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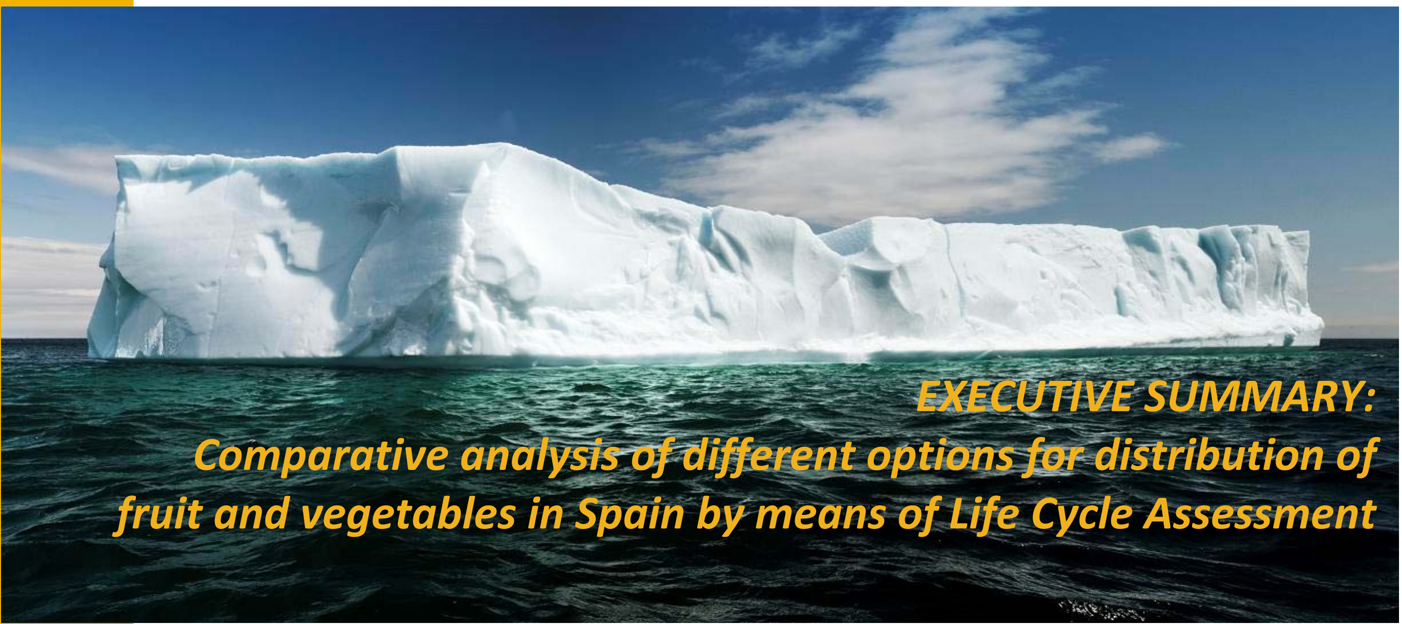

EXECUTIVE SUMMARY:
Comparative analysis of different options for distribution of fruit and vegetables in Spain by means of Life Cycle Assessment

Date: December 2017
Commissioned by: ARECO

United Nations
Educational, Scientific and
Cultural Organization

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*The idea of creating the UNESCO chair ESCI-UPF came about from the **Environmental Management Research Group (GiGa)**, founded at ESCI in 2004 by Dr Fullana i Palmer, seeking to extend and exchange Life Cycle knowledge and its application to the prevention of climate change on a more international scale. GiGa has since 2011 been the UNESCO Chair in Life Cycle and Climate Change. It should be stressed that in October 2010 the statutes of the ESCI-UPF were modified, for its Article one c) to read, as its objective: "The provision of training and research services in the international area of business, extending to any sphere of business management, environmental management, sustainability and international relations".*

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Title of the document:

EXECUTIVE SUMMARY: Comparative analysis of different options for distribution of fruit and vegetables in Spain by means of Life Cycle Assessment (LCA)

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CONTENTS

LIST OF ACRONYMS

ADEME	French environment and energy management agency
ARECO	Association of Logistics Operators for Eco-sustainable Reusable Items
CML	Centre for Environmental Science at Leiden University
CO_2	Carbon dioxide
PE-NR	Use of primary (non-renewable) energy
PE-R	Use of primary (renewable) energy
ESCI	Escuela Superior de Comercio Internacional
FEFCO	European Federation of Corrugated Board Manufacturers
ISO	International Organisation for Standardisation
ITENE	Packaging, Transport & Logistics Research Institute
LBP	Chair of Building Physics. Stuttgart University
MJ	Megajoules
AP	Acidification Potential
ADP	Abiotic Resource Depletion Potential
GWP	Global Warming Potential
ODP	Ozone Depleting Potential
EP	Eutrophication Potential
HDPE	High Density Polyethylene
POCP	Photochemical Oxidant Creation Potential
PP	Polypropylene
TP	Toxicity Potential
SIM	Foundation for Reusable Systems *(Stiftung Initiative Mehrweg)*

1. Background and introduction

Containers and packaging play a vital role in the distribution and logistics chain of fruit and vegetables. They protect the product and also act as a support for labelling, with information on the product, and help to be able to stack their contents. Over the last few years there has been increasing concern about the large quantity of containers and packages in circulation and about the associated environmental impact.

