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Carbon Footprint of Packaging Systems for Fruit and Vegetable Transports in Europe

On behalf of

Stiftung Initiative Mehrweg

Fraunhofer IBP

Title of the study:	**Carbon Footprint of Packaging Systems for Fruit and Vegetable Transports in Europe**

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Abstract

It is difficult to imagine everyday life without fresh fruit and vegetables being provided through retail. Providing these goods year-round in sufficient quantity and quality however requires complex logistic processes which mainly involve the use of two different packaging systems: Reusable Plastic Containers (RPC) and single-use Cardboard Boxes (CB).

On behalf of *Stiftung Initiative Mehrweg (SIM)* (the Foundation for Reusable Systems), the Department Life Cycle Engineering (GaBi) of the Fraunhofer Institute for Building Physics (IBP) conducted a carbon footprint to quantify the greenhouse gas emissions induced by both food packaging systems. The study, which was conducted according to the international standards ISO 14040 and ISO 14044 is intended to support market players in decision-making processes and can contribute to corporate sustainability reports (such as GRI or GHG Protocol, for instance).

The study considers production, service life and end of life of both packaging systems. The analyses of the respective life cycles are completed by subsequent comparisons. Based on actually performed food transportation services (data provided by the companies Euro Pool Systems and IFCO Systems GmbH) the greenhouse gas emissions due to the use of reusable packaging systems will be compared to the greenhouse gas emissions induced by identical services performed with single-use containers. The comparison is based on the functional unit of the transport of 1,000 t of fruit or vegetables in the considered countries Germany, France, Italy, the Netherlands and Spain. Figure 1 is a schematic representation of the life cycles of the packaging systems under study. In the case of the single-use system, a new container must be produced for every transport; in the reusable system, however, the containers are assumed to be reused for 50 times after undergoing inspection and cleaning after each use.

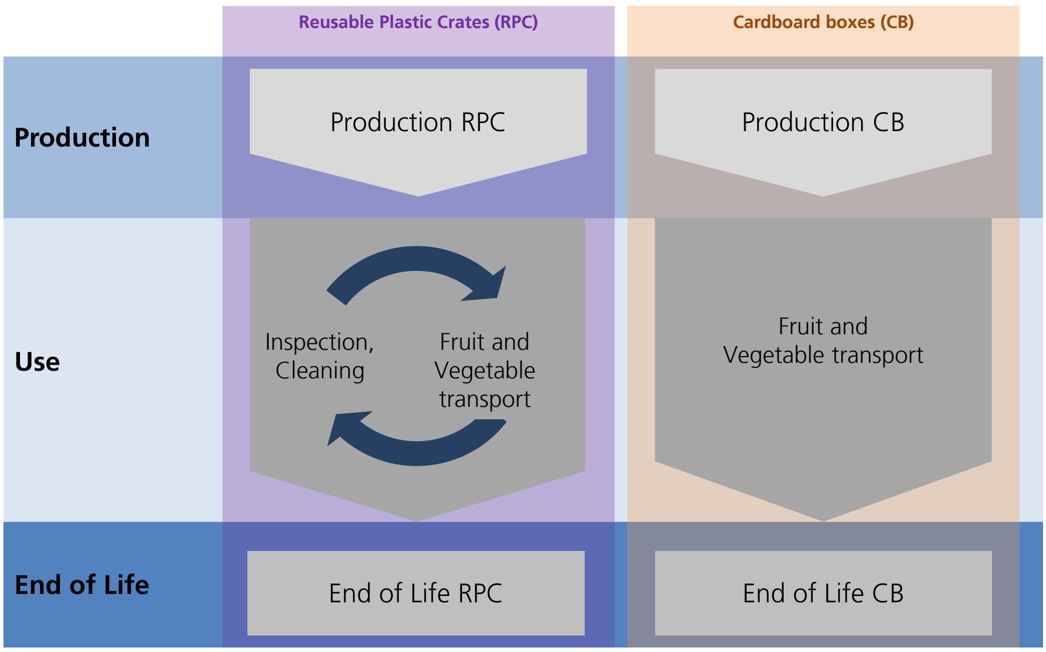

Figure 1: **Schematic representation of the life cycles of the packaging systems under consideration**

The greenhouse gas emissions induced by performing the defined transport services for the reusable system were found to be about 60% lower than the greenhouse gas emissions associated with the single-use system (see Figure 2).

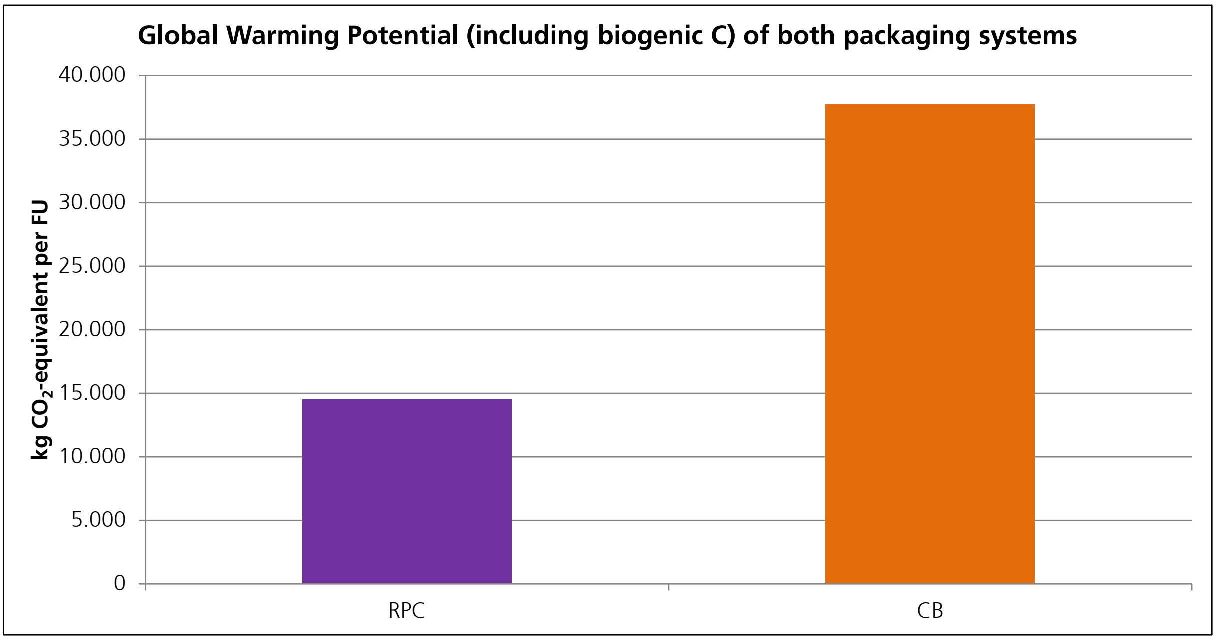

Figure 2: Comparison of the greenhouse gas emissions from RPC and CB

Referring to the transport of 1,000 t of fruit and vegetables, the reusable system (RPC) will cause approximately 14.5 t of carbon dioxide (CO_2) equivalents, whereas the single-use system (CB) will generate 37.7 t of CO_2 equivalents. While the initial expenditure for manufacturing reusable containers exceeds the expenditure for producing single-use containers, this will pay off during the service life and result in lower greenhouse gas emissions along the entire life cycle.

Through a sensitivity analysis, the underlying assumptions were analyzed with regard to their impact on the result of the study. In all variations considered, the reusable system was found to have significantly less greenhouse gas emissions than the single-use system, thus proving the assumptions and the background model to be highly stable. The study is confined to the analysis of the Global Warming Potential. By definition, other impact categories will not be examined. Further limitations regarding the results are described in the study.

A critical panel review of the study (which is required in ISO 14040 and ISO 14044 for studies containing comparative assertions) was performed. The report on the outcome of the review process is contained in annex A9 – Report on the critical review

List of abbreviations

Abbreviation	Meaning
C	Carbon
CB	Cardboard Box
CH_4	Methane
CO_2	Carbon dioxide
EPS	Euro Pool System GmbH
FEFCO	European Federation of Corrugated Board Manufacturers
GWP	Global Warming Potential
IFCO	IFCO Systems GmbH
ILCD	The International Reference Life Cycle Data System
ISO	International Standardization Organization
kg	Kilogram
km	Kilometer
L	Liter
LCA	Life Cycle Assessment
LKW	Truck
PE	Polyethylene
PP	Polypropylene
RPC	Reusable foldable Plastic Container
SIM	Stiftung Initiative Mehrweg (Foundation for Reusable Systems)
t	Tonne
ts	thinkstep

Glossary

English	Explanation
Packaging system	Collective term for the packaging analyzed
Reusable Plastic Container (RPC)	
Single-use Cardboard Box (CB)	
Greenhouse gas emissions	The emission of gases relevant to the green-house effect during the life cycle of the product
Distribution Center	Food retailer, central storage facility, distribution center
Service Center	Inspection and cleaning center
Retail	Point of Sale
Average breakage rate	Percentage of damaged RPCs per rotation
Carbon Footprint	Systematic analysis of the release of emissions relevant to greenhouse effect (along the entire product life cycle)
Greenhouse gas emissions	The emission of greenhouse relevant gases. Besides carbon dioxide (CO_2), these include among others: methane, nitrous oxide, fluorinated hydrocarbons as well as sulphur hexafluoride and nitrogen trifluoride
Biogenic CO_2	Carbon dioxide with carbon of recent origin. During biomass growth, the carbon is absorbed from the atmosphere.
Global Warming Potential (GWP)	Environmental impact category. Greenhouse-relevant emissions are grouped and converted to a reference unit (kg CO_2-equivalent, in this case).
Anthropogenic climate change	Climate change induced by human activities

1. Introduction and goal of the study

This study determines the greenhouse gas emissions (Carbon Footprint) caused by packaging systems used for fruit and vegetable transports in Europe. The assessment is focused on the two packaging systems that bear the highest market relevance, namely Reusable Plastic Containers (RPC) and single-use Cardboard Boxes (CB) [2].

The main objective of this study is to quantify the greenhouse gas emissions from the Reusable, Foldable Plastic Containers (RPC) and the single-use Cardboard Boxes (CB) and to compare these results. To achieve the main objective, processes along the entire value chain of both packaging systems will be investigated, analyzing the life cycle phases of production, service life, and end of life.

The study was conducted on behalf of *Stiftung Initiative Mehrweg (SIM)* [the Foundation for Reusable Systems]. The main objective derives from SIM's declared aim of reducing greenhouse gas emissions caused by fruit and vegetable transportation in Europe. By commissioning this study, SIM ensures that the founder's will is implemented, which has been set out in § 2 (1) of the foundation articles, namely by "... promoting public interest in areas related to … environmental protection" with the aim of "contributing to safeguarding the natural environment and resources". In this context, climate protection constitutes one of the greatest challenges. The study is conducted due to the interest expressed by stakeholders (logistics companies or retail, for instance) and the public.

SIM intends to share the findings of this study with other market players. These include organizations of the packaging and food industries, logistics companies and the customers (private and commercial end-users). The findings will be used to analyze process chains. Furthermore, knowledge about the classification of greenhouse gas emissions caused by the reusable and single-use systems is improved. Generally, the results of the study are suited to be further used in corporate environmental reports, e.g. to support an environmental management system or for reports according to the GHG Protocol or the Global Reporting Initiative (GRI).

Further, the aim of the study is to provide the public with information on the greenhouse gas emissions associated with the respective packaging systems, and can be used by SIM and its members for communication purposes. The study ties in with previous LCA studies commissioned by SIM [13]; its main focus, however, is on contributions to the Global Warming Potential, which is currently being considered as a crucial environmental challenge. The study examines the packaging systems (RPC and CB) that bear the greatest relevance to the market.

The study enables manufacturers and customers of returnable and non-returnable systems to identify greenhouse gas emissions along the value chain. It was conducted by the Department of Life Cycle Engineering (GaBi) of the Fraunhofer Institute for Building Physics (IBP). It was performed according to the requirements specified in ISO 14040 [19] and ISO 14044 [20].

In the study, comparative assertions about the packaging systems under consideration are being made. According to the requirements set out in ISO 14040 [19] and ISO 14044 [20], a critical panel review was performed by independent external experts. Further information on the critical review process is given in Chapter 2.11. The summary of the critical review is included in annex A9 – Report on the critical review.

2. Scope of the study

The scope of the study, which is defined in the following sections, ensures full traceability and reproducibility of the findings obtained. Moreover, the detailed description of the scope of the study assures that the analysis of the examined packaging systems is based on consistent data material.

2.1 Product systems

The study takes a look at the two packaging systems that currently bear the greatest market relevance for fruit and vegetable transportation in Europe [2], namely one returnable system and one non-returnable packaging system. In the case of the returnable system, Reusable foldable Plastic Containers (RPC) are examined. In the case of the non-returnable system, single-use Cardboard Boxes (CB) are examined.

This study assesses these packaging systems in accordance with the requirements specified in the underlying standards ISO 14040 [19] and ISO 14044 [20].

In Figure 3 the life cycles of both product systems are schematically represented.

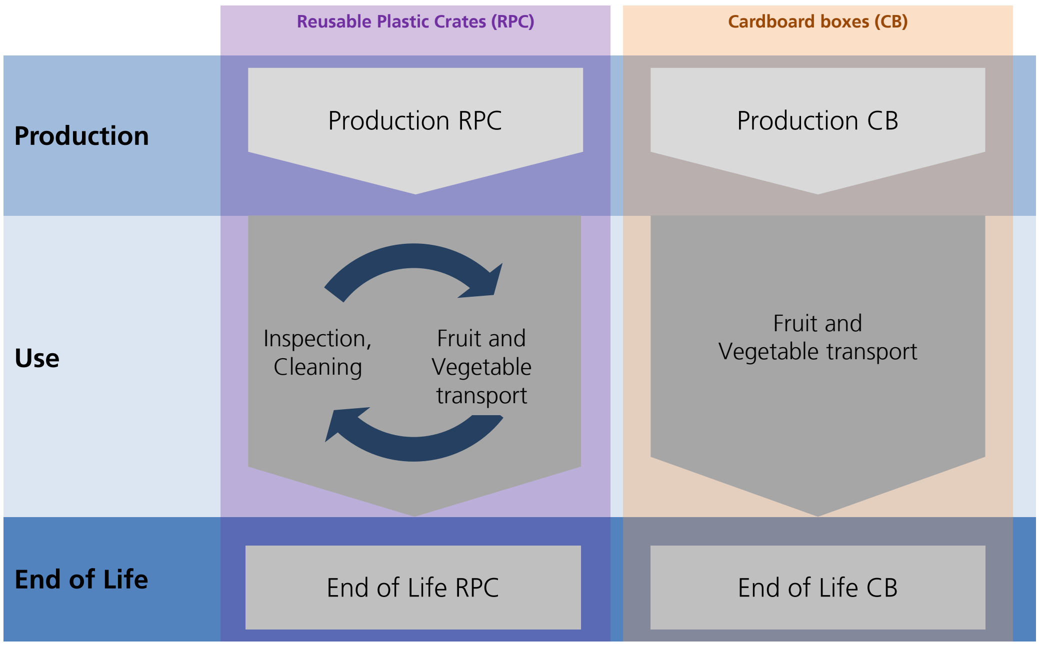

Figure 3: Schematic representation of the respective life cycles of the packaging systems under consideration

After manufacture, the Reusable Plastic Containers are going to be used for several times until their technical end of life is reached, whereas the single-use Cardboard Boxes will be directly disposed of after manufacture and one-off use. Therefore, the CB are not being reused.

Since both container systems differ, a reference container (see Chapter 3.1) is defined for subsequent evaluation. For each packaging system, the technical characteristics of the reference container are listed in Table 1.

