaning, at least in open or larger closed pools, belt washers have become established that can clean up to several thousand boxes per hour. (Home - EDT GmbH 2022). With circulation figures of 50 or more, the multipath crates achieve an indicator value of +2 for the costs considered here.

One-way climbers are usually used in the form of boxes. They are available at prices below 1 euro. The cardboard boxes must be collected separately. Depending on whether they are handed in loose or compacted (e.g. by a baler), revenue can also be generated from the disposal costs. Within the scope of this study, it was assumed that the cardboard boxes can be handed in free of charge. In the case of disposable cardboard packaging, the costs can drop to less than 3 cents per liter of filling material and use (indicator value 0).

Reusable trays have so far only been a niche solution, even though various market players are currently making efforts to introduce a system across the board. Initial design and functional samples are already available, so the cost can be estimated at around 2.00 euros/(L x use) per piece. It is likely that the reusable trays will be made of HDPE or PP. Cleaning would be similar to the reusable trays in belt washers, although smaller systems or larger capacity are possible. An indicator value of +1 would be achieved with 50 circulations.

In the case of plant trays, it is mainly disposable systems that have been established to date. About 150 million are used per year in Germany alone (cf. section 7.2). The **disposable trays are** mostly made of polystyrene and cost about 25 cents each. The disposal costs were based on the typical royalties for polystyrene packaging, even though, strictly speaking, these are only relevant for B2B packaging if the trays are passed on to the end consumer. Tray manufacturers account for a certain amount of tray-to-tray recycling (Normpack about 50 percent). Exactly what the recycling paths are and whether they lead to savings is not known. However, it can be assumed that the above price takes into account the recyclate share. In the case of disposable trays, the sum of the costs considered here is over 4 cents per liter of plant bale volume (indicator value -1).

The costs for the currently established **coffee-to-go reusable cups** made of PP are around 55 cents per unit. Assuming that cleaning is carried out analogously to B2B packaging in an industrial belt washer, this results in costs of less than 1 cent per cleaning. A calculation for a household dishwasher, neglecting labor costs, would even yield significantly lower values. Whether and under what conditions additional labor costs are incurred in the catering sector when reusable systems are introduced can hardly be answered in general terms and clearly depends on the

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

specific situation. It is still questionable whether similarly high circulation figures can be realized for the returnable cups in practice as for the B2B systems. Since the systems are still being set up, little is known about the achievable circulation figures, and no reliable data is yet available on cleaning. An indicator value of -1 seems realistic.

Costs of 3 to 19 cents per piece are typical for **disposable coffee-to-go cups. In** addition to the size of the cups, performance aspects such as double wall or surface structures also play a role. Royalties are 2 percent for paper-based cups and 10 to 15 percent for plastic-based cups. Comparing the reusable cups with disposable cups of higher performance, an indicator value of -2 appears justified.

6.3.4 Technological Sovereignty

Technological sovereignty can be thought of both at the level of available skills and at the level of doing business (manufacturing and distribution) (BMWi 2019; BMBF 2021). It addresses the ability to create local value by reducing dependence on third parties and negative influences from external phenomena (pandemics, natural disasters, etc.). Technological sovereignty is often discussed at the state or regional level, addressing key technologies and critical infrastructure. Typical debates relate, for example, to the expansion of the 5G standard (Hegemann 2020)access to data in social media (Welchering 2021) or the production of semiconductors and microchips. (Leitner 2020). The term "digital sovereignty" has also become established in this context. But technological sovereignty has also received new attention away from the digital in the context of the Corona pandemic. Examples include the lack of availability of personal protective equipment (respirators, disinfectants, etc.) (Biermann et al. 2020) and also the shortage of simple but not insignificant products such as toilet paper (Weyh 2020). Short-term shortages are not so much due to a genuine shortage of resources, which leads to slowly but steadily rising market prices and usually allows sufficient time to find alternatives, but are based on a high degree of dynamism in complex supply chains and the difficult-to-predict behavior of consumers and market players. For example, the development of demand is not infrequently linked to the dynamics of topics in social media, which can cause rapid rises or falls. Furthermore, in recent decades, in the spirit of lean production, warehousing has been reduced and switched to just-in-time delivery. As a result, it is difficult to respond to fluctuations in demand and system stability is declining.

Since the beginning of 2021, European industry has been suffering from a drastic shortage of raw materials and significant price increases, even for bulk materials (Deutsche Welle 2021). In the plastics industry, there is a shortage of basic polymers, additives and even reinforcing materials. The inventories of many companies have been depleted and the situation is described by some as threatening their existence. A backlog of demand following the Corona pandemic is cited as the cause of this development. At the same time, there are delays in restarting and repairing equipment, as well as a lack of personnel who are in quarantine, for example. This situation exists on a global scale, but varies greatly in its severity. Furthermore, bottlenecks (bottle necks) exist in the area of transportation for many goods. For example, there are not enough sea containers

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

available, which is currently due to a lack of loading and distribution capacities at many seaports and still as a result of the blockade of the Suez Canal by the container ship "Ever Given".

Assessment standard/indicator: Independence from imports

A technical system is all the more sovereign the fewer raw materials and precursors have to be supplied externally in order to operate it. In this context, it is useful to define at what point something is considered "external". Usually, this is the national border, since ensuring technological sovereignty is ultimately also a task of the state (BMWi 2019).

The independence from imports can therefore be used as an evaluation standard for the technological sovereignty of a packaging system. For this purpose, the dependence on imports is first developed as a variable. In the case of single-use systems, we understand this to mean the imported packaging volume, based on the production volume, minus the exported packaging (empty or filled):

$$Importabhängigkeit_{EW} = \frac{Import}{Produktion - Export}$$

If recyclate from separately collected own packaging is used in single-use systems, this reduces the dependence on imports. However, since recyclates are also subject to global trade, they are only taken into account in the case of a closed loop system.

$$ImportabhängigkeitEW = \frac{Import}{(Produktion - Export)} \times (1 - Rezyklatanteil)$$

In the case of reusable systems, the dependency on imports is reduced to the proportion of imports required to compensate for the losses in the cycle in relation to the quantity in use. Not all packaging losses have to be compensated by new material, but only the proportion of shrinkage that causes packaging and its material to leave the cycle. In the case of packaging materials that are removed from the cycle by rejection, on the other hand, it can be assumed that the material is recycled, so that no replacement with virgin material is required. For the independence from imports, the identical value is used as for material-equivalent disposable systems:

$$Importabhängigkeit\ MW = Importabhängigkeit_{EW} \times Verlustquote$$

As a rule, imports are also matched by exports, which could be redirected to cover national needs in the event of a shortfall in imports. However, in a non-state-controlled market economy and assuming that companies are faithful to their

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

contracts, a rapid adjustment in the event of a crisis is neither realistic nor likely to be possible without major political upheaval.

As desirable is a high import independence, this results from the import dependence:

$$Import\boldsymbol{un}abhängigkeit \; = \; 100\,\% - \; Importabhängigkeit$$

This estimation, which takes place at the level of the packaging itself, is highly simplified. In particular, it neglects the fact that even if the packaging demand could be fully covered by national production without imports, possibly by means of imports in the upstream chain, this would result in reduced technological sovereignty. However, a correspondingly comprehensive analysis of the upstream chain cannot be carried out within the scope of this brief study. It is reasonable to assume that where a lot of packaging is imported, a lot of precursors are also imported and vice versa, so that the proposed indicator should be largely directionally reliable.

For plastic packaging, based on data from GVM, the following results are obtained. (Pupil 2020):

$$Import\boldsymbol{un}abhängigkeit_{EW,Kunststoff,2018} \; = \; 100\,\% - \frac{1596\,\frac{t}{a}}{\left(4461\frac{t}{a} - 1678{,}1\,\frac{t}{a}\right)} = 43\,\%$$

For packaging made of paper, cardboard and paperboard (PPK), independence is significantly more favorable:

$$Import\boldsymbol{un}abhängigkeit_{EW,PPK,2018} = 100\,\% - \frac{1093\,\frac{t}{a}}{\left(9063\frac{t}{a} - 2185\,\frac{t}{a}\right)} = 84\,\%$$

Materials for reusable systems are also included in the GMM data. However, it is assumed that these are rather negligible in relation to total consumption and that explicit consideration would tend to increase the import dependency of single-use systems. The import dependency of the single-use systems is assessed rather conservatively by the described approach.

Taking into account the values for PPK and plastics, the following proposal is made for the ordinal scale in the case of independence from imports (Table 18). The rating "neutral" is based on the already quite good value for PPK. The rating "poor" is based on the value for plastic.

Table 18: Assessment of independence from imports

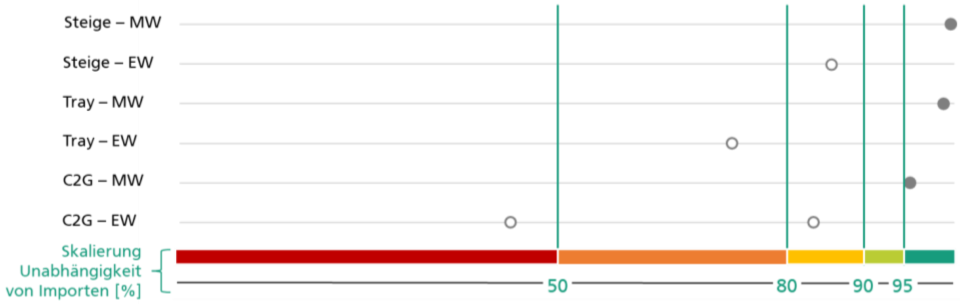
Indicator	-2 (bad)	-1 (rather bad)	0 (neutral)	+1 (rather good)	+2 (good)
Independence from imports	< 50 %	50 to < 80 %	80 to < 90 %	90 to < 95 %	≥ 95%

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

Determination of the values for the investigated systems

The following graph shows the results for the investigated reusable systems (MW) and the corresponding single-use alternatives (EW). Notes on how the values were determined are given in the text below the figure. Tables with the data used can be found in chap. 9.4.16.

Figure 39: Technological sovereignty represented by independence from imports.



Multipurpose crates for fruits and vegetables have shrinkage rates of 0.8 percent in established systems (Muske 2021). They thus achieve almost complete independence from imports:

$$Import\boldsymbol{un}abhängigkeit_{Mehrwegsteige,2018} = 100\,\% - \frac{1596\,\frac{t}{a}}{\left(4461\frac{t}{a} - 1678{,}1\,\frac{t}{a}\right)} \times 0{,}8\,\% = 99{,}5\,\%$$

Since most of the multiway crates can still be manufactured from recycled materials from old crates, the estimate is conservative. This results in an indicator value of +2.

For **disposable cartons** used as transport packaging, the values for PPK are assumed. As a rule, no coating is applied. Information on closed loop systems is not available. The known situation at a discounter showed that local disposal companies are commissioned even for large quantities, so that close material cycles are rather unlikely:

$$Import\boldsymbol{un}abhängigkeit_{Einwegkartonsteige,2018} = 84\,\%$$

This results in an indicator value of 0.

No data are yet available for **reusable plant trays.** The loss rates are likely to be similar to those for reusable trays. If the plant trays are also used in the B2C sector, the loss rate could increase. A maximum shrinkage rate of 2.5 percent seems realistic (indicator value: +2):

$$Import\boldsymbol{un}abhängigkeit_{Mehrwegtray,2018} = 100\,\% - \frac{1596\,\frac{t}{a}}{\left(4461\frac{t}{a} - 1678{,}1\,\frac{t}{a}\right)} \times 2{,}5\,\% = 98{,}6\,\%$$

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

Disposable plant trays are partly recycled directly in the same application as a result of separate collection. This makes them less dependent on imports. A reuse rate for recyclate of 50 percent is assumed. This results in an indicator value of -1:

$$Import\boldsymbol{un}abhängigkeit_{Einwegtray,2018} = 100\,\% - \frac{1596\,\frac{t}{a}}{\left(4461\frac{t}{a} - 1678{,}1\,\frac{t}{a}\right)} \times 50\,\% = 71{,}3\,\%$$

Initial studies are available for **coffee-to-go returnable cups**, which still show a fairly high shrinkage rate of 10 percent (Pachaly 2021). It can be assumed that these are effects of the build-up of stocks and of use for private purposes :

$$Import\boldsymbol{un}abhängigkeit_{Mehrwegbecher,2018} = 100\,\% - \frac{1596\,\frac{t}{a}}{\left(4461\frac{t}{a} - 1678{,}1\,\frac{t}{a}\right)} \times 10\,\% = 94{,}3\,\%$$

Although the dependence on imports is lower for paper than for plastic and the loss of returnable cups is still comparatively high (due to external use, lack of awareness and dissemination, etc.), a high degree of independence from imports has already been achieved for the returnable system at the current early stage of development (indicator value +1).

No specific data from individual manufacturers are available for **coffee-to-go disposable cups**, so the import dependency for PPK packaging is applied across all applications. If the plastic content for the cup's coating is taken into account at 5.5 percent (4 to 7 percent according to (Kauertz et al. 2019) separately, the result is independence from imports:

$$Import\boldsymbol{un}abhängigkeit_{Einwegbecher,2018} = 100\,\% - \frac{94{,}5\,\% \times 1596\,\frac{t}{a}}{\left(4461\frac{t}{a} - 1678{,}1\,\frac{t}{a}\right)} - \frac{5{,}5\,\% \times 1093\,\frac{t}{a}}{\left(9063\frac{t}{a} - 2185\,\frac{t}{a}\right)} = 81{,}8\,\%$$

This results in an indicator value of 0. Since the disposable cups are not kept in a closed cycle, recycling is not taken into account. On the contrary, it can be expected that a large part of the material is sent to incineration via residual waste.

For disposable cups made of PS (vending machine cups), the rating is significantly worse (indicator value -2):

$$Import\boldsymbol{un}abhängigkeit_{Automatenbecher,2018} = 100\,\% - \frac{1093\,\frac{t}{a}}{\left(9063\frac{t}{a} - 2185\,\frac{t}{a}\right)} = 42{,}7\,\%$$

The preceding analysis on technological sovereignty based on the import independence of the various packaging materials can only be a first approach for the use of this evaluation category. In the future, this criterion must be further developed so that complex upstream chains and specific materials can also be mapped with it. Against the background of experience with shortages in 2020 and 2021, however, this seems worthwhile.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

7 Results for the reusable systems studied

7.1 Climbing (container, O+G boxes)

7.1.1 Application description

Flat crates, also known as "crates", traditionally made of wood, cardboard and, since the early 1990s, plastic, are used for the supply chain, especially for loose but also packaged fresh produce from the fruit and vegetable, meat and baked goods segments. The crates are assigned to the small load carriers (KLT). The crates are filled at the producer's premises, usually stacked on pallets, secured separately for transport if required (e.g. with edge protectors, wrapping film or conveyor belts) and transported to retailers via the various trade stages. In addition, if necessary, treatment takes place in maturing plants before the goods are delivered to the retail trade.

7.1.2 Status for disposable and reusable solutions

The most common **disposable solution** is cardboard boxes. Generally, cardboard boxes made of standard solid board and corrugated board are used in the fruit and vegetable sector, with the latter predominating in the market and often being double-walled. Disposable wooden solutions are usually made of peeled or sawn wood, chipboard and hardboard. Both varieties are typically manufactured in the country of filling and transported to local fruit and vegetable growers. Once filled, they are transported to distribution centers, and from there they eventually reach retail stores or consumption points. Once their purpose is fulfilled, they are usually disposed of on site. In individual cases, the disposable packaging is passed on to the end customer together with food sold, who then disposes of it via household waste disposal.

With regard to cardboard boxes and wooden boxes, which are used for fruits and vegetables and other food products, there is a wide variation in terms of dimensions and filling volumes, as well as variants.

In the early 1990s, plastic **multiway crates** came onto the market in four sizes (Euro Pool System 2021a), which contributed to the standardization of fruit and vegetable distribution in a European pool. Subsequent developments of these MW crates included, on the one hand, additional dimensions, with these generally taking into account Euro pallet dimensions. On the other hand, in addition to the rigid crates, foldable variants were also launched on the market, which allow a significant volume reduction (67 to 87 percent) (Euro Pool System 2021c) , during handling of empties. In addition, MW crates are now equipped with code markings, so that process automation and tracking & tracing of the transport units have been simplified. Today, rental models are predominantly in use, for example through a daily rental that only ends when the crate is returned (Hofmeister et al. 2021).

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

Here, the company itself is not the owner (closed pool). The advantage of the rental system is that this also serves as an incentive system for the return. In an open pool, companies could also bring in their own stock and pay no rent for the crate itself, instead paying only per use for the service of cleaning and logistics (Hofmeister et al. 2021).

The empty multi-way crates are collected at the retail level and picked up by the pool operator (sometimes by a subcontracted logistics service provider) and transported to washing and sanitation centers. There they are washed and disinfected. At the same time, a quality check is carried out automatically and/or by visual inspection. The cleaned/disinfected crates are then delivered to the producers as required for the next filling.

If defective crates are identified during quality control, they are repaired - depending on the reusable solution and pool operator - or sorted out and disposed of, usually by feeding them for recycling.

The reusable stock of fruit and vegetable crates has increased significantly in recent years: while in 2006 there were about 200 million crates in circulation in Europe, in 2017 the stock was already 600 million crates (Behrens et al. 2018). The 2018 EKUPAC study shows 8 rotations per year for fruit and vegetable crates. Relevant key data from the major players in multiuse crates are summarized in Table 19 compiled.

Table 19: Key data Actors: Foldable multiway risers

	Euro Pool System (EPS)	**IFCO**	**WBG Pooling**
Rise movements	1.3 billion /year (Europe) (Euro Pool System 2021a)	1.2 billion /year (Europe) (Muske 2021)	n.a.
Material	HDPE	PP	PP
Colors (O/G segment)	green, blue, black	black, green	light blue
Weight [g]	550-2070 (Euro Pool System 2021c)	840-2000 (IFCO 2021)	1430-1980 (WBG pooling 2021a, 2021b)
Filling volume [L]	9.25 to 47.14		22 till 45
Filling weight [kg]	5 to 20	5 to 20	20
Area dimensions [mm]	400 x 300 600 x 400	400 x 300 600 x 400	600 x 400
Codes	2D barcode, linear barcode	GRAI Code	GRAI Code, RFID Label

7.1.3 Circularity, performance and sustainability

In chapter 6 of this study, various categories including indicators for evaluating packaging systems are considered. The indicators are calculated for different packaging systems, presented graphically and compared across applications. In the

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

following, the most important aspects concerning the multiway system are summarized again. Figure 40, at the end of this section, gives a comparative overall profile of reusable and disposable crates based on the categories studied.

Circularity

The **circulation number of** multi-way platforms is currently already very high. Most frequently, circulation figures between 100 and 150 were researched in the literature or mentioned in the interviews. However, experience in recent years suggests that a maximum circulation of 100 is more realistic. By definition, single-use systems have a circulation rate of 1.

Plastic multi-way conveyors achieve high **material efficiency** even at low circulation rates. At circulation rates in the region of 100, single-use cartonboard crates are far behind. Compared to packaging systems for other applications, the material intensity of returnable crates is also particularly low, at less than one gram of packaging material per use and per liter of product.

The return **rate of** materials from reusable crates reaches over 99 percent. By comparison, the return rate of single-use packaging from collection by dual systems, industry solutions and via single-use deposit systems reaches only 76 percent - if the material flows recycled for energy, which are not available for material recycling within a circular economy, are not taken into account. This means that for the circular economy, reusable systems alone represent a very good starting point because they ensure the return of materials and material losses are largely absent.

In the case of foldable or collapsible fruit and vegetable trays, the repairability **of** moving parts in the reusable segment is definitely given, but is applied differently in the respective pools. In this study, the reparability is therefore rated as good. The repairability of disposable crates, on the other hand, is neither intended nor practiced as a disposable packaging material.

The principle **recyclability of** the multiway crates is very good. They are mostly made of a monomaterial (PP or HDPE) that is only slightly filled and can be mechanically recycled very well. All sub-steps in the recycling of these materials are state of the art, which means that the practical recyclability in Germany can also be regarded as very good.

The data on the **recycling rate of** multi-way crates in the literature and from the expert interview show a high bandwidth. In contrast to the use of recycled materials, the values at the upper end predominate here. On average, a recycling rate of 80 percent can be assumed. Stacks that circulate in a pool system and are sorted out there achieve almost 100 percent. Differences to this value in the literature studies are mostly due to assumptions about the disposal of damaged crates during use. The less this occurs, the closer the recycling rate is to 100 percent.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

There are also many different specifications for the **proportion of recycled** material used in multi-path boarding. There are reports of up to 70 percent recycled material being used. However, it is also often described that only virgin material is used. This is justified by the necessary approval of the products for contact with food.

Multi-way boarding has a very low potential for **plastic emissions**. Deposits or rentals ensure recycling, and there are no loose parts. Littering in particular is likely to occur much more frequently with single-use carton crates. If coatings, adhesives, etc. are also used with the cartons, this is also associated with plastic emissions. Mechanical stress and abrasion occur in all crates, especially indoors, so that the quantities released are likely to be retained by cleaning measures.

Performance

Modularity is already a given for multi-way pools today. The area dimension of 600 mm x 400 mm or subdimensions thereof, based on Euro pallet size, is used by several pool operators. Overall, the modularity for returnable crates is rated very well. In the one-way transport crate market, uniform area dimensions have also developed over time. However, there are also many individual EW solutions, and their modularity was rated neutrally.

The **volume reducibility of** multiway crates is given by their foldability. The indicator value is significantly influenced by the height of the crate, i.e. is it a rather flat crate (e.g. for berries) or a high crate (e.g. for melons, bananas).

The multiway crates offer very good **product protection** with a low breakage rate during the full load processes, which can, however, be negatively influenced by external influences (e.g. possibly inadequately selected load unit securing). Better process integration would exploit the existing potential. Qualitatively, the breakage rates of reusable solutions are rated as lower compared to single-use solutions. For example, it was listed that the rigid walls of MW crates allowed for better stackability and offered better protection in case of impacts. For the present study, the indicator values are assigned neutral for the multi-use crates and poor for the single-use crates.