As a result of this concern, of the controversial results of other studies (ADEME, 2000) and of having detailed knowledge of the environmental impact associated with the logistics of fruit and vegetable distribution in Europe, in 2004 Stiftung Initiative Mehrweg (SIM) commissioned the study on *"The Sustainability of Packaging Systems for Fruit and Vegetable Transport in Europe based on Life-Cycle-Analysis- 2004",* which was later updated in 2009. The study was made by the Fraunhofer Institute for Building Physics (LBP), the University of Stuttgart and PE International. The *Escuela Superior de Comercio Internacional* (ESCI-UPF) took part as a contributor by providing data for Spain, analysing the distribution options with disposable cardboard and wooden boxes and with reusable plastic boxes.

In 2005 the Universidad Politécnica de Valencia made a comparative study in cooperation with ITENE on cardboard boxes and foldable plastic boxes for Spain (Capuz and Aucejo, 2005). The results of this study conclude that recyclable cardboard boxes are the best option from the environmental and economic standpoint. These results nevertheless contradict the ones obtained in the ADEME (2000) and SIM (2004) studies, in which reusable plastic boxes are the ones with lowest environmental impact and lowest cost.

For the reasons mentioned in the preceding paragraph, the Association of Logistics Operators for Eco-sustainable Reusable Items (ARECO) commissioned the UNESCO Chair in Life Cycle and Climate Change (ESCI-UPF) with an **in-depth review of the existing studies and the adaptation to reality in Spain and an update of the study performed for SIM in 2009**. Since the use of wooden boxes for distribution of fruit and vegetables is negligible in Spain, only plastic boxes and cardboard boxes are compared. As for the analysis, this focusses on the environmental aspect.

2. Definition of the objective and scope of the study

2.1 Objective

The purpose of this study is to obtain objective, scientifically-based information on the environmental impact associated with fruit and vegetable distribution on the internal Spanish (peninsular) market, by comparing two packaging solutions: disposable cardboard boxes and reusable plastic boxes.

Life Cycle Assessment (LCA) methodology was used for this purpose, enabling analysing the environmental impact associated with every stage in the life of the boxes, from when the raw materials are extracted for their production until these become waste. This procedure is regulated by ISO standards 14040 and 14044 and is endorsed by the European Union as the best tool for supporting decision-making.

2.2 Systems analysed and their functions

The fruit and vegetable distribution systems compared should, as well as guaranteeing a proper distribution of the product, guarantee its proper labelling, minimum hygiene and safety conditions and ergonomic conditions (not exceeding the weight limits permitted by legislation) among other characteristics typical of packaging systems.

The types of boxes considered are shown in Figure 1.

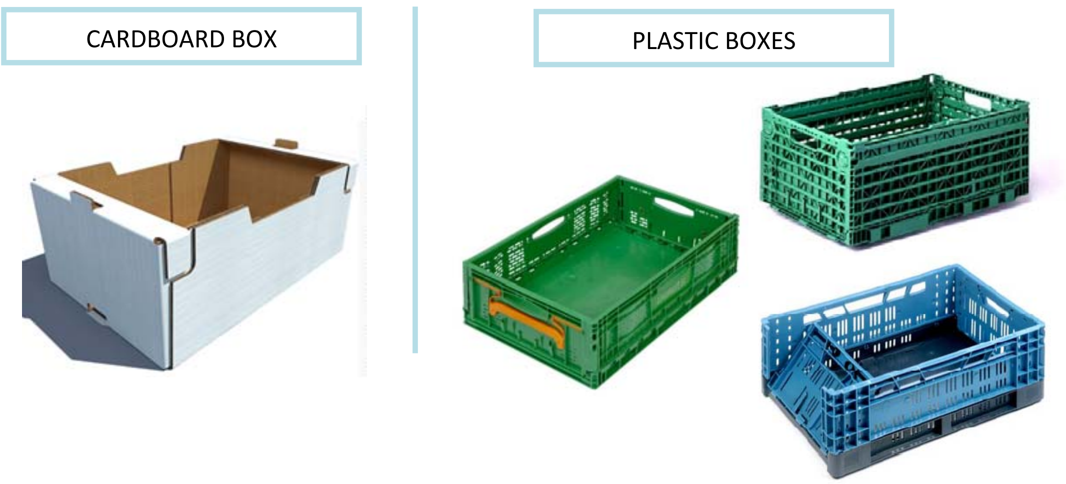


Figure 1. An example of cardboard and plastic boxes considered in this study. Source: UNIQ[1], 2016. ARECO[2], 2016.