Table 1: Technical properties of the reference containers

	Reusable Plastic Container (RPC)	Single-use Cardboard Box (CB)
Material	Polypropylene and polyethylene	Cardboard
Type of use	Reusable system	Single-use system
Preparation for reuse	Distribution, inspection and cleaning	-
Rotations	50	1
Average breakage rate	0.53%	-
End of life	Energy recovery, material recovery	
Weight of the container [kg]	1.82	0.78
Dimensions [mm]	600x400x210	
Filling load [kg]	15	
Containers per pallet [-]	40	
Layers per pallet [-]	10	
Pallets per truck [-]	33	
RPC (folded) per pallet/truck [-]	304 / 10,032	-
Reference period of data collection [year]	2012-2017	2012-2017
Geographical representativeness, foreground system	Germany, France, Netherlands, Spain, Italy	
Geographical representativeness, background system	European average values (EU)	
Technical representativeness	Data on production and use provided by European companies and associations	

The reference containers are characterized by identical transport and load capacities and share the same internal and external dimensions. There are differences in terms of the materials used, the type of use and the weight. Besides, the RPCs can be folded for empty transportation.

For both packaging systems, a load of 15 kg fruit and vegetables is assumed.

Basically, the use of data provided by European industries and associations and the use of background data allow the results to be transferred in the European context. This requires an adjustment of the transport distances, which in this study is addressed through parameter variations.

The study examines the transportation of food by trucks as this represents the core business of SIM members. Other modes of transport or intermodal transports are not considered in the scope of this study.

2.2 Product function and functional unit

To ensure comparability of different packaging systems, the functional unit needs to be the same for all systems under consideration. The functional unit describes the quantified benefit of the systems that are to be compared. The calculated greenhouse gas emissions always refer to the functional unit (unless otherwise noted).

The study analyses the greenhouse gas emissions from fruit and vegetable transports in Europe. The functional unit is defined as the transport of 1,000 t of fruit and vegetables within the considered countries Germany, France, the Netherlands, Spain and Italy and is hence:

The distribution of 1,000 t of fruit or vegetables in Reusable Plastic Containers (RPC) or in single-use Cardboard Boxes (CB)

To fulfill the functional unit, the containers must hence be filled 66,667 times, assuming a given load capacity of 15 kg per container.

Approximately 55% of the acreage used for cultivating fruit and 58% of the acreage for cultivating vegetables in Europe [6] are located in the countries under review; about 54% of the population of the European Union live in these countries [5]. Therefore, a relevant part of the European food market is being represented.

Since the introduction of the Reusable Plastic Containers, a great variety of RPCs have been in circulation. Meanwhile, reusable systems are well established on the market and have proven operational stability for many years. On average, there are about 50 rotations in an RPC life cycle, with an average of 5 rotations per year [7], [16]. This corresponds to a calculated service life of 10 years. Taking account of an average breakage rate of 0.53% [7], [16] per rotation, this results in a total demand of 1,687 RPC for fulfilling the functional unit. Considering the rotations along the entire life cycle is in line with the usual procedures adopted when examining reusable systems [17]. The entire life cycle includes a demand of 1,334 RPC (66,667 fillings / 50 rotations per RPC) and 353 RPC that need to be replaced (1,334 RPC * 0.53% breakage rate* 50 rotations). Stresses and strains acting on RPC (e.g. due to UV radiation or material embrittlement) are reflected by the breakage rate. Assuming a weight of 1.82 kg per RPC, this corresponds to a total weight of 3,070 kg of plastic material [8], [15].

In the case of the non-returnable system CB, a new container is required for each of the 66,667 fillings. Assuming a weight of 0.78 kg per CB, this corresponds to a total demand of 52,200 kg of cardboard.

2.3 System boundary

The present study analyses the greenhouse gas emissions of both packaging systems along the entire life cycle. The life cycles and the system boundaries of both packaging systems are described in Figure 4. They comprise the life cycle stages production, use and end of life.

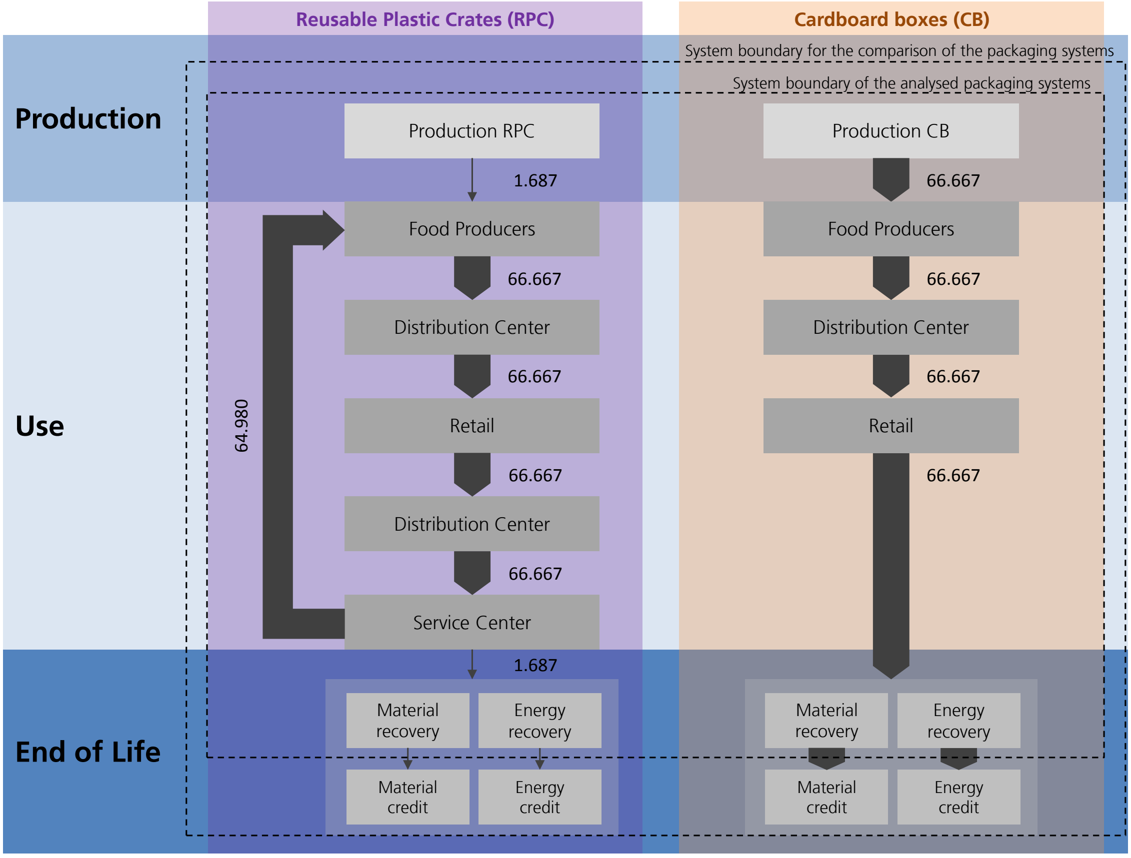

Figure 4: System boundaries and return rates of both packaging systems (in pieces)

For both packaging systems, the system boundary covers the supply of raw materials, the production and distribution of the empty and filled containers and the expenditures and credits for material and energy recovery.

Properties like e.g. design variations (shape, color and size), printability, product hygiene, product protection or ease of use are not considered in the scope of this study. For the purposes of this analysis, the systems are considered to be equivalent due to their identical dimensions and transport capacities.

For both packaging systems, proper use is assumed, i.e. both systems are not supposed to suffer loss (e.g. due to theft or further use for other purposes) or be subjected to inappropriate disposal.

2.4 Allocation procedures

In the background system, i.e. in processes from the GaBi database [26], allocations according to ISO 14040/44 [19], [20] occur. Documentation of the allocation procedures is available online [25].

In the foreground system, allocations are made for the materials used. Regarding the synthetic materials (plastics) used in the RPCs, an economic allocation is performed in the scope of material recovery to account for material degradation. In the case of the CB system, an allocation is done in terms of the recycling rate and the resulting average material life cycles of the cellulose used. Further information on this is given in Chapter 3.3.

2.5 Cut-off criteria

No general cut-off criteria have been defined for this study. As described in Chapter 2.3, the system boundary is defined with regard to the relevance to the goal of the study. For processes within the system boundary, all available data on energy and material flows were included in the model. The study is going to analyze the production, utilization and the end of life of both packaging systems. The study does not include the production of infrastructure (buildings, machinery, etc.). In cases where appropriate inventory data for reproducing inputs or outputs is lacking, approximate values were used (data based on conservative assumptions concerning the impact on the Global Warming Potential).

Concerning the manufacture of RPC, energy and mass flows for materials, energy, auxiliary and operating materials such as lubricating oil, additive compounds (UV absorbents, antioxidants) indicated by the manufacturer [3] are represented as well as packaging materials (PP strapping and LDPE films) (compiled in Figure 6 in section 'Auxiliary and operating materials'). The impact of the examined auxiliary and operating materials on the overall result and RPC production is negligible.

CB production considers the mass and energy flows for raw materials, energy, additive compounds (starch, printing color, NaOH, etc.) reported in FEFCO (2015) [11] and packaging materials (PE-sheets, etc.) (compiled in Figure 8 in section 'Auxiliary and operating materials').

2.6 Selection of the Global Warming Potential (GWP) as environmental impact category

The declared aim of the SIM Foundation is to promote environmental protection and to reduce greenhouse gas emissions [24]. There is now broad consensus that climate change is a crucial field of action and that the reduction of greenhouse gas emissions is of major importance in all areas of daily life [4], [27], [28].

Due to the relevance of greenhouse gas emissions and the reduction of these emissions the present study focuses on the anthropogenic (induced by human activities) climate change. In previous studies, which analyzed further impact categories, it was found that GWP is well suited to represent the environmental relevance of the systems considered here [13]. The associated environmental impact category is the *Global Warming Potential (GWP*), which is expressed in kg CO_2 equivalents. In the context of a carbon footprint analysis, all substances relevant to global warming will be identified and converted to carbon dioxide (CO_2) equivalents. Characterization factors are used for conversion. The environmental impact category 'Global Warming Potential' will be analyzed for a period of 100 years (GWP100). For this purpose, the characterization factors [21] recommended by ILCD in version v1.09 will be used, which were taken from the 2007 IPCC 2007 report [18], and include the emission and uptake of biogenic carbon[1]. In the scope of this study, the uptake and emission of biogenic carbon will be reported separately.

The impact category is an impact *potential*, meaning an approximation to an environmental impact, which may occur. A precondition for this is that the emissions will follow the underlying mechanism of action and occur under specific environmental boundary conditions. Moreover, the life cycle inventory analysis (LCI) includes only those parts of the environmental loads, which are to be attributed to the functional unit. This is why the results of a life cycle impact assessment (LCIA) provide relative statements and do not give any information on possible effects on e.g. category endpoints or exceedance of threshold values.

2.7 Limitations to the study

As defined in the section on aim and scope of the study, the present study focuses on the analysis of the Global Warming Potential. By definition, further impact categories are not considered.

The collected foreground data relates (a) to the configuration of the transport containers according to the manufacturers' specifications and (b) to actual transport distances provided by EPS (Euro Pool System GmbH) and IFCO Systems GmbH in the countries considered. The background data (e.g. on materials and energy) are European average data, which generally allow for a transfer of the results in a European context. This would require that the production and transportation processes in the respective country correspond to the selected European average values. In addition, transferability requires that primary data on container configuration and transport distances are available. Besides, calculations for the returnable system are based on the assumption of a well-established, stable system[2] - otherwise, initial expenditures for transport containers would have to be taken into account.

2.8 Requirements on data quality

The data collected for the foreground system, particularly for transport distances and volumes, breakage rates of the Reusable Plastic Containers and their cleaning refers to the base years 2016 and 2017. The collected data was measured, calculated or estimated by experts and then validated against values taken from literature. Data collection and assumptions are dealt with in Chapter 3. Data used in the model for the background system (e.g. for production of raw materials, supply of thermal and electrical energy) were taken from the GaBi database [26]. Foreground data determine mainly the system configuration (transport distances, the mass of the transport containers, etc.). The specific environmental profile results from the linking with the background data. The influence of the foreground data was checked by conducting a sensitivity analysis.

2.9 Type and format of the report

The report is structured according to the requirements specified in ISO standards 14040/44 [19], [20]. As prescribed in the standards, the results of the study have been presented completely,

[1] Carbon that is absorbed from the atmosphere during biomass growth.

[2] The reusable pool system has been established and operated in a stable manner for several years in a relatively constant market. The existing pool of reusable containers and the initial equipment ensure the fulfilment of the functional unit.

correctly and in an unbiased manner. The report is intended to provide readers with reproducible results, i.e. data and assumptions are documented in reasonable detail.

2.10 Software and database

The LCA model was designed using the GaBi Software [26] and provides the basis for calculations of the greenhouse gas emissions. The used database is up to date (Service Pack 34, 2017). A list of the used datasets is given in Annex A8 – Documentation of the background data.

2.11 Critical review

In compliance with the requirements set out in ISO 14040/44 [19], [20] a critical review has to be performed by independent external experts if a study containing comparative assertions is to be published. For the present study a critical review was done by

- Christina Bocher (DEKRA); chairperson of the review panel
- Ivo Mersiowsky (Quiridium)
- Sebastian Spierling (Hochschule Hannover/ Hanover University of Applied Sciences and Arts).

The review report is included in annex A9 – Report on the critical review.

3. Life cycle inventory analysis (LCI)

To determine the greenhouse gas emissions of the two packaging systems under consideration, LCI models are created. The life cycles of the packaging systems and the related system boundaries are schematically represented in Figure 4 in chapter 2.3.

Newly manufactured, inspected and cleaned RPC are supplied to the food producers, filled and then shipped to the distribution centers. From there, they are forwarded to retailers. After use, the RPC will be folded, stacked, and returned to the distribution centers. Here, they are collected and sent to service centers for inspection. Damaged RPC are sorted out and sent to material recovery (theoretically, energy recovery would be possible in this case, too). Undamaged RPC will be cleaned, exchanged between service centers if need be (regrouping) and then supplied to the food producer for further use.

CB containers will not be reused, i.e. the containers will be directed to material or energy recovery immediately after use. Due to this fact, neither return transports to the distribution centers nor transports to service centers and food producers are necessary. However, more containers need to be manufactured in order to fulfill the functional unit.

Reference containers

The definition of a reference container forms an essential basis for the comparison of both packaging systems. The load capacity (15 kg) and the external dimensions of the containers (600x400x210 mm) are identical. In the last few years, the size of 210 mm has become a standard height for containers used in returnable packaging systems. This height is hence used as a basis in this study. The containers differ in terms of material, empty weight and other characteristics. Table 2 gives an overview of the actually used plastic containers (EPS [8], IFCO [15]) and Cardboard Boxes (FEFCO [10]) and the corresponding model reference containers featuring identical load capacities and the same internal and external dimensions. The values for the corresponding reference containers were calculated.

Table 2: Basic data and modeled reference containers from [8], [10], [15]

	Reusable Plastic Container (RPC)			Single-use Cardboard Box (CB)	
Model	**Model 216**	**Model LL6420**	**Modeled reference RPC**	**FEFCO CF 1**	**Modeled reference CB**
Material	HD-PE	PP	**HD-PE/PP-Mix**	Cardboard	**Cardboard**
Weight of container [kg]	1.82	1.83	**1.82**	0.69	**0.78**
Dimension, external [mm]	600x400x 211	600x400x 216	**600x400x 210**	600x400x 180	**600x400x 210**
Max. load [kg]	20	20	**15**	10	**15**
Container per pallet (with load)	44	40	**40**	Not defined	**40**
Layers per pallet (with load)	11	10	**10**	Not defined	**10**
Pallets per truck (27 t load weight)	33	33	**33**	Not defined	**33**
Layers per pallet (folded)	76	78	**76**		**-**

The following chapters will provide details on the inventory analysis (LCI) data of production (Chapter 3.1), utilization (Chapter 3.2) and end of life (Chapter 3.3).