Today, multipath installations are already frequently marked with the GRAI code at the level of the individual box. Both optical codes and radio technology are used. Due to the non-destructive circuitry and less than five percent additional costs for e.g. RFID sensors per use, the crates can **be digitized** very well. There would also be potential for additional sensor technology. With the multiple use of packaging systems for the same application, digitization also offers the potential for process optimization.

The separate consideration of the **transport distance** makes it clear that the performance of multi-way risers in this respect is influenced in particular by the product to be transported compared to single-use solutions. The distances upstream and downstream of use are negligible compared to the area of use for MW risers, so that MW solutions are advantageous over single-use solutions for

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

areas of use with less than 500 km product generation and consumption distance (i.e. redistribution distance).

Sustainability

The **greenhouse gas emissions of** multi-way boarding are lower than those of one-way boarding. The main influencing factor is the number of circulations, although decentralized distribution structures as well as weight reductions and other performance categories also promote the advantageousness of multi-way boarding.

All the reusable crates investigated performed better than the disposable variants in the **cumulative energy input** category. Although up to one third of the total primary energy is recovered at the end of life for single-use systems made of cardboard in some cases, the CED of the evaluated plastic multiway cartons is lower over the entire life cycle.

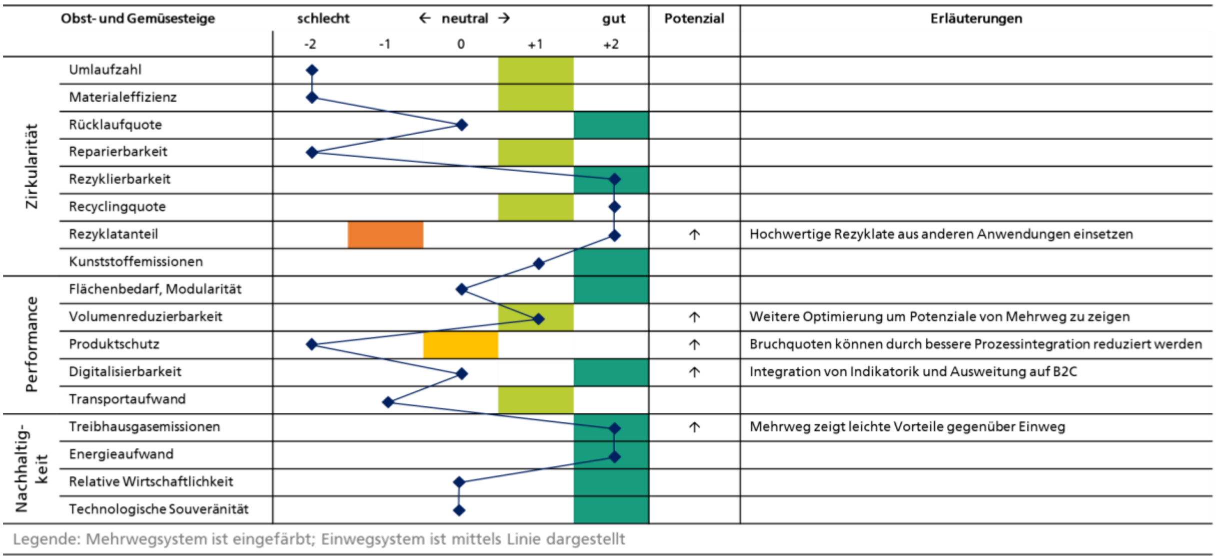
If the costs for production (from recyclate) and disposal for single-use systems are compared with those for production, cleaning, repair and shrinkage for reusable systems in order to evaluate the **relative economic efficiency**[35] , clear advantages for the reusable systems already emerge at circulation numbers of around 50. For the cost groups mentioned, the total value at 50 circulations is less than one cent per liter of product and use. If the transport costs for the competing single-use and reusable systems are similar, there are clear advantages for the reusable systems.

Reusable systems are generally used regionally in open or closed cycles. Only shrinkage has to be compensated by new material. They therefore contribute to the establishment of robust business relationships between producers, logistics service providers and retailers. Established pools that are no longer growing achieve a high degree of import independence and contribute to **technological sovereignty.**

35 For the specific definition of relative economic efficiency in this study, see Sect. 6.3.3.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

Figure 40: Overview for fruit and vegetable crates



7.1.4 Optimization potential

Among the demonstrators examined here, the multi-way platform is probably the best established returnable system. Consequently, it has the lowest potential for optimization due to previous improvements in terms of pool management and the high circulation figures already achieved. In very many of the categories examined in this study, the returnable kiosk performs significantly better than its likewise long-established competitor, the single-use kiosk made of cardboard. Nevertheless, some potentials or future requirements for further improvement compared to the single-use boardwalks were identified.

A large number of the good ratings for multi-way climbs are based on the high circulation figures. However, there is always debate about the level of these figures. The industry should agree on monitoring mechanisms and communication options to provide transparent information about the circulation figures achieved in practice.

Optimization of the circulation figures should be one of the top priorities in product and system development. The target value for reusable systems should be 100 on average. In order to increase the circulation figures, improvements in the breaking strength of collapsible crates are useful, for example. New test procedures laid down in standards could help here. Improving communication with users or developing new incentive systems to reduce shrinkage would also probably have a positive effect.

By expanding the systems beyond B2B transport, further disposable packaging can be substituted. Examples include the use of multi-way crates as transport boxes in online retail or as take-away boxes in retail. This should be tested in model trials.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

Policymakers would have to set the framework for the widespread implementation of reusable packaging in trade and industry by means of appropriate requirements. The specifications for advanced recycling rates or reusable circulation rates could be made binding as either/or conditions in suitable legal acts. The expert proposals for the delegated act on the circular economy in the context of the European Taxonomy Regulation can be used as a model here (Platform on Sustainable Finance (PSG) 2022)..

Reusable crates in particular are also often used in international trade, e.g. between the EU and neighboring countries such as the UK, Switzerland and the Western Balkan states. There is a risk that these reusable plastic products will be burdened with already introduced or soon to be implemented plastic taxes on every single circulation across borders of economic areas. Legislators in Brussels, the EU member states and also trading partners in the external area should make regulations that exclude such tax payments burdening the reusable systems.

The multiway bars are made of thermoplastic monomaterial. This makes them very easy to recycle after they have to be sorted out, e.g. due to damage. Changes to the material base should be made in such a way that they do not have a recycling-critical effect in the future. Composite solutions that are difficult to recycle, elastomer gating parts and other forms of material mixes should also be avoided in the future. Improvements in performance should be achieved from improved shape or surface textures.

Further developments in the reprocessing of the thermoplastics used by means of improved additives and process optimization can further advance high-quality plastics recycling in the future. In practice, the crates sorted out of the reusable systems are almost always fed into material recycling. There is still considerable potential for improvement in the proportion of recycled material, which is currently also due to the fact that the systems are growing and the crates sorted out and available for recycling are not sufficient to cover the demand for new material. Nevertheless, the aim should be to use as high a proportion of recycled material as possible in the manufacture of multiway crates. If necessary, consideration could be given to obtaining the material for new reusable solutions and the growth of existing reusable solutions from high-quality recyclates from other applications. Manufacturers must comply with the requirements of food legislation. These should be subjected to critical scrutiny by legislators with a view to promoting a circular plastics economy. For the comparative product transport carton, recycling has been established for many decades. However, the loss percentage of approx. 15 percent, which is recorded in every paper recycling step, can hardly be reduced any further; here, further advantages for the returnables are possible.

In terms of repairability, modularity and volume reducibility, reusable crates are exemplary products. The gains in volume reducibility made by folding systems have already shown that they take up hardly any more storage space and transport volume than disposable cartons.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

In terms of product protection, multiway crates can already score with a low breakage rate during full load processes. Better process integration, for example by means of adequate load unit securing and more prudent handling with forklifts, would bring even further improvements.

Multi-way trains can be used to exploit the potential of digitization. Consideration could be given to whether optical codes or radio labels could be used to achieve permeability to the end customer, e.g., through automatic registration when end customers take the boxes home. The boxes could then be used in the online retail of food or as transport boxes for purchases in supermarkets. It would also be interesting to integrate sensors that indicate aging of the crate due to temperature changes and UV radiation, and recommend the crate for removal for recycling (incl. necessary repairs at the molecular level: chain linkage, extension, removal of contaminants, etc.).

7.2 Plant trays

7.2.1 Application description

Plant trays are transport aids for a different number of plants. Recesses for the plant pots enable safe transport and simplify handling.

The plant trays are filled by the plant producers, in some cases they already use them during cultivation. For subsequent transport, the filled plant trays are usually picked on CC containers and transported to retailers via wholesalers, distribution systems and marketing. Unlike the Steige application example, plant trays are also occasionally used by end customers. They therefore partly represent a B2C application, i.e. when customers purchase several plants, for example, they take them with them in a plant tray.

Empty reusable trays are collected from retailers and, if necessary, picked up by the pool operator (through a logistics service provider) and transported to washing and hygiene centers. There they are washed and disinfected accordingly, and at the same time a quality check is carried out automatically or by visual inspection. The cleaned plant trays are then delivered to the plant producers for the next filling. If defective reusable trays are identified during quality control, they are sorted out - depending on the reusable solution and pool operator - and disposed of like the disposable trays or recycled.

7.2.2 Status for disposable and reusable solutions

Plant trays are currently more than 95 percent disposable solutions on the market (Weschnowsky 2021; Deutsche Umwelthilfe e.V. 2021). Deutsche Umwelthilfe estimates that the annual amount of waste generated by the use of disposable planter trays is around 150 million trays, which corresponds to around 21 million kilograms of (Deutsche Umwelthilfe e.V. 2021). According to BaumarktManager (2021) there are currently around 55 different tray sizes.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

For example, Normpack® currently lists **disposable plant trays** with four different area dimensions in its product overview (Normpack 2021). These have 1 to 30 holes, resulting in a total of 81 variants for disposable plant trays.

EW plant trays are made of polystyrene (PS). According to the company, Normpack trays are 100 percent recyclable (Royal FloraHolland 2021). Currently, a Normpack tray consists of 90 percent recycled material, 50 percent recycled from previous plant trays and 40 percent from other recycling, it said. 10 percent primary raw materials are required due to coloring or lack of recycled material, he said.

The **reusable solution** "Palettino" has been on the market for 20 years (HAWITA Technoplant 2021). The trays are offered with two surface dimensions. With the Danish dimension, 4 trays each fit on a CC board[36] , and with the Euro dimension, 8 trays form a pallet layer (cf. Table 20).

Royal FloraHolland launched the "Floratino" reusable solution in the plant tray sector at the end of 2013. Currently, five tray types exist with the same external dimensions but different number of holes per tray (Royal FloraHolland 2021). They are made of polyethylene and range in weight from 375 to 411 grams (Royal FloraHolland 2021). The 6-hole Floratino tray is currently manufactured from 100 percent virgin material (van Paassen and Scholten 2020).

Pöppelmann's TEKU® "MS + R" product series for transport and culture trays comprises 6 different reusable solutions (cf. Table 20). They are made of polyethylene or polypropylene. (Pöppelmann 2021)

Table 20: Key data plant trays

Solution	Area dimension [mm]	Number of trays	Source
Normpack®	270 x 250 400 x 280 560 x 310 560 x 250	10 per CC board 6 per CC board 4 per CC board 5 per CC board	(Koskela et al. 2014)
Palettino®	530 to 540 x 300 to 315 390 x 275	4 per CC board 8 per pallet layer	(HAWITA Technoplant 2021)
Floratino®	540 x 310	4 per CC board 8 per pallet layer	(Royal FloraHolland 2021)
TEKU® "MS + R"	395 x 280 385 x 284 565 x 383 432 x 432	6 per CC board 6 per CC board 3 per CC board 2 per CC board	(Pöppelmann 2021)

36 For more information on CC containers, see chapter 6.2.1

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

7.2.3 Circularity, performance and sustainability

In chapter 6 of this study, various categories including indicators were proposed to evaluate packaging systems. The indicators were calculated for different packaging systems, presented graphically and compared across applications. In the following, the most important aspects concerning reusable trays are summarized again. Figure 41 gives a comparative overall profile of reusable and single-use trays based on the categories studied.

Circularity

The **number of** reusable trays in **circulation** is already high. The greatest potential here lies in the higher penetration of reusable solutions on the market, thus increasing pool flexibility and intensifying reuse. By definition, single-use systems have a circulation rate of 1.

Reusable trays are expected to have about the same **material efficiency** as reusable crates. A material input of around one gram per liter of product and use seems realistic. Since reusable trays are still under development, this assumes that similarly high circulation rates can be achieved. Since the mass of disposable trays is about half that of reusable trays, material efficiency is significantly worse (approx. 10 grams per liter of product and use) than for disposable trays.

As long as reusable trays are used exclusively in the B2B sector, a **return rate** analogous to that of reusable trays can be expected. However, since opening up to the B2C market is being considered and may also make sense in order to save on further packaging materials, this return rate will in practice be
be somewhat lower in practice. According to the manufacturer, disposable trays currently achieve a return rate of 55 percent.

Plant trays are made of mono-material, identification options are printed/fused on; and they have no moving components. **Reparability** is irrelevant from today's perspective for both disposable and reusable and was therefore rated "neutral".

The basic **recyclability of** reusable trays is very good. They are mostly made of a monomaterial (PP or HDPE) that can be mechanically recycled very well. All sub-steps of the recycling of these materials are state of the art, which means that the practical recyclability can also be regarded as very good.

The **recycling rate of** the reusable plant trays is stated by one pool operator to be 100 percent. They are made of a high-quality mono-material, which is reused in the production of new trays.

The recycled **content of the** reusable trays is 100 percent. Such a high use of recyclate is possible because these products do not require approval for contact with food.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

Reusable trays are pawned so that littering is unlikely or only temporary. Mechanical stress can be very high in some cases due to the weight of the plants, and brittleness is likely due to UV radiation over a longer period of time. Therefore, it can be assumed that some trays will break or splinter over time, resulting in minor **plastic emissions.** The effects described above also occur with disposable trays, although they are likely to have a much greater impact due to the smaller wall thicknesses and lack of labelling.

Performance

With regard to **modularity,** the establishment of uniform surface dimensions for plant trays is relevant, which is currently being discussed by the industry as part of the development of a Europe-wide reusable solution ("Flowertray" project). In the field of EW plant trays, there are still a large number of different tray sizes. In principle, it is disadvantageous from the point of view of a uniform area measurement to adhere to the parallel distribution paths for plant trays by means of pallets (food retail) and CC containers (construction/plant market).

The **volume reducibility of** reusable trays is given by their nestability. However, this is limited by their design (e.g. the height of the tray rim). Furthermore, the standardization and compatibility of the number and arrangement of holes also influences the nestability of plant trays. Due to their comparatively low height, plant trays perform worse than the other demonstrators by definition of indicator value.

The product protection currently realized with EW plant trays must also be guaranteed by future reusable solutions. The interview partners agree on this. Due to the currently not yet available data, the breakage rate was rated as neutral.

Due to the non-destructive circulation, reusable trays, with a simultaneous interest in growth parameters for the transported plants (moisture, pH, radiation, etc.), exhibit a very high level of **digitalizability.** This potential cannot be activated if the disposable trays are only used once because of the high costs involved.

The separate consideration of the **transport distance** also illustrates for plum trays that the distances upstream and downstream of the use are negligible compared to the application area. Therefore, MW solutions for regional application of plant trays are evaluated favorably compared to disposable solutions.

Sustainability

In comparison, reusable trays for plants perform better than single-use trays in the **GHG emissions** category. The main drivers of GHG emissions from reusable trays are transport and cleaning processes. However, the study situation for plant trays in this category is rather poor, so further testing is recommended.

Reusable trays for plants show a **cumulative energy input that is** about 25 percent lower and thus better than that of disposable trays. However, only one study with one variant each for disposable and reusable could be evaluated for the

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

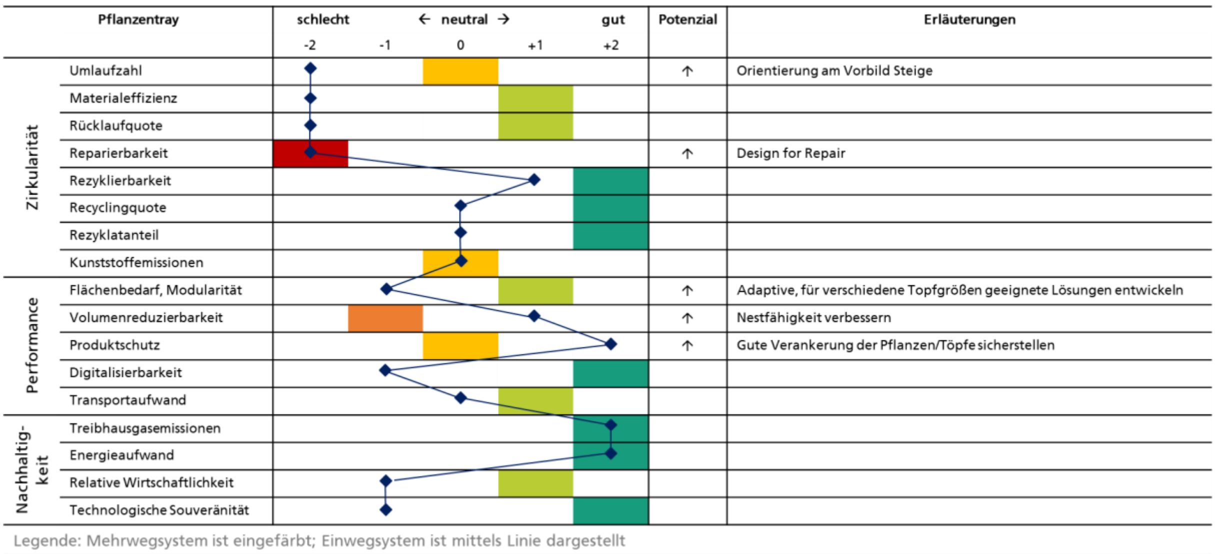
assessment. For this reason, the advantages would have to be validated in further studies.

Provided that more than 50 cycles are achieved with the reusable trays, they show similarly good **relative cost-effectiveness**[37] as the crates. However, the costs for cleaning are more significant. Assuming that the trays are cleaned on each cycle, an increase in the number of cycles would hardly save any costs. In practice, however, it has already been shown that cleaning is not necessary for every cycle. The economic efficiency of the reusable systems is therefore even better than calculated in the model calculation.

Since disposable trays are already largely made of recyclate and the amount of plastic used has already been reduced as far as possible, they have good relative cost-effectiveness compared to other disposable packaging. Nevertheless, this cannot compete with that of reusable systems.

The **technological sovereignty of** an established reusable system results from the import dependency for the materials used and the shrinkage rate. This results in a very high technological sovereignty for reusable trays, which is only slightly below that for crates. However, since the reusable tray system is still being developed, this situation may become less favorable in the next few years until extensive saturation is reached in the market. In all likelihood, the fact that the material pool is planned to be built up from recyclates will have an advantageous effect. Disposable trays achieve a high level of technological sovereignty thanks to a fairly high recyclate content, but this is nevertheless lower than for reusable trays.

Figure 41: Overview for plant trays



37 For the specific definition of relative economic efficiency in this study, see Sect. 6.3.3.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

7.2.4 Optimization potential

Compared to the crates, the study and data situation for plant trays is still insufficient.

In the case of plant trays, the greatest challenge in product design is to establish a uniform area dimension for two parallel distribution paths, i.e. by means of pallets (food retailing) and CC contai ners (construction/plant market), so that the multitude of current tray sizes can be reduced and modularity improved at the same time. Furthermore, product design must also focus on optimal nestability of plant trays (by, among other things, standardizing and making compatible the number and arrangement of holes). The product design thus lays essential foundations for optimal logistical processes, such as the optimal utilization of means of transport as well as handling during handling and cleaning. The variety of reusable trays is limited compared to disposable trays. Good solutions must be developed that nevertheless allow the plants and plant pots to be firmly anchored.

In terms of circulation figures, the reusable trays should achieve similar values to the crates. However, this remains to be seen in practice and it would be good if the pool operators could document the actual circulation figures in a reliable manner. Especially in the sustainability categories, further improvements compared to single-use trays can be achieved by optimizing usage. The designs for the reusable trays to date take into account aspects of lightweight construction, so that hardly any further gains are expected in material efficiency, apart from those brought about by higher circulation figures.

Replacement of defective components is not yet planned for the trays. If feasible, this should be taken into account in the future, whereby disadvantages in terms of robustness must be avoided. If necessary, a redesign could also address aspects of modularity and volume reduction at the same time. More efficient solutions should be developed for nesting in particular. Adaptability to different pot sizes would also be a gain.

Reusable plant trays are made of thermoplastic plastic monomaterial based on recyclates. After they have to be sorted out, e.g. due to damage, they can be recycled again. Nevertheless, further developments in the reprocessing of thermoplastics through improved additives and process optimization are possible and sensible. In particular, environmentally friendly stabilization against aging processes is also worthwhile in the case of plant trays.

7.3 Coffee to go cup

7.3.1 Application description

The coffee-to-go cup is representative of a wide range of packaging that enables ready-to-eat food to be taken away or eaten on the go (take-away food). The corresponding packaging systems play a central role for many fast food

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

restaurants, bakeries and companies from the system catering sector with a counter service, for online and pick-up services and drive-ins. Without them, the respective business model would be almost inconceivable.

The Gesellschaft für Verpackungsmarktforschung (Society for Packaging Market Research) determined an annual consumption volume for the "disposable tableware and packaging for immediate consumption" sector of 281,186 tons in 2017 (Gesellschaft für Verpackungsmarktforschung mbH (GVM) 2018). This corresponds to approximately 3.4 kilograms per person per year. Since 1994, the quantity has increased by an average of 2.5 percent per year. The plastic share of disposable tableware and packaging for immediate consumption is approximately 27.6 percent and has increased at an above-average rate of 3.9 percent per year since 1994.