[1] www.grupouniq.com UNIQ is the new Agro-Quality Stamp promoted by the Spanish Association *of* Corrugated Cardboard Containers and Packaging Manufacturers (AFCO). It replaces the previous Plaform stamp. The 15 largest producers of the sector in Spain are in this group.

[2] Pictures provided by the members of ARECO: Euro Pool Systems, IFCO and Logifruit.

The main characteristics of the two distribution systems being compared are shown in Table 1.

The cardboard boxes are made and transported to the local producers of fruit and vegetables (production stage). After being filled, these are taken to the unloading and/or consumption points (service life). After their purpose has been fulfilled, they are managed as waste.

After their service life plastic boxes, on the other hand, are collected, inspected, washed, repaired (should this be necessary) and distributed again among local fruit producers to be used a second time. Once their whole useful life is over and they can no longer be repaired and reused, the boxes are managed as waste and replaced with new boxes.

Table 1. Main features of the systems analysed.

	Representative cardboard box	**Average plastic box**
Material	Cardboard	Polypropylene (PP) and polyethylene (HDPE)
Type of service	Single use	Reusable
Reuse	-	Inverse logistics and washing
End-of-life processing	80% recycling[3] 20% Incineration	100% recycling[4]
Weight of box (kg)	0.807[5]	1.87
Sizes (mm)	600x400x180[6]	600x400x187
Weight of load (kg)	15	15
Full boxes per pallet	48	48
Layers per pallet	12	12
Pallets per truck	33	33
Folded boxes per pallet	-	264

[3] According to REPACAR data (2014) roughly 80% of cardboard boxes are recycled each year in Spain. No specific data has been found about boxes for distributing fruit and vegetables. Although the percentage of recycling is suspected to possibly be lower in this case, due to contamination of the cardboard by organic material, the mean treatment destination of cardboard boxes in general was assumed as a conservative estimate; that is, **80% recycling was maintained**.

[4] Data provided by the companies belonging to ARECO.

[5] According to a personal notification from SAICA (27/06/2016), boxes with UNIQ stamp measuring 600x400x180 with a top strip have a weight varying according to the grammage and finish of the cardboard ranging from 0.797 to 0.817 kg. In this study the mean of the two was used: 0.807 kg.

[6] According to UNE standard UNE 137005:2005 (International Agreement for standardising sizes of corrugated cardboard boxes), reference CF1 corresponds to sizes of 600x400 mm at the base and a variable height depending on the type of product. In this study, to make this functionally equivalent to the plastic box, a height of 180 mm was considered, corresponding to the data available of FEFCO reference CF1 (2012).

2.2.1 Scenarios examined

This study analyses two possible scenarios with regard to the parameters defining the service life of the product of plastic boxes:

- **Conservative scenario (base):** 10 years' useful life, 10 rotations per year
- **Technical scenario:** 15 years' useful life, 10 rotations per year

N.B.: Since the results have proved to be highly similar in both cases, **this executive summary will only give the data and results of the conservative scenario.**

2.2.2 Functional unit (or comparison unit)

The **functional unit** is the measurement of the function of the systems analysed which enables these to be compared. In this case the outset functional unit is as follows:

"The distribution of 1000 tons of fruit and vegetables in (disposable) cardboard boxes or in (reusable) plastic boxes".

To translate this functional unit into reference flows (that is, into numbers of plastic and cardboard boxes needed) we took into account that each box can carry 15 kg of product. This means that **to transport those 1000 tons 66,667 units of boxes are needed**. In the conservative scenario, plastic boxes have a 10-year lifetime and used in 10 rotations a year. This means that **during the 10 years of the plastic boxes' useful lifetime, they could have 6,666,700 fills**.

To be able to take into account the effect of the rotations and useful life of plastic boxes, the outset functional unit was changed for the conservative scenario into:

"The distribution of 6,666,700 boxes full of fruit and vegetables, with a transported weight of 15 kg per box, in (single use) cardboard boxes or (reusable) plastic boxes".