3.1 Production of the containers

To fulfill the functional unit (see Chapter 2.2), the non-returnable system requires more containers than the returnable system. In the following section, the modeling process for the production of the Reusable Plastic Containers (RPC) and the single-use Cardboard Boxes (CB) is described.

Reusable Plastic Containers (RPC)

The Reusable Plastic Containers (RPC) investigated in this study are either made of polypropylene (PP) or of high-density polyethylene (HD-PE). Examples of empty RPC containers made from polypropylene and from HD-PE, respectively, are shown in Figure 5.

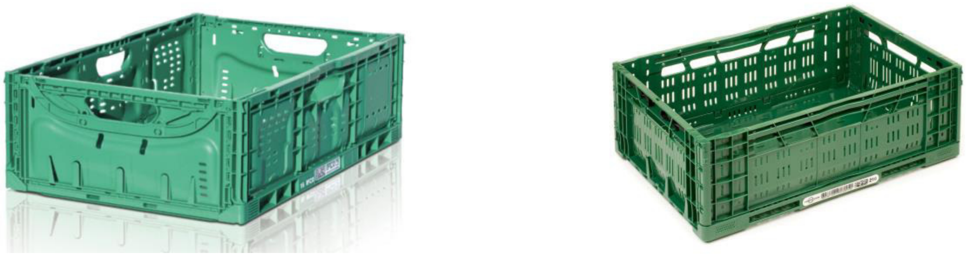

Figure 5: Reusable Plastic Containers [7], [16]

In the LCA model, the manufacture of both types of plastic containers (made of polypropylene, PP or high-density polyethylene, HD-PE) is represented using data sets provided by PlasticsEurope [23]. These include average data provided by the European plastics industry for manufacturing the granulate including the upstream processes. Figure 6 presents a scheme of the LCA model for RPC production.

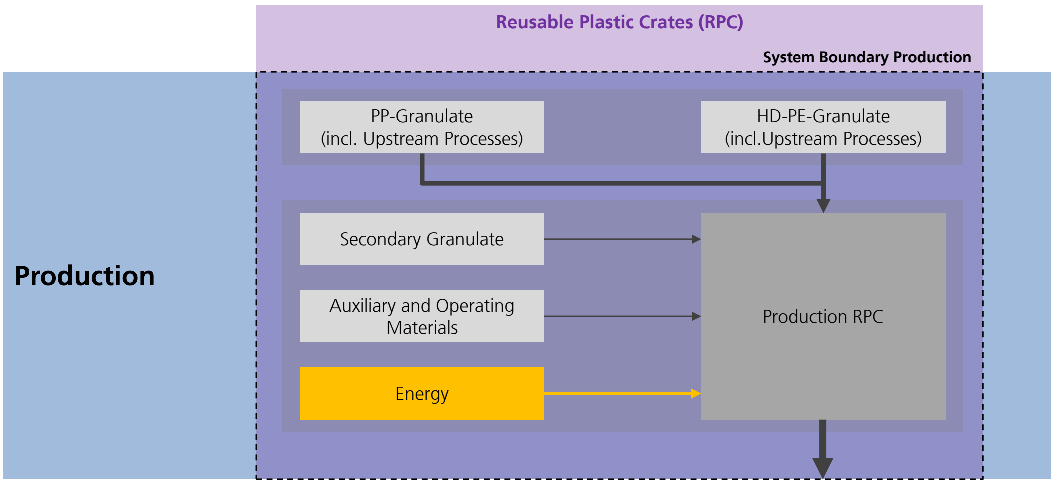

Figure 6: Production process of the Reusable Plastic Containers

According to the assumptions made, the HD-PE and PP granulates will be transported to the production site over a distance of 300 km. The RPC used by IFCO are made of PP [15]; the ones used by EPS are made of HD-PE [8]. In the model, RPC are represented by a mix of materials and technologies, which is calculated on the basis of the RPC stock quantities circulating in the countries under survey. Hence, 49.5 percent of the model reference containers are made of PP, while 50.5 percent are made of HD-PE [7], [16]. It is basically possible to add recycled secondary granulate to the primary granulate. For RPC made from HD-PE [7], the current mixture ratio is 100% primary granulate and 0% secondary granulate; RPC made from PP contain a 20% share of secondary granulate [16]. The secondary granulate is recovered from damaged RPC. The admixture of additives ensures resistance to light, heat, etc. Subsequently, the RPC will be manufactured through a plastic injection molding process to be then distributed to the food producers. After first delivery, the service life of the RPC begins.

Single-use Cardboard Box (CB)

The data for the analyzed single-use Cardboard Boxes (CB) was published by the European Federation of Corrugated Board Manufacturers (FEFCO). The provided data is available at an adequate level of detail [10], [11]. The inventory data submitted by these sources was completely transferred into modeling. Figure 7 shows an example of a single-use Cardboard Box.

Figure 7: Single-use Cardboard Box [13]

Figure 8 presents a scheme of the LCA model for CB production.

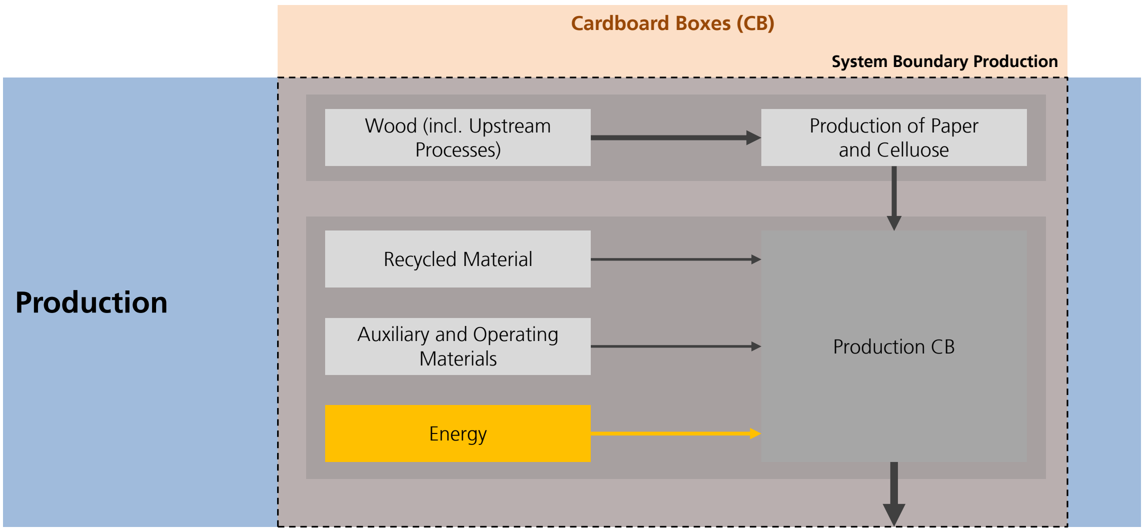

Figure 8: Production process of the single-use Cardboard Boxes

For manufacturing the CB, cellulose is extracted from wood (hardwood and softwood [11]) and used for box production. In addition to wood, minor shares of recycling material are used. In this process, Kraftliner and Semi Chemical Fluting as an intermediate product are the essential components. Per tonne of Semi Chemical Fluting, 0.09 t of recycled paper and 0.95 t wood are used; for each tonne of Kraftliner, 0.36 t of recycled paper and 1.11 t wood. For 1 t of cardboard used for manufacturing the CB examined in this study, a total of 1.1 t of precursors are required [11], of which approximately 0.7 t is Semi Chemical Fluting and 0.4 t Kraftliner [10]. The manufactured cardboard is further processed, and the CB is subsequently distributed to the food producers. After delivery, the service life of the CB begins.

3.2 Container service life

To ensure comparability of both container systems, an identical function must be fulfilled. For the present case, this was defined in Chapter 2.2 as the transport of 1,000 t of fruit and vegetables in the countries under assessment Germany, Spain, Italy, France and the Netherlands. The following section will focus on modeling the service life of both packaging systems.

Transport routes, distances, volumes and Euro classes

To determine the transport routes and to calculate the distances, data provided by EPS, IFCO and from literature are used.

In the graph in Figure 9, the steps of transportation are described and numbered for both packaging systems; the corresponding transport distances are also indicated.

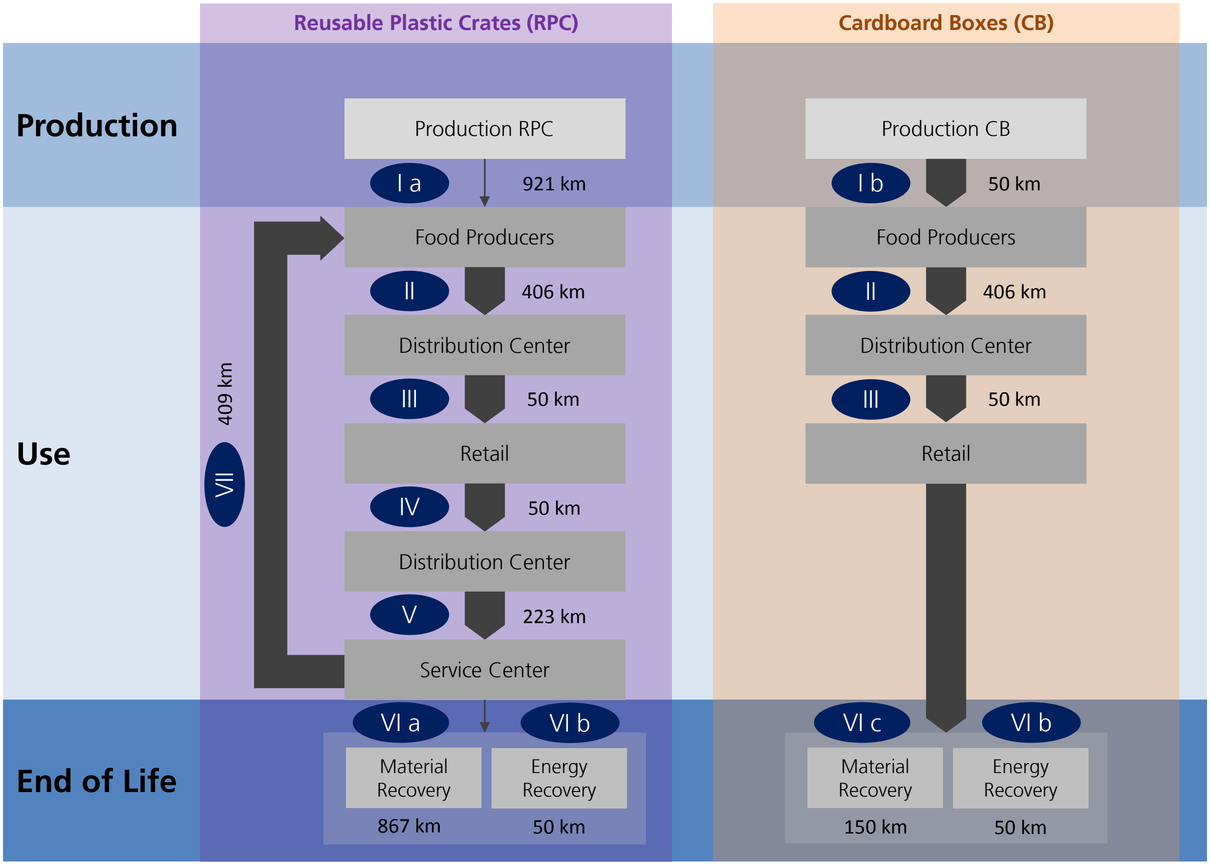

Figure 9: Transport routes of the two packaging systems

The transport distances of routes II, III and VI b are identical for both packaging systems. They were calculated or researched. Transport distances I a and I b and VI a and VI c differ, however. The transport distances IV, V and VII are only present in the RPC system. The transport distances I a, I b, IV, V, VI a, VI c and VII were provided by IFCO [16], EPS [7] and FEFCO [11].

The transport distances are documented in Table 3.

Table 3: Average transport distances of an average transport rotation for both packaging systems in Germany, Spain, Italy, France and the Netherlands

Transport route	Distance [km]		Truck		Data origin	
	RPC	CB	Truck capacity [t]	Capacity utilization [%]	RPC	CB
I a and I b	921	50	27	73	[7], [16]	[9]
II	409	409	27	70	Assumption	
III	50	50	17.3	70	[1]	
IV	50	-	17.3	70	[1]	n/a
V	223	-	27	70	[7], [16]	n/a
VI a and VI c	867	150	27	92	[7], [16]	Assumption
VI b	50	50	27	92	Assumption	
VII	409	-	27	60	[7], [16]	n/a

The information regarding transport distances largely stems from primary data collections performed by EPS [7] and IFCO [16], which were complemented with data and assumptions contained in the secondary sources supplied by ADEME [1] and FEFCO [9]. The transports IV, V and VII do not occur in the non-returnable system. The data collected by EPS and IFCO provides the basis for the volume-weighted transport distance in the relevant countries. Capacity utilization also includes possible empty runs.

FEFCO's 2016 annual statistics report specifies 672 production sites for cardboard containers in Europe (125 of which are located in Germany, 81 in Italy, 89 in Spain and 61 in France) [9]. If the number of production sites (proceeding on the assumption of uniform distribution) is considered in relation to the area of the countries investigated, a distance of approximately 50 km results. This value is hence assumed to be equal to the transport distance for the first delivery I b.

The distance for transport route II derives from the assumption that the delivery distance of the food to be transported is equal to the transport distance of the return transports (transport route VII). Regarding the return transports (transport route VII), only the additional fuel consumption is allocated to the RPC because the trucks are heading south in order to pick up food, irrespective of forwarding RPC.

There is a large number of waste incineration plants in the countries considered, which are often located close to urban agglomerations. For both systems the transport distance towards energy recovery is hence assumed to be 50 km. As there are fewer cardboard recycling companies, the transport distance is assumed to be 150 km.

The fleet of trucks is composed of different Euro classes. In Table 4 the percentage distribution of the current, averaged IFCO [16] and EPS [7] truck fleets is given. This fleet mix provides the basis for all assumed transport operations involving both packaging systems. Used background data (such as Diesel, for instance) is European average data.

Table 4: Mix of Euro classes for the trucks used and for both packaging systems

European emissions class	Share in the fleet mix
Euro4	7%
Euro5	33%
Euro6	60%

The capacity and the external dimensions of the reference containers are identical (see Chapter 3.1). For 40 containers, the load of fruit and vegetables is 600 kg per pallet. To this weight, the empty weight of the containers (RPC 1.82 kg; CB 0.78 kg) is added plus the weight of the pallets (12 kg). For a truck with a capacity of 27 t, the total load capacity amounts to 33 pallets and hence to 1,320 containers; a truck with a capacity of 17.3 t can carry 18 pallets or 720 containers. Table 5 shows the transport loads for trucks with a capacity of 27 t or 17.3 t per container system.

Table 5: Transport loads of trucks with a capacity of 27 t and 17.3 t

	Maximum truck load	
	RPC	**CB**
Filling weight of the containers [kg]	15	15
Weight of the container [kg]	1.82	0.78
Weight of the pallet [kg]	12	12
Containers per pallet [pieces]	40	40
Weight of the filled pallet [kg]	685	643
Pallets per truck (27 t capacity) [pieces]	33	33
Load weight, truck (27 t capacity) [kg]	22,598	21,230
Pallets per truck (17.3 t capacity) [pieces]	18	18
Load weight, truck (17.3 t capacity) [kg]	12,326	11,580

In most cases, the containers are transported by a truck with a capacity of 27 t (transport routes I, II and V-VII). However, smaller trucks with a capacity of 17.3 t are used to carry out transportation steps III and IV (delivery to retailers of both systems and return of the RPC from retail to the distribution center). As shown in Table 5, the truck load weight is exceeded in neither case; the transport quantity is limited by the available volume.