The "to-go cup" was initially invented by Lawrence Luellen at the beginning of the 20th century as a disposable paper cup for cold drinks. With the onset of the Spanish flu (1918-1920), aspects of hygiene became the decisive selling point that drove its spread. Its use as a coffee-to-go cup began with the New York grocery store chain "7-Eleven". After coffee had increasingly established itself as a luxury food among broad sections of the population, the snack chain began offering coffee in cups made of foamed polystyrene in 1964. In the 1980s, the disposable cup with lid was introduced at Starbucks (Gräf 2018). The coffee-to-go cup gained negative attention when Stella Liebeck, who suffered third-degree burns when she spilled coffee from a to-go cup, sued the fast-food chain McDonald's for $640,000 in pain and suffering and punitive damages. (Schneider 2014).

92 percent of Germans drink coffee, 72 percent even daily. 17 percent consume coffee-to-go several times a week or even daily, and another 50 percent occasionally. These figures alone suggest several billion uses per year. Coffee-to-go is drunk in roughly equal proportions on the way to or from work or during leisure time. (Aral 2018)

The fill volume of beverage cups for out-of-home consumption varies from about 80 to 600 milliliters. The average fill size is 227 milliliters. The cup consists of up to three components: Cup, lid and sleeve for hot beverages. In addition, there are aids for stirring, carrying or straws. (Kauertz et al. 2019)

7.3.2 Status for disposable and reusable solutions

In the area of **disposable cups,** cardboard with polyethylene coating and polystyrene (PS) dominate in terms of the materials used. In addition, there are also cups made of cardboard with polylactide coating as well as plastic cups made of expanded polystyrene (EPS), polypropylene (PP) or polylactide (PLA). The mass of the cups varies between about 4.1 and 18.2 grams per cup, depending on size, material type and design (single- or double-walled). The plastic content of the cardboard cups is about 4 to 7 percent. The disposable lid is mostly made of polystyrene and weighs 3.2 grams. (Kauertz et al. 2019)

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

The consumption of disposable beverage cups for hot drinks is estimated at approximately 2.8 billion per year in Germany. The total quantity is made up of approximately 1.66 billion cardboard cups and 1.14 billion plastic cups. Of the total quantity, around 1.1 to 1.2 billion cups are used in the to-go sector. (Kauertz et al. 2019)

Various systems can be distinguished in the case of **reusable cups** for the to-go sector:

- Private reusable containers ("bring your own", BYO system),
- provider-specific returnable cups (usually including a coffee credit) and
- Returnable cups in a pool system.

In 2015, German Environmental Aid launched the project "Be a cup heroine!" (Deutsche Umwelthilfe e.V. 2015). The project also addressed the need for pool systems. In response, numerous offers for private reusable cups initially emerged, primarily as promotional gifts. Since 2016, the first pool systems have been established in Germany. (Pachaly 2021).

The introduction of a pool system is associated with high effort and great risks, as this only becomes attractive when a high area coverage is achieved with many locations. Consequently, company-specific or municipal solutions were initially established, mostly in large cities (Düsseldorf Becher (RP-Online 2017), FreiburgCup (FreiburgCup 2021), "Stay true to your cup" in Mannheim (Mannheim Climate Protection Agency 2021); Back Cup in the Höxter district (District of Höxter - Department of Environment, Construction and Geoinformation 2021). These cups still have a high diversity of materials. For example, cups made of polylactide, polypropylene with a disposable lid made of polystyrene or those made of styrene-acrylonitrile copolymer with a lid made of TPE and a closure made of polypropylene are in use. These municipal solutions make it difficult to distribute them beyond the region, which would be useful for travelers, commuters or professional drivers, for example.

Against this background, the expansion of supra-regional pool systems that rely exclusively on polypropylene cups and lids is an important development for the permanent establishment of reusable systems. The currently most important systems are:

- RECUP (> 8900 issuing points) (ReCup 2021) ,
- FAIRCUP (> 3200 outlets) (FairCup GmbH 2021) ,
- CUPFORCUP (> 1000 distribution points) (CUPFORCUP Ltd. 2022) and
- VYTAL (n.d. to the issuing points) (VYTAL Global Ltd. 2022).

The first three systems relied on a €1 deposit system. Vytal uses a digital approach instead. Those who use such a cup must register, and if they do not return it after 14 days, the loan is converted into a purchase. ReCup is considering introducing this system, known as "digital cashless," in parallel (Pachaly 2021). The systems are financed by a system fee per location. Another system based on polypropylene cups is the ÖkoCup (moBrands GmbH 2022). Unlike the others, this is a purchase cup that must be purchased from the distributor. The deposit is set at a uniform

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

0.50 euros. Vending machines are also available for the return of the cups. To ensure that hygiene regulations are observed when handling returnable cups, there are guidelines, leaflets and instructional videos for consumers and distributors, e.g. the leaflet for handling coffee-to-go cups brought in by the German Food Association. (German Food Association 2020).

Assuming that single-use systems are only used once and that approx. 6 million reusable cups have been issued to date, reaching an average of 15 uses per year (Pachaly 2021), the current usage share for reusable systems is approximately 3.1 percent (Table 21).

Table 21: Comparison of the distribution of the systems (Kauertz et al. 2019)

System	Material	Uses	Share of uses
Disposable cups	PS	1 140 000 000	39,4 %
	PPK+PE	1 660 000 000	57,4 %
Reusable cup	Plastic	90 000 000	3,1 %

The reusable systems are currently recording significant growth rates both in terms of the number of dispensing points, the number of cups dispensed and the number of uses. It can therefore be expected that the share of usage will increase significantly in the coming years.

A further boost to the uptake of reusable systems could come from a targeted levy on disposable systems. Behavioral economic analyses show the high potential of price increases on single-use cups. They were even significantly more effective than discounts on reusable cups. An effect referred to as loss aversion. (Poortinga and Whitaker 2018).

7.3.3 Circularity, performance and sustainability

In chapter 6 of this study, various categories including indicators were proposed to evaluate packaging systems. The indicators were calculated for different packaging systems, presented graphically and compared across applications. In the following, the most important aspects concerning returnable cups are summarized again. Figure 42 gives a comparative overall profile of returnable and disposable cups based on the categories studied.

Circularity

The **number of** reusable cups in **circulation** is already high. The greatest potential here lies in the higher market penetration of reusable solutions, thus increasing pool flexibility and intensifying reuse.

From as few as 5 uses, the **material efficiency of** reusable cups reaches that of competing disposable cups. The circulation figures achievable in practice are still

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

unknown. In principle, however, the material consumption per use and liter of filling material will be higher than for other reusable applications, since protection against heat and the necessary stability place higher demands on the cup.

In the area of dispensing points, a **return rate of** 90 percent was determined for reusable cups. It is to be expected that this return rate will also be similar for the entire pool, as there are usually fewer losses in the professional sector than in the B2C sector. If reusable cups become more widespread, it can be assumed that the return rate will increase, as special effects such as cup collection in private households are then likely to be less significant. Since large quantities of disposable cups are used for out-of-home consumption, it can be assumed that they are primarily added to residual waste via public trash cans. This material stream is generally not available for the circular economy.

Repairability is irrelevant from today's perspective and was therefore rated neutral.

The basic recyclability **of** coffee-to-go returnable cups is very good. In practice, cups are almost exclusively made of PP monomer material, which can be mechanically recycled very well. All sub-steps in the recycling of these materials are state of the art, which means that the practical recyclability can also be regarded as very good.

The **recycling rate of** reusable cups is generally assumed to be very high (> 90 percent) because they are made of a high-quality monomaterial. Cups from pool systems are almost exclusively recycled at the end of their useful life.

No information is given in the literature on the **recycled content of** C2G returnable cups. According to information from an expert interview, it is less than 10 percent. The rules for the use of recyclate in food contact, especially in the use of plastic products for hot beverages, stand in the way of higher recyclate use.

Plastic emissions due to littering are not to be expected due to the deposit on the reusable cups. However, cups are likely to be destroyed occasionally at events, for example, and remain in the environment. Undeposited disposable cups are a typical find at clean-ups and represent a serious environmental problem.

Performance

Modularity is used as an evaluation criterion in this study, particularly for transport packaging. Since coffee-to-go cups represent product packaging, their indicator value is assumed to be neutral here, in the sense of irrelevant.

The **volume** reducibility **of** returnable cups is given by their nestability. The exact dimension is limited by their design (e.g. the height of the cup rim).

Due to the higher stability of reusable cups, a lower breakage rate and thus better **product protection** and user protection are expected. Due to the currently not yet available data, the breakage rate was assessed as rather good.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

In the case of returnable cups, the costs for optical codes or passive radio technology are hardly significant due to the higher number of cups in circulation, so that they can **be digitized to a** high degree. At the same time, the returnable cup is a particularly interesting object in direct interaction with the consumer. For example, future events can be advertised or information about the ingredients of the beverages can be provided.

Even if not provable by the currently published studies, it is assumed that for coffee-to-go cups the **transport distances** upstream and downstream of the use are also negligible compared to the area of use. Furthermore, for this B2C demons trator, the area of use is local, and thus low distances are required during use. However, an evaluation was not carried out due to a lack of data.

Sustainability

Even though the studies examined set very different framework conditions, the reusable cups show a slightly better median result than the disposable cups in terms of **greenhouse gas emissions. In** particular, plastic reusable cups have advantages in this category due to adequate take-back logistics, responsible consumer behavior, rinsing and other processes powered by eco electricity, and the absence of disposable lids.

On average, however, the disposable cups are slightly better than reusable cups in the **cumulative energy expenditure** category. The results indicate that this could be due, among other things, to the lower volumes of the reusable cups compared to the disposable cups. It should be examined whether reusable cups with the same volume perform better here.

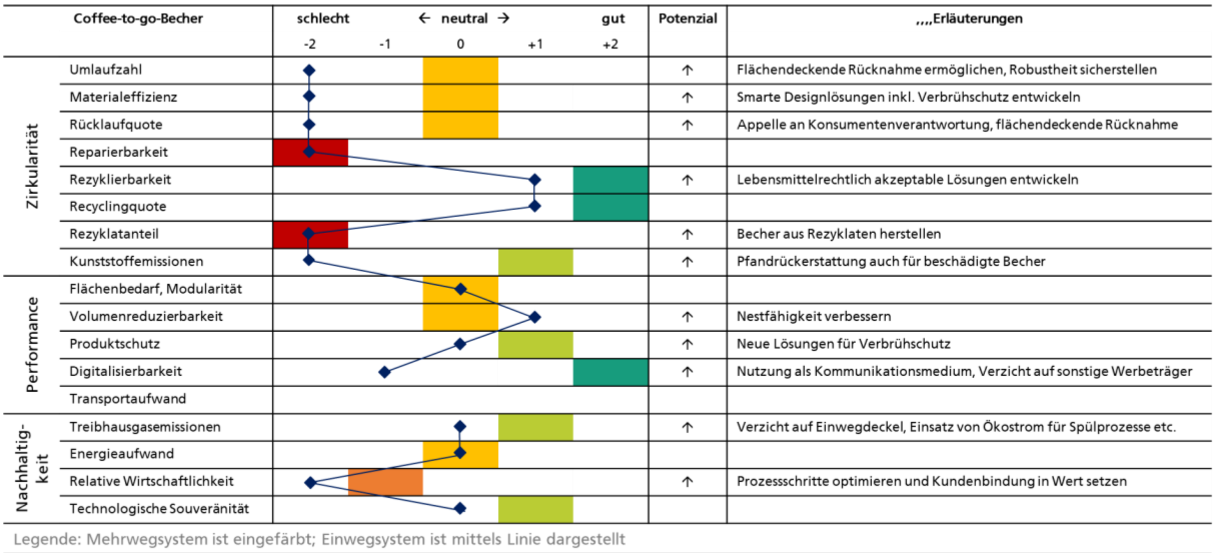
The **relative cost-effectiveness**[38] of reusable cups is still largely unknown. In particular, there is a lack of information on the location and type of cleaning as well as on any additional personnel required at the dispensing points. Nevertheless, it can be expected that the cups will have a somewhat lower cost per use than the competing disposable cups.

Due to a currently still high attrition rate and the necessary set-up of the systems, **technological sovereignty is** lower than for other reusable systems. However, this should continue to improve as penetration increases. Disposable cups made of paper or cardboard also have quite good technological sovereignty, as the import share for paper is rather low. In the case of a plastic coating or a cup made entirely of plastic, technological sovereignty is significantly lower.

38 For the specific definition of relative economic efficiency in this study, see Sect. 6.3.3.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

Figure 42: Overview for coffee-to-go cups



7.3.4 Optimization potential

Compared to the disposable cup, the coffee-to-go reusable cup has some development potential. With a correspondingly high number of cups in circulation, the main drivers here lie in an optimized use phase involving consumers, since they are important players in the cycle - in contrast to the other two demon-trators investigated. The introduction of a comprehensive and decentralized take-back and rinsing logistics system and an appeal to consumers to take responsibility for their own behavior could increase the number of items in circulation and the return rate.

A strong argument in favor of the reusable cup would be if it were also made of recycled material. Here, solutions acceptable under food law must be developed.

It is to be expected that bepfanded reusable cups will hardly be littered. However, they could also be used as a valuable information platform against littering. Damaged cups should be taken back for a deposit refund.

Nestability should be optimized so that there are no disadvantages in terms of storage space requirements. The fact that reusable cups allow a higher material input with simultaneously low material intensity due to high circulation rates should be used to improve drinking comfort and scalding protection.

As B2C packaging, the cup offers an ideal basis for communication to and with the customer. Information can be provided about return points, but the cup can also function as an advertising medium when coupled with a smartphone and app and substitute other advertising media. Other applications are also conceivable, such as monitoring drinking behavior, etc.

To extend the benefits in greenhouse gas emissions, reusable cups should consistently dispense with disposable lids. The cumulative energy input should be

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

reduced by increasing the efficiency of cleaning processes and reducing the use of materials.

Economic efficiency can be ensured through efficient logistics and cleaning processes. In addition, however, reusable cups can also improve customer loyalty; this could be evaluated as part of further studies.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

8 Other categories without ratings

Other categories that were investigated but ultimately not included in the final evaluation are listed below. They either turned out to be irrelevant (material criticality and critical additives) or the data basis did not allow an accurate evaluation (resource depletion).

8.1 Material criticality

Raw material risks can lead to supply and price risks in the short to long term in the serial process of manufacturing products. In addition, product manufacturers are increasingly being held accountable for the environmental and social impacts of raw material extraction and processing. Sales and image risks can therefore arise from the use of raw materials that are to be assessed as critical in this respect. The identification of raw material risks is therefore an important aspect for sustainable product development.

The term raw material criticality describes risks of raw material supply. In analyzing them, the supply situation of raw materials is reviewed on the basis of geological, structural-technical, geopolitical, economic, ecological, and social-societal criteria (Kranich et al. 2019).

Evaluation measure/indicator

The criticality assessment method is based on the analysis of supply risk and susceptibility (vulnerability) of economies, industries or companies to supply shortages. A few years ago, such an assessment was described in VDI 4800, Sheet 2 (VDI guideline)for the first time in a standard. It defines a total of 16 criteria for supply risk, which can be assigned to the following three main categories: geological and structural-technical, geopolitical and regulatory, and economic aspects of raw material supply. Geological raw material risks refer to the availability of raw material quantities that have not yet been mined and their range, based on current production figures. An example of structural factors is the extraction of raw materials as a by-product, where extraction is determined by the economic viability of the main product. Geopolitical and regulatory risks arise, for example, from country concentration of raw material deposits or production, as well as framework conditions such as non-tariff trade barriers. Economic criteria assess the supply and demand situation. They also include the price volatility of raw materials and the assessment of adaptability through substitution of the raw material.

According to VDI 4800, Sheet 2, vulnerability refers to a company and not, for example, to an economy or an industry. (VDI guideline)vulnerability refers specifically to a company and not, for example, to an economy or an industry. Indicators for its evaluation are, for example, the risk-related share of a raw material in the contribution margin, the proportional purchase value of a raw

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

material in the total raw material purchase and the raw material value for the product function.

For the purposes of the considerations in this study, vulnerability is not considered, but focuses solely on supply risk.

Materials to be considered

The demonstrator products under consideration (reusable transport crates and crates, reusable coffee cups and reusable plant trays) are generally made from the plastics polyethylene (PE) or polypropylene (PP). Both are thermoplastic polyolefins. Their basic building blocks, ethylene and propylene, are produced predominantly (>99 percent) from fossil raw materials. Crude oil predominates, while natural gas accounts for a small proportion, especially in the USA for the production of polyethylene. Biobased PE and PP grades are available on the market in small quantities, totaling less than 400,000 t/a, out of a total PE and PP production volume of about 200 million t/a. Due to these volume ratios, the consideration of criticality is limited to the fossil-based polymers.

The production of fossil-based plastics in the EU has a high dependence on the import of petroleum as a raw material (84.9 percent in 2011) (Bilici, N., Pehlivanli, R., & Ashirkhanova, K. 2017). Accordingly, the import dependency is high, but due to a large number of importing countries, it is currently not critical. Demand for crude oil for plastics production and energy supply will increase worldwide in the coming years, but with a moderate increase in consumption, it should be possible to continue to ensure supply (Gaedicke et al. 2020). Even if the supply situation for crude oil were to become critical in the medium term (in 20 to 30 years), plastics production could switch to other sources. Polyethylene can be produced just as cost-effectively as from light petroleum fractions from the liquid associated gas of natural gas production. Ethylene and propylene can also be produced from the chemical intermediate methanol. The latter is currently produced mainly from natural gas, but its production from coal, which is still available in large quantities, or from non-finite sources such as biomass or carbon dioxide and renewable hydrogen offers further alternatives that are not critical from the point of view of raw material supply. Increased efforts to reduce climate gas emissions may, however, lead to changes in the prices of fossil raw materials in the future and thus alter the economics of supply.

Polyethylene and polypropylene raw materials need to be treated with stabilizing additives for their processing and to ensure long shelf life. The primary and secondary antioxidants and light stabilizers used for this purpose are also largely based on petrochemical feedstocks. In addition to the basic element carbon, they contain phosphorus and nitrogen. The latter is obtained for organic syntheses via the Haber-Bosch process as ammonia from atmospheric nitrogen and hydrogen and is thus available in non-limited quantities - assuming a sufficient energy supply for this endothermic high-pressure reaction. Phosphate ores are the source of phosphorus for use in organic chemistry. These are currently classified by the German Raw Materials Agency (Al Barazi et al. 2021) in risk group 2, medium risk, with regard to security of supply. (Al Barazi et al. 2021). However, when assessing

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

the risk to the supply of phosphorus for the production of specialty chemicals, it must be taken into account that by far the predominant use of phosphorus is in the fertilizer industry, which accounts for 82 percent of the phosphates mined worldwide (Killiches 2013). In addition to the chemical industry, the food and beverage industry and the animal feed industry also use phosphorus-containing basic chemicals. In the chemical industry, on the other hand, the use of phosphates in detergents and cleaning agents has been steadily declining for years. We therefore assume that there will also be no fundamental supply risks in the coming decades for the proportionally very low supply of phosphorus to the specialty chemicals sector of plastics additives. Here, too, however, there may be price increases due to the limited nature of phosphate ore as a resource.

Conclusion: The analysis conducted as part of this study did not yield any significant results on the criticality of the reusable plastic packaging considered. We conclude that the category of raw material o material criticality is not considered further in the analysis of the demonstrators.

8.2 Critical additives

Many plastic products contain additives that alter their physical-mechanical properties, e.g. flame retardants, plasticizers or stabilizers. The additives used used to include chemicals that are now understood to be "substances of very high concern" *(SVHC, Substances of Very High Concern, a list of critical chemicals according to the European Chemicals Agency, ECHA)* under the REACH Regulation (EC 1907/2006), or even classified as "persistent organic pollutants" *(POPs, Persistent Organic* Pollutants*, according to the United Nations Stockholm Convention)* (UNEP). Examples of such chemicals (elements, compounds, or groups of chemical compounds) include organic halogen-containing compounds such as DDT, polychlorinated biphenyls (PCBs), dioxins, brominated flame retardants, and polyfluorinated surfactants. But also some phthalate esters, which are used as plasticizers in some plastics, lead-containing pigments, simple aromatics such as benzene and toluene, or polycyclic aromatic hydrocarbons (PAHs) are among them.

For classification as SVHC, a substance must at least meet the criteria of Article 57 of the REACH Regulation. (EC 1907/2006) comply:

- Carcinogenic according to Article 57a *(classification in category 1A or 1B carcinogenicity hazard class according to CLP)*;
- mutagenic according to Article 57b *(classification in the hazard class germ cell mutagenicity of category 1A or 1B according to CLP)*;
- Toxic to reproduction according to Article 57c *(classification in category 1A or 1B reproductive toxicity hazard class according to CLP)*;
- persistent, bioaccumulative and toxic according to Article 57d in accordance with the criteria in Annex XIII of the REACH Regulation (PBT substances);
- very persistent and very bioaccumulative according to Article 57e in accordance with the criteria in Annex XIII of the REACH Regulation (vPvB substances);

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

- there is scientific evidence of probable serious effects on human health or the environment, for example neurotoxic substances and endocrine disruptors; such substances are assessed on a case-by-case basis under Article 57f.

Following these criteria, 54 substances or substance groups were classified as SVHCs by February 2020 and included in the list of substances subject to authorization in Annex XIV of the REACH Regulation. A number of other substances/groups of substances, 52 in number, among them the POPs from the Stockholm Convention, were already subject to restrictions when the REACH Regulation came into force and are listed in its Annex XVII (EC 1907/2006).

Evaluation measure/indicator

The extent to which critical additives may be contained in the corresponding demonstrator products (reusable transport crates and crates, reusable coffee cups and reusable plant trays) is being considered. These are generally made from the plastics polyethylene (HDPE) or polypropylene (PP). The transport boxes and cups are products that come into contact with food. They are therefore subject to EFSA (European Food Safety Authority) regulations for food contact substances. Only the approximately 600 substances approved in Europe and listed in the current version of Regulation EU 10/2011 (EU 10/2011) may be used as additives and polymer production aids for plastics.

In plastics, the base polymer is usually processed in the form of a formulation (compound) with various additives. These are substances that are added to improve the processing, functionality and aging properties of the polymer. Plastic additives can essentially be divided into the following 4 categories. (Hansen et al. 2013):

- Functional additives (stabilizers, antistatics, flame retardants, plasticizers, lubricants, slip agents, curing agents, blowing agents, biocides, etc.)
- Dyes (pigments, soluble dyes, etc.)
- Fillers (mica, talc, kaolin, clay, chalk, barium sulfate, etc.)
- Reinforcing materials (mainly glass fibers, carbon fibers).