2.2.3 System boundaries

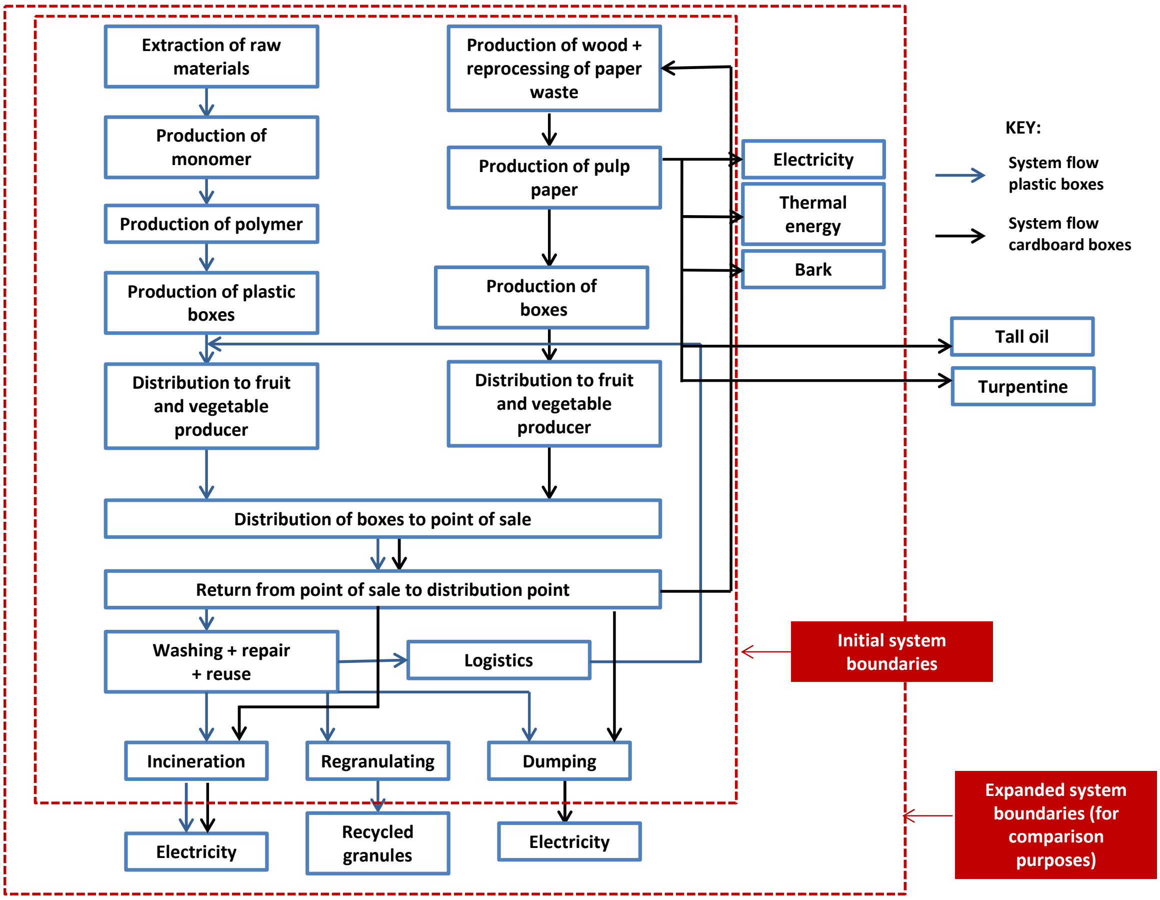
The study includes the full life cycle of both distribution systems, considering the stages of extracting the raw material for manufacturing the boxes, the production process, that of distribution and use, and those of recycling or final placing at a dump or incinerator after their useful life is over. Auxiliary systems such a transporting raw materials for manufacturing the boxes, obtaining electric power from primary energy sources, extracting and burning fuel for transporting the boxes or transporting waste are also included in this analysis, from a lifecycle standpoint.

The production of capital goods (equipment, machinery, trucks) is outside the limits of the production system, since these are in general not relevant in the analysis due to the depreciation per product made or transported.

After the remains of the boxes have been managed as waste, this involves the arrangement of secondary material to be reused in other products (recycling of plastic boxes) and also the recovery of energy in the form of electricity in the event of the remains of plastic or cardboard boxes being incinerated or placed in a dump. This fact entails the incorporation of new functions in the system being used, as well as that of transporting the fruit and vegetables, such as having a certain amount of recycled material and/or electricity available.

This "methodological problem" of adding new functions to the system is solved in the case of LCA by "system expansion" (see section 2.2.4). The two distribution systems will only be comparable if this system is expanded in this way, since this will ensure that both comply with the same functional unit.

Figure 2 displays the boundaries of the systems analysed, both initial and expanded.


Extraction of raw materials
Production of monomer
Production of polymer
Production of plastic boxes
Distribution to fruit and vegetable producer
Production of wood + reprocessing of paper waste
Production of pulp paper
Production of boxes
Distribution to fruit and vegetable producer
Electricity
Thermal energy
Bark
Tall oil
Turpentine
KEY:
System flow plastic boxes
System flow cardboard boxes
Distribution of boxes to point of sale
Return from point of sale to distribution point
Washing + repair + reuse
Logistics
Initial system boundaries
Incineration
Regranulating
Dumping
Electricity
Recycled granules
Electricity
Expanded system boundaries (for comparison purposes)