Inspection and cleaning of the Reusable Plastic Containers

Only the RPC are subject to inspection and cleaning. A scheme of the inspection and cleaning processes is presented in Figure 10.

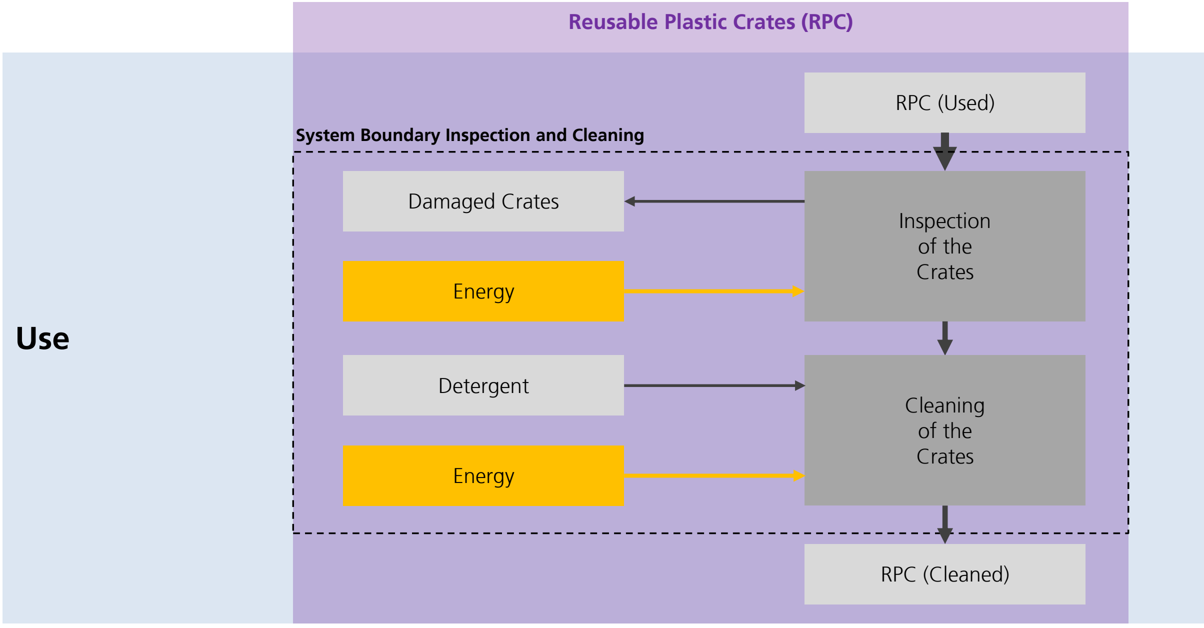

Figure 10: RPC inspection and cleaning in the service center

After every use, the functionality of the containers will be checked first, damaged containers will be sorted out and enter the end of life stage. Intact containers will be rinsed after inspection. Per container, this process requires on average 0.97 L of water and 0.003 L of detergent. Besides, electrical and thermal energy are required for inspection and cleaning. About half of the energy requirement for cleaning is thermal energy [7], [16]. In the scope of a parameter variation, the potential supply of thermal energy through a cogeneration plant (CHP) is investigated. After cleaning, the containers are redistributed to the food producers. Newly manufactured containers do not undergo inspection and cleaning at the first delivery. The RPC has a service life of 50 rotations and an average breakage rate per rotation of 0.53% [7], [16]. This agrees with values reported in other critically reviewed studies [12], [13]. The data on inspection and cleaning was provided by IFCO and EPS.

3.3 End of container life

This chapter focuses on the end of life of both packaging systems. For each system, there is an option for material or energy recovery. In the case of material recovery, the materials have to be shredded in a first step and will then undergo several steps of further processing. During these processing steps, energy input is required and additional greenhouse gas emissions will emerge; the avoided manufacture of primary materials will however be credited. In the case of energy recovery, greenhouse gases will be released during incineration processes. At the same time, usable electrical energy can be generated, which will be correspondingly credited. Figure 11 represents the end of life for both packaging systems.

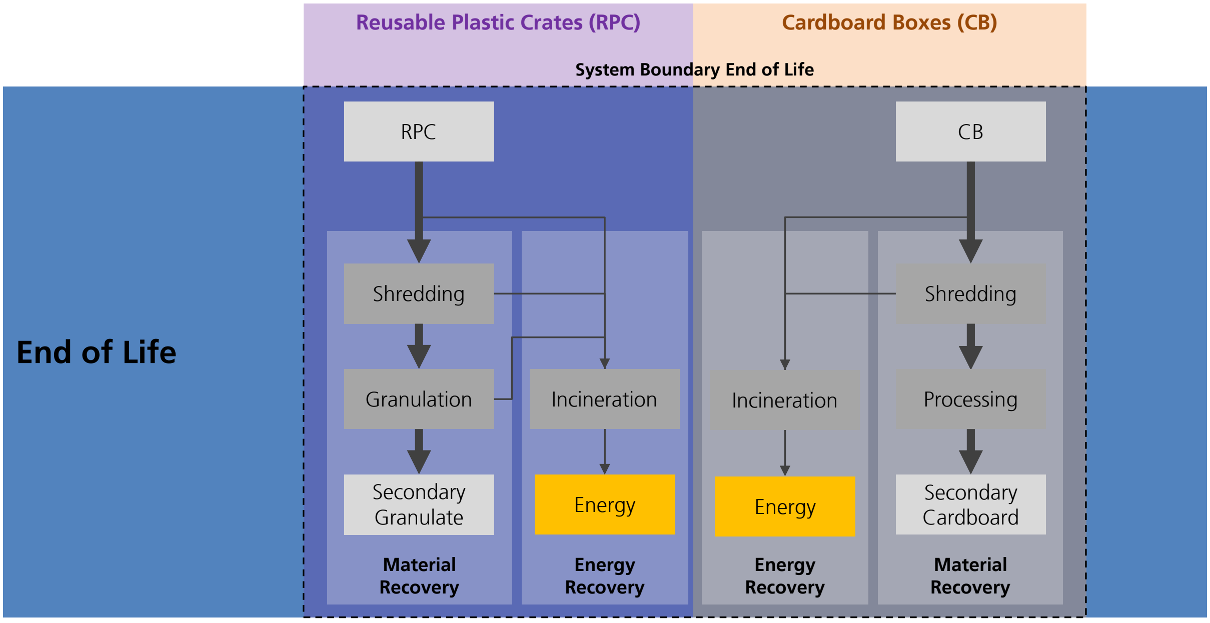

Figure 11: End of life of the packaging systems under consideration

In the base case, part material and part energy recovery are done for both systems. In terms of material recovery, the required share of secondary materials is processed and recycled for CB and RPC production (see Chapter 3.1). The remaining share is accounted for in the model, depending on the material or energy recovery described below. The assumed distribution rates will be described subsequently.

Material recovery

In the case of material recovery, the materials used for both packaging systems are reprocessed and provided for recovery to be used in further applications; in this way, the manufacture of (primary) materials for these applications is avoided. In both systems, the materials need to be shredded first before they can be subjected to further transformation steps.

The LCA model provides credits for material recovery and the ensuing, avoided production of primary materials at the end of life. By definition, temporal aspects of greenhouse gas emission are not examined in the scope of the assessment methodology. Due to the system, plastics are available source-sorted at the end of life. This allows for material recovery or re-use in similar applications. This circumstance is conducive to circular use of materials. The secondary material obtained from CB is mainly applied for manufacturing other products, such as Wellenstoff (recovered fiber-based fluting) and Testliner [11].

Energy recovery
To recover energy, both packaging systems are incinerated in a waste incineration plant and transformed into electrical and thermal energy. The GaBi database contains specified data sets for the incineration of cardboard and plastics. These datasets are used for evaluation. When comparing these systems, the electrical energy generated is accounted for and credited. Thermal energy is considered as waste heat and is therefore not credited.

Assumed distribution rate
The distribution rate of the materials at the end of life results from assumptions concerning the technically possible lifespan of the materials. In the case of cardboard packaging, the fiber material is assumed to last an average total of 6.7 life cycles, which is the basis for calculating the percentage of energy recovery (100 / 6.7 = 15 %) [10]. Regarding subsequent life cycles it is assumed that the fiber material will be used for applications other than CB manufacturing. The fiber length is reduced by each material recovery. Fibers that are too short will be sorted out used for manufacturing sanitary paper.

In the case of plastics, material recovery will shorten the polymer chains, by which the technical quality of the material is reduced. The price of secondary granulates amounts to approximately 70 to 85% of the price of primary materials. In the study, the mean value of 77.5% is assumed as the residual value of the secondary material. Hence, the loss in value per material life cycle is 22.5% [3]. If the plastic is separated by type and recycled, e.g. if it is used for producing identical reusable containers, this can substitute primary material, and the material will not suffer any significant loss in quality. In the current base case scenario, the recycled quantity of secondary material is approximately 10% [16], and the residual materials are assumed to enter some unspecified secondary use.

4. Results

In this chapter the results of the individual life cycles of both packaging systems will be described. Graphical representations of the life cycle phases and stages are given in the preceding Chapter 3 of the Life Cycle Inventory analysis (LCI). The focus is on the impact category 'Global Warming Potential' including biogenic carbon (incl. biogenic C), which has been introduced in Chapter 2.6.

4.1 Life Cycle of the Reusable Plastic Container (RPC)

Based on the previously determined values of the inventory analysis (LCI), an LCA model of the RPC packaging system's life cycle will be created and analyzed. The contributions to the Global Warming Potential (incl. biogenic C) are compiled in Table 6 along the respective life cycle phases.

Table 6: Greenhouse gas emissions of the reusable system throughout its entire life cycle

Life cycle phase	GWP (incl. biogenic C) [kg CO_2 eq.]	Relative contribution
Production	5,255	36%
Service life	10,864	75%
End of life	-1,593	-11%
Total	**14,526**	**100%**

It becomes evident that the service life of the RPC has a relevant impact on the entire life cycle. All in all, the proportionate contribution to the greenhouse gas emissions amounts to 75%. This fact is to be attributed to the number of logistics processes and to RPC cleaning and inspection. 36% of the greenhouse gas emissions occur in the production phase. On account of the product's assumed service life of 50 rotations per RPC the attributable share of production impacts is comparatively small. As a consequence, the expenditures or credits at the end of life will also decrease, which (due to material recovery) result in a final credit of -11% of the greenhouse gas emissions released during the life cycle.

In Table 7 there is a detailed representation of the RPC life cycle stages and associated greenhouse gas emissions (incl. biogenic C).

Table 7: Detailed compilation of the greenhouse gas emissions of the reusable system

Life cycle stage		GWP (incl. biogenic C) [kg CO_2 eq.]	Relative contribution
Production	Plastic granulate	4,775	33%
	Production RPC	332	2%
	Transport	147	1%
Service life	Transport	7,632	53%
	Inspection and cleaning	3,233	22%
End of life	Transport	110	1%
	Shredding and granulation	376	3%
	Incineration	2,022	14%
	Recovery of electrical energy	-408	-3%
	Recovered secondary granulate	-3,693	-25%
Total		**14,526**	**100%**

A large part (33%) of the greenhouse gas emissions in the production phase is caused by the production of plastic granulate. Only minor shares are attributed to RPC production itself through a plastic injection molding process (2%) and to first delivery to the food producers (1%).

During use, the largest part of the greenhouse gas emissions occurs due to transportation (53%). Apart from the food transports to the distribution centers, particularly the return transports of cleaned RPC to the food producers and transports from the distribution centers to the service centers are relevant in this context. RPC inspection and cleaning cause about 22% of the greenhouse gas emissions. This percentage is mainly due to the energy requirement for RPC inspection and cleaning.

At the end of life, a large part of the emissions is caused by incineration of RPC (14%). Although only a share of 22.5% of the materials used in RPC is used for energy recovery at the end of life, the related greenhouse gas emissions clearly exceed those due to shredding and granulating. It is true that the energy released from incineration is used in recovering electrical energy; nevertheless, the credits obtained from this (-3%) clearly fail to compensate for the incineration emissions. Here, the secondary granulate that was gained through material recovery induces significantly bigger credits (-25%) and is thus to be preferred as the more favorable RPC recovery procedure with respect to greenhouse gas emissions. The biogenic CO_2 balance is attached in Annex A2 – Biogenic CO2 balance.

4.2 Life cycle of the single-use Cardboard Box (CB)

By analogy to the procedure in Chapter 4.1, an LCA model for the life cycle of the CB packaging system is created and analyzed. The contributions to the Global Warming Potential (including biogenic C) are listed in Table 8 for the individual life cycle phases.

Table 8: Greenhouse gas emissions of the single-use system throughout its entire life cycle

Life cycle phase	GWP (incl. biogenic C) [kg CO_2 eq.]	Relative contribution
Production	-39,681	-105%
Service life	1,157	3%
End of life	76,246	202%
Total	**37,723**	**100%**

Evidently, the service life of the CB only has a minor impact on the total greenhouse gas emissions (3%) whereas the life cycle phases production (-105%) and end of life (202%) bear significantly greater relevance.

A look at the Global Warming Potential (incl. biogenic C) clearly reveals that the production phase is characterized by an overall negative emission due to sequestration of biogenic carbon. The sequestrated carbon will however be released at the end of life, which leads to significantly higher emissions in the end-of-life phase.

A detailed compilation of CB greenhouse gas emissions (incl. biogenic C) is given in Table 9.

Table 9: Detailed compilation of the greenhouse gas emissions of the single-use system

Life cycle stage		GWP (incl. biogenic C) [kg CO_2 eq.]	Relative contribution
Production	Raw material extraction	-115,256	-306%
	Production of paper and cellulose	70,182	186%
	Production CB	5,196	14%
	Transport	198	1%
Service life	Transport	1,157	3%
End of life	Transport	476	1%
	Shredding and processing	20,741	55%
	Incineration	15,053	40%
	Recovery of electrical energy	-2,083	-6%
	Recovered secondary material[3]	42,060	111%
Total		**37,723**	**100%**

With regard to raw material production, most noteworthy is the large amount of carbon dioxide sequestration (-306%). During growth, the trees used for fiber production absorb a corresponding amount of carbon, which is the reason for the negative contribution to the balance. During paper and cellulose production (mainly Kraftliner and Semi Chemical Fluting), however, large quantities of greenhouse gases (186%) are released, which is primarily due to the energy demand of the production processes. CB production itself only has a minor share in contributions to the production emissions (14%). Transportation to the food producers (1%) is virtually negligible.

In the service life of the CB boxes, only emissions due to transportation occur (3%).

[3] Sequestrated carbon, which is being credited to the next material life cycle. From an accounting point of view, the carbon must be eliminated from the balance calculations and be transferred to the subsequent life cycle, unless sequestration is granted for a minimum period of 100 years (see Annex A2-3).

Assessing the entire life cycle of the CB system, the end of life causes the highest amount of greenhouse gas emissions. The processing is energy intensive and causes a correspondingly high percentage of emissions (55%). Although the stored energy can be recovered by recovering the energy from cardboard, the credits (-6%) for this do not compensate for emissions released during incineration (40%). Cellulose recovery, too, largely contributes to the greenhouse gas emissions as the process is energy intensive on the one hand; on the other hand, however, it does not allow crediting any storage of biogenic carbon (as is the case with primary materials) (111%). The biogenic carbon dioxide balance is attached in Annex A2 – Biogenic CO2 balance.

5. Interpretation

In this section, both packaging systems are compared with respect to their greenhouse gas emissions. To assure the stability of the model, a sensitivity analysis will be conducted to identify parameters that influence the overall result.