Polyethylene and polypropylene raw materials need to be provided with stabilizing additives for their processing and, in order to ensure a long shelf life. Primary and secondary antioxidants and light stabilizers are used for this purpose (Wegmann et al. 2016). Furthermore, depending on the application, these polyolefins also contain processing aids such as lubricants and lubricating agents, for example, in screw caps. (Gall et al. 2020). Mineral fillers, especially talc or chalk, serve to increase the mechanical stability and reduce the price of the compounds, since they are inexpensive mineral additives. (Knerr and Hersche 2016). An overview of the most important functional additives in plastics has been compiled by ECHA together with plastics manufacturers and is available on the Internet (https://echa.europa.eu/de/mapping-exercise-plastic-additives-initiative).

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

Potentially harmful additives used in PE and PP from the overview of toxic substances in plastics in. (Hansen et al. 2014):

- Triclosan (biocide, on Norwegian priority list) but: no food approval and statement: "exposure of consumers from plastics is assumed negligible".
- Lead-containing pigments
- Malachite green hydrochloride, malachite green oxalate (dye)
- C.I. Disperse Yellow 3 and C.I. Solvent Yellow 14 (yellow dyes)
- PAHs from black dyes
- UV stabilizers, antioxidants and other stabilizers:
  due to low concentrations (0.1 - 1.0 percent) only low exposure risk for consumers

In polymers other than PE, PP and PS, which are relevant for the examples considered here, especially the polyvinyl chloride PVC as well as in rubber compounds, toxic additives such as phthalates, brominated flame retardants, bisphenol-A and its esters, lead, tin and cadmium compounds, formaldehyde, acetaldehyde, nonylphenol compounds, MTBE (methyl tert-butyl ether) or benzene used to be added. All these substances or substance classes have not been and are not usually used in the thermoplastic materials (PE, PP, PS) for cups, reusable transport boxes and plant trays.

These polyolefins do not require plasticizers, since their base polymers already result in flexible materials - unlike PVC, which is very brittle and hard in its pure form; stabilizers containing lead, tin or cadmium, as in PVC, are not necessary, since no aggressive hydrochloric acid can be generated during processing, and flame retardants are not common in the applications. In addition to critical ingredients in PVC recyclates from the construction sector (flooring, window profiles), flame retardants in particular can still be found today as critical ingredients in plastics of many electrical and electronic items (Wagner and Schlummer 2020). In the case of reusable beverage cups made of duromer resins (melamine resin), hazards due to the formation of formaldehyde must be taken into account.

Studies have been described, see e.g. the overview in (Hahladakis et al. 2018), in which migration of antioxidants, light stabilizers, and processing aids commonly used in PP and HDPE into food or food simulants has been observed. However, the authors emphasize that if the legal requirements that ensure the safety of plastic materials in contact with foodstuffs are observed, these materials do not pose any hazards even when recycled.

Conclusion: The observations carried out as part of this study lead to the conclusion that reusable plastic packaging does not contain any critical additives, in the sense of those that are highly hazardous to the environment, if the material manufacturers adhere to the regulations of the chemicals legislation in force in the EU. Consequently, the category "critical additives" is not considered further in the analysis of the demonstrators.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

8.3 Resource depletion

Natural resources, biotic and abiotic, are fundamental to environmental and socioeconomic assessment (Crenna et al. 2018). However, impacts on global resource depletion are most often measured by valuing the use of abiotic resources, such as fossil fuels, minerals, metals, or water. The value of abiotic resource depletion of a substance (e.g., lignite or hard coal) is a measure of its resource depletion and is mainly measured as an assessment metric through life cycle assessment (LCA). Resource depletion depends on the quantity and scarcity of the resources used as well as the extraction rate within the life cycle of a product and thus on the constraints on resource availability for present and future generations (Hauschild et al. 2013) .

Usually, abiotic resource depletion is formed by characterization factors that measure the quantity and scarcity of resources used in antimony equivalents [Sb-eq. Other indicators calculate mineral depletion in iron or oil equivalents [kg Fe-eq. or kg oil-eq.] or monetary resource availability [$]. Characterization factors for abiotic resource depletion are sensitive to changes in production over time and globally available reserves.

Abiotic resource depletion is one of the most frequently discussed impact categories in LCAs. A variety of methods exist for calculating this impact category (van Oers and Guinée 2016). The different methods reflect differences in problem definition within an LCA. However, the debate on the characterization of depletion-related impact categories in LCA is ongoing (Guinée and Lindeijer 2008; Klinglmair et al. 2014; Stotz et al. 2017). Other LCA indicators, such as the "global resource indicator" (Adibi et al. 2017) ,characterize resource use in terms of the circular economy. This indicator is the first to consider the recyclability and criticality of resource use in a multi-criteria indicator that complements scarcity aspects. However, this approach was not found in the current literature on packaging systems, but could be used in future studies to better consider recycling and criticality when evaluating resource use. In this report, we mainly evaluated studies that report resource depletion in antimony equivalents. Resource depletion is also determined in relation to the single-use system, since it is not possible to establish uniform limits for the absolute numbers of different systems. However, only figures based on the same unit, e.g. Sb eq./functional unit, are related.

Conclusion: Resource use as an environmental impact category is considered to have low robustness. Although the environmental impact category is recommended by the Joint Research Center and the EC, this category is assigned robustness level III, meaning that the category is recommended but its application and interpretation are very uncertain. Due to the fact that resource depletion has been investigated in only a few studies here, and this partly on the basis of different methods, this category could not be evaluated due to the insufficient data basis.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

9 Appendix

9.1 Calculation for comparison in primary energy consumption

In the following, the calculation procedure for determining the ratio of primary energy expenditures for reusable to disposable systems is presented. The presentation of the results can be found in Figure 7, chap. 4.4, as well as in Table 22, later in this section.

For single-use systems, the calculation takes into account complete recycling plus cleaning of the granules; for reusable systems, production (apportioned to circulation figures), repair and cleaning are included. A breakage rate of 1 percent was assumed for the repair and 50 percent for the replacement of components. The latter is expressed in additional injection molding effort. The cleaning effort is calculated on a mass basis. Any additional costs for granulate cleaning due to the higher surface area at the expense of the disposable systems were not taken into account.

$$PEA_{EW} = PEA_{EW,SP} + PEA_{EW,REC} + PEA_{EW,CLE} + PEA_{EW,TR}$$

$$PEA_{EW} = m_{EW} * (PEF_{Strom}EV_{SP} + PEF_{Strom}EV_{REC} + PEF_{Gas}EV_{CLE}) + s_{EW} * PEF_{Diesel}(EV_{leer} + EV_{Ladung} * m_{EW})$$

$$PEA_{MW} = PEA_{MW,SP} + PEA_{MW,REP} + PEA_{MW,CLE} + PEA_{MW,TR}$$

$$PEA_{MW} = m_{MW} * \left(\frac{PEF_{Strom}EV_{Sp}(1 + RQ * RA) + PEF_{Strom}EV_{Rec}}{UZ} + PEF_{Strom}EV_{Clean}\right) + s_{MW} * (EV_{leer} + EV_{Ladung} * m_{MW})$$

$$m_{MW} = MV * m_{MW}$$

$$s_{MW} = SV * s_{EW}$$

With the calculation variables:

EV	Energy consumption for injection molding (here: 2.7 kWh/kg), recycling (here: 1.0 kWh/kg), cleaning (here: 0.11 kWh/kg), empty transport (here: 2.9 kWh/km), cargo transport (here: 0.09 kWh/tkm)
m	Mass of packaging, base value for disposable:1000 kg per 25 tons load.
MV	Mass ratio for reusable/disposable (here: varies to 2 and 5).
PEA	Primary energy consumption
PEF	Primary energy factor for electricity, gas, diesel
RQ	Repair rate (here: 1 percent)

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

RA Repair share (here: 50 percent)
s Distance, base value: 750 km
SV Distance ratio reusable/disposable (here: varies to 0.5, 1 and 2)
UZ Number of revolutions (varies here from 1 to 100)

With indexes:

CLE Cleaning
EW One way
MW Reusable
REC Recycling
REP Repair
SP Injection molding
TR Transportation

Calculation result: $PEA_{EW} = 6\ 432\ \mathrm{kWh}$

Table 22: Calculation results for the ratio PEA_{MW} / PEA_{EW} as a function of the varied parameters circulation ratio, mass ratio and line ratio

UZ	$MV = 2{,}0$ $SV = 0{,}5$	$MV = 2{,}0$ $SV = 1{,}0$	$MV = 2{,}0$ $SV = 2{,}0$	$MV = 5{,}0$ $SV = 0{,}5$	$MV = 5{,}0$ $SV = 1{,}0$	$MV = 5{,}0$ $SV = 2{,}0$
1	1,39	1,60	2,00	3,18	3,38	3,79
2	0,82	1,02	1,43	1,73	1,94	2,34
3	0,62	0,83	1,23	1,25	1,46	1,86
4	0,53	0,73	1,14	1,01	1,21	1,62
5	0,47	0,67	1,08	0,87	1,07	1,48
10	0,35	0,56	0,96	0,58	0,78	1,19
15	0,32	0,52	0,93	0,48	0,69	1,09
20	0,30	0,50	0,91	0,43	0,64	1,05
25	0,28	0,49	0,90	0,40	0,61	1,02
30	0,28	0,48	0,89	0,39	0,59	1,00
35	0,27	0,47	0,88	0,37	0,58	0,98
40	0,27	0,47	0,88	0,36	0,57	0,97
45	0,26	0,47	0,88	0,35	0,56	0,96
50	0,26	0,46	0,87	0,35	0,55	0,96
55	0,26	0,46	0,87	0,34	0,55	0,95
60	0,26	0,46	0,87	0,34	0,54	0,95
65	0,26	0,46	0,87	0,33	0,54	0,95
70	0,25	0,46	0,87	0,33	0,53	0,94

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

UZ	$MV = 2{,}0$ $SV = 0{,}5$	$MV = 2{,}0$ $SV = 1{,}0$	$MV = 2{,}0$ $SV = 2{,}0$	$MV = 5{,}0$ $SV = 0{,}5$	$MV = 5{,}0$ $SV = 1{,}0$	$MV = 5{,}0$ $SV = 2{,}0$
75	0,25	0,46	0,86	0,33	0,53	0,94
80	0,25	0,46	0,86	0,33	0,53	0,94
85	0,25	0,46	0,86	0,32	0,53	0,93
90	0,25	0,45	0,86	0,32	0,53	0,93
95	0,25	0,45	0,86	0,32	0,52	0,93
100	0,25	0,45	0,86	0,32	0,52	0,93

9.2 Conducted expert interviews

In addition to the literature review, much of the information in this study was also gathered through expert interviews and has been highlighted where appropriate in the text. The following interviews were conducted:

Fruit and vegetable risers:

- Bekuplast: Andreas Robbert
- IFCO: Bodo Muske
- Schoeller Group: Richard Kellerer
- WBG Pooling: Klaus Endebrock, Ann-Kathrin Herzog, Gerit Hofemeister

Plant trays

- Fraunhofer IML: Wolfgang Lammers
- Schoeller Allibert: Patrick Breukers
- Stiftung Initiative Mehrweg: Günter Gerland, Jens Oldenburg

Coffee-to-go cups:

- reCup: Florian Pachaly

Injection molding of reusable systems:

- Haidlmaier: Mario Haidlmaier

We would like to take this opportunity to thank all the people interviewed once again for their cooperation.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

9.3 Limitations of the study

9.3.1 Data quality assessment

On the basis of expert opinions

We distinguish between the opinion of external experts and the self-assessment of the authors' own expertise, if this has been included in the processing. The evaluation takes place with a single number between 1 and 4 and is performed with the following nomenclature (Table 23):

Table 23: Pedigree matrix for expert evaluation

Points	1	2	3	4
Stage	**Formal expertise**	**Structured Expert opinion**	**Expert opinion**	**Sound Assumption**
Evaluation of the expertise	Fully informed about the subject of the study; information against the background of (empirical) data collection.	Based on some empirical data or on traceable procedure with formal expertises	Informed about the subject of the study, but without a corresponding data basis	Based on speculative or unverifiable assumptions.

A distinction is made between the assessment of data quality from the survey of external experts, marked as [X], and the self-assessment of own expertise, if this has been incorporated: [X]*.

Based on literature and internet sources as well as databases

Literature and internet sources are evaluated by means of a 5 x 4 matrix. The result shows a quintuple of 5 numbers between 1 and 4.

[v, w, x, y, z]: Assessment of data quality from literature and internet sources.

A single source from which several values have been taken may also be assessed differently in terms of the quality of different data.

Table 24: Pedigree matrix for evaluating literature and internet sources.

Points	1	2	3	4
Category/level	**Very good**	**Rather Good**	**Rather bad**	**bad**

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

Completeness	The subject of the investigation is identical	Subject of the investigation is similar or partly corresponds to the subject of the investigation	Subject is comparable but different	Subject is only very vaguely comparable with the object of study
Material and/ or or geometric representativeness	Materials or products investigated are identical to those in the study	Materials or products investigated are similar to those in the study	Materials or products investigated are comparable to those in the study	Materials or products investigated are only vaguely comparable with those in the study
Geographical representativeness	Germany	Socioeconomically and/or climatically similar region (e.g., Central Europe).	Socioeconomically and/or climatically different (EU, USA)	Socioeconomically very different (e.g. world, China) or no boundary conditions specified
Temporal representativeness	< 5 years	5 to 10 years	> 10 to 15 years	> 15 years or no information on the time reference
Source reliability	All relevant data and calculation paths are traceable and correct; official reports, peer-reviewed publications	Calculation method is simplified, but correct or initial data partly inaccurate, market and technology reports of associations	Calculation path is highly simplified or not entirely correct, initial data (partly only roughly) estimated	Calculation path is grossly simplified, flawed and difficult to understand

9.3.2 Comparability of life cycle assessment studies

The values for the environmental impact categories - greenhouse gas emissions and cumulative energy expenditure - were taken from the literature, which refers exclusively to the ISO 14040 series of standards. These standards describe the principles and guidance for a life cycle assessment (ISO 14040:2006; ISO 14044:2006). In impact assessment, the emission and consumption data of an activity or over a product life cycle are compiled in the form of environmental impact categories. Nevertheless, different calculation bases and boundary conditions as well as assumptions can be found in the individual studies. The result of an environmental impact category of packaging systems is significantly dependent on the assumptions. Examples of this are, among others, assumptions on the number of items in circulation or transport distances, but also recyclate use and estimates on material losses as well as return rates. How different these assumptions are in some cases in the individual studies has already been addressed in the respective performance and circularity categories. Therefore, the results of the GHG emissions and the CED for the studied variants should always be considered with the respective assumed values of the performance and circularity categories. In order to compare results of the environmental impact categories of different sources for single-use and reusable systems in this meta-analysis, consistency of results and calculation basis must be ensured, for example, with respect to background data and system boundaries. A consistency of the studies is not completely given, therefore this may

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

lead to uncertainties in the data interpretation apart from the already noted data quality from literature and internet sources using Pedigree matrix. Possible uncertainties and problems in the comparability of LCA results of different studies among each other are pointed out for example by Roßmann et al. (2021) or Weidema (2019) point out.

In addition to different boundary conditions and assumptions, some of the studies examined use different modeling and calculation bases. In most cases, the results are given in the so-called substitution approach. This means that credits for avoided emissions are awarded for secondary resources and energy gains at the end of life if primary resources and energies can be replaced by their provision. Examples include when primary energy is replaced by providing heat and electricity when waste is incinerated. In principle, this is common practice in life cycle assessments - although the use of credits is sometimes criticized (Brander and Wylie 2011). Particularly when comparing plastic and paper packaging, the influence on the result due to the inclusion or exclusion of credits at the end of life can lead to different statements.

For the reasons mentioned above, it is mostly discouraged to compare individual results from different studies due to lack of consistency (Weidema 2019). However, this was partly necessary for the present meta-analysis. The comparison of single-use and reusable systems presented here on the basis of environmental impact using data from different studies therefore reflects an initial estimate and is subject to uncertainty due to its dependence on the assumptions and boundary conditions made. In this study, an attempt was made to establish a basis for comparison by converting the results of the publications considered to a functionally equivalent reference unit, 1000 liters of packaged goods. In detail, individual systems, e.g. for different packaged goods, would have to be investigated separately with reliable assumptions in order to demonstrate the actual advantages of reusable or disposable packaging.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

9.4 Tabular data on the categories studied

9.4.1 Circulation number

Table 25: Rotation numbers and service life for fruit and vegetable crates

System	Circulation number	Lifetime	Source/Expert	Pedigree-Classification
One way	1	Utilization cycle	By definition	
Reusable	1-150		(ADEME 2000)	[1,1,2,4,1]
Reusable	50-100	10	(Albrecht et al. 2009)	[1,1,1,3,1]
Reusable	200	20	(Levi et al. 2011)	[1,1,1,3,1]
Reusable	50 - 200	20	(Albrecht et al. 2013)	[1,1,1,3,1]
Reusable	30 - 70		(Accorsi et al. 2014)	[1,1,2,2,2]
Reusable	700	13,75	(Koskela et al. 2014)	[2,1,2,2,1]
Reusable	20 - 200		(Battini et al. 2016)	[1,1,2,2,2]
Reusable	23,4 - 72,9		(Franklin Associates 2016)	[1,1,3,2,1]
Reusable	100	10	(Baruffaldi et al. 2019)	[1,1,2,2,2]
Reusable	100 - 150	10	(Abejón et al. 2020)	[1,1,2,2,1]
Reusable		7	(Accorsi et al. 2020)	[1,1,2,2,1]
Reusable	150	1,5	(Antala et al. 2020)	[3,3,4,1,3]
Reusable	50	5	(Del Borghi et al. 2020).	[1,1,2,3,2]
Reusable	150		(López-Gálvez et al. 2021)	[1,1,2,1,1]
Reusable	1 - 125		(Tua et al. 2019)	[1,1,2,1,1]
Reusable	50		(Hofmeister et al. 2021)	[1]
Reusable	250		(Haidlmair 2021)	[1]
Reusable	50 - 100	7-10	(Muske 2021)	[1]
Reusable		10-15	(Kellerer 2021)	[1]
Reusable	100 - 200	5-20	(Robbert 2021)	[1]

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

Table 26: Circulation numbers and service life for plant trays

System	Circulation number	Lifetime	Source/Expert	Pedigree rating
One way	1	Utilization cycle	By definition	
Reusable	70		(van Paassen and Scholten 2020)	[1,1,1,1,1]
Reusable	100 - 200		(Breukers 2021)	[1]
Reusable		> 5 years [39]	(HAWITA Technoplant 2021)	[1,1,1,1,4]

Table 27: Circulation figures and service life for coffee-to-go cups

System	Circulation number	Lifetime	Source/Expert	Pedigree rating
One way	1	Utilization cycle	By definition	
Reusable	15 / year	> 5 years[40]	(Pachaly 2021)	[1]

9.4.2 Material efficiency

Table 28: Material intensity for fruit and vegetable crates

System	Specifica tion	average mass [g]	Uses/ Circulation number	Product volume [L]	Material-intensity [g/(L x service)]	Source/Exp ert	Pedigree rating
Reusable	PP	1400	5	22,3	12,56	UMSICHT	[1]*
Reusable	PP	1650	5	29,8	11,07	UMSICHT	[1]*
Reusable	PP	1859	5	36,9	10,08	UMSICHT	[1]*
Reusable	PP	2050	5	44,2	9,28	UMSICHT	[1]*
Reusable	PP	1400	50	22,3	1,26	UMSICHT	[1]*
Reusable	PP	1650	50	29,8	1,11	UMSICHT	[1]*
Reusable	PP	1859	50	36,9	1,01	UMSICHT	[1]*
Reusable	PP	2050	50	44,2	0,93	UMSICHT	[1]*
Reusable	PP	1400	125	22,3	0,50	UMSICHT	[1]*
Reusable	PP	1650	125	29,8	0,44	UMSICHT	[1]*

[39] 5 years product warranty
[40] The current cups have been in circulation since May 2017 at the earliest.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

System	Specification	average mass [g]	Uses/ Circulation number	Product volume [L]	Material-intensity [g/(L x service)]	Source/Expert	Pedigree rating
Reusable	PP	1859	125	36,9	0,40	UMSICHT	[1]*
Reusable	PP	2050	125	44,2	0,37	UMSICHT	[1]*
One way	Cardboard	420	1	22,3	18,8	UMSICHT	[1]*
One way	Cardboard	490	1	29,8	16,4	UMSICHT	[1]*
One way	Cardboard	550	1	36,9	14,9	UMSICHT	[1]*
One way	Cardboard	620	1	44,2	14,0	UMSICHT	[1]*

Table 29: Material intensity for plant trays

System	Specification	Mean. Mass [g]	Uses/circulation	Product volume [L]	Material intensity [g/(L x Service)]	Source/Expert	Pedigree rating
One way	PS	135 (8 pots)	1	0,75(1)	22,5	(Dobers and Lammers 2017; Pöppelmann 2021)	[1,1,1,1,1], [3]*, [1,1,1,1,1]
Reusable	HDPE	400 (10 pots)(2)	5	0,75(1)	10,67	(Dobers and Lammers 2017; Pöppelmann 2021)	[1,1,1,1,1], [3]* [1,1,1,1,1]
Reusable	HDPE	400 (10 pots)(2)	50	0,75(1)	1,07	(Dobers and Lammers 2017; Pöppelmann 2021)	[1,1,1,1,1], [3]* [1,1,1,1,1]
Reusable	HDPE	400 (10 pots)(2)	125	0,75(1)	0,43	(Dobers and Lammers 2017; Pöppelmann 2021)	[1,1,1,1,1], [3]* [1,1,1,1,1]

(1) The volume corresponds to the average volume of 12-13 cm pots

(2) The tray size and pot count take into account an identical utilization per area.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

Table 30: Material intensity for coffee-to-go cups

System	Specification	average mass [g]	Uses/circulation	Product volume [L]	Material intensity [g/(L x Service)]	Source/Expert	Pedigree rating
One way	Paper/PE	8,3	1	0,30	27,7	(Martin et al. 2018)	[1,1,1,1,2]
Disposable vending machine cups	PS	4,1	1	0,18	22,8	(Kauertz et al. 2019)	[1,1,1,1,2]
One way	Cardboard/PE	7,8	1	0,20	39,0	(Kauertz et al. 2019)	[1,1,1,1,2]
One way	Cardboard double wall/PE	12,0	1	0,20	60,0	(Kauertz et al. 2019)	[1,1,1,1,2]
One way	Cardboard/PE	10,7	1	0,30	35,7	(Kauertz et al. 2019)	[1,1,1,1,2]
One way	Cardboard double wall/PE	18,2	1	0,30	60,7	(Kauertz et al. 2019)	[1,1,1,1,2]
Reusable	Ceramics	310	750	0,30	1,4	(Martin et al. 2018)	[1,1,1,1,3]
Reusable	PP	41	100	0,40	1,0	(Pachaly 2021)	[1]
Reusable	PP	33	5	0,30	22,00	(Pachaly 2021)	[1]
Reusable	PP	33	50	0,30	2,20	(Pachaly 2021)	[1]
Reusable	PP	33	125	0,30	0,88	(Pachaly 2021)	[1]

9.4.3 Returns and material losses

Table 31: Response rates for fruit and vegetable batches

System	Specification	Response rate	Source/Expert	Pedigree rating
Reusable	PP	>99 %	(Muske 2021)	[2]
One way	Cardboard	86 %	(Student 2020)	[3,1,1,1,3]

Table 32: Response rates for plant trays

System	Specification	Response rate	Source/Expert	Pedigree rating
One way	PS	55 %	(Normpack 2021)	[3,1,1,1,4]
Reusable	HDPE	>95 %	(Oldenburg 2021)	[2]

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

Table 33: Return rates for coffee-to-go cups

System	Specification	Response rate	Source/Expert	Pedigree rating
One way	PS, PPK	53 %	(Kauertz et al. 2019); Fraunhofer UMSICHT	[1,1,1,1,1] [4}*
Reusable	PP	90 %	(Pachaly 2021)	[2]

9.4.4 Repairability

Table 34: Repairability and resulting indicator values in fruit and vegetable figs.