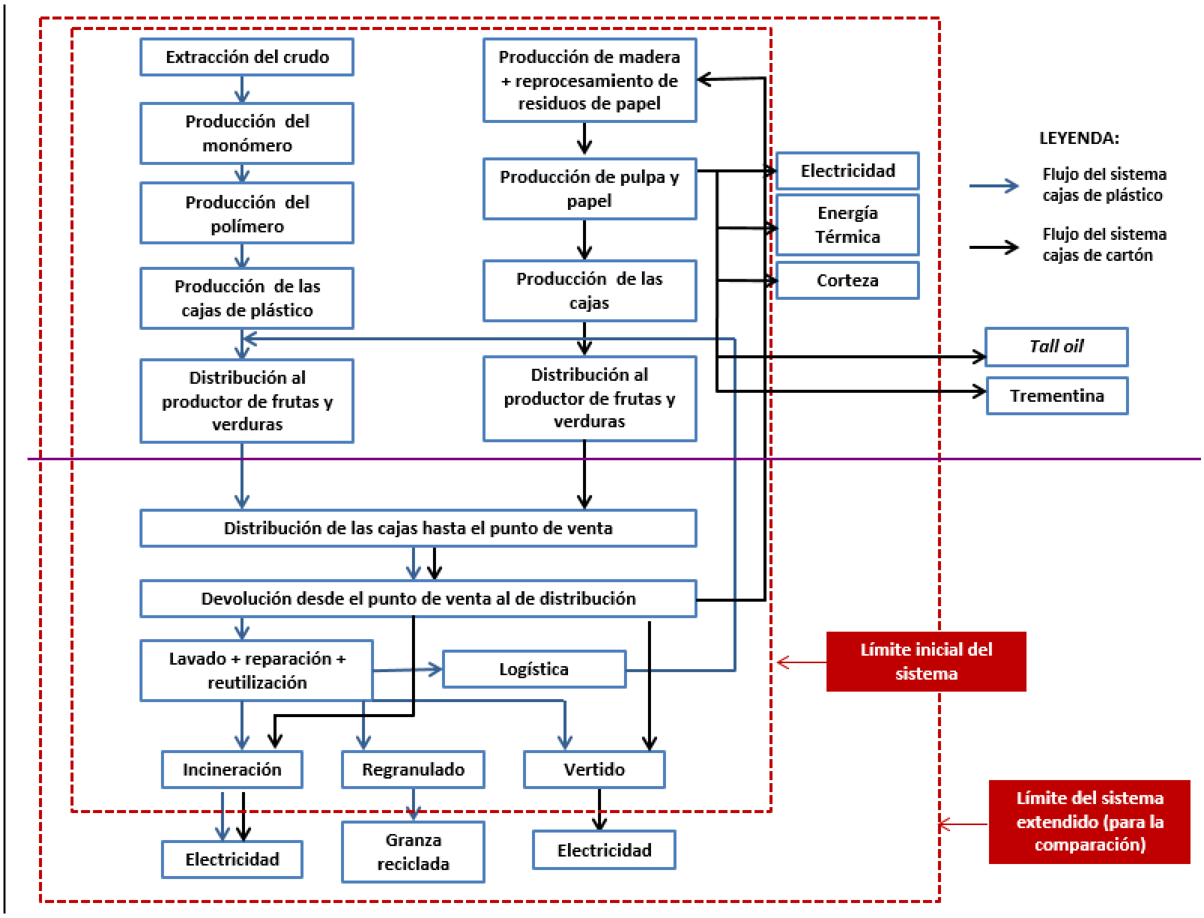


Figure 2. System boundaries

2.2.4 Expansion of the system

The recovery of materials and energy through flows of waste from processed boxes entails adding new functions to the main function of transporting and distributing fruit and vegetables of the system being studied. For both transport alternatives to be equivalent, one has to assign (or allocate) the environmental impact between the different functions produced by the system and account for only the part covering the main function shared by both systems in the calculation of environmental impact.

Whenever possible, UNE-EN ISO 14044:2006[7] standard recommends avoiding allocation by expanding the boundaries of the system examined so as to include obtaining (in this case the material or energy) from alternative production sources (see table 1, section 2.2.6). This is what is known as making a "system expansion", which entails subtracting the environmental impact associated with obtaining materials and energy from other production sources. Figure 3 is a schematic view of the process for expanding the system (as an example in the case of energy).

[7] UNE EN ISO 14044. Environmental management. Life cycle assessment. Requisites and directives.

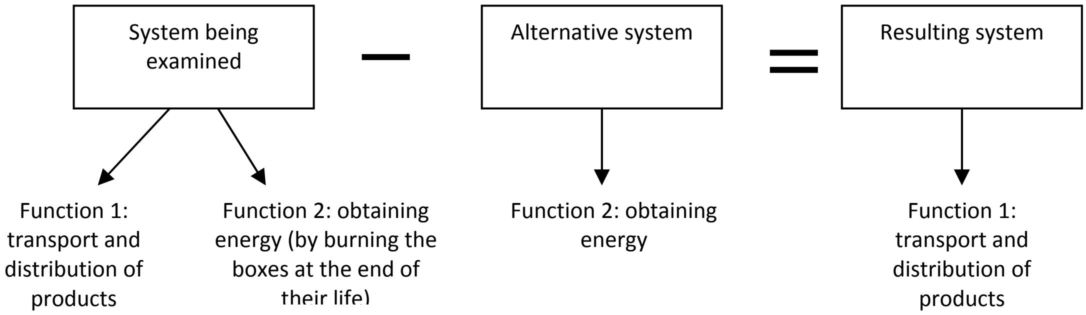


Figure 3. System expansion diagram

2.2.5 Processing of biogenic CO_2

In keeping with the recommendations of the ILCD (2011), the absorption and emission of CO_2 from biogenic sources has been considered neutral in this study. For this purpose both the absorption of biogenic origin CO_2 in obtaining the paper and cardboard needed for cardboard boxes and its release after the useful life is over by incineration of the waste generated have been taken into account.