5.1 Comparison of the systems

The main goal of the study (besides identifying the specific drivers of both packaging systems) is to compare both systems in terms of their greenhouse gas emissions along the entire life cycle. To this end, the emissions that were determined for the individual life cycle phases of the respective packaging system are summed up and compared to each other.

Figure 12 presents a comparison of the greenhouse gas emissions (including storage and emission of biogenic carbon) of both systems along the respective life cycle.

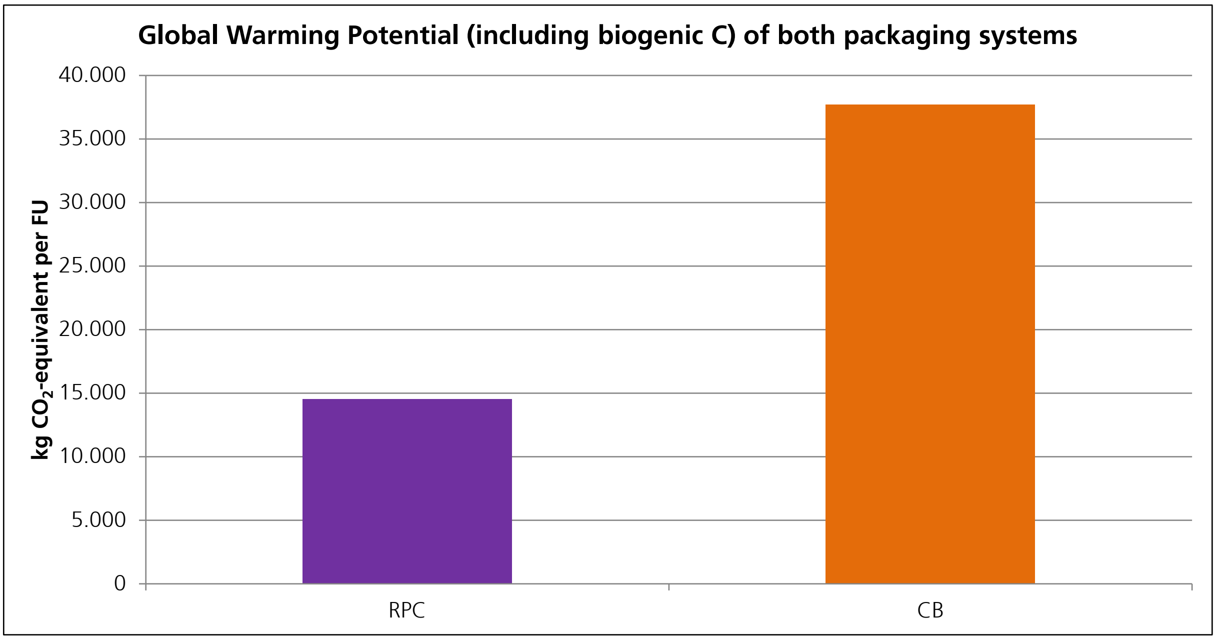

Figure 12: Comparison of the greenhouse gas emissions from RPC and CB

In this comparison RPC (purple) was found to cause approximately 60% less greenhouse gas emissions during its life cycle than CB (orange) in order to fulfill the task of transporting 1,000 t of fruit and vegetables, which had been defined as the functional unit.

In Table 10 the absolute GWP contributions (incl. biogenic C) along the life cycle are compiled, itemized by life cycle phases.

Table 10: Comparison of RPC and CB across the life cycle

Life cycle phase	GWP (incl. biogenic C) [kg CO_2 eq.]	
	RPC	CB
Production	5,255	-39,681
Service life	10,865	1,157
End of life	-1,593	76,246
Total	**14,526**	**37,723**

In the case of the RPC system, the service life is the dominant life cycle phase. This fact is due to the - compared to the CB system - more complex logistics services required, namely return transports to service centers and return delivery to food producers, as well as inspection and cleaning. Moreover, RPC have a higher weight than CB; accordingly, trucks consume more Diesel fuel for RPC transports. Using efficient recycling processes, the materials can be provided for reuse with no significant deterioration in quality, which is rewarded by granting credits. In this context, this situation is represented by a negative emission[4]. All in all, RPC production contributes about one third to greenhouse gas emissions throughout the entire life cycle, which is due to manufacturing the plastic granulate, in particular.

In the case of the CB system, the service life of the boxes is characterized by lower greenhouse gas emissions. This is mainly attributable to the lower expenditure for logistics (compared to the RPC system) and the lower weight of the CB containers. During production, negative emissions occur, which are due to the sequestration of biogenic carbon in the wood used for paper and cellulose production. At the end of life, however, the sequestrated biogenic carbon is either released by incineration or allocated to the next life cycle, if the material is being recovered. To this end, the biogenic carbon uptake that was originally attributed to the material will be credited to the next life cycle, as a sequestration of at least 100 years cannot be expected for the product under assessment. The biogenic GWP share is separately treated in Annex A2 – Biogenic CO2 balance, explanatory notes are given in Annex A3 – Carbon cycle.

When considered along the entire life cycle, the greater expenditure in manufacturing the RPC containers is compensated for by their reuse, thus resulting in lower overall greenhouse gas emissions. The more often RPC are reused, the lower the greenhouse gas emissions to fulfill the functional unit. Further investigations on RPC rotation are reported in Chapter 5.2.2, Chapter 5.3 and Annex A1 – Sensitivity analysis.

[4] Due to avoiding the primary production of plastics.

5.2 Sensitivity analysis

A sensitivity analysis is conducted to identify assumptions that have a potentially relevant effect on the systems under study and were assessed as plausible and technically feasible (as agreed with the client). By varying these assumptions (parameter variation) the effects of the varied values or modified assumptions on the overall system are examined. The examined parameter variations are specified in Table 11; the basic value and the varied value is given for each parameter. Besides, this table gives an overview of the relative impact of the parameter variations on the packaging systems. All relative figures relate to the base case of the respective packaging system.

Table 11: Parameter variations

Description, assumptions made in the parameter variation				Results	
No.	**Parameter**	**Basic value**	**Variation**	**RPC**	**CB**
1a	Distance wood production to cellulose production	FEFCO 2015 (Table 17) [11]	+20%	0.0%	0.2%
1b	Distance wood production to cellulose production		-20%	0.0%	-0.2%
2a	Distance RPC production to food producer	921 km	600 km	-0.4%	0.0%
2b	Distance RPC production to food producer	921 km	1,200 km	0.3%	0.0%
3a	Share of primary granulate in RPC production	90.1%	50%	-7.9%	0.0%
3b	Share of primary granulate in RPC production	90.1%	0%	-17.7%	0.0%
4a	RPC rotations	50	25	19.9%	0.0%
4b	RPC rotations	50	100	-10.0%	0.0%
5a	Transport distance food producer to distribution center	409 km	300 km	-10.3%	-0.7%
5b	Transport distance food producer to distribution center	409 km	600 km	18.0%	1.2%
6a	Transport distance distribution center to retail	50 km	20 km	-3.4%	-0.2%
6b	Transport distance distribution center to retail	50 km	100 km	5.6%	0.4%
7	CHP energy generation for cleaning (thermal energy)	0%	100%	-1.0%	0.0%
8a	Share of material recovery, RPC	77.5%	100%	-17.6%	0.0%
8b	Share of material recovery, RPC	77.5%	0%	60.5%	0.0%
9a	Share of material recovery, CB	85%	100%	0%	-1.5%
9b	Share of material recovery, CB	85%	0%	0%	8.4%
10	Credits for thermal energy	0%	100%	-5.4%	-7.6%

Parameters 1 and 2 examine the impact of varying transport distances on the production and initial delivery of the packaging systems. Parameter 3 analyzes the impact of different percentages of secondary granulate on RPC production. Parameters 4 through 6 examine various characteristics affecting the service life of both packaging systems. As agreed with the Client, parameter 7 analyzes the impact of an alternative energy supply in the service centers.

Parameters 8 through 10 vary the end of life and the resulting credits for both packaging systems. The variations selected are explained in the representation of the associated results.

In Figure 13 the relative deviations compared to the base case are graphically represented, sorted by their impact on the overall result. To improve clarity, parameter variations that do not have any impact on the considered packaging systems were not included. It was found that variations 8b, 4a, 5b, 3b, 8a, 5a and 4b influence the results for the RPC system (purple) by more than 10%. Regarding the CB system (orange), there is no parameter variation in which the results differ by more than 10%. Thus, the examined parameters have a stronger impact on the RPC system than on the CB system.

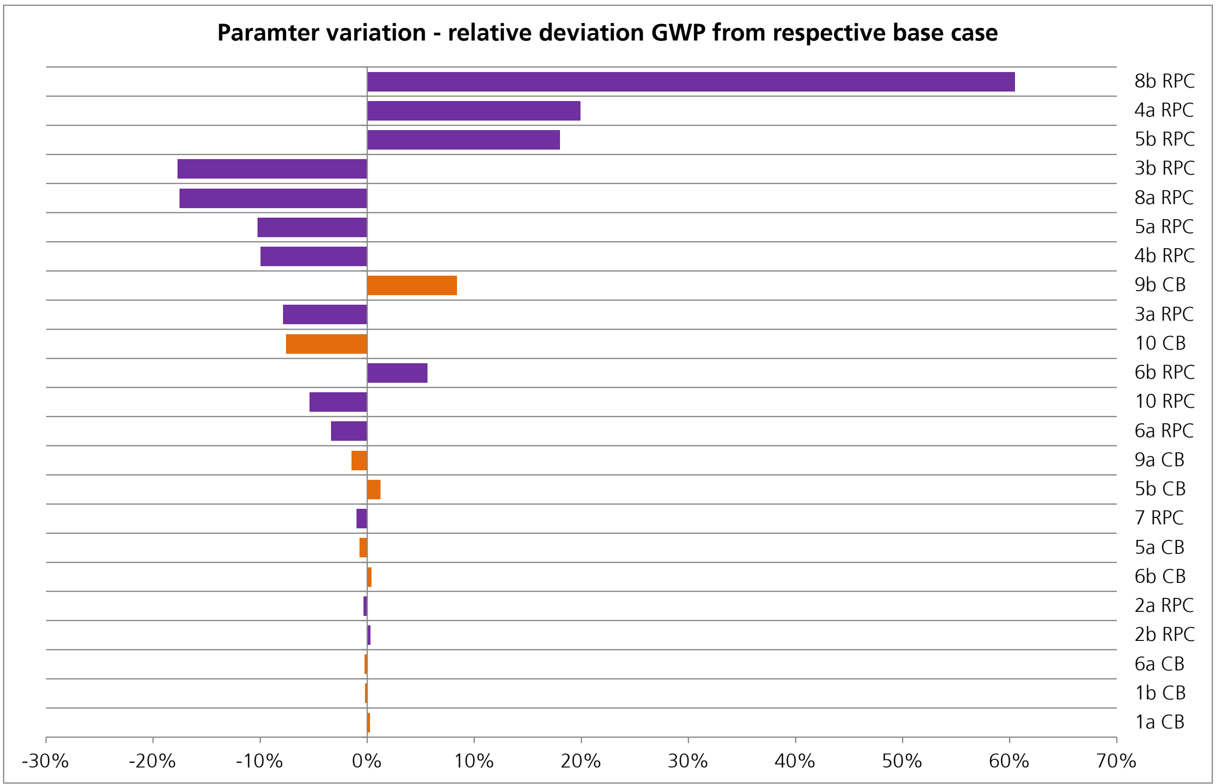

Figure 13: Parameter variation - relative deviation of GWP contributions from the respective base case, sorted by impact intensity

The following sections are going to describe those groups of parameter variations, in which one variation affects the respective overall result by more than 10%. Groups in which the entire parameter variation has a weaker impact will be described in Annex A1 – Sensitivity analysis.

5.2.1 Production

Percentage of primary granulate in RPC production (parameter variation 3a/3b)
This study proceeds on the assumption that the RPC are made of 90% primary materials. In the sensitivity analysis, this value is reduced to 50% (3a) or 0% (3b). Table 12 shows the effects of the parameter variation.

Table 12: Effects of parameter variation 3a & 3b on RPC compared to the base case

	3a	3b	Base case
Percentage of primary granulate RPC production	50%	0%	90.1%
GWP [kg CO_2 eq.]	13,386	11,950	14,526
Relative deviation	-7.9%	-17.7%	-

It becomes evident that a reduction in the share of primary materials in RPC production leads to a reduction of the greenhouse gas emissions.

5.2.2 Service life and transportation

RPC rotations (parameter variation 4a/4b)
In the base case scenario, the number of RPC rotations has been set to 50. In practice, this value tends to be exceeded. In the scope of a parameter variation, the impact of the number of RPC rotations and thus of the technical lifetime of RPC is examined; this implicitly also includes a variation of the breakage rate[5]. To this end, the number of rotations per RPC is halved to 25 rotations (4a) or doubled to 100 rotations (4b). Table 13 shows the results of the parameter variation.

Table 13: Effects of parameter variation 4a & 4b on RPC compared to the base case

	4a	4b	Base case
RPC rotations	25	100	50
GWP [kg CO_2 eq.]	17,421	13,079	14,526
Relative deviation	19.9%	-10.0%	-

Halving the number of rotations results in an increase in greenhouse gas emissions by almost 20%, whereas doubling the number of rotations could reduce greenhouse gas emissions by as much as 10%, approximately.

Since the average actual RPC lifespan currently exceeds 50 rotations, practical greenhouse gas emissions are expected to be lower than assumed in the base case scenario. Extending the use of RPC to more than 50 rotations would further reduce the volume of greenhouse gas emissions calculated for the base case.

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[5] The variation of RPC rotation rates additionally covers a variation of the breakage rate. In the base case, the variant "25 rotations" implies a breakage rate of about 1%.

Transport distance from the food producer to the distribution center (RPC & CB; parameter variation 5a/5b)

The average transport distance (409 km) between the food producer and the retail distribution centers was calculated on the basis of primary data provided by EPS and IFCO. According to the aim of the study, this transport distance has been assumed to be identical for both RPC and CB. In the scope of parameter variation 5a and 5b, the impact of a shorter (300 km) or longer (600 km) transport distance on greenhouse gas emissions is investigated for both packaging systems. In the case of the RPC system, the effect of varied transport distances is still enhanced due to the return transports, as a shortened transport distance between the food producer and the distribution center will also result in shorter return transports between the service center and the food producers, of course. By analogy, this also applies to increasing the transport distance. In the case of the CB system, this effect does not occur as there is no need for return transports.

Table 14 and Table 15 present the effects of variations in the transport distances between food producer and distribution center.

Table 14: Effects of parameter variation 5a & 5b on RPC compared to the base case

	5a RPC	5b RPC	Base case
Transport distance food producer to distribution center	300 km	600 km	409 km
GWP [kg CO_2 eq.]	13,034	17,142	14,526
Relative deviation	-10.3%	18.0%	-

Table 15: Effects of parameter variation 5a & 5b on CB compared to the base case

	5a CB	5b CB	Base case
Transport distance food producer to distribution center	300 km	600 km	409 km
GWP [kg CO_2 eq.]	37,455	38,192	37,723
Relative deviation	-0.7%	1.2%	-

Here, the results pertaining to the RPC system are subject to clearly greater changes. On the one hand, this is due to the above-mentioned double impact of the parameter, which also results in a change of the transport distances regarding the return transport of the cleaned RPC back to the food producer. As explained above, transportation is attributed greater relevance due to the greater weight of the RPC compared to the CB containers. This is why a variation of the transport distances will induce a more significant change of RPC results compared to the CB results.