System	Indicator value	Source/Expert	Pedigree rating
One way	-2	Fraunhofer IML	[1]*
Reusable	-1	(Kellerer 2021)	[1]
Reusable	-1	(Robbert 2021)	[1]
Reusable	+2	Hofemeister (WBG Pooling) 2021	[1]
Reusable	+2	(Muske 2021)	[1]

Table 35: Reparability and resulting indicator values for plant trays.

System	Indicator value	Source/Expert	Pedigree rating
Reusable	0	Fraunhofer IML	[1]*
One way	0	Fraunhofer IML	[1]*

Table 36: Reparability and resulting indicator values for coffee-to-go cups.

System	Indicator value	Source/Expert	Pedigree rating
Reusable	0	Fraunhofer IML	[1]*
One way	0	Fraunhofer IML	[1]*

9.4.5 Recyclability

Table 37: Materials and derived indicator values (IW) for Principle Recyclability (PriRe) and Practical Recyclability (PraRe) for fruit and vegetable stones.

System	Material	IWPriRe	IWPraRe	Source/Expert	Pedigree rating
One way	Cardboard	+2	+2	(Burger et al. 2021)	[1,1,1,1,1]
Reusable	PP / HDPE	+2	+2	(Abejón et al. 2020)	[1,1,2,2,1]
Reusable	PP	+2	+2	(Accorsi et al. 2014)	[1,1,2,2,2]

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

System	Material	IWPriRe	IWPraRe	Source/Expert	Pedigree rating
Reusable	PP	+2	+2	(ADEME 2000)	[1,1,2,4,1]
Reusable	PP / HDPE	+2	+2	(Albrecht et al. 2009)	[1,1,1,3,1]
Reusable	PP / HDPE	+2	+2	(Del Borghi et al. 2020).	[1,1,2,3,2]
Reusable	PP	+2	+2	(Franklin Associates 2016)	[1,1,3,2,1]
Reusable	PP	+2	+2	(Gruyters et al. 2019)	[1,1,2,1,1]
Reusable	HDPE	+2	+2	(Koskela et al. 2014)	[2,1,2,2,1]
Reusable	PP / HDPE	+2	+2	(Krieg et al. 2018)	[1,1,1,1,2]
Reusable	PP	+2	+2	(Levi et al. 2011)	[1,1,1,3,1]
Reusable	PP	+2	+2	(Lo-Iacono-Ferreira et al. 2021)	[1,1,1,1,1]
Reusable	PP	+2	+2	(López-Gálvez et al. 2021)	[1,1,2,1,1]
Reusable	PP	+2	+2	(Singh et al. 2006)	[1,1,3,3,1]
Reusable	PP	+2	+2	(Tua et al. 2019)	[1,1,2,1,1]
Reusable	PP / HDPE	+2	+2	(Hofmeister et al. 2021)	[3]
Reusable	PP / HDPE (PA, PET)	+2	+2	(Haidlmair 2021)	[2]
Reusable	PP	+2	+2	(Muske 2021)	[3]
Reusable	PP	+2	+2	(Kellerer 2021)	[1]
Reusable	PP / HDPE	+2	+2	(Robbert 2021)	[1]

Table 38: Materials and derived indicator values (IW) for Principle Recyclability (PriRe) and Practical Recyclability (PraRe) for plant trays.

System	Material	IWPriRe	IWPraRe	Source/Expert	Pedigree rating
One way	PS	+2	+1	(van Paassen and Scholten 2020)	[1,1,1,1,1]
Reusable	HDPE	+2	+2	(van Paassen and Scholten 2020)	[1,1,1,1,1]
Reusable	PP	+2	+2	(van Paassen and Scholten 2020)	[1,1,1,1,1]
Reusable	PP / HDPE	+2	+2	(Breukers 2021)	[1]

Table 39: Materials and derived indicator values (IW) for Principle Recyclability (PriRe) and Practical Recyclability (PraRe) for coffee-to-go cups.

System	Material	IWPriRe	IWPraRe	Source/Expert	Pedigree rating
One way	PP, PET	+2	+2	(Cottafava et al. 2021)	[1,1,2,1,1]
One way	PLA	+2	0	(Cottafava et al. 2021)	[1,1,2,1,1]

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

System	Material	IWPriRe	IWPraRe	Source/Expert	Pedigree rating
One way	Cardboard/PE	+2	-2[41]	(Cottafava et al. 2021)	[1,1,2,1,1]
Reusable	PP, PET	+2	+2	(Cottafava et al. 2021)	[1,1,2,1,1]
Reusable	PLA	+2	0	(Cottafava et al. 2021)	[1,1,2,1,1]
One way	Cardboard/PE	+2	+2	(Foteinis 2020)	[1,1,2,1,1]
Reusable	PP	+2	+2	(Foteinis 2020)	[1,1,2,1,1]
One way	PP	+2	+2	(Garrido and Del Alvarez Castillo 2007).	[1,1,2,3,1]
Reusable	PP	+2	+2	(Garrido and Del Alvarez Castillo 2007).	[1,1,2,3,1]
Reusable	PP	+2	+2	(Pachaly 2021)	[1]

9.4.6 Recycling rate

Table 40: Materials and recycling rate (RQ) as well as derived indicator values (IW) for O/G rises.

System	Material	RQ (%)	IWRQ	Source/Expert	Pedigree rating
One way	Cardboard	89	+2	(Burger et al. 2021), table 84	[1,1,1,1,1]
Reusable	PP / HDPE	70	+1	(Abejón et al. 2020)	[1,1,2,2,1]
Reusable	PP	80	+1	(Accorsi et al. 2014)	[1,1,2,2,2]
Reusable	PP	20	-2	(ADEME 2000)	[1,1,2,4,1]
Reusable	PP / HDPE	70	+1	(Albrecht et al. 2009)	[1,1,1,3,1]
Reusable	PP / HDPE	93	+2	(Del Borghi et al. 2020).	[1,1,2,3,2]
Reusable	PP	100	+2	(Franklin Associates 2016)	[1,1,3,2,1]
Reusable	HDPE	20	-2	(Koskela et al. 2014)	[2,1,2,2,1]
Reusable	PP / HDPE	77,5	+1	(Krieg et al. 2018)	[1,1,1,1,2]
Reusable	PP	95	+2	(Levi et al. 2011)	[1,1,1,3,1]
Reusable	PP	55	0	(Lo-Iacono-Ferreira et al. 2021)	[1,1,1,1,1]
Reusable	PP	79	+1	(López-Gálvez et al. 2021)	[1,1,2,1,1]
Reusable	PP	100	+2	(Singh et al. 2006)	[1,1,3,3,1]
Reusable	PP	100	+2	(Tua et al. 2019)	[1,1,2,1,1]
Reusable	PP / HDPE	100	+2	Herzog (WBG Pooling) 2021	[1]
Reusable	PP	100	+2	(Muske 2021)	[1]
Reusable	PP	100	+2	(Kellerer 2021)	[1]
Reusable	PP / HDPE	100	+2	(Robbert 2021)	[1]

[41] Specification in the literature source: PE-coated cardboard is incinerated

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

Table 41: Materials and recycling rate (RQ) and derived indicator values (IW) for plant trays.

System	Material	RQ (%)	IWRQ	Source/Expert	Pedigree rating
One way	PS	51,5	0	(Burger et al. 2021), table 84	[1,1,1,1,1]
Reusable	PP / HDPE	100	+2	(Breukers 2021)	[1]

Table 42: Materials and recycling rate (RQ) and derived indicator values (IW) for C2G cups.

System	Material	RQ (%)	IWRQ	Source/Expert	Pedigree rating
One way	PP, PET	85	+1	(Cottafava et al. 2021)	[1,1,2,1,1]
One way	PLA	0	-2	(Cottafava et al. 2021)	[1,1,2,1,1]
One way	Cardboard/PE	0	-2	(Cottafava et al. 2021)	[1,1,2,1,1]
Reusable	PP, PET	85	+1	(Cottafava et al. 2021)	[1,1,2,1,1]
Reusable	PLA	0	-2	(Cottafava et al. 2021)	[1,1,2,1,1]
One way	Cardboard/PE	0	-2	(Foteinis 2020)	[1,1,2,1,1]
One way	Cardboard/PE	100	+2	(Foteinis 2020)	[1,1,2,1,1]
One way	PP	7	-2	(Garrido and Del Alvarez Castillo 2007).	[1,1,2,3,1]
Reusable	PP	100	+2	(Pachaly 2021)	[1]

9.4.7 Recycled content

Table 43: Materials and recyclate proportions (RA) and derived indicator values (IW) for O/G risers.

System	Material	RA (%)	IWRA	Source/Expert	Pedigree rating
One way	Cardboard	83	+2	Ecoinvent database; data set "corrugated board, mixed fiber, double wall, at plant".	[1,1,1,1,1]
Reusable	PP / HDPE	30	0	(Abejón et al. 2020)	[1,1,2,2,1]
Reusable	PP	0	-2	(ADEME 2000)	[1,1,2,4,1]
Reusable	PP / HDPE	70	+2	(Albrecht et al. 2009)	[1,1,1,3,1]
Reusable	HDPE	0	-2	(Koskela et al. 2014)	[2,1,2,2,1]
Reusable	PP / HDPE	10	-2	(Krieg et al. 2018)	[1,1,1,1,2]
Reusable	PP	0	-2	(Levi et al. 2011)	[1,1,1,3,1]
Reusable	PP	0	-2	(Lo-Iacono-Ferreira et al. 2021)	[1,1,1,1,1]
Reusable	PP	0	-2	(López-Gálvez et al. 2021)	[1,1,2,1,1]

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

System	Material	RA (%)	IWRA	Source/Expert	Pedigree rating
Reusable	PP	0	-2	(Singh et al. 2006)	[1,1,3,3,1]
Reusable	PP	61	+1	(Tua et al. 2019)	[1,1,2,1,1]
Reusable	PP / HDPE	0	-2	(Hofmeister et al. 2021)	[3]
Reusable	PP / HDPE (PA, PET)	45	+1	(Haidlmair 2021)	[2]
Reusable	PP	>30	0	(Muske 2021)	[3]
Reusable	PP / HDPE	35	0	(Robbert 2021)	[1]

Table 44: Materials and recycled content (RA) and derived indicator values (IW) for plant trays.

System	Material	RA (%)	IWRA	Source/Expert	Pedigree rating
One way	PS	0	-2	(van Paassen and Scholten 2020)	[1,1,1,1,1]
Reusable	HDPE	0	-2	(van Paassen and Scholten 2020)	[1,1,1,1,1]
Reusable	PP	100	+2	(van Paassen and Scholten 2020)	[1,1,1,1,1]
Reusable	PP / HDPE	100	+2	(Breukers 2021)	[1]

Table 45: Materials and recycled content (RA) and derived indicator values (IW) for C2G cups.

System	Material	RA (%)	IWRA	Source/Expert	Pedigree rating
One way	Cardboard/PE	0	-2	(Cottafava et al. 2021)	[1,1,2,1,1]
One way	PP	0	-2	(Garrido and Del Alvarez Castillo 2007).	[1,1,2,3,1]
Reusable	PP	0	-2	(Garrido and Del Alvarez Castillo 2007).	[1,1,2,3,1]
Reusable	PP	<10	-2	(Pachaly 2021)	[1]

9.4.8 Space requirements and modularity

Table 46: Modularity and resulting indicator values for fruit and vegetable figs.

System	Indicator value	Source/Expert	Pedigree rating
Reusable	2	(Kellerer 2021)	[1]
Reusable	2	Dobers (Fraunhofer IML)	[1]*

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

System	Indicator value	Source/Expert	Pedigree rating
One way	-1 or +1	Dobers (Fraunhofer IML)	[1]*

Table 47: Modularity and resulting indicator values for plant trays

System	Indicator value	Source/Expert	Pedigree rating
Reusable	0	(Breukers 2021)	[1]
Reusable	+1	(Oldenburg 2021)	[1]
One way	-1	Dobers (Fraunhofer IML)	[1]*

Table 48: Modularity and resulting indicator values for coffee-to-go cups

System	Indicator value	Source/Expert	Pedigree rating
Reusable	0	Dobers (Fraunhofer IML)	[1]*
One way	0	Dobers (Fraunhofer IML)	[1]*

9.4.9 Volume reducibility

Data (a) to (c) refer to the three previously mentioned points in the utilization cycle where volume reduction takes place:

(a) Foldable / collapsible

(b) Nestability

(c) Compressibility in the disposal phase

Table 49: Volume reducibility and resulting indicator values for fruit and vegetable figs.

System	Volume reduction factor	Indicator value	Source/Expert	Pedigree-Classification
Reusable (a), (c)	3,4-7,9[42]	0 ... +1	(Euro Pool System 2021b)	[1,1,1,1,1]
Reusable (a), (c)	3,1-8,5[42]	0 ... +1	(IFCO 2021)	[1,1,1,1,1]
One way (a)	8[43]	+1	Dobers (Fraunhofer IML)	[4]*
One way (c)	10	+2	Fraunhofer UMSICHT	[1]*

42 The range results from the different height of the unfolded crates, with the same height when folded. For comparison with a disposable banana crate, the larger value should be selected.

43 The value refers to the new cardboard box of the banana box not yet glued.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

Table 50: Volume reducibility and resulting indicator values for plant trays.

System	Volume reduction factor	Indicator value	Source/Expert	Pedigree rating
Reusable (b),(c)	2,6	-1	Dobers (Fraunhofer IML)	[4]*
One way (b)	6	+1	Dobers (Fraunhofer IML)	[4]*
One way (c)	4-10	0 ... +2	Dobers (Fraunhofer IML)	[4]*

Table 51: Volume reducibility and resulting indicator values for coffee-to-go cups.

System	Volume reduction factor	Indicator value	Source/Expert	Pedigree rating
Reusable (b),(c)	5,4	0	Dobers (Fraunhofer IML)	[4]*
One way (b)	11	+2	Dobers (Fraunhofer IML)	[4]*
One way (c)	7	+1	Fraunhofer UMSICHT	[1]*

9.4.10 Product protection

Table 52: Breakage rate with resulting indicator values for fruit and vegetable sticks

System	Breakage rate	Indicator value	Source/Expert	Pedigree rating
One way	4 %	-2	(Lange et al. 2013)	[1,1,1,2,2]
One way	4 %	-2	(Euro Pool System 2021c)	[1,1,1,1,3]
Reusable	0,1 %	+1	(Lange et al. 2013)	[1,1,1,2,2]
Reusable	0,53 %	0	(Krieg et al. 2018)	[1,1,1,1,3]
Reusable	0,1 %	+1	(Euro Pool System 2021c)	[1,1,1,1,3]

Table 53: Breakage rate with resulting indicator values for plant trays

System	Breakage rate	Indicator value	Source/Expert	Pedigree rating
One way	k. A.	+2	Dobers (Fraunhofer IML)	[4]*
Reusable	k. A.	0	Dobers (Fraunhofer IML)	[4]*

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

Table 54: Breakage rate with resulting indicator values for coffee-to-go cups

System	Breakage rate	Indicator value	Source/Expert	Pedigree rating
One way	k. A.	0	Dobers (Fraunhofer IML)	[4]*
Reusable	k. A.	+1	Dobers (Fraunhofer IML)	[4]*

9.4.11 Digitizability

Table 55: Cost share for digitization of crates (assumption transponder 10 ct/piece); Source indication and Pedigree rating refer to market price

System	Circulation number	Market price [€/pc]	Cost share of digitization [%]	Source/Expert	Pedigree rating
One way	1	0,90	11 %	(Value Pack 2021)	[1,1,1,1,1]
Reusable	5	7,00	0,3 %	a) (Robbert 2021) b) (Box Factory 2021)	a) [1] b) [1,1,1,1,1]
Reusable	50	7,00	0,03 %		
Reusable	125	7,00	0,003 %		

Table 56: Cost share for digitization of plant trays (assumption transponder 10 ct/piece); Source reference and Pedigree rating refer to market price

System	Use / Circulation	Market price [€/pc]	Cost share of digitization [%]	Source/Expert	Pedigree rating
One way	1	0,25	29 %	(Oldenburg 2021)	[1]
Reusable	5	2,00	1 %	(Oldenburg 2021)	[2]
Reusable	50	2,00	0,1 %		
Reusable	125	2,00	0,01 %		

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

Table 57: Cost share for digitization of coffee-to-go cups (assumption transponder 10 ct/piece); source reference and Pedigree rating refer to market price

System	Use / Circulation	Market price [€/pc]	Cost share of digitization [%]	Source/Expert	Pedigree rating
One way	1	0,136	42 %	(Metro 2021)	[1,1,1,1,1]
One way	1	0,026	79 %		
Reusable	5	0,55	3 %	(Schorm 2021)	[1,1,1,1,1]
Reusable	50	0,55	0,3 %		
Reusable	125	0,55	0,12 %		

*The cost of royalties was estimated from information provided by distributors offering licensing as a service (https://www.bechershop.de/thermo-automatenbecher-150-ml-braun-weiss?c=48)

**Cleaning costs were conservatively estimated based on data for a commercial belt washer (240 L/h, 24.7 kW average power consumption). A typical dishwasher load of 3,070 standard plates per hour was assumed. The costs for electricity were assumed to be 20 ct/kWh and for water and wastewater 4.00 €/m³. It was assumed that labor costs of €25/hour would be incurred for handling. This results in costs of approx. 1 ct per standard plate. Furthermore, we assume that a crate corresponds to about 10 standard plates, a plant tray to 5 and a coffee-to-go cup to one standard plate. This results in a cost of 10 ct for crates, 5 ct for plant trays and 1 ct for C2G cups per cleaning.