2.2.6 Selection of relevant impact categories

The categories of environmental impact analysed in this study are shown in Table 2. These have been developed by the Centre for Environmental Science at Leiden University (CML) [Heijungs et al, 1992; Guinée et al., 2001] updated in April 2015, except for the category of Photochemical Oxidant Creation Potential, in which the characterisation factors of IMPACT 2000+ [Jolliet et al, 2003] have been used:

Table 2. Categories of environmental impact considered

Impact category	Measuring unit	Acronym
Use of primary (renewable) energy	MJ	PE-R
Use of primary (non-renewable) energy	MJ	PE-NR
Global Warming Potential	kg CO_2 eq.	GWP
Ozone Layer Depletion Potential	kg R11 eq.	ODP
Acidification Potential	kg SO_2 – eq.	AP
Eutrophication Potential	kg Phosphate – eq.	EP
Photochemical Oxidant Creation Potential	kg Ethene – eq.	POCP

2.2.7 Collection of information and data sources

For the production stages of plastic and cardboard boxes the data obtained from the SIM report (2009)[8] was used, but this has been updated with the GaBi database (2016). This means, for example, that the consumption of electric energy to produce the boxes has been updated to the representative electricity production mix for the 2012-2018 period, instead of the 1998-2003 included in the SIM report.

Likewise, the raw materials or some ancillary materials used in the process have also been updated with the same database, in order to include the most recent data available.

For the stages of distribution and inverse logistics (in the case of reusable plastic boxes) data provided by the companies belonging to ARECO on fruit and vegetable distribution in Spain for 2015 was used.

[8] The data from the SIM report (2009) was compiled through questionnaires sent to the partners in the project as well as to industrial companies (FEFCO for production of cardboard boxes, German Umweltbundesamt for production of plastic polymers and Bekuplast, Didac Injection and SchoellerArcaSystems - the largest suppliers of IFCO and EUROPOOL – for production of plastic boxes). European representativeness was guaranteed by having international support partners take part (FEBE EcoLogic, Escuela Superior de Comercio Internacional (ESCI-UPF) and Bio Intelligence Services) which provided specific data for Italy, Spain and France, respectively. The relevant background data on energy, transport and ancillary materials was taken from the GaBi 4 database corresponding to the 1998-2003 period. Other agents involved were also consulted (box producers, federations, ink manufacturers, fruit and vegetable producers) to complete the data inventory.

2.2.8 GaBi database (update)

The GaBi database on LCA used in the 2009 SIM study, GaBi 2008, has been updated to the GaBi 2016[9] version. This database has updates, amongst others, of the energy mixes for production of electricity and fuels, representative for the 2012-2018 period, as well as the data on production of materials of 20 business associations in respect of the GaBi 2013 version.

2.2.9 Validation of data

The data used in this study for the production processes was compiled by industries, partners and members of the SIM project (2009) and validated by Thinkstep (formerly known as PE International) and LBP. The data collected was validated using existing and published data from different sources (ej. EYERER 1996, EYERER & REINHARDT 2000, GaBi 2003, IKP 2005, GaBi 2008) or by using the engineering knowledge of experts from PE International and LBP.

The data on the distribution and logistics processes of the boxes provided by the ARECO members was processed and validated by LCA experts from the UNESCO Chair in Life Cycle and Climate Change (ESCI-UPF).

2.2.10 Calculation and simulation tools

For modelling and obtaining results the GaBi 7 Life Cycle Assessment engineering software was used. This was developed by the *Chair of Building Physics* (LBP in German) of the Life Cycle Engineering Department of the University of Stuttgart and Thinkstep (formerly known as PE International).

2.2.11 Critical review

To comply with the requisites established by ISO 14040 for comparative assertions open to the public, an external critical review was carried out by a panel made up of 3 independent experts. The experts belong to the University of Cantabria, the Spanish Association for Standardization and Certification (AENOR) and the Center for Energy, Environmental and Technological Research (CIEMAT).

[9] For further information the Thinkstep web page may be consulted: http://www.gabi-software.com/support/latestupdate/, in which the innovations included in this new update are detailed in comparison with previous versions.

3. Results

The results of the study are given in this section, analysing these in absolute and relative terms, and making an analysis of contribution by stages in the life cycle. An analysis of the sensitivity of the data and most relevant parameters of the study is also made to observe their effect on the results.