5.2.3 End of life

Material recovery of RPC (parameter variation 8a/8b)
At present, a large share of the used RPC (77.5%) is used for material recovery at the end of life. In the scope of a parameter variation it is investigated how complete material recovery (parameter variation 8a; 100%) or complete energy recovery (parameter variation 8b; 0%) will affect greenhouse gas emissions.

The current assumption regarding the share of material recovery amounts to 77.5% (see Chapter 3.3). Recently, there are efforts going on to use 100% recycled granulate obtained from used RPC for manufacturing new RPC containers. First studies into this approach assume that the use of sorted materials will allow for a theoretically unlimited number of life cycles. The process is currently undergoing certification through the European Food Safety Authority (EFSA). To include this approach in the evaluation, the share of material recovery in parameter variation 8a is assumed to be 100%. To fully represent the impact of the parameter, a material recovery share of 0% (i.e. complete energy recovery) is assumed as most extreme scenario. Table 16 presents the results of the parameter variation.

Table 16: Effects of parameter variation 8a & 8b on RPC compared to the base case

	8a	8b	Base case
Percentage material recovery RPC	100%	0%	77.5%
GWP [kg CO_2 eq.]	11,975	23,313	14,526
Relative deviation	-17.6%	60.5%	-

Complete material recovery will reduce greenhouse gas emissions by almost 18%; whereas complete energy recovery will result in about 60% higher greenhouse gas emissions. With regard to greenhouse gas emissions, material recovery is hence the preferred solution for the RPC system.

5.3 Break-even analysis

In the single-use system, a new CB has to be produced for every rotation. In the reusable system, however, the packaging units are reused. In the base case scenario it is assumed that an RPC is reused 50 times before the material is recovered. In practice, however, RPC containers are already used more than 50 times.

To represent the effects of RPC lifespans on the overall result, the average Global Warming Potential per rotation was calculated as a function of the number of rotations. The results are given in Figure 14.

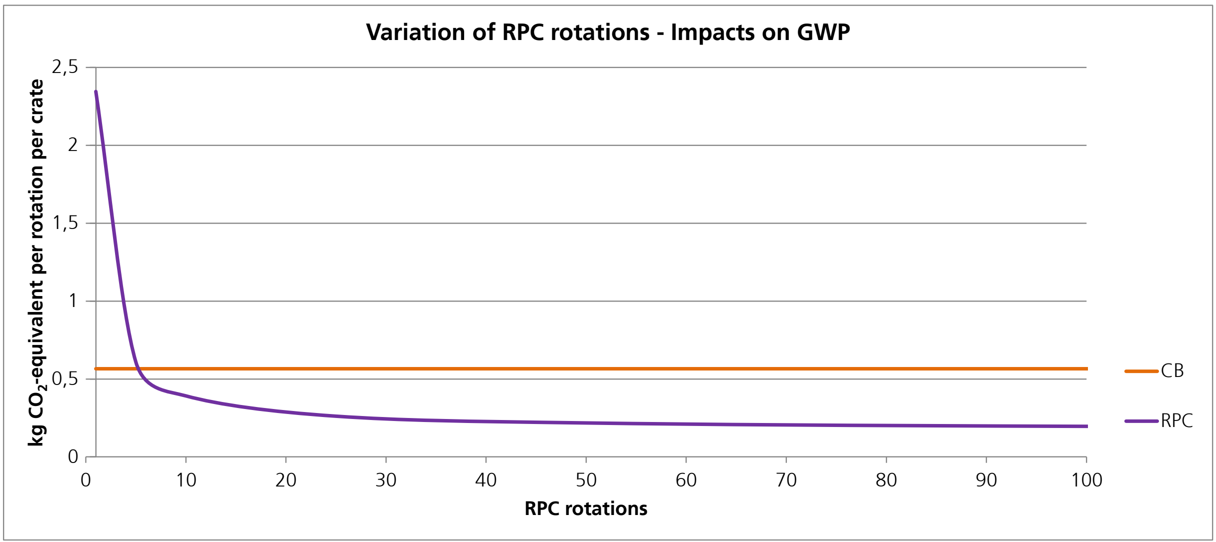

Figure 14: Break-even-analysis as a function of RPC rotations

It is found that RPC greenhouse gas emissions undershoot CB greenhouse gas emissions as early as at the 6th rotation. At the same time it is shown that the reduction in greenhouse gas emissions per rotation is slowly decreasing. After 100 rotations, the emission is 0.20 kg CO_2 eq. Here, the limiting value is determined by the emission released during the service life, as every RPC rotation requires a full logistic cycle. In the current analysis, this limiting value is 0.16 kg CO_2 eq. In this context, the additional reduction potential following an increase in the number of rotations continues to decrease. In the case of 50 rotations, the greenhouse gas emission per rotation is 0.22 kg CO_2 eq.; assuming 100 rotations, it is 0.20 kg CO_2 eq. per cycle. This corresponds to an average reduction of 0.2% per additional rotation when assuming 50 to 100 rotations. When assuming 500 rotations, the emission amounts to 0.18 kg CO_2 eq.; for every additional rotation beyond 100 rotations, the reduction is merely 0.02%. The greenhouse gas emissions of the CB system are equal to 0.57 kg of CO_2 eq. per rotation.

6. Conclusion

The present study to quantify the carbon footprint of packaging systems was conducted according to the requirements specified in ISO 14040 [19] and ISO 14044 [20].

The study considered the two packaging systems bearing the greatest relevance to the market, namely (a) Reusable, foldable Plastic Containers (RPC) and (b) single-use Cardboard Boxes (CB). For both packaging systems, production, service life and end of life were analyzed. The study did not consider the production of infrastructure (buildings, production facilities, trucks used for logistics processes).

The result of study shows that the reusable system (RPC) generates less greenhouse gas emissions compared to the single-use system (CB). Regarding the entire life cycle, the Reusable Plastic Containers (RPC) will cause approximately 60% less GHG relevant emissions than the Cardboard Boxes (CB) (in the base case scenario under consideration).

Considering the expected product lifespan, the attributable percentage of greenhouse gas emissions generated during production and at the end of life is very small, due to the reuse of the plastic containers (RPC). Regarding the CB production phase, the biogenic carbon that was sequestrated in the renewable raw materials has been credited to the product system. The sequestrated carbon will leave the product system at the end of life, either remaining sequestrated in the material or in the form of an emission (see Annex A3 – Carbon cycle). The production of paper and cellulose is energy-intensive - in the present study on greenhouse gas emissions it was thus identified as one of the major drivers. Compared to the CB system, the service life of the RPC causes higher emissions, which are however compensated for by the smaller quantity of emissions released during production and at the end of life of the RPC containers. The higher amount of greenhouse gas emissions released during the RPC service life is attributable to the more complex logistics processes, the higher empty weight of the containers and the required cleaning of used containers. The greenhouse gas emissions were calculated on the basis of the actually performed RPC transport services, relying on data submitted by EPS and IFCO [7], [16]. For comparison, the greenhouse gas emissions associated with performing the same transport services for the CB system were also calculated. The results and findings of this study relate to *the Distribution of 1,000 t of fruit or vegetables in Reusable Plastic Containers (RPC) or in single-use Cardboard Boxes (CB)*, based on the assumptions and limitations defined in the sections on goal and scope of the study.

The concluding sensitivity analysis confirms the stability of the model by examining variations of selected parameters. In the case of the RPC system, the impact on the overall result is generally stronger than in the case of the CB system. Notwithstanding, the greenhouse gas emissions generated along the entire life cycle of the CB system were found to exceed the GHG emissions of the RPC system in all of the parameter variations performed.

Generally, the results of the study can be transferred to other European countries. In this respect, the restrictions and limitations discussed in Chapter 2.7 need to be considered. It can be assumed that production and recovery of both packaging systems are not affected by this and that only modifications of the transport distances occur. In the scope of the sensitivity analysis it was found that the fundamental outcome of the study, namely that the RPC system causes less greenhouse gas emissions along its life cycle, remains valid even if the transport distances are modified.

This study identifies the greenhouse gas emissions of RPC and CB along the entire life cycle of both systems. The insights obtained can be used by stakeholders and the interested public. The comparison of the packaging systems supports market actors in selecting transport packaging systems with regard to climate impacts. In this context it should be specially noted though that the considered transport packaging systems mainly serve to protect the transported goods, i.e. fruit and vegetables, the carbon footprint of which can be several times higher. In addition, the calculated results can be used in environmental reports prepared by partner companies or customers.

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Annex

A1 – Sensitivity analysis

Transport distance wood production to cellulose production (parameter variation 1a/1b)

The transport distances for the production of Semi Chemical Fluting (SCF) and Kraftliner (KL) were taken from [11], where the transport distances are indicated separately by category (transports by road, rail and sea). As a major share of the transports is done by trucks (80% in the case of Kraftliner, 94% in the case of Semi Chemical Fluting) only these transport distances will be varied since - on account of the small share - variations of the transport distances of the other transport options would have only minor effects on the overall result. In Table 17 the volume-weighted transport distances are indicated as well as the average truck transport services associated with the production of SCF and KL. In the scope of the sensitivity analysis, these values are (a) increased by 20% and (b) reduced by 20%.

Table 17: Transport distances in SCF and KL production according to [11]

	FEFCO 2015 [11]	1a Max (+20%)	1b Min (-20%)
Wood SCF, new	110 km	132.0 km	88.0 km
Wood SCF, recovered	419 km	502.8 km	335.2 km
Wood KL, new	94 km	112.8 km	75.2 km
Wood KL, recovered	324 km	388.8 km	259.2 km

The effects of the parameter variation are presented in Table 18.

Table 18: Effects of parameter variation 1a & 1b on CB compared to the base case

	1a	1b	Base case
GWP [kg CO_2 eq.]	37810	37635	37723
Relative deviation	0.2%	-0.2%	-

Evidently, the effects on the overall system are insignificant.

Distance RPC production to food producer (parameter variation 2a/2b)

In the countries included in the study, the initial delivery distance following RPC production is equal to 921 km. In the scope of a parameter variation these values were adapted to 600 km (2a) or 1,200 km (2b). Table 19 shows the effects of the parameter variation.

Table 19: Effects of parameter variation 2a & 2b on RPC compared to the base case

	2a RPC	2b RPC	Base case
Distance RPC production to food producer	600 km	1200 km	921 km
GWP [kg CO_2 eq.]	14,475	14,571	14,526
Relative deviation	-0.4%	0.3%	-

Evidently, the effects on the overall system are insignificant.

Transport distance distribution center to retail (RPC & CB; parameter variation 6a/6b)
The transport distance between the distribution center and the retailer is assumed to be 50 km. To identify the sensitivity of this parameter, this value is changed to a shorter (20 km, parameter variation 6a) and a longer (100 km, parameter variation 6b) distance.

Table 20: Effects of parameter variation 6a & 6b on RPC compared to the base case

	6a RPC	6b RPC	Base case
Transport distance distribution center to retail	20 km	100 km	50 km
GWP [kg CO_2 eq.]	14035	15345	14526
Relative deviation	-3.4%	5.63%	-

Table 21: Effects of parameter variation 6a & 6b on CB compared to the base case

	6a CB	6b CB	Base case
Transport distance distribution center to retail	20 km	100 km	50 km
GWP [kg CO_2 eq.]	37632	37847	37723
Relative deviation	-0.2%	0.4%	-

Table 20 and Table 21 show the effects of the parameter variation on both transport systems. Due to the generally higher relevance of transport processes in the life cycle of the Reusable Plastic Containers (RPC) compared to the CB system, a variation of the transport distance will also exert a correspondingly greater effect on the RPC; nevertheless, the effect on both systems is rather moderate.

Use of a Combined Heat and Power (CHP) plant to supply energy required for cleaning (parameter variation 7)
In the scope of this parameter variation the thermal energy required for cleaning is assumed to be generated in cogeneration plants at the service centers. Cogeneration will supply electricity, in addition. In the scope of this parameter variation the thermal energy requirement is completely fulfilled by CHP-generated energy; the CHP plant also supplies around 50% of the required electricity. Table 22 presents the effect of using cogeneration.

Table 22: Effects of parameter variation 7 on RPC compared to the base case

	7 RPC	Base case
Share of thermal energy from CHP	100%	0%
GWP [kg CO_2 eq.]	14,381	14,526
Relative deviation	-1%	-

The greenhouse gas emissions will be reduced by 1%, approximately. For each inspected and cleaned RPC unit, this corresponds to a reduction of approximately 4.5%[6] in the GHG emissions released by the service centers

[6] Relates only to the GHG emissions due to inspection and cleaning.

Material recovery of CB (parameter variation 9a/9b)

Proceeding on the assumption that material recovery will reduce both fiber length and quality of cellulose and paper products, a technically feasible maximum of 6.7 life cycles is anticipated, with hygiene paper as the final application. Consequently, 100/6.7=15% of the material will be "deteriorated" in each life cycle and hence be discarded to energy recovery, while the residual material will undergo material recovery processes.

In the scope of parameter variation 9a the share of CB material recovery is assumed to be 100%, i.e. it is assumed to recover material without any appreciable loss in quality. In parameter variation 9b a total energy recovery after the first use is assumed. Table 23 shows the effects of the parameter variation on the Global Warming Potential.

Table 23: Effects of parameter variation 9a & 9b on CB compared to the base case

	9a	9b	Base case
Share of material recovery, CB	100%	0%	85%
GWP [kg CO_2 eq.]	37,164	40,891	37,723
Relative deviation	-1.5%	8.4%	-

In the case of the CB system, a higher percentage of material recovery will induce a slight reduction in greenhouse gas emissions, whereas total energy recovery will increase emissions. It is true that electricity is generated in the process of energy recovery, the credits resulting from this are however not sufficient to compensate for the emissions due to incineration. In the case of the CB system, material recovery is hence to be preferred over energy recovery.

Credits for thermal energy (parameter variation 10)

In the base case scenario it is assumed that the thermal energy gained from energy recovery is not put to use. In the scope of parameter variation 10, the heat is assumed to be fed completely into local district heating networks, for which credits are awarded accordingly. The results of this parameter variation are represented in Table 24 and Table 25.

Table 24: Effects of parameter variation 8 on RPC compared to the base case

	10 RPC	Base case
Credits for thermal energy	100%	0%
GWP [kg CO_2 eq.]	13,746	14,526
Relative deviation	-5.4%	-

Table 25: Effects of parameter variation 8 on CB compared to the base case

	10 CB	Base case
Credits for thermal energy	100%	0%
GWP [kg CO_2 eq.]	34,863	37,723
Relative deviation	-7.6%	-

It is found that feeding thermal energy into the local district heating network has a favorable effect on the carbon footprint of both packaging systems under consideration.

A2 – Biogenic CO_2 balance

Table 26 gives an overview of the emission or sequestration of biogenic carbon. The values relate to the relevant functional unit (transportation of 1,000 t of fruit or vegetables). In this context, negative values represent carbon sequestration, positive values the release of carbon. Details concerning the sequestration and "back transfer" of carbon credits into the system are explained in annex A3 – Carbon cycle.

For the returnable system, the biogenic share of the emissions is less than 1%. This contribution can be attributed to the release of biogenic carbon during wastewater treatment. In this process, organic substances adhering to RPC surfaces are rinsed off and the sequestrated carbon is subsequently released. The small share of biogenic carbon is due to the petroleum-based product system.

Table 26: Biogenic CO_2 balance of the returnable system

Life cycle stage		Biogenic CO_2 emissions [kg CO_2 eq.]
Production	Plastic granulate	-1
	Production RPC	0
	Transport	0
Service life	Transport	0
	Inspection and cleaning	110
End of life	Transport	0
	Shredding and granulation	0
	Incineration	0
	Electrical energy recovery	0
	Recovered secondary granulate	1
Total		**110**

Apart from the release of adhering organic substances on RPC surfaces during cleaning, the residual emission of 110 kg biogenic CO_2 is due to rounding differences. As the transported organic substances (in this instance: foods) were not included in the analysis, it is generally admissible to exclude the resulting emission of 110 kg biogenic CO_2 eq. In the present study, this option is however not chosen in order to assure consistency of the results with the background model.