9.4.12 Transport effort

Table 58: Transport effort for one application and resulting indicator values for O/G risers

System	Transport distance	Indicator value	Source/Expert	Pedigree rating
Reusable	1408 km	-2	(Albrecht et al. 2013)	[1,1,3,2,1]
One way	1103 km	-2	(Albrecht et al. 2013)	[1,1,3,2,1]
Reusable	843 km	-1	(Abejón et al. 2020)	[1,1,2,1,1]
One way	1153 km	-2	(Abejón et al. 2020).	[1,1,2,1,1]
Reusable	374 km	+1	(Del Borghi et al. 2020).	[1,1,3,1,1]
One way	853 km	-1	(Del Borghi et al. 2020).	[1,1,3,1,1]
One way	850 km	-1	(Del Borghi et al. 2020).	[1,1,3,1,1]
Reusable	943 km	-1	(López-Gálvez et al. 2021)	[1,1,2,1,1]
One way	1217 km	-2	(Del Borghi et al. 2020).	[1,1,3,1,1]

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

System	Transport distance	Indicator value	Source/Expert	Pedigree rating
One way	1275 km	-2	(Del Borghi et al. 2020).	[1,1,3,1,1]
Reusable	1438 km	-2	(Koskela et al. 2014)	[2,1,2,2,1]
One way	1275 km	-2	(Koskela et al. 2014)	[2,1,2,2,1]
Reusable	408 km	+1	(Accorsi et al. 2014)	[1,1,2,2,2]
One way	803 km	-1	(Accorsi et al. 2014)	[1,1,2,2,2]

Table 59: Transport effort for one application and resulting indicator values for plant trays

System	Transport distance	Indicator value	Source/Expert	Pedigree rating
Reusable	1611 km	-2	(van Paassen and Scholten 2020)	[1,1,3,3,2]
Reusable	1511 km	-2	(van Paassen and Scholten 2020)	[1,1,3,3,2]
One way	1275 km	-2	(van Paassen and Scholten 2020)	[1,1,3,3,2]
One way	1225 km	-2	(van Paassen and Scholten 2020)	[1,1,3,3,2]
One way	1350 km	-2	(van Paassen and Scholten 2020)	[1,1,3,3,2]
Reusable	411 km	+1	(van Paassen and Scholten 2020)	[1,1,3,3,2]
One way	635 km	0	(van Paassen and Scholten 2020)	[1,1,3,3,2]
Reusable	454 km	+1	(Dobers and Lammers 2017)	[1,1,1,1,1]
One way	1226 km	-2	(Dobers and Lammers 2017)	[1,1,1,1,1]

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

9.4.13 Greenhouse gas emissions

Table 60: GHG emissions in CO_2 equivalents and indicator value for fruit and vegetable sticks

System	Material	CO_2 equivalents [kg CO_2 eq./. 1000 L]	IW	Source/Expert	Pedigree rating
Reusable	Plastic (PP, PE)	6,40	+2	(Albrecht et al. 2013)	[1,1,3,2,1]
Reusable	Plastic (PP, HDPE)	4,51	+2	(Abejón et al. 2020).	[1,1,2,1,1]
Reusable	Plastic (PP, HDPE)	5,21	+2	(Del Borghi et al. 2020).	[1,1,3,1,1]
Reusable	Plastic (PP)	1,25	+2	(López-Gálvez et al. 2021)	[1,1,2,1,1]
Reusable	Plastic (PP)	17,33	+2	(Levi et al. 2011)	[1,1,2,3,1]
Reusable	Plastic (PE)	46,83	0	(Koskela et al. 2014)	[2,1,2,2,1]
Reusable	Plastic (PP, PE)	4,77	+2	(Accorsi et al. 2014)	[1,1,2,2,1]
Reusable	Plastic (PP, PE)	4,32	+2	(Krieg et al. 2018)	[1,1,1,1,2]
One way	Cardboard	12,29	+2	(Albrecht et al. 2013)	[1,1,3,2,1]
One way	Cardboard	37,73	+1	(Abejón et al. 2020)	[1,1,2,1,1]
One way	Cardboard	53,65	0	(Del Borghi et al. 2020).	[1,1,3,1,1]
One way	Cardboard	12,25	+2	(López-Gálvez et al. 2021)	[1,1,2,1,1]
One way	Cardboard	13,84	+2	(Levi et al. 2011)	[1,1,2,3,1]
One way	Cardboard	44,69	+1	(Koskela et al. 2014)	[2,1,2,2,1]
One way	Cardboard	13,89	+2	(Accorsi et al. 2014)	[1,1,2,2,2]
One way	Cardboard	11,23	+2	(Krieg et al. 2018)	[1,1,1,1,2]
One way	Wood	6,46	+2	(Albrecht et al. 2013)	[1,1,3,2,1]
One way	Wood	8,85	+2	(Del Borghi et al. 2020).	[1,1,3,1,1]
One way	Wood	38,75	+1	(López-Gálvez et al. 2021)	[1,1,2,1,1]
One way	Wood	6,22	+2	(Accorsi et al. 2014)	[1,1,2,2,1]
One way	Wood (MDF)	14,41	+2	(Del Borghi et al. 2020).	[1,1,3,1,1]
One way	Chipboard	14,06	+2	(Del Borghi et al. 2020).	[1,1,3,1,1]
One way	Plastic (PP, HDPE)	152,60	-1	(Del Borghi et al. 2020).	[1,1,3,1,1]
One way	Plastic (PP, PE)	35,12	+1	(Accorsi et al. 2014)	[1,1,2,2,1]

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

Table 61: GHG emissions in CO_2 equivalents and indicator value for plant trays.

System	Material	CO_2 emissions [kg CO_2 -eq./. 1000 L]	IW	Source/Expert	Pedigree rating
Reusable	Plastic (HDPE)	6,11	+2	(van Paassen and Scholten 2020)	[1,1,1,1,2]
Reusable	Plastic (PP)	8,93	+2	(van Paassen and Scholten 2020)	[1,1,1,1,2]
Reusable	PS, PE?	10,32	+2	(Dobers and Lammers 2017)	[1,1,1,1,3]
One way	PE?	14,53	+2	(Dobers and Lammers 2017)	[1,1,1,1,3]
One way	Plastic (PS)	20,68	+1	(van Paassen and Scholten 2020)	[1,1,1,1,2]
One way	Plastic (PS)	30,98	+1	(van Paassen and Scholten 2020)	[1,1,1,1,2]
One way	Cardboard (Paper/cardboard)	26,50	+1	(van Paassen and Scholten 2020)	[1,1,1,1,2]
One way	Cardboard (kraft/testliner)	21,48	+2	(van Paassen and Scholten 2020)	[1,1,1,1,2]
One way	Cardboard (kraft/testliner)	17,87	+2	(van Paassen and Scholten 2020)	[1,1,1,1,2]

Table 62: GHG emissions in CO_2 equivalents and indicator value for C2G cups

System	Material	CO_2 equivalents [kg CO_2 eq./. 1000 L]	IW	Source/Expert	Pedigree rating
Reusable	Porcelain	65,56	0	(Ligthart 2007)	[1,1,3,3,2]
Reusable	Ceramics/porcelain	132,22	-1	(Ligthart 2007)	[1,1,3,3,2]
Reusable	Plastic (PP)	18,63	+2	(Cottafava et al. 2021)	[2,3,3,1,1]
Reusable	Plastic (PP)	61,78	0	(Kauertz et al. 2019)	[1,1,1,1,2]
Reusable	PP with lid	165,61	-1	(Kauertz et al. 2019)	[1,1,1,1,2]
Reusable	Plastic (PE)	16,00	+2	(Melbinger 2018)	[2,1,2,1,3]
Reusable	Plastic (PE)	60,00	0	(Melbinger 2018)	[2,1,2,1,3]
Reusable	Plastic (PLA)	29,13	+2	(Cottafava et al. 2021)	[2,3,3,1,1]
Reusable	Plastic (PET)	22,58	+2	(Cottafava et al. 2021)	[2,3,3,1,1]

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

System	Material	CO_2 equivalents [kg CO_2 eq./. 1000 L]	IW	Source/Expert	Pedigree rating
Reusable	Glass	23,00	+2	(Cottafava et al. 2021)	[2,3,3,1,1]
Reusable	BYO system	Conversion could not be performed	-	(Kauertz et al. 2019)	[1,1,1,1,2]
One way	Plastic (PS)	71,67	0	(Ligthart 2007)	[1,1,3,3,2]
One way	Plastic (PS; 180 mL; with lid)	121,06	0	(Kauertz et al. 2019)	[1,1,1,1,2]
One way	Plastic (PS; 180 mL; without lid)	68,00	0	(Kauertz et al. 2019)	[1,1,1,1,2]
One way	Plastic (PS; insert cup)	50,00	0	(Ligthart 2007)	[1,1,3,3,2]
One way	Plastic (PP)	82,50	+2	(Cottafava et al. 2021)	[2,3,3,1,1]
One way	Paper with PE coating	21,17	+2	(Melbinger 2018)	[2,1,2,1,3]
One way	Paper with PE coating	52,00	0	(Melbinger 2018)	[2,1,2,1,3]
One way	Plastic (PLA)	92,50	0	(Cottafava et al. 2021)	[2,3,3,1,1]
One way	Plastic (PET)	122,50	+1	(Cottafava et al. 2021)	[2,3,3,1,1]
One way	Paper	21,11	+1	(Ligthart 2007)	[1,1,3,3,2]
One way	Paper (single wall with lid)	75,85	+1	(Kauertz et al. 2019)	[1,1,1,1,2]
One way	Paper (single wall without lid)	29,75	+1	(Kauertz et al. 2019))	[1,1,1,1,2]
One way	Paper (double-walled with lid)	77,40	+1	(Kauertz et al. 2019)	[1,1,1,1,2]
One way	Paper (double-walled without lid)	31,25	+1	(Kauertz et al. 2019)	[1,1,1,1,2]
One way	Paper (single wall with lid)	51,87	+2	(Kauertz et al. 2019)	[1,1,1,1,2]
One way	Paper (single wall without lid)	21,10	+1	(Kauertz et al. 2019)	[1,1,1,1,2]

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

System	Material	CO_2 equivalents [kg CO_2 eq./. 1000 L]	IW	Source/Expert	Pedigree rating
One way	Paper (double-walled with lid)	53,87	+1	(Kauertz et al. 2019)	[1,1,1,1,2]
One way	Paper (double-walled without lid)	23,10	+1	(Kauertz et al. 2019)	[1,1,1,1,2]
One way	Cardboard	72,50	0	(Cottafava et al. 2021)	[2,3,3,1,1]

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

9.4.14 Cumulative energy expenditure

Table 63: Cumulative energy expenditure and indicator values for fruit and vegetable sticks

System	Material	KEAtotal [MJ per 1000 L]	IW	Source/Expert	Pedigree rating
Reusable	Plastic (PP, PE)	85,57	+2	(Albrecht et al. 2013)	[1,1,3,2,1]
Reusable	Plastic (PP, HDPE)	86,98	+2	(Abejón et al. 2020).	[1,1,2,1,1]
Reusable	Plastic (PP, HDPE)	(1)	-	(Del Borghi et al. 2020).	[1,1,3,1,1]
Reusable	Plastic (PP)	34,58	+2	(López-Gálvez et al. 2021)	[1,1,2,1,1]
One way	Cardboard	465,94	+2	(Albrecht et al. 2013)	[1,1,3,2,1]
One way	Cardboard	209,39	+2	Abejón et al. 2020	[1,1,2,1,1]
One way	Cardboard	0,00	0	(Del Borghi et al. 2020).	[1,1,3,1,1]
One way	Cardboard	222,92	+2	(López-Gálvez et al. 2021)	[1,1,2,1,1]
One way	Cardboard	(1)	-	(Accorsi et al. 2014)	[1,1,2,2,2]
One way	Wood	227,19	+2	(Albrecht et al. 2013)	[1,1,3,2,1]
One way	Wood	694,44	+2	(Del Borghi et al. 2020).	[1,1,3,1,1]
One way	Wood	1589,58	0	(López-Gálvez et al. 2021)	[1,1,2,1,1]
One way	Wood	-	0	(Accorsi et al. 2014)	[1,1,2,2,1]
One way	Wood (MDF)	(1)	-	(Del Borghi et al. 2020).	[1,1,3,1,1]
One way	Wood (chipboard)	(1)	-	(Del Borghi et al. 2020).	[1,1,3,1,1]
One way	Plastic (PP, HDPE)	(1)	-	(Del Borghi et al. 2020).	[1,1,3,1,1]
(1) Calculation could not be reproduced					

Table 64: Cumulative energy expenditure and indicator values for plant trays

System	Material	KEAtotal [MJ per 1000 L]	IW	Source/Expert	Pedigree rating
Reusable	PS, PE?	168,55	+2	Confidential	[1,1,1,1,3]
One way	PE?	226,05	+2	Confidential	[1,1,1,1,3]

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

Table 65: Cumulative energy consumption for C2G cups

System	Material	KEAtotal [MJ per 1000 L]	IW	Source/Expert	Pedigree rating
Reusable	Plastic (PP)	1000,00	0	(Kauertz et al. 2019)	[1,1,1,1,2]
Reusable	Plastic (PP; with lid)	3222,22	0	(Kauertz et al. 2019)	[1,1,1,1,2]
One way	Plastic (PS; 180 mL; with lid)	1888,89	0	(Kauertz et al. 2019)	[1,1,1,1,2]
One way	Plastic (PS; 180 mL; without lid)	1055,56	2	(Kauertz et al. 2019)	[1,1,1,1,2]
One way	Paper (single wall with lid)	2100,00	2	(Kauertz et al. 2019)	[1,1,1,1,2]
One way	Paper (single wall without lid)	950,00	0	(Kauertz et al. 2019)	[1,1,1,1,2]
One way	Paper (double-walled with lid)	2400,00	1	(Kauertz et al. 2019)	[1,1,1,1,2]
One way	Paper (double-walled without lid)	1250,00	0	(Kauertz et al. 2019)	[1,1,1,1,2]
One way	Paper (single wall with lid)	1566,67	2	(Kauertz et al. 2019)	[1,1,1,1,2]
One way	Paper (single wall without lid)	800,00	0	(Kauertz et al. 2019)	[1,1,1,1,2]
One way	Paper (double-walled with lid)	1866,67	2	(Kauertz et al. 2019)	[1,1,1,1,2]
One way	Paper (double-walled without lid)	1100,00	0	(Kauertz et al. 2019)	[1,1,1,1,2]

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

9.4.15 Relative profitability

Table 66: Specific total costs per liter of product and use for fruit and vegetable crates

System	Material	Use / Circulation	Volume [L]	Market price [€/pc]	Surcharges		spec. total costs [ct/ (L x use)}	Source/Expert	Pedigree rating
					License fees	Washing [€/use]			
One way	PPK	1	23	0,81	0%	- €	3,5	(Value Pack 2021)	[1,1,1,1,1]
One way	PPK	1	22	0,9945	0%	- €	4,5		
One way	PPK	1	14	0,9595	0%	- €	6,9		
Reusable	PP-C	5	14	6,5	0%	0,10 €	10,0	(Robbert 2021)	[1]
Reusable	PP-C	50	14	6,5	0%	0,10 €	1,6		
Reusable	PP-C	125	14	6,5	0%	0,10 €	0,8		
Reusable	HDPE	5	32	8,05	0%	0,10 €	5,3	(Box Factory 2021)	[1,1,1,1,1]
Reusable	HDPE	50	32	8,05	0%	0,10 €	0,8		
Reusable	HDPE	500	32	8,05	0%	0,10 €	0,4		

Table 67: Specific total costs per liter of filling material and use for plant trays

System	Material	Use / Circulation	Volume [L]	Market price [€/pc]	Surcharges		spec. total costs [ct/ (L x use)}	Source/Expert	Pedigree rating
					License fees	Washing [€/pc.]			
One way	PS	1	6	0,25	10%	- €	4,6	(Oldenburg 2021)	[1]
Reusable	HDPE	5	6	2,00	0%	0,05 €	7,5	(Oldenburg 2021)	[2]
Reusable	HDPE	50	6	2,00	0%	0,05 €	1,5		
Reusable	HDPE	500	6	2,00	0%	0,05 €	1,1		

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

Table 68: Specific total costs per liter of product and use for coffee-to-go cups

System	Material	Use / Circulation	Volume [L]	Market price [€/pc]	Surcharges		spec. total costs [ct/(L x use)}	Source/Expert	Pedigree rating
					License fees	Washing [€/pc.]			
One way	PPK (single wall)	1	0,3	0,08	2%	- €	27,2	(Greenbox 2021)	[1,1,1,1,1]
One way	PPK (vending machine cup)	1	0,18	0,05	2%	- €	28,3		
One way	PPK (Reef Cup)	1	0,25	0,14	2%	- €	57,1		
One way	PPK+PE	1	0,3	0,0966	2%	- €	32,8	(Rausch 2021)	[1,1,1,1,1]
One way	PPK+PE double	1	0,3	0,1848	2%	- €	62,8		
One way	PPK+PLA	1	0,3	0,1057	2%	- €	35,9		
One way	PS	1	0,3	0,136	15%	- €	52,1	(Metro 2021)	[1,1,1,1,1]
One way	PP	1	0,2	0,026	10%	- €	14,3		
One way	PLA (not for hot beverages)	1	0,3	0,064	15%	- €	24,5		
Reusable	PP	5	0,3	0,55	0%	0,01 €	40,0	(Schorm 2021)	[1,1,1,1,1]
Reusable	PP	50	0,3	0,55	0%	0,01 €	7,0		
Reusable	PP	500	0,3	0,55	0%	0,01 €	3,7		

*The cost of royalties was estimated from information provided by distributors offering licensing as a service (https://www.bechershop.de/thermo-automatenbecher-150-ml-braun-weiss?c=48).

**Cleaning costs were conservatively estimated based on data for a commercial belt washer (240 L/h, 24.7 kW average power consumption). A typical dishwasher load of 3070 standard plates per hour was assumed. The costs for electricity were assumed to be 20 ct/kWh and for water and wastewater 4.00 €/m^3 . It was assumed that handling would incur labor costs of €25/hour. This results in costs of approx. 1 ct per standard plate. Furthermore, we assume that a crate corresponds to about 10 standard plates, a plant tray to 5 and a coffee-to-go cup to one standard plate. This results in a cost of 10 ct for crates, 5 ct for plant trays and 1 ct for C2G cups per cleaning.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

9.4.16 Technological sovereignty

Table 69: Independence from imports for fruit and vegetable figs

System	Specification	Independence from imports	Source/Expert	Pedigree-Classification
Reusable	PP	99,5	(Muske 2021) (Pupil 2020)	[1] [3,3,1,1,3]
One way	Cardboard	84,1	(Student 2020)	[3,3,1,1,3]

Table 70: Independence from imports for plant trays

System	Specification	Independence from imports	Source/Expert	Pedigree rating
One way	PS	71,3	(Normpack 2021) (Student 2020)	[3,1,1,1,3] [3,3,1,1,3]
Reusable	HDPE	98,6	(Oldenburg 2021)	[2]

Table 71: Independence from imports for coffee-to-go cups

System	Specification	Independence from imports	Source/Expert	Pedigree rating
Reusable	PP	94,3	(Pachaly 2021) (Student 2020)	[2] [3,3,1,1,3]
One way	PPK	81,8	(Kauertz et al. 2019); (Pupils 2020)	[1,1,1,1,1] [3,3,1,1,3]
One way	PS	42,7	(Student 2020)	[3,3,1,1,3]

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

10 L iterature list

2018/852/EU: Directive amending Directive 94/62/EC on packaging and packaging waste. Available online at https://eur-lex.europa.eu/legal-content/DE/TXT/PDF/?uri=CELEX:32018L0852&from=DE, last checked 01.02.2022.

94/62/EC: Packaging and Packaging Waste Directive. Available online at https://eur-lex.europa.eu/legal-content/DE/TXT/PDF/?uri=CELEX:31994L0062&from=DE, last checked 29.03.2022.

Abejón, R.; Bala, A.; Vázquez-Rowe, I.; Aldaco, R.; Fullana-i-Palmer, P. (2020): When plastic packaging should be preferred: life cycle analysis of packages for fruit and vegetable distribution in the Spanish peninsular market. In: *Resources, Conservation and Recycling* 155. DOI: 10.1016/j.resconrec.2019.104666.

Accorsi, Riccardo; Baruffaldi, Giulia; Manzini, Riccardo (2020): A closed-loop packaging network design model to foster infinitely reusable and recyclable containers in food industry. In: *Sustainable Production and Consumption* 24, pp. 48-61. DOI: 10.1016/j.spc.2020.06.014.

Accorsi, Riccardo; Cascini, Alessandro; Cholette, Susan; Manzini, Riccardo; Mora, Cristina (2014): Economic and environmental assessment of reusable plastic containers: A food catering supply chain case study. In: *International Journal of Production Economics* 152, pp. 88-101. DOI: 10.1016/j.ijpe.2013.12.014.

ADEME (2000): Analyse du cycle de vie des caisses en bois, carton ondulé et plastique pour pommes. LCA of Wooden Boxes, Cardboard Boxes and Plastic Crates for Apples. Agence de l'Environnement et de la Maîtrise de l'Énergie (ADEME), 2000. Available online at https://www.google.com/search?client=firefox-b-d&q=Analyse+du+cycle+de+vie+des+caisses+en+bois%2C+carton+ondul%C3%A9+et+plastique+pour+pommes, last checked 07/27/2021.

Adibi, N.; Lafhaj, Z.; Yehya, M.; & Payet, J. (2017): Global Resource Indicator for life cycle impact assessment: Applied in wind turbine case study. In: *Journal of Cleaner Production* (165), pp. 1517-1528. DOI: 10.1016/j.jclepro.2017.07.226.

Al Barazi, Siyamend; Damm, Sophie; Huy, Dieter; Liedtke, Maren; Schmidt, Michael (2021): DERA-Rohstoffliste. Hg. v. Deutsche Rohstoffagentur (DERA) in der Bundesanstalt für Geowissenschaften und Rohstoffe (BGR) (DERA Rohstoffinformationen).

Albrecht, Stefan; Beck, Tabea; Barthel, Leif; Fischer, Matthias; Deimling, Sabine; Baitz, Martin (2009): The sustainability of packaging system for fruit and vegetable transport in Europe based on Life-cycle Analysis. Update 2009. Executive Summary. Ed. by Stiftung Initiative Mehrweg. Available online at https://www.google.com/search?client=firefox-b-d&q=The+sustainability+of+packaging+system+for+fruit+and+vegetable+transport+in+Europe+based+on+Life-cycle+Analysis, last checked 07/21/2021.

Albrecht, Stefan; Brandstetter, Peter; Beck, Tabea; Fullana-i-Palmer, Pere; Grönman, Kaisa; Baitz, Martin et al. (2013): An extended life cycle analysis of packaging systems for fruit and vegetable transport in Europe. In: *Int J Life Cycle Assess* 18 (8), pp. 1549-1567. DOI: 10.1007/s11367-013-0590-4.

Antala, D. K.; Satasiya, R. M.; Chauhan, P. M. (2020): Design, development and performance evaluation of transportation container for sapota fruit. In: *J Food Sci Technol*. DOI: 10.1007/s13197-020-04865-w.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

Aral (ed.) (2018): Trends in coffee enjoyment. Aral Coffee Study 2018. Available online at https://www.aral.de/de/global/retail/presse/trends-beim-kaffee-genuss.html, last checked 16.12.2021.

Baruffaldi, G.; Accorsi, R.; Volpe, L.; Manzini, R.; Nilsson, F. (2019): Sustainable operations in reusable food packaging networks. In: Riccardo Accorsi and Riccardo Manzini (Eds.): Sustainable food supply chains. Planning, design, and control through interdisciplinary methodologies. London: Academic Press, pp. 293-304. Available online at https://www.scopus.com/inward/record.uri?eid=2-s2.0-85081932212&doi=10.1016%2fB978-0-12-813411-5.00020-X&partnerID=40&md5=7eb016b959d6eec0cb669188b33f140a.

Battini, D.; Calzavara, M.; Persona, A.; Sgarbossa, F. (2016): Sustainable Packaging Development for Fresh Food Supply Chains. In: *08943214* 29 (1), pp. 25-43. DOI: 10.1002/pts.2185.

BaumarktManager (2021): Industry solution for reusable plant trays in sight. Available online at https://www.baumarktmanager.de/branchenloesung-fuer-mehrweg-pflanzentrays-in-sicht-26072021, last checked on 14.12.2021.

Behrens, Rudolf; Janßen, Ingrid; Kuhn, Ekart; Zimmermann, Peter (2018): Entwicklungen und Trends im Markt der Mehrweg Transport Verpackungen in Deutschland und Europa. Ed. by EKUPAC.