3.1.1 Overall results

Table 3 shows the disaggregated results, broken down by emissions and impact avoided or incorporated, and aggregated results (emissions – avoided) for the conservative scenario. As can be seen, **plastic boxes display a better environmental performance than the cardboard ones for all the impact categories**. In the aggregated results on energy consumption (Table 4) it can be also seen that the consumption of primary energy from renewable and non-renewable sources (PE-R + PE-NR) is lower in the case of plastic boxes, which is closely associated with a lower consumption of materials from renewable and non-renewable sources as a whole than those made of cardboard.

Figure 4 shows the results for the conservative scenario. The results have been standardised with the box contributing most to each of the impact categories in question.

Table 3. Results of absolute environmental impact

IMPACT CATEGORY	UNIT	Plastic boxes	Cardboard boxes
EMISSIONS			
AP	kg SO_2-eq	4,924	18,505
EP	kg phosphate-eq.	1,011	6,164
GWP	kg CO_2-eq.	1,638,163	32,279,558
ODP	kg R11-eq.	0.002	0.081
POCP	kg Ethene-eq.	496	1,640
AVOIDED OR INCORPORATED			
AP	kg SO_2-eq.	912	13,638
EP	kg phosphate -eq.	108	3,789
GWP	kg CO_2-eq.	290,450	21,413,737
ODP	kg R11-eq.	0.000	0.004
POCP	kg Ethene -eq.	30	777
EMISSIONS-AVOIDED			
AP	kg SO_2-eq.	4,012	4,867
EP	kg phosphate -eq.	902	2,376
GWP	kg CO_2-eq.	1,347,713	10,865,821
ODP	kg R11-eq.	0.002	0.077
POCP	kg Ethene -eq.	466	863

Table 4. Absolute results of the energy indicators

INDICATOR	UNIT	Plastic boxes	Cardboard boxes
CONSUMPTIONS			
PE-R+PE-NR	MJ	36,157,015	229,069,722
PE-NR	MJ	33,098,358	79,062,871
PE-R	MJ	3,058,656	150,006,851
SAVINGS			
PE-R+PE-NR	MJ	10,132,653	168,764,773
PE-NR	MJ	9,951,176	129,884,217
PE-R	MJ	181,477	38,880,555
CONSUMPTIONS-SAVINGS			
PE-R+PE-NR	MJ	26,024,361	60,304,949
PE-NR	MJ	23,147,182	-50,821,347
PE-R	MJ	2,877,179	111,126,296

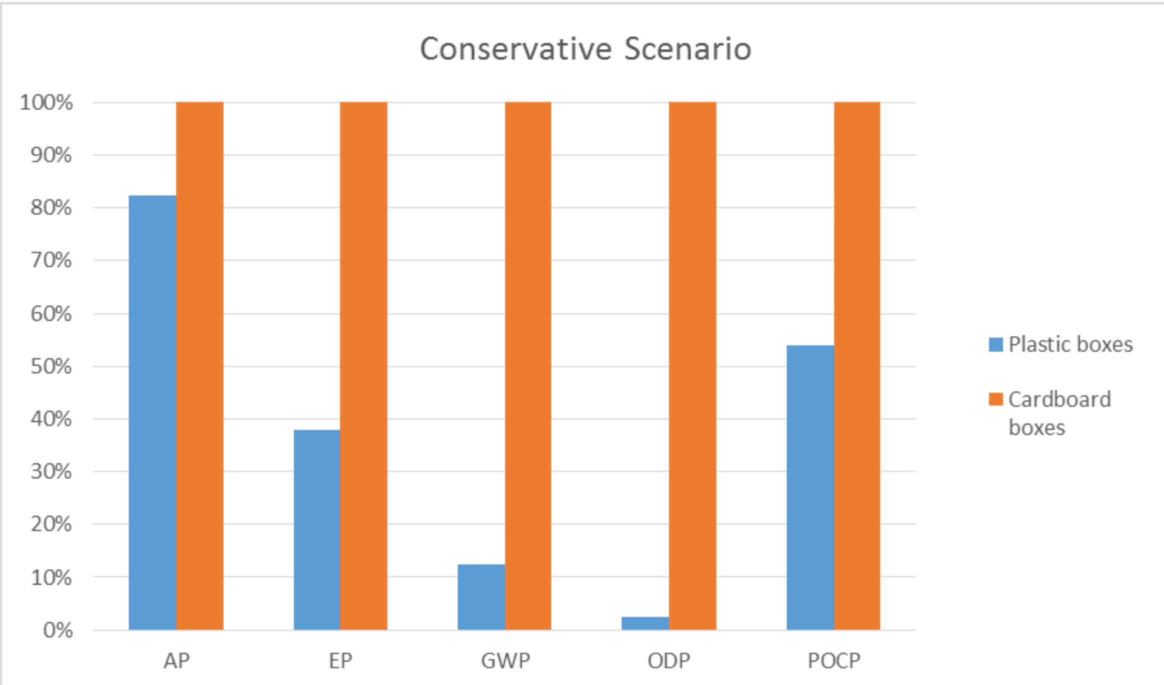


Figure 4. Results on comparison of boxes

As regards the energy results displayed in the Table 4, one should stress that the energy used in the manufacturing and distribution of the boxes which is recovered in the end-of-life stage represents 28% in the case of plastic boxes and 74% in that of cardboard boxes in the conservative scenario.