Table 27 shows the biogenic CO_2 balance of the single-use system. During raw material production, large quantities of biogenic carbon are sequestrated, which are partially compensated for by the energy-intensive production of paper and cellulose. The sequestrated carbon is re-released at the end of life. In this respect, the most important contributions stem from energy recovery and the recovery of secondary material.

Table 27: Biogenic CO_2 balance of the non-returnable systems

Life cycle stage		Biogenic CO_2 emissions [kg CO_2 eq.]
Production	Raw material extraction	-118,894
	Paper and cellulose production	40,233
	Production CB	-66
	Transport	0
Service life	Transport	0
End of life	Transport	0
	Shredding and processing	-77
	Incineration	14,748
	Electrical energy recovery	2
	Recovered secondary material[7]	63,909
Total		**-146**

The remaining emission of -146 kg biogenic CO_2 is due to rounding differences in the LCA data sets used.

It is found that both CO_2 balances are approximately closed, which is - especially in the case of the CB system - an indicator that the examined system has been correctly modeled. The effect on the overall result is however moderate, due to the closed biogenic CO_2 balance.

In addition, Table 28 specifies the GWP without the share of biogenic carbon.

Table 28: GWP (excl. biogenic C) for both packaging systems

	GWP (excl. biogenic C) [kg CO_2 eq.]	
Life cycle phase	**RPC**	**CB**
Production	5,256	39,047
Service life	10,755	1,157
End of life	-1,594	-2,336
Total	**14,417**	**37,869**

Here, too, it can be seen that the amount of RPC greenhouse gas emissions is clearly lower than that of the CB system. The negligible deviations are accounted for by the aforementioned rounding differences in the biogenic CO_2 balance.

[7] Sequestrated carbon, which is being credited to the next material life cycle. From an accounting point of view, the carbon must be eliminated from the balance calculations unless sequestration is granted for a minimum period of 100 years.

A3 – Carbon cycle

The diagram in Figure 15 describes the biogenic carbon cycle for the cardboard container system, which provides the basis for modeling the biogenic share of GWP.

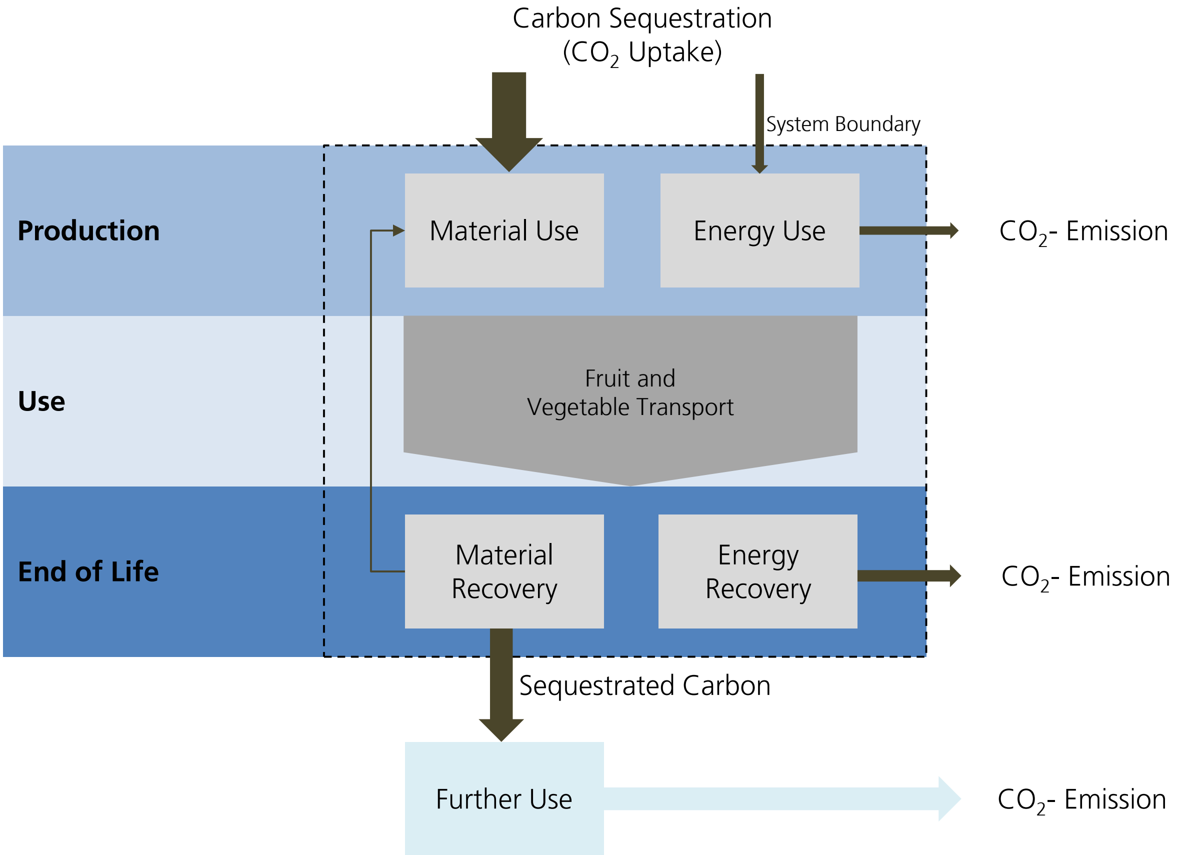

Figure 15: Schematic representation of the biogenic carbon cycle

Biogenic carbon enters the system through the renewable raw materials used. A large share of this carbon is used as material input, a smaller share is used as energy input in the production process. The share of biogenic carbon that is used as an energy input will leave the respective system in the form of an emission, whereas the material share remains sequestrated in the CB system for a certain period. Following their use as transport containers, large quantities of the Cardboard Boxes (CB) will be recovered for material use while smaller quantities will be used for energy recovery. During energy recovery, the share of biogenic carbon leaves the studied system in the form of an emission. In the case of material recovery, the share of biogenic carbon leaves the respective system as carbon that is deposited in the product. This closes the carbon balance. After one or several further recovery processes, the percentage initially used for material recovery also becomes an emission. This is particularly the case with short-lived products like paper and cardboard, the material life cycles of which do not exceed the survey period of 100 years.

A4 – Global Warming Potential as an impact category

As implied by the term, the mechanism of the greenhouse effect can be observed on a smaller scale in greenhouses or glasshouses. This effect also occurs on a global scale. The short-wave solar radiation reaching the earth surface is partially absorbed there (which results in direct warming) and partially reflected as infrared radiation. In the troposphere, the reflected share is absorbed by so-called greenhouse gases and irradiated in all directions, so that a certain percentage is radiated back to earth. This, in turn, enhances global warming.

In addition to the natural greenhouse effect, an anthropogenic share of the greenhouse effect, which is due to human activities, occurs. For instance, anthropogenic greenhouse gases include carbon dioxide, methane and CFCs. Figure 16 describes the main processes associated with the anthropogenic greenhouse effect. Any assessment of the greenhouse effect should account for the potential, long-term global effects.

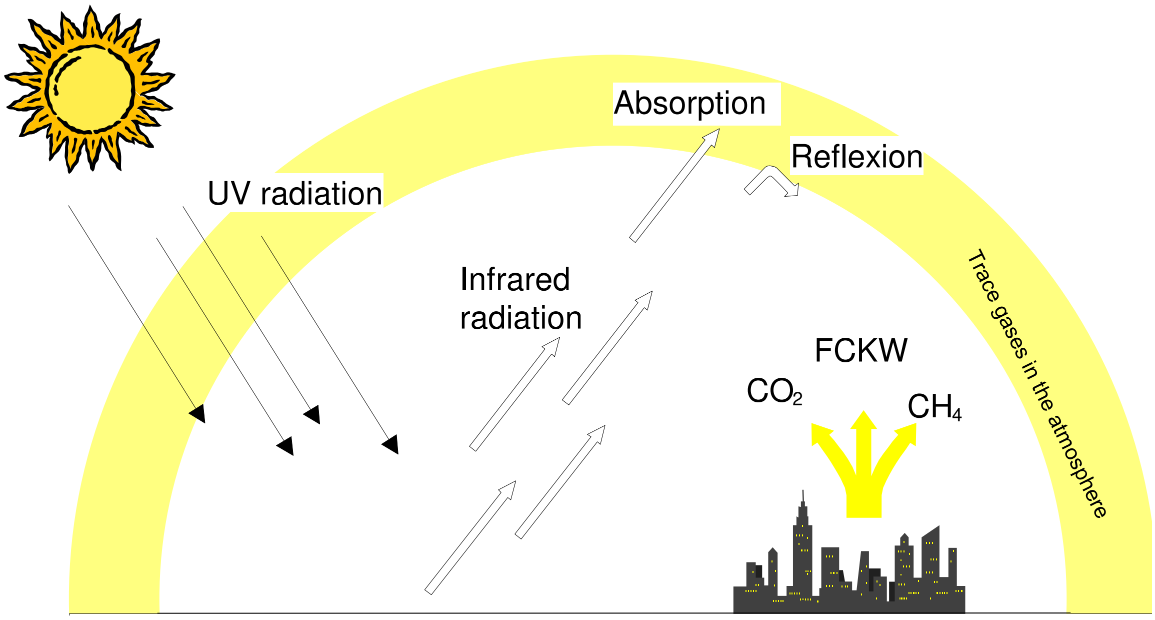

Figure 16: Anthropogenic greenhouse effect [22]

The Global Warming Potential (GWP) is quantified in carbon dioxide equivalents (CO_2 eq.). This means that all emissions are considered in relation to carbon dioxide (CO_2) to evaluate their potential contribution to the greenhouse effect. As the gas retention period in the atmosphere is also included in the calculations, it is essential to state the time horizon implied in the assessment. Usually, a time horizon of 100 years is assumed.

A5 – Results per transport rotation

Table 29 summarizes the greenhouse gas emissions of the packaging systems for an average transport rotation, i.e. the (proportionate) production and recovery as well as the logistics processes of both packaging systems. The results are listed in Table 29.

Table 29: Greenhouse gas emissions of an average transport rotation

Life cycle phase	**GWP (incl. biogenic C) [kg CO_2 eq.]**	
	RPC	**CB**
Production	0.08	-0.60
Service life	0.16	0.02
End of life	-0.02	1.15
Total	**0.22**	**0.57**

The diagram in Figure 17 shows the results per transport rotation

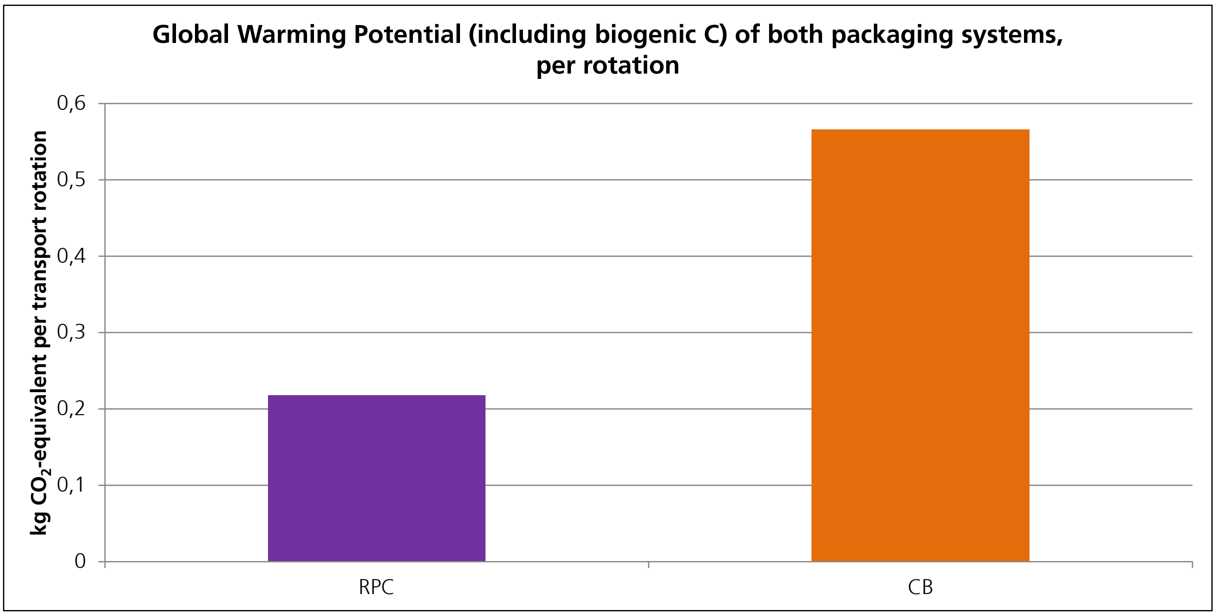

Figure 17: Greenhouse gas emissions of an average transport rotation

A6 – Results per truck load

The greenhouse gas emissions per truck load are represented in Figure 18. The values relate to the frame of reference defined in the base-case scenario. By definition, the greenhouse gas emissions originating from the food produces are not taken into consideration; only greenhouse gas emissions caused by the packaging systems are considered. Table 30 presents the average greenhouse gas emissions of the base-case scenario for a truck carrying 1,320 packaging units.

Table 30: Average greenhouse gas emissions of the considered packaging systems per truck load

Life cycle phase	GWP (incl. biogenic C) [kg CO_2 eq.]	
	RPC	**CB**
Production	104.1	-785.7
Service life	215.1	22.9
End of life	-31.5	1,509.7
Total	**287.7**	**746.9**

Figure 18 shows the average greenhouse gas emissions per truck load of 1,320 packaging units.

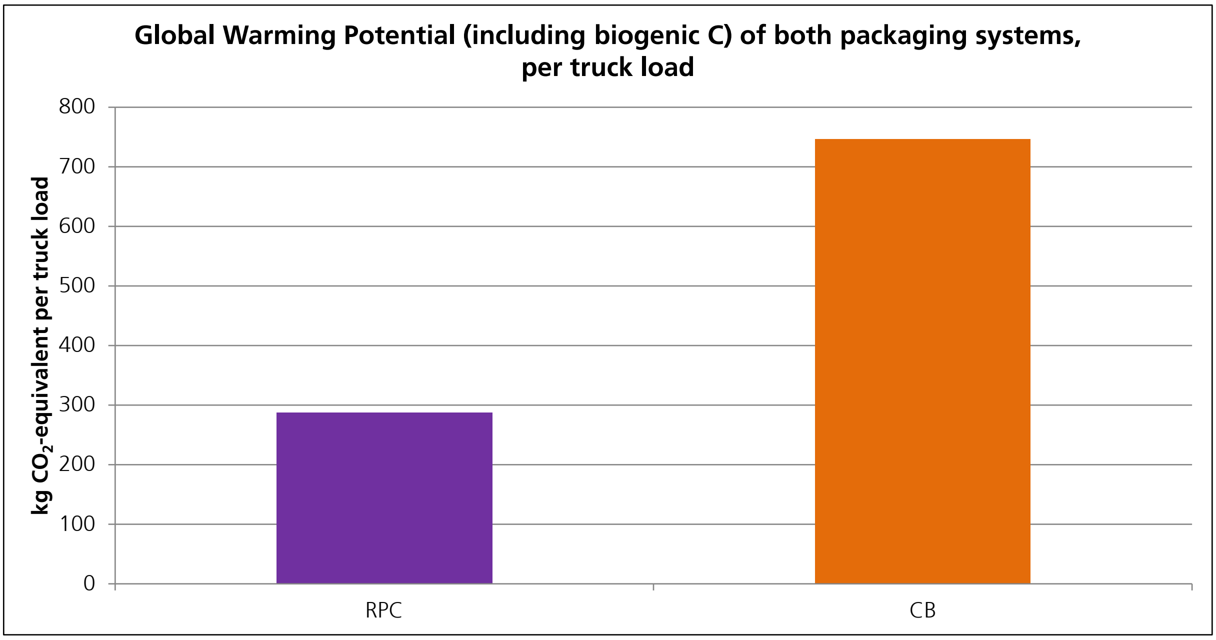

Figure 18: Average greenhouse gas emissions of the packaging systems per truck load

A7 – Results of the life cycle inventory analysis (LCI) for the base case

ISO 14044 defines the life cycle inventory analysis result (LCI result) as the "outcome of a life cycle inventory analysis that catalogues the flows crossing the system boundary and provides the starting point for life cycle impact assessment". As the complete life cycle inventory analysis (LCI) includes hundreds of flows, Table 31 presents a choice of flows, which were selected according to their relevance to the subsequent life cycle impact assessment (LCIA). This was done to make the relation between the inventory analysis (LCI) results and the life cycle impact assessment (LCIA) results more transparent. The reported elementary flows represent the outputs of the LCA model, which contribute as greenhouse gases to climate change.