Bertling, Jürgen; Zimmermann, Till; Istel, Katharina; Jedelhauser, Michael (2021): Kunststoffe in der Landwirtschaft. In: *Garbage and Waste* (9). DOI: 10.37307/j.1863-9763.2021.09.04.

Bettermarks (2022): quartiles and boxplots. Available online at https://de.bettermarks.com/mathe/quartile-und-boxplots/, last checked Feb. 22, 2022.

Biermann, Katja; Jacobs, Luisa; Polke-Majewski, Karsten (2020): Waiting for the masks. Protective masks are in short supply in clinics. The German armed forces and customs are bringing in what they can get. But so far, no one knows exactly how many are actually needed. Published by Zeit Online. Available online at https://www.zeit.de/wirtschaft/2020-03/schutzausruestung-coronavirus-atemmasken-schutzanzuege-krankenhaeuser-knappheit-hersteller, last checked 16.12.2021.

Bilici, N., Pehlivanli, R., & Ashirkhanova, K. (2017) Innovation and Global Issues in Social Sciences. Available online at https://www.researchgate.net/profile/Efekan-Oezkan-2/publication/330509892_Sel_ve_Taskinlar_Sadece_Bir_Dogal_Afet_mi_Aksu_Cayi_Alt_Havzasi_Ornegi/links/5ddc56bc458515dc2f4dbdcc/Sel-ve-Taskinlar-Sadece-Bir-Dogal-Afet-mi-Aksu-Cayi-Alt-Havzasi-Oernegi.pdf#page=1079.

Blümm, Florian (2021): Climate Protection Statistics 2021: Energy Mix Germany vs Europe vs Worldwide. Available online at https://www.tech-for-future.de/klimaschutz-ranking/, last checked on 23.03.2022.

BMBF (2021): Technologisch souverän die Zukunft gestalten. BMBF Impulse Paper on Technological Sovereignty. Ed. by Federal Ministry of Education and Research (BMBF). Available online at https://www.bmbf.de/SharedDocs/Publikationen/de/bmbf/pdf/technologisch-souveraen-die-zukunft-gestalten.pdf?__blob=publicationFile&v=2.

BMU (ed.) (2018): 5-Punkte-Plan des Bundesumweltministeriums für weniger Plastik und mehr Recycling. Available online at https://www.bmuv.de/download/5-punkte-plan-des-bundesumweltministeriums-fuer-weniger-plastik-und-mehr-recycling/, last checked 21.02.2022.

BMWi (2019): Industrial Strategy 2030: Guidelines for a German and European Industrial Policy. Ed. by Federal Ministry for Economic Affairs and Energy (BMWi). Available online at

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

https://www.bmwi.de/Redaktion/DE/Publikationen/Industrie/industriestrategie-2030.pdf?__blob=publicationFile&v=20.

Box Factory (ed.) (2021): fruit/vegetable box. Available online at https://www.dieboxfabrik.de/stapelbehaelter/obstkisten-gemuese-kisten/obst/gemuesekiste-600x400x170mm-volle-vpe, last checked 21.12.2021.

Brander, Matthew; Wylie, Charlotte (2011): The use of substitution in attributional life cycle assessment. In: *Greenhouse Gas Measurement and Management* 1 (3-4), pp. 161-166. DOI: 10.1080/20430779.2011.637670.

Breukers, Patrick (2021): Plant trays (Schoeller Group). Interview with Kerstin Dobers and Jürgen Bertling. Digital via Microsoft Teams.

Federal Ministry for the Environment (BMU) (ed.) (2020): Abfallvermeidungsprogramm des Bundes unter Beteiligung der Länder. Available online at https://www.bmuv.de/fileadmin/Daten_BMU/Download_PDF/Abfallwirtschaft/fortschreibung_abfallvermeidungsprogramm_bund_laender_bf.pdf, last checked 21.02.2022.

Federal Government (ed.) (2018): More recycling in Germany. Available online at https://www.bundesregierung.de/breg-de/aktuelles/mehr-recycling-in-deutschland-1507858, last checked 23.03.2022.

Burger, Alexandar; Cayé, Nicolas; Jaegermann, Corinna; Schüler, Kurt (2021): Aufkommen und Verwertung von Verpackungsabfällen in Deutschland im Jahr 2019. ed. by Federal Environment Agency (UBA Texte, 148/2021). Available online at https://www.umweltbundesamt.de/sites/default/files/medien/1410/publikationen/2021-11-23_texte_148-2021_aufkommen-verwertung-verpackungsabfaelle-deutschland-2019_bf.pdf, last checked 16.03.2021.

COM(2018) 28 final (2018): European Strategy for Plastics in the Circular Economy, dated 16.01.2018. Available online at https://eur-lex.europa.eu/resource.html?uri=cellar:2df5d1d2-fac7-11e7-b8f5-01aa75ed71a1.0002.02/DOC_2&format=PDF, last checked 13.03.2022.

COM(2019) 640 final (2019): The European Green Deal, dated Dec. 11, 2019. Available online at https://eur-lex.europa.eu/legal-content/DE/TXT/?qid=1576150542719&uri=COM%3A2019%3A640%3AFIN, last checked Mar. 13, 2022.

COM(2020) 98 final (2020): EU Action Plan for the Circular Economy. Reference: European Commission. Available online at https://eur-lex.europa.eu/resource.html?uri=cellar:9903b325-6388-11ea-b735-01aa75ed71a1.0016.02/DOC_1&format=PDF, last checked 13.03.2022.

Container Centralen GmbH (ed.) (2018): CC Container. The European standard for flower and pot plants. Available online at https://www.container-centralen.com/wp-content/uploads/2018/05/DE_leaflet_2018_CC-Container_Produktblatt.pdf, last checked 23.03.2022.

Conversio (ed.) (2020): Material flow diagram plastics 2019. Available online at https://www.vci.de/ergaenzende-downloads/kurzfassung-stoffstrombild-kunststoffe-2019.pdf, last checked on 31.01.2022.

Cottafava, Dario; Costamagna, Mattia; Baricco, Marcello; Corazza, Laura; Miceli, Davide; Riccardo, Luigi E. (2021): Assessment of the environmental break-even point for deposit return systems through an LCA analysis of single-use and reusable cups. In: *Sustainable Production and Consumption* 27, pp. 228-241. DOI: 10.1016/j.spc.2020.11.002.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

Crenna, Eleonora; Sozzo, Sara; Sala, Serenella (2018): Natural biotic resources in LCA: Towards an impact assessment model for sustainable supply chain management. In: *Journal of Cleaner Production* 172, pp. 3669-3684. DOI: 10.1016/j.jclepro.2017.07.208.

CUPFORCUP GmbH (ed.) (2022): Cupforcup. Available online at https://cupforcup.de/, last checked 11.04.2022.

Del Borghi, A.; Parodi, S.; Moreschi, L.; Gallo, M. (2020): Sustainable packaging: an evaluation of crates for food through a life cycle approach. In: *International Journal of Life Cycle Assessment*. DOI: 10.1007/s11367-020-01813-w.

Detzel, Andreas; Kauertz, Benedikt; Grahl, Brigitte; Heinisch, Jürgen (2016): Prüfung und Aktualisierung der Ökobilanzen für Getränkeverpackungen. Ed. by Federal Environment Agency (TEXTE, 19/2016). Available online at https://www.umweltbundesamt.de/sites/default/files/medien/378/publikationen/texte_19_2016_pruefung_und_aktualisierung_der_oekobilanzen_fuer_gertaenkeverpackungen_0.pdf.

Deutsche Umwelthilfe e.V. (ed.) (2015): Becherheld - Mehrweg to go. DUH-Becherheldkampagne 2015. Available online at https://www.duh.de/becherheld/, last checked 16.12.2021.

Deutsche Umwelthilfe e.V. (ed.) (2020): PET bottles. Available online at https://www.mehrweg-mach-mit.de/getraenkeverpackungen/pet-flaschen/, last checked on 17.03.2022.

Deutsche Umwelthilfe e.V. (ed.) (2021): The plastic waste problem of the plant trade. Available online at https://www.duh.de/projekte/pflanzenhandel//, last checked 14.12.2021.

Deutsche Welle (ed.) (2021): Plastic is also becoming scarce - why is that? Available online at https://www.dw.com/de/auch-plastik-wird-knapp-warum-ist-das-so/a-57061666, last checked 16.12.2021.

DNV (2021): Circular economy. How are companies transitioning? Available online at https://www.dnv.com/news/is-the-circular-economy-transition-fast-enough--206722, last checked on 29.03.2022.

Dobers, Kerstin; Lammers, Wolfgang (2017): Vergleichende ökologische Bewertung von Einweg- und Mehrwegpaletten im Pflanzenhandel. Study for the Landgard Foundation in cooperation with toom Baumärkte. Ed. by Fraunhofer IML.

Dörfelt, Stefan (2018): Empty kilometers and empty runs - How to reduce and avoid them. MMLogistics. Available online at https://www.mm-logistik.vogel.de/leerkilometer-und-leerfahrten--wie-man-sie-reduziert-und-vermeidet-a-673353/, last checked on 14.12.2021.

EC 1907/2006: Regulation on the Registration, Evaluation, Authorization and Restriction of Chemicals (REACH). Available online at https://eur-lex.europa.eu/legal-content/DE/TXT/PDF/?uri=CELEX:32006R1907, last checked 22.02.2022.

EC 1935/2004: Regulation on materials and articles intended to come into contact with food. Available online at https://eur-lex.europa.eu/legal-content/DE/TXT/PDF/?uri=CELEX:32004R1935&from=DE, last checked 22.02.2022.

ESG Enterprise (ed.): SFDR, NFRD, and CSRD: Guidance on EU Taxonomy. Available online at https://www.esgenterprise.com/esg-reporting/eu-taxonomy-sfdr-nfrd-csrd/, last checked 30.03.2022.

EU 10/2011: Regulation on plastic materials and articles intended to come into contact with food. Available online at https://eur-lex.europa.eu/legal-content/DE/TXT/PDF/?uri=CELEX:02011R0010-20150226&from=MT, last checked 30.03.2022.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

EU 2019/665: Implementing Decision amending Decision 2005/270/EC establishing the formats of the tables for the database pursuant to Directive 94/62/EC of the European Parliament and of the Council on packaging and packaging waste. Available online at https://eur-lex.europa.eu/legal-content/DE/TXT/PDF/?uri=CELEX:32019D0665&from=EN, last checked 22.02.2022.

EU 2019/904 (2019): Directive the reduction of the impact of certain plastic products on the environment. Plastics Single-Use Directive, dated 2019. Available online at https://eur-lex.europa.eu/legal-content/DE/TXT/PDF/?uri=CELEX:32019L0904, last checked 01/02/2022.

EU 2020/852 (DV): Delegated Regulation supplementing Regulation (EU) 2020/852. Available online at https://eur-lex.europa.eu/resource.html?uri=cellar:d84ec73c-c773-11eb-a925-01aa75ed71a1.0014.02/DOC_1&format=PDF, last checked 04.02.2021.

EU RL 2008/98: Directive on Waste (Waste Framework Directive), dated 19.11.2008. Available online at https://eur-lex.europa.eu/legal-content/DE/TXT/PDF/?uri=CELEX:32008L0098&from=DE, last checked 22.02.2022.

EU Technical Expert Group on Sustainable Finance (ed.) (2020): Taxonomy Report: Technical Annex. Available online at https://ec.europa.eu/info/sites/default/files/business_economy_euro/banking_and_finance/documents/200309-sustainable-finance-teg-final-report-taxonomy-annexes_en.pdf, last checked 22.02.2022.

EU, Euratom 2020/2053 (2020): Decision on the European Union's own resources system and repealing Decision 2014/335/EU, Euratom, 14.12.2020. Available online at https://eur-lex.europa.eu/legal-content/DE/TXT/PDF/?uri=CELEX:32020D2053&qid=1646674309201&from=EN, last checked 13.03.2022.

Euro Pool System (ed.) (2021a): Together for the Circular Supply Chain. Available online at https://www.europoolsystem.com/de/, last checked 14.12.2021.

Euro Pool System (ed.) (2021b): Klappsteige. The advantages of the folding riser. Product data sheet. Available online at https://cdn2.hubspot.net/hubfs/5799001/Download%20centre/Leaflets/Leaflet%20Foldable%20green%20-%20DE%20-%20Final.pdf, last checked 12/14/2021.

European Commission (ed.): Climate change consequences. Available online at https://ec.europa.eu/clima/change/consequences_en, last checked 10.12.2021.

EY (ed.) (2021): Plastic and packaging taxes in Europe. Available online at https://assets.ey.com/content/dam/ey-sites/ey-com/en_gl/topics/tax/tax-pdfs/ey-plastics-and-packaging-taxes-webcast-summary.pdf, last checked 22.02.2022.

FairCup GmbH (ed.) (2021): Das Pfandsystem für To-Go oder Take away. Available online at https://fair-cup.de/, last checked 16.12.2021.

Fazio, S.; Biganzioli, F.; Laurentiis, V. de; Zampori, L.; Sala, S.; Diaconu, E. (2018): Supporting information to the characterisation factors of recommended EF Life Cycle Impact Assessment methods. Version 2 from ILCD to EF 3.0. ed. v. Publications Office of the European Union. Available online at https://eplca.jrc.ec.europa.eu/permalink/TR_SupportingCF_FINAL.pdf.

FEFCO (ed.) (2018): European Database for Corrugated Board Life Cycle Studies. Corrugated Packaging; Cepi ContainerBoard. Available online at https://www.fefco.org/download/file/fid/2626, last checked 10/12/2021.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

Foteinis, Spyros (2020): How small daily choices play a huge role in climate change: The disposable paper cup environmental bane. In: *Journal of Cleaner Production* 255, pp. 120294. DOI: 10.1016/j.jclepro.2020.120294.

Franklin Associates (2016): Comparative life cycle assessment of reusable plastic containers and display- and non-display-ready corrugated containers used for fresh produce application. prepared for IFCO Corporation. Available online at https://nanopdf.com/download/comparative-life-cycle-assessment-of-reusable-plastic-containers-and_pdf, last checked 03/23/2022.

FreiburgCup (ed.) (2021): The deposit system. Available online at https://freiburgcup.de/de/wie.php, last checked 16.12.2021.

Frischknecht, Rolf; Wyss, Franziska; Büsser Knöpfel, Sybille; Lützkendorf, Thomas; Balouktsi, Maria (2015): Cumulative energy demand in LCA: the energy harvested approach. In: *Int J Life Cycle Assess* 20 (7), pp. 957-969. DOI: 10.1007/s11367-015-0897-4.

Gaedicke, Christoph; Franke, Dieter; Ladage, Stefan; Lutz, Rüdiger; Pein, Martin; Rebscher, Dorothee et al. (2020): BGR Energiestudie 2019. ed. by Federal Institute for Geosciences and Natural Resources (BGR). Available online at https://www.bgr.bund.de/DE/Themen/Energie/Downloads/energiestudie_2019.pdf?__blob=publicationFile&v=6.

Gall, Markus; Schweighuber, Andrea; Buchberger, Wolfgang; W. Lang, Reinhold (2020): Plastic Bottle Cap Recycling-Characterization of Recyclate Composition and Opportunities for Design for Circularity. In: *Sustainability* 12 (24), pp. 10378. DOI: 10.3390/su122410378.

Garrido, Nuria; Del Alvarez Castillo, M. Dolors (2007): Environmental evaluation of single-use and reusable cups. In: *Int J Life Cycle Assess* 12 (4), pp. 252-256. DOI: 10.1065/lca2007.05.334.

Gesellschaft für Verpackungsmarktforschung mbH (GVM) (2018): Abfallaufkommen durch Einweggeschirr und andere Verpackungen für den Sofortverzehr. Available online at https://www.nabu.de/imperia/md/content/nabude/abfallpolitik/181022_gvm-studie_einweggeschirr_sofortverzehr.pdf, last checked 23.03.2022.

Gräf, Alexander (2018): Coffee-to-go / Kaffee-zumnehmen Geschichte. Ed. v. Greenape. Available online at https://greenape.de/kaffee/coffee-to-go-kaffee-zum-mitnehmen-herkunft, last checked 12/16/2021.

Greenbox (ed.) (2021): Paper cups for hot drinks. Available online at https://www.biologischverpacken.de/sortiment/becher/pappbecher/, last checked 21.12.2021.

Gruyters, W.; Defraeye, T.; Verboven, P.; Berry, T.; Ambaw, A.; Opara, U. L.; Nicolai, B. (2019): Reusable boxes for a beneficial apple cold chain: A precooling analysis [Boîtes réutilisables pour une chaîne du froid bénéfique pour les pommes: analyse de préréfrigération]. In: *International Journal of Refrigeration* 106, pp. 338-349. DOI: 10.1016/j.ijrefrig.2019.07.003.

Guinée, J. B.; Lindeijer, E. (2008): Handbook on life cycle assessment: operational guide to the ISO standards. Vol. 7: Springer Science & Business Media.

Hahladakis, John N.; Velis, Costas A.; Weber, Roland; Iacovidou, Eleni; Purnell, Phil (2018): An overview of chemical additives present in plastics: migration, release, fate and environmental impact during their use, disposal and recycling. In: *Journal of Hazardous Materials* 344, pp. 179-199. DOI: 10.1016/j.jhazmat.2017.10.014.

Haidlmair, Mario (2021): Plastic-based reusable systems (Haidlmaier Group). Interview with Stephan Kabsci and Jürgen Bertling. Digital via MsTeams.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

Hansen, Erik; Nilson, Nils H.; Lithner, Delilah; Lassen, Carsten (2013): Hazardous substances in plastic materials. Ed. by COWI in cooperation with Danish Technological Institute. Vejle, Denmark. Available online at https://www.byggemiljo.no/wp-content/uploads/2014/10/72_ta3017.pdf.

Hansen, Erik; Nilsson, Nils; Vium, Kristine Slot Ravnholt (2014): Hazardous substances in plastics. Survey of chemical substances in consumer products No. 132, 2014. ed. by The Danish Environmental Protection Agency. Available online at https://www2.mst.dk/Udgiv/publications/2014/12/978-87-93283-31-2.pdf.

Hauschild, M. Z.; Goedkoop, M.; Guinée, J.; Heijungs, R.; Huijbregts, M.; Jolliet, O.; et al. (2013): Identifying best existing practice for characterization modeling in life cycle impact assessment. In: *The International Journal of Life Cycle Assessment* (18(3)), pp. 683-697. DOI: 10.1007/s11367-012-0489-5.

HAWITA Technoplant (ed.) (2021): Palettino. The clever and proven reusable system. Available online at https://www.palettino.de/, last checked 12/14/2021.

Hegemann, Lisa (2020): Federal government wants to exclude manufacturers from 5G expansion if necessary. Ed. by Zeit Online. Available online at https://www.zeit.de/digital/internet/2020-11/it-sicherheit-gesetz-g5-netz-ausbau-huawei, last checked on 16.12.2021.

Heim - EDT GmbH (2022): Crate washing systems & crate washing machines. Ed. v. (heimedt.de). Available online at https://heimedt.de/kistenwaschanlage/, last checked 29.03.2022.

Hofmeister, Gerit; Herzog, Ann-Kathrin; Endebrock, Klaus (2021): Mehrwegsteigen (WGB Pooling). Interview with Kerstin Dobers and Anna Schulte. Digital via Microsoft Teams.

IFCO (ed.) (2021): Black Lift Lock (Europe). Available online at https://www.ifco.com/wp-content/uploads/IFCO-DS-1003-BLACK-LL-DE-DE-21-03-30.pdf, last checked 14.12.2021.

IN4climate.NRW (ed.) (2020): Chemisches Kunststoffrecycling - Potenziale und Entwicklungsperspektiven. A contribution to the defossilization of the chemical and plastics processing industry in NRW. Discussion paper of the Circular Economy working group. Available online at https://epub.wupperinst.org/frontdoor/deliver/index/docId/7605/file/7605_Kunststoffrecycling.pdf, last checked 13.03.2022.

Infras (ed.) (2019): Handbook of Emission Factors 4.1. Available online at https://www.hbefa.net, last checked 20.02.2022.

IPCC (ed.) (2014): Climate change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. Geneva, Switzerland. Available online at https://www.ipcc.ch/report/ar5/syr/, last checked Dec. 10, 2021.

ISO 14040:2006: Environmental management - Life cycle assessment - Principles and framework. Available online at https://www.iso.org/standard/37456.html.

ISO 14044:2006: Environmental management - Life cycle assessment - Requirements and guidelines. Available online at https://www.iso.org/standard/38498.html.

Kauertz, b.; Schlecht, S.; Markwardt, S.; Rubik, F.; Heinrich, J.; Kolbe, P.; Hake, Y. (2019): Investigation of the ecological significance of disposable beverage cups in out-of-home consumption and possible measures to reduce consumption. Ed. v. Federal Environment Agency (TEXTE, 29/2019). Available online at https://www.umweltbundesamt.de/sites/default/files/medien/1410/publikationen/2019-02-20_texte_29-2019_einweggetraenkebechern_im_ausser-haus-verzehr_final.pdf.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

Kauertz, Benedikt; Bick, Carola; Schlecht, Samuel; Busch, Miriam; Markwardt, Stefanie; Wellenrether, F. (2018): Life cycle assessment comparison of composite beverage cartons with PET non-refillable and glass refillable bottles in the beverage segments juice/nectar, UHT milk and fresh milk. Final report after critical review. Ed. by ifeu - Institute for Energy and Environmental Research Heidelberg.

Kellerer, Richard (2021): Obst- und Gemüsesteigen (Schoeller Alibert). Interview with Stephan Kabasci and Anna Schulte. Digital via Microsoft Teams.

Kent, Robin (2009): What's Your Process Energy Fingerprint? Ed. v. Plastics Technology. Available online at https://www.ptonline.com/articles/whats-your-process-energy-fingerprint, last checked 03/03/2022.

Killiches, Franziska (2013): Phosphate. Mineral raw material and indispensable nutrient for food security worldwide. Ed. by the Federal Institute for Geosciences and Natural Resources (BGR) on behalf of the Federal Ministry for Economic Cooperation and Development. Available online at https://www.bgr.bund.de/DE/Themen/Zusammenarbeit/TechnZusammenarbeit/Politikberatung_SV_MER/Downloads/phosphat.pdf?__blob=publicationFile&v=4.