Table 31: Quantified emissions related to the functional unit of the base case

Greenhouse gas emissions		Reusable system (RPC)				Single-use system (CB)			
Emission	Unit	Total	Production	Service life	End of life	Total	Production	Service life	End of life
Carbon dioxide (biogenic and fossil)	[kg]	13,866.4	4,998.8	10,290.2	-1,422.6	35,741.7	-41,548.6	1,108.4	76,181.8
Nitrous oxide	[kg]	20.9	8.9	18.2	-6.1	61.3	57.8	1.4	2.0
Methane (biogenic and fossil)	[kg]	6.3	8.3	3.5	-5.4	16.1	15.8	0.4	-0.1
Volatile organic compounds (no methane; NMVOC)	[kg]	0.5	0.1	0.4	-0.1	1.5	1.4	0.0	0.0
Other	[kg]	0.1	0.0	0.1	0.0	1.0	0.9	0.0	0.1

A8 – Documentation of the background data

The following tables provide information on the data sets that bear relevance to the results and were used when modeling the product systems. The tables report on the use of this data in the RPC and/or CB system model (column RPC/CB), the geographical reference and the reference year. Using the GUID and the name of the respective data set, the data documentation can be retrieved under http://www.gabi-software.com/support/gabi/gabi-database-2017-lci-documentation/.

Fuels and energy

National average data for fuels and electricity grid mixes were taken from the 2017 GaBi database. Table 32 specifies the data sets used when modeling the product systems.

Table 32: Energy datasets used in the life cycle inventory analysis (LCI)

RPC /CB	Energy	Region	Data set	Data provider	Reference year	GUID
RPC/CB	Diesel	EU-28	Diesel mix at refinery	ts	2017	{244524ed-7b85-4548-b345-f58dc5cf9dac}
RPC	Natural gas	EU-28	Natural gas mix	ts	2017	{c6387e19-933f-4726-a7ad-7a8050aa418c}
RPC/CB	Process steam	EU-28	Process steam from natural gas 95%	ts	2017	{104dbecc-4f6c-456b-9e44-722bc9c41e75}
RPC/CB	Electricity	EU-28	Electricity grid mix	ts	2017	{001b3cb7-b868-4061-8a91-3e6d7bcc90c6}
RPC/CB	Thermal energy	EU-28	Thermal energy from natural gas	ts	2017	{cfe8972e-6b51-4a17-b499-d78477fa4294}

Raw materials and processes

Data on raw materials, intermediate products and process modules were taken from the 2017 GaBi database. Table 33 specifies the relevant data sets, which were applied when modeling the product systems.

Table 33: Material and process data sets used in the life cycle inventory analysis (LCI)

RPC /CB	Material / process	Site	Data set	Data provider	Reference year	GUID
RPC	Cogenera-tion plant	GLO	Gas CHP	ts	2017	{54573f47-229e-4b43-89d0-d8b0d29f0c52}
CB	Beech wood (hardwood)[8]	EU-27	Beech log free forest track	ts	2017	{ABC7C96E-E1BD-4AC0-92C9-7AEE03E014EB}
CB	Spruce (softwood)[8]	EU-27	Spruce log free forest track	ts	2017	{12eec3c1-5c82-4c94-ada2-6805f6c94ae2}
RPC/ CB	Shredder	DE	Granulator	ts	2017	{df0ed190-bda2-4b78-831b-a5b728d6d640}
RPC/ CB	Municipal waste water treatment	EU-28	Municipal waste water treatment (mix)	ts	2017	{9805e7ee-b500-46b4-a0f0-37b09e00a3fa}
RPC	Waste incineration of plastics	EU-27	Waste incineration of plastics (PE, PP, PS, PB)	ELCD/ CEWEP	2017	{e01167ad-6cf8-47a7-8df9-e89bf35cb704}
CB	Paper / Card-board in waste incineration plant	EU-28	Paper / Cardboard in waste incineration plant	ts	2017	{0730a97b-bda5-4b9b-8632-8f2c52271f92}
RPC	Pelletizing and com-pounding	DE	Pelletizing and compounding	ts	2017	{0f4c3fb4-bc30-43e5-8567-e41ffa5487b0}
RPC	Polyethylene granulate	EU-27	Polyethylene, HDPE, granulate, at plant,	PlasticsEu rope	2014	{652939FF-9892-740D-68F7-0000208D2E34}
RPC	Polypropylen e granulate	EU-27	Polypropylene, PP, granulate, at plant,	Plastics-Europe	2014	{5070854E-E2FB-A816-C4BA-00000BB60D3D}
CB	Sawmill, wood chips softwood	EU-28	Sawmill, wood chips softwood	ts	2017	{962B2511-40BB-4B3E-8DB6-615422F9E346}

Transports

The transports mentioned in the study were modeled using an average transport distance and modes of transport. The 2017 GaBi database was used for modeling the transport processes. The transports were modeled using the GaBi data sets for global transportation and are presented in Table 34.

[8] Internal GaBi data set: The GaBi data sets are based on the same fundamentals as the publicly available data sets; however, they relate to 'atro wood', i.e. absolutely dried (sequestration: 1.85 kg CO_2 per kilogram wood 'atro').

Table 34: Data sets relating to means of transportation

RPC /CB	Means of transport	Site	Data set	Data provider	Reference year	GUID
RPC/ CB	Truck	GLO	Truck, Euro 0 - 6 mix, 20 – 26 t gross weight / 17.3t payload capacity	ts	2017	{30eef797-312a-447a-9272-4d271ac60289}
RPC/ CB	Truck	GLO	Truck-trailer, 1980s, 34 – 40 t gross weight / 27t payload capacity	ts	2017	{100ca71d-d72b-4046-8d81-06ec44b806a9}
RPC/ CB	Truck	GLO	Truck-trailer, Euro 4, 34 – 40 t gross weight / 27t payload capacity	ts	2017	{05168254-9d64-473a-8dc5-16cb5bf3c45f}
RPC/ CB	Truck	GLO	Truck-trailer, Euro 5, 34 – 40 t gross weight / 27 t payload capacity	ts	2017	{d8764ef3-e29e-4c98-bb8d-6598d140f822}
RPC/ CB	Truck	GLO	Truck-trailer, Euro 6, 34 – 40 t gross weight / 27 t payload capacity	ts	2017	{485c4342-849c-4b29-95e0-fb651cabc84b}

A9 – Report on the critical review

Carbon Footprint of Packaging Systems for Fruit and Vegetable Transports in Europe

Critical Review Panel Report

Commissioned by
Fraunhofer Institute for
Building Physics IBP

Review Panel chaired by
DEKRA Assurance Services GmbH
Sustainability Services
May 2018

CONTENT

SUMMARY

The subject of this review is the study “Carbon Footprint of Packaging Systems for Fruit and Vegetable Transports in Europe”. The study was commissioned by the Stiftung Initiative Mehrweg (SIM) and conducted by the Fraunhofer Institute for Building Physics (IBP).

The comparative assertion shows that, considering the entire life cycle for the given goal and scope, packaging systems based on reusable plastic containers (RPC) have a lower carbon footprint compared to single-use cardboard boxes (CB). This results mainly from the reusability of the RPC (assumed number of rotations) on the one hand and the energy intensive paper and cellulose production of the CB with single-use on the other hand. For the communication and the transferability of the results it has to be considered that the study is based on European average data and an existing and stable market for RPCs is given. The study therefore reflects the functioning of a well-established system, but not the rebuild or change of transport packaging. For the interpretation of the results, it should be kept in mind that the carbon cycle (biogenic carbon) dominates the CO_2-balance of the CB.

The critical review panel confirms that the carbon footprint study meets the ISO 14040/44 standards in terms of methodological compliance and formal requirements. Further, the critical review confirms that the data sources and life cycle models appear sufficiently consistent and robust to support the interpretations. Assumptions, calculations and results are transparently and appropriately presented to inform decision makers and stakeholders.

As per ISO 14040/44, this critical review does not imply an endorsement of the LCA method, nor of any comparative assertion based on this LCA.

Stuttgart, 7. May 2018

Christina Bocher
DEKRA Assurance Services GmbH
Chair of Review Panel

Dr.-Ing. Ivo Mersiowsky
Quiridium GbR
Co-reviewer

Sebastian Spierling
University of Applied Sciences
and Arts Hannover
Co-reviewer

DEKRA
On the safe side.

CRITICAL REVIEW REPORT

1. Introduction

The subject of this review is the study “Carbon Footprint of Packaging Systems for Fruit and Vegetable Transports in Europe”. The study was commissioned by the Stiftung Initiative Mehrweg (SIM) and conducted by the Fraunhofer Institute for Building Physics (IBP) in accordance with the international standards on Life Cycle Assessment (LCA) ISO 14040/44. This critical review report refers to the final version of the comparative carbon footprint study, dated 13 April 2018.

Where Life Cycle Assessment (LCA) studies are conducted to derive comparative assertions to be disclosed to the public, the ISO 14040/44 standards require that a critical review is conducted by a panel of independent external experts.

The objectives of this critical review were to –

- Ascertain whether the LCA study meets the ISO 14040/44 standards in terms of methodological compliance and formal requirements;
- Conduct a review of the subject matter, providing an appraisal of data sources, life cycle models, assumptions, calculations, and results in terms of transparency, appropriateness and data quality.

The critical review consisted of an analysis of the report with regard to methodological and technical aspects and was conducted as follows:

- The Fraunhofer IBP provided a draft report of the German Carbon Footprint study to the review panel for the first reading. Based on this report he review panel compiled a table with questions, comments and recommendations for the LCA practitioner.
- One face-to-face meeting took place between practitioner and review panel where the underlying model and data was reviewed and questions and comments discussed.
- All in all, the review panel held four online meetings to assess the German study.
- After completion, an English translation of the final Carbon Footprint Study was provided to the critical review panel. The review panel convened one more time through a web conference, to approve the English version and provide a Critical Review Panel Report in English.

2. Review Panel

The review panel consisted of the following members:

Christina Bocher	DEKRA Assurance Services GmbH, Stuttgart	Chair of review panel
Dr.-Ing. Ivo Mersiowsky	Quiridium GbR, Tübingen	Co-reviewer
Sebastian Spierling	Hochschule Hannover / University of Applied Sciences and Arts Hannover	Co-reviewer

3. Goal & Scope

Goal and scope of this study are the quantification of greenhouse gas emissions induced by transportation packaging systems – this interest derives from the mission of the SIM foundation as well as the public interest on climate change.

The study has been conducted with the goal to provide current carbon footprint data (CO_2-emissions) over the entire life cycle – production, service life, end-of-life – for the two packaging systems considering their haul capacity. The results shall inform decision makers and other stakeholders, such as actors of the packaging and food industry, logistic companies and the interested public. The study ties in with previous LCA studies commissioned by SIM. The present study looks at greenhouse gas emissions only. European average data for materials, production and transport processes have been used as well as average transport distances for Germany, France, Italy, the Netherlands and Spain. In addition, an established, stable market for reusable plastic crates is being assumed. The results and interpretations have to be looked at in the context of this goal and scope.

The selection of both packaging systems (reusable plastic crate and single-use cardboard crate) reflects the market relevance of these packaging systems for fruit and vegetable transport in Europe. Both product systems – reusable plastic containers (RPC) and single-use cardboard boxes (CB) – are sufficiently described. The processes considered in both options, as well as the time, technological and geographical coverage are transparently defined. The calculation method and the reference to the functional unit – distribution of 1,000 t of fruit or vegetables in reusable plastic container (RPC) or in single-use cardboard boxes – are described in detail.

4. Life Cycle Inventory

The relevant primary and secondary data used in this study are sufficiently documented in this report. The data quality and the model are consistent and robust, based on plausibility checks of the present study.

The carbon cycle (biogenic carbon) was explained separately, due to its significant relevance on the overall results. The results with and without sequestrated carbon are displayed separately. This is of special relevance for the single-use cardboard box system based on renewable materials, because the biogenic carbon being sequestrated for a relatively short time dominates the results: negative CO_2-emissions have to be accounted for in the production phase (absorbed during biomass growth) and respective potential CO_2-emissions released at end-of-life, since the sequestration cannot be granted for a minimum time period of 100 years even in case of material reuse. The critical review panel discussed this topic and the correct and transparent reporting in the model in great detail.

Relevant technical parameters were described in a transparent manner. The proxy data used in the background system (generic fuels, materials and transportation processes) were sourced from the GaBi database. Foreground data (e.g. configuration of transport containers, transport distance) are based on data from manufacturers and industry associations.

The modelling and calculation were conducted in the GaBi LCA software rendering a complete life cycle inventory (LCI) of all substances and energy flows. A reduced selection of relevant greenhouse gas entries is reported to provide a transparent link between the inventory and impact assessment results. The review panel confirms that the entire LCI was included in the subsequent characterisation step.

5. Life Cycle Impact Assessment

The Life Cycle Impact Assessment (LCIA) of the study is restricted to greenhouse gas emissions in terms of a CO_2-footprint (carbon footprint). All relevant greenhouse gas emissions were assessed as per IPPC characterisation factors from the 4th Assessment Report (2007) for a 100 year timeframe.

A sensitivity analysis has been conducted, to determine the impact of selected parameters: the main driver identified is the assumed number of rotations of the reusable plastic container (RPC), followed by transportation distance, the weight of the RPCs and their material recovery at end-of-life. The CBs are dominated by the production process, therefore the variation of the parameters in the foreground system have only limited impact on the results. The sensitivity analysis and the parameter variation show that the results are robust.

6. Interpretation & Conclusions

Following the goal and scope, the study compares the carbon footprint of both packaging systems. The results show that reusable plastic crates (RPC) generate less greenhouse gas emissions than single-use cardboard boxes (CB). Even single-use systems based on renewable materials cannot profit from the advantage of the sequestration of biogenic carbon, since they are used only once and have a relatively short service life.

The study mentions the relevant assumptions and limitations. These include especially the prerequisite of a well-functioning, stable market for transport packaging made of reusable plastic crates and that the assumed number of rotations and reuses is being reached. For the communication and transferability of the results it has to be considered:

- The study is based on European average data. The transferability of the results requires that these average data are representative for the respective country considered.
- Transport packaging for fruit and vegetables has been modelled. In the case of transport packaging for other transport goods it needs to be considered that the configuration of the packaging has a significant impact (e.g. geometry, weight).
- The study considers transportation via truck only. The results can therefore not be transferred to other means of transport without significant changes.
- Furthermore, the results depend considerably on the transport distances selected in the model, which need to be adapted in the specific case.

All in all, the data and model seem sufficiently consistent and robust to support the conclusions of the study and to allow a basic transferability.

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