Klimaschutzagentur Mannheim (ed.) (2021): Bleib deinen Becher treu. Available online at https://www.bleibdeinembechertreu.de/, last checked 16.12.2021.

Klinglmair, M.; Sala, S.; Brandão, M. (2014): Assessing resource depletion in LCA: a review of methods and methodological issues. In: *Int J Life Cycle Assess* (19 (3)), 580-592. DOI: 10.1007/s11367-013-0650-9.

Klooster, R. ten; Koejer, B. de; Lange, J. de (2017): Towards a generic set of packaging material key figures. Ed. by 28th IAPRI Symposium on Packaging. 28th IAPRI Symposium on Packaging. Available online at https://ris.utwente.nl/ws/portalfiles/portal/21754833/Klooster_Koeijer_Lange_Towardsagenericsetofpackagingmaterialkeyfigures_IAPRI.pdf.

Klöpffer, Walter; Grahl, Brigit (2009): Life Cycle Assessment (LCA). A guide for education and profession. Weinheim: Wiley-VCH.

Knerr, Michael; Hersche, Emil (eds.) (2016): Füllstoffe und Verstärkungsmittel (Handbuch Kunststoff Additive, Ralph D. Maier, Michael Schiller (eds.)).

Koskela, Sirkka; Dahlbo, Helena; Judl, Jáchym; Korhonen, Marja-Riitta; Niininen, Mervi (2014): Reusable plastic crate or recyclable cardboard box? A comparison of two delivery systems. In: *Journal of Cleaner Production* 69, pp. 83-90. DOI: 10.1016/j.jclepro.2014.01.045.

KPMG (ed.) (2021): Plastic Tax - Reduce, Reuse, Recycle. Available online at https://home.kpmg/xx/en/home/insights/2021/09/plastic-tax.html, last checked 21.02.2022.

Kranich, Sebastian; Krommes, Sandra; Rieder, Rosina (2019): Evaluation of the raw material criticality method according to VDI 4800 in the product development process: case study of an electric vehicle drive system. In: *NachhaltigkeitsManagementForum* 27 (1), pp. 53-63. DOI: 10.1007/s00550-018-0481-z.

Kreis Höxter - Fachbereich Umwelt, Bauen und Geoinformationen (ed.) (2021): Unser regionales Pfandbechersystem. Available online at https://kreis-hx.maps.arcgis.com/apps/Cascade/index.html?appid=71e85c138117497685493703009a78a2/, last checked 16.12.2021.

Krieg, Hannes; Gehring, Florian; Fischer, Matthias; Albrecht, Stefan (2018): Carbon Footprint von Verpackungssystemen für Obst- und Gemüsetransport in Europa. Ed. by Stiftung Initiative Mehrweg.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

Fraunhofer IBP. Available online at https://www.stiftung-mehrweg.de/fileadmin/user_upload/SIM_CF_Bericht_De.pdf.

KrWG (2012): Kreislaufwirtschaftsgesetz: Act to promote the circular economy and ensure the environmentally sound management of waste. KrWG, from Last amended by Art. 1 G v. 23.10.2020. Available online at https://www.gesetze-im-internet.de/krwg/BJNR021210012.html.

Lammers, Wolfgang (2021): Mehrwegsteigen (Dept. Packaging Logistics of Fraunhofer IML). Interview with Kerstin Dobers. Digital via Microsoft Teams.

Lange, Volker; Pelka, Michael; Kreyenschmidt, Judith (2013): Determination of spoilage of fresh fruits and vegetables depending on packaging type. Executive Summary. Fraunhofer IML; University of Bonn. Available online at https://www.stiftung-mehrweg.de/fileadmin/user_upload/downloads-save-food-studie/savefoodstudie_de.pdf.

Lebensmittelverband Deutschland (ed.) (2020): Merkblatt "Pool-Geschirr". Hygiene when handling reusable tableware within deposit pool systems. Available online at https://www.lebensmittelverband.de/de/lebensmittel/sicherheit/hygiene/hygiene-beim-umgang-mit-mehrweg-bechern-behaeltnissen-pool-geschirr, last checked on 17.03.2022.

Leitner, Felix von (2020): Commentary: Digital sovereignty at a bargain price - from Europe and Mozilla. Ed. v. heise online. Available online at https://www.heise.de/meinung/Kommentar-Digitale-Souveraenitaet-zum-Schnaeppchenpreis-von-Europa-und-Mozilla-4874038.html, last checked 16.12.2021.

Levi, Marinella; Cortesi, Sara; Vezzoli, Carlo; Salvia, Giuseppe (2011): A Comparative Life Cycle Assessment of Disposable and Reusable Packaging for the Distribution of Italian Fruit and Vegetables. In: *Packag. Technol. Sci.* 24 (7), pp. 387-400. DOI: 10.1002/pts.946.

Ligthart, T. N. (2007): Single use Cups or Reusable (coffee) Drinking Systems: An Environmental Comparison. TNO. Netherlands. Available online at https://www.tno.nl/media/2915/summary-research-drinking-systems.pdf.

Lo-Iacono-Ferreira, Vanesa G.; Viñoles-Cebolla, Rosario; Bastante-Ceca, María José; Capuz-Rizo, Salvador F. (2021): Carbon Footprint Comparative Analysis of Cardboard and Plastic Containers Used for the International Transport of Spanish Tomatoes. In: *Sustainability* 13 (5), p. 2552. DOI: 10.3390/su13052552.

López-Gálvez, Francisco; Rasines, Laura; Conesa, Encarnación; Gómez, Perla A.; Artés-Hernández, Francisco; Aguayo, Encarna (2021): Reusable Plastic Crates (RPCs) for Fresh Produce (Case Study on Cauliflowers): Sustainable Packaging but Potential Salmonella Survival and Risk of Cross-Contamination. In: *Foods (Basel, Switzerland)* 10 (6). DOI: 10.3390/foods10061254.

Martin, S.; Bunsen, A.; Ciroth, A. (2018): Case Study Ceramic Cup vs. Paper Cup. Greendelta GmbH. Available online at https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwi8x8m889v2AhWPlqQKHbOkAbIQFnoECAYQAQ&url=https%3A%2F%2Fnexus.openlca.org%2Fws%2Ffiles%2F6229&usg=AOvVaw0NCfTz81occ9BlJY-qtujm.

Meiko (ed.) (2021): Technical data sheet M-iQ B-M54 V8 N02 P8. Country version: Germany. Available online at https://cdn.meiko-company.com/miplan_media/m_iplan/M-iQ_B-M54_V8_N02_P8%C3%BEDEU%C3%BEDE%C3%BEDS.pdf, last checked 03.03.2022.

Melbinger, Isabella (2018): Opportunities and limitations of single-use and reusable systems for coffee to go with special consideration of selected life cycle analyses. Master thesis. Karl-Franzens-University.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

Available online at https://unipub.uni-graz.at/obvugrhs/download/pdf/3107961?originalFilename=true.

Metro (ed.) (2021): Drinking cups. Available online at https://www.metro.de/marktplatz/product/e61fa857-2372-4dc1-a967-efd892336fbe, last checked 21.12.2021.

moBrands GmbH (ed.) (2022): Der nachhaltige Mehrwegbecher. Available online at https://oekocup.de/, last checked on 11.04.2022.

Morris, Jeffrey (1996): Recycling versus incineration: an energy conservation analysis. In: *Journal of Hazardous Materials* 47 (1-3), pp. 277-293. DOI: 10.1016/0304-3894(95)00116-6.

Muske, Bodo (2021): Obst- und Gemüsesteigen (IFCO). Interview with Jürgen Bertling. Digital via Microsoft Teams.

NABU (ed.) (2021): Der NABU-Mehrweg-Guide. The most important questions and answers on reusable and disposable. Available online at https://www.nabu.de/umwelt-und-ressourcen/ressourcenschonung/einzelhandel-und-umwelt/mehrweg/nabumehrwegguide.html, last checked 23.03.2022.

Normpack (ed.) (2021): Recycling pool - The life cycle of a disposable plant tray. Available online at https://normpack.nl/de/recyclingpool, last checked 23.03.2022.

Normpack (ed.) (2022): The life cycle of a disposable plant tray. Available online at https://normpack.nl/de/recyclingpool, last checked 11.04.2022.

No. 10/2011 (EU) (2011): Regulation on plastic materials and articles intended to come into contact with food, 14.01.2011. Available online at https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2011:012:0001:0089:DE:PDF, last checked 13.03.2022.

Oldenburg, Jens (2021): Plant trays (Stiftung Initiative Mehrweg). Interview with Jürgen Bertling. Digital via Microsoft Teams.

Pachaly, Patrick (2021): Coffee-to-Go Cup (ReCup). Interview with Kerstin Dobers and Jürgen Bertling. Digital via Microsoft Teams.

Pfaender, Rudolf (ed.) (2016): Additive für das werkstoffliche Recycling von Kunststoffen. 4th ed.: Carl Hanser Verlag GmbH & Co. KG (Handbuch Kunststoff Additive, Ralph D. Maier, Michael Schiller (eds.)). Available online at https://www.hanser-elibrary.com/doi/10.3139/9783446432918.015, last checked 03/13/2022.

Pladerer, Christian; Meissner, Markus; Dinkel, Fredy; Zschokke, Mischa; Dehoust, Günter; Schüler, Doris (2008): Comparative Life Cycle Assessment of various Cup Systems for the Selling of Drinks at Events. Focussing on major events such as the European Football Championships UEFA EURO 2008(TM) in Austria and Switzerland as well as the German "Bundesliga". Austrian Institute of Ecology; Carbotech AG; Öko-Institut e.V. Germany. Available online at http://www.meucopoeco.com.br/environmental_study.pdf.

Poortinga, Wouter; Whitaker, Louise (2018): Promoting the Use of Reusable Coffee Cups through Environmental Messaging, the Provision of Alternatives and Financial Incentives. In: *Sustainability* 10 (3), p. 873. DOI: 10.3390/su10030873.

Pöppelmann (ed.) (2021): Multiway Climbing - MS Series, R. TEKU(R) Product Range. Available online at https://www.poeppelmann.com/de/teku/produkte/detail/ms-r/fromPid-

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

529/?tx_pptekudatabase_frontendteku%5BsearchParams%5D%5Bproduktgruppe%5D=6&cHash=069cd2b3763661534a7878cc5eb694b5, last checked 14.12.2021.

Potting, Jose; Hekkert, Marko; Worrell, Ernst; Hanemaaijer, Aldert (2017): Circular Economy: Measuring Innovation in the Product Chain. Policy Report. PBL Netherlands Environmental Assessment Agency. The Hague. Available online at https://dspace.library.uu.nl/handle/1874/358310, last checked 02.11.2020.

Rausch (ed.) (2021): Hot beverage cups. Available online at https://www.rausch-packaging.com/de/heissgetraenke-becher-frisch-fein-doppelwandig.html, last checked 21.12.2021.

ReCup (ed.) (2021): RECUP & REBOWL - All products in one system. Available online at https://recup.de/, last checked 16.12.2021.

RFID card (2020): McDonald's and Starbucks are Planning to Adopt RFID Technology McDonald's and Starbucks are Planning to Adopt RFID Technology. Available online at https://www.rfidcard.com/mcdonalds-and-starbucks-are-planning-to-adopt-rfid-technology/, last checked 03/23/2022.

RFID journal (ed.) (n.d.): How much does an RFID tag cost today? Available online at https://www.rfidjournal.com/faq/how-much-does-an-rfid-tag-cost-today, last checked on 17.03.2022.

Robbert, Andreas (2021): Recyclability of plastic crates. Interview with Kerstin Dobers and Jürgen Bertling.

Roßmann, M.; Stratmann, M.; Rötzer, N.; Schäfer, P.; Schmidt, M. (2021): Comparability of LCAs - Review and Discussion of the Application Purpose. Cham.: Springer (Albrecht S., Fischer M., Leistner P., Schebek L. (eds) Progress in Life Cycle Assessment 2019).

Royal FloraHolland (ed.) (2021): The life cycle of a disposable plant tray. Available online at https://www.royalfloraholland.com/de/nachricht/warum-ist-das-recycling-von-einweg-trays-so-wichtig, last checked 12/14/2021.

RP-Online (ed.) (2017): In Düsseldorf, you can now buy your coffee in a deposit cup. Available online at https://rp-online.de/nrw/staedte/duesseldorf/cup-for-cup-pfandbecher-fuer-coffee-to-go-kaffee-in-duesseldorf_aid-19478055, last checked on 08.04.2022.

Schneider, Jürgen (2014): Hot and liquid. New lawsuit against McDonald's coffee. Ed. by Süddeutsche Zeitung. Available online at https://www.sueddeutsche.de/wirtschaft/neue-klage-gegen-mcdonald-s-kaffee-heiss-und-fluessig-1.1867442, last checked 16.12.2021.

Schorm (ed.) (2021): Reusable cups. Available online at https://www.mehrwegbecher.com/coffee-to-go-becher-pp-0-3l-braun, last checked 21.12.2021.

Schröer, Alisa (2020): HolyGrail 2.0: Digital Watermarks Make Sorting Easier. Ed. v. greiner packaging. Available online at https://www.greiner-gpi.com/de/Magazin/HolyGrail-2.0-Digitale-Wasserzeichen-erleichtern-das-Sortieren_s_274785, last checked on 17.03.2022.

Schüler, K. (2020): Aufkommen und Verwertung von Verpackungsabfällen in Deutschland im Jahr 2018. ed. by Umweltbundesamt. Gesellschaft für Verpackungsmarktforschung mbH (GVM) (UBA Texts, 166/2020). Available online at https://www.umweltbundesamt.de/sites/default/files/medien/479/publikationen/texte_166-2020_aufkommen_und_verwertung_von_verpackungsabfaellen_in_deutschland_im_jahr_2018.pdf.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

Shamsuyeva, Madina; Endres, Hans-Josef (2021): Plastics in the context of the circular economy and sustainable plastics recycling: Comprehensive review on research development, standardization and market. In: *Composites Part C: Open Access* 6, pp. 100168. DOI: 10.1016/j.jcomc.2021.100168.

Singh, S. Paul; Chonhenchob, Vanee; Singh, Jagjit (2006): Life cycle inventory and analysis of re-usable plastic containers and display-ready corrugated containers used for packaging fresh fruits and vegetables. In: *Packag. Technol. Sci.* 19 (5), pp. 279-293. DOI: 10.1002/pts.731.

SPD, Bündnis 90/Die Grünen, FDP (eds.) (2021): Mehr Fortschritt wagen. Coalition agreement. Available online at https://www.bundesregierung.de/resource/blob/974430/1990812/04221173eef9a6720059cc353d759a2b/2021-12-10-koav2021-data.pdf?download=1, last checked 21.02.2022.

Städte-Gemeindebund Nordrhein-Westfalen (ed.) (2003): Mitteilungen - Umwelt, Abfall, Abwasser. Costs for street paper bins. Available online at https://www.kommunen.nrw/informationen/mitteilungen/datenbank/detailansicht/dokument/kosten-fuer-strassenpapierkoerbe.html, last checked 16.12.2021.

Statista (ed.) (2022): Statistics on the packaging industry in Germany. Available online at https://de.statista.com/themen/4330/verpackungsindustrie-in-deutschland/#dossierKeyfigures, last checked on 21.02.2022.

Stotz, P. M.; Niero, M.; Bey, N.; Paraskevas, D. (2017): Environmental screening of novel technologies to increase material circularity: A case study on aluminium cans. In: *Resources, Conservation and Recycling* (127), 96-106. DOI: 10.1016/j.resconrec.2017.07.013.

Tandt, Ellen de; Demuytere, Cody; van Asbroeck, Elke; Moerman, Hiram; Mys, Nicolas; Vyncke, Gianni et al. (2021): A recycler's perspective on the implications of REACH and food contact material (FCM) regulations for the mechanical recycling of FCM plastics. In: *Waste management (New York, N.Y.)* 119, pp. 315-329. DOI: 10.1016/j.wasman.2020.10.012.

Tua, Camilla; Biganzoli, Laura; Grosso, Mario; Rigamonti, Lucia (2019): Life Cycle Assessment of Reusable Plastic Crates (RPCs). In: *Resources* 8 (2), p. 110. DOI: 10.3390/resources8020110.

Federal Environment Agency (ed.) (2018): Packaging consumption in Germany remains very high. Available online at https://www.umweltbundesamt.de/presse/pressemitteilungen/verpackungsverbrauch-in-deutschland-weiterhin-sehr, last checked on 31.01.2022.

Federal Environment Agency (ed.) (2020): Verpackungsabfälle. Available online at https://www.umweltbundesamt.de/daten/ressourcen-abfall/verwertung-entsorgung-ausgewaehlter-abfallarten/verpackungsabfaelle#verpackungen-uberall, last checked 22.02.2022.

Federal Environment Agency (ed.) (2021): Recyclability of Packaging: New minimum standard. Available online at https://www.umweltbundesamt.de/themen/recyclingfaehigkeit-von-verpackungen-neuer, last checked 17.03.2022.

UNEP (ed.): Stockholm Convent. 2022. Available online at http://www.pops.int/, last checked 11.04.2022.

Valtokari, Antti (2021): Digitalization and innovation will unlock sustainability. Ed. v. Huhatamaki. Available online at https://www.huhtamaki.com/en/highlights/sustainability/digitalization-and-innovation-will-unlock-sustainability/, last checked 03/17/2022.

van Oers, Lauran; Guinée, Jeroen (2016): The Abiotic Depletion Potential: Background, Updates, and Future. In: *Resources* 5 (1), p. 16. DOI: 10.3390/resources5010016.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

van Paassen, Mike; Scholten, Jasper (2020): Comparative Life Cycle Assessment of one-way plant trays versus returnable plant trays. Public report. Ed. by Royal FloraHolland. Blonk Consultants.

VDI Guideline, 2018: VDI 4800 Blatt 2 - Ressourceneffizienz - Bewertung des Rohstoffaufwands.

vdp (ed.) (2015). Available online at file:///C:/Users/bj/Downloads/Papierrecyceln.pdf.

vdp (ed.) (2021). Available online at file:///C:/Users/bj/Downloads/Kompass_en.pdf.

VDP - Verband deutscher Papierfabriken (ed.) (2021): Papier-Kompass.

German Association of the Automotive Industry (VDA) (ed.) (2018): Small load carrier (KLT) system: Technical recommendation. VDA 4500, Part 1. version 2.0.

Verbraucherzentrale (ed.) (2020): Mehrweg oder Einweg: Verwirrung total beim Pfand. Available online at https://www.verbraucherzentrale.de/wissen/umwelt-haushalt/abfall/mehrweg-oder-einweg-verwirrung-total-beim-pfand-11504, last checked on 22.12.2021.

VerpackG (2021): Law on the marketing, return and high-quality recycling of packaging. VerpackG, from last amended by Article 2 G. v. 22.09.2021 BGBl. I p. 4363. Available online at https://www.gesetze-im-internet.de/verpackg/VerpackG.pdf, last checked on 31.01.2022.

VYTAL Global GmbH (ed.) (2022): Welcome ot reusable. Available online at https://www.vytal.org/, last checked 11.04.2022.

Wagner, Swetlana; Schlummer, Martin (2020): Legacy additives in a circular economy of plastics: Current dilemma, policy analysis, and emerging countermeasures. In: *Resources, Conservation and Recycling* 158, pp. 104800. DOI: 10.1016/j.resconrec.2020.104800.

WBG-Pooling (ed.) (2021a): WBG-Pooling-Foldable-Crate 6412 light blue. Product data sheet. Available online at https://wbg-pooling.eu/wp-content/uploads/2021/04/wbg-pooling-produktdatenblatt-WBG-Pooling-Foldable-Crate-6412-light-blue-DE.pdf, last checked 12/14/2021.

WBG-Pooling (ed.) (2021b): WBG-Pooling-Foldable-Crate 6423 light blue. Product data sheet. Available online at https://wbg-pooling.eu/wp-content/uploads/2021/04/wbg-pooling-produktdatenblatt-WBG-Pooling-Foldable-Crate-6423-light-blue-DE.pdf, last checked 12/14/2021.

Wegmann, Alex; Le Gal, André; Müller, Daniel (eds.) (2016): Antioxidants (Handbook of Plastic Additives, Ralph D. Maier, Michael Schiller (eds.)).

Weidema, Bo P. (2019): Consistency check for life cycle assessments. In: *Int J Life Cycle Assess* 24 (5), pp. 926-934. DOI: 10.1007/s11367-018-1542-9.

Welchering, Peter (2021): Digital sovereignty - Blackout shows: Facebook logins are risky. Ed. by ZDF. Available online at https://www.zdf.de/nachrichten/digitales/facebook-blackout-login-100.html, last checked 16.12.2021.

Wertpack (ed.) (2021): Flachsteige/Stecksteige. Available online at https://www.wertpack.de/detail/flachsteige-stecksteige__748.html, last checked 21.12.2021.

Weschnowsky, Sven (2021): Flowertray: Industry solution to replace disposable plant trays. Available online at https://taspo.de/kategorien/flowertray-branchenloesung-zum-ersatz-von-einweg-pflanzentrays/, last checked 12/14/2021.

Weyh, Florian Felix (2020): Die große Toilettenpapierkrise: Hamsterkäufe und Lieferketten im Kapitalismus. Ed. v. Deutschlandfunkkultur. Available online at https://www.deutschlandfunkkultur.de/die-grosse-toilettenpapierkrise-hamsterkaeufe-und-100.html, last checked 16.12.2021.

ERROR! USE THE HOME TAB TO APPLY ÜBERSCHRIFT 1 TO THE TEXT THAT YOU WANT TO APPEAR HERE.

Wincentsen, D. L. (2013): Encyclopedia of Global Warming and Climate Change. Ed. v. Reference Reviews.

Zampori L., Pant R. (2019): Suggestions for updating the Product Environmental Footprint (PEF) method. EUR 29682 EN. Ed. v. Publications Office of the European Union. Available online at https://eplca.jrc.ec.europa.eu/permalink/PEF_method.pdf .