To analyse the influence of the impact of the systems analysed, the results of environmental impact were standardised to the mean emissions of different European regions of the 25 (+3) for year 2000 (see Figure 5). This was done for the impact categories analysed with CML 2015 for which these mean emissions were available.

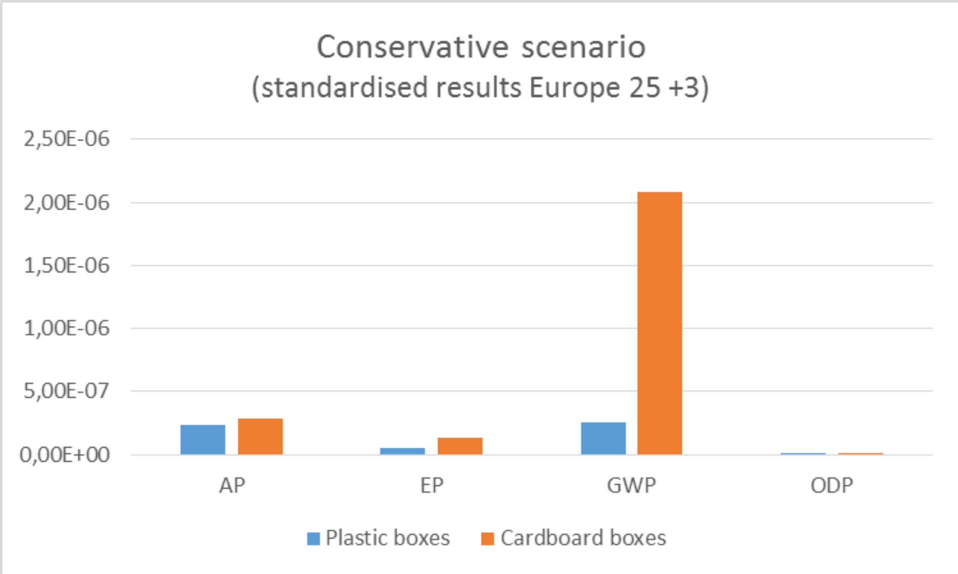


Figure 5. Results of environmental impact standardised to mean regional emissions of Europe 25 (+3) for year 2000

From the results displayed in Figure 5, it can be appreciated that the impact categories to which the greatest contribution is made by the systems analysed in respect of the mean regional emissions in Europe are the Global Warming Potential and the Acidification Potential. They make a much lesser contribution to Eutrophication Potential, and practically none at all to the Ozone Layer Depletion Potential.

3.1.2 Scaling of results to the mobilisation of annual boxes in Spain

If the difference between disposable cardboard boxes and reusable plastic ones is scaled from a functional unit applied to the total number of boxes mobilised for the distribution organised in Spain over one year (roughly 550 million fills[10]), the impact on the most influential impact category, GWP, would mean annual savings of -785,239,967 kg of CO_2-eq. for the conservative scenario (10 reuses a year). Table 5 details the calculations made. This represents 0.24% of the emissions generated by Spain in 2014 in both cases[11].

[10] Data provided by ARECO (January 2017).

[11] The emissions of equivalent CO_2 in Spain in 2014 were 328,926 million tons (MAGRAMA, 2016). Dividing the tons that have been calculated which could be saved by this value gives a total contribution of 0.24% (for both the technical scenario and for the conservative one).

Table 5. Scaling of results to the 550 million units of boxes mobilised in Spain yearly for organised distribution

INDICATOR	UNIT	Plastic boxes	Cardboard boxes
RESULTS OF THE LCA STUDY			
GWP/UF	kg CO_2-eq.	1,347,713	10,865,821
Fills/UF	Number	6,666,700	6,666,700
GWP/fill	kg CO_2-eq.	0.202	1.630
SCALED TO 550 MILLION ANNUAL UNITS IN SPAIN			
Fills/year	Number	550,000,000	550,000,000
GWP/year	kg CO_2-eq.	111,185,757	896,425,724
Annual savings	kg CO_2-eq.	-785,239,967	

3.1.3 Contribution of different stages in the life cycle of the two options

The following sections display the results broken down by stages in the life cycle: production, service life and end-of-life for each of the boxes. In both cases tables are given with absolute and relative results, and for both the impact categories and the energy consumption indicators selected.

Plastic boxes

Tables 6 and 7 show the results of the contribution of each of the stages in the life cycle of the reusable plastic boxes.

Table 6. Results of contribution of environmental indicators by stages in the life cycle of PLASTIC BOXES

EMISSIONS	UNIT	Production Subtotal	Service life Subtotal	End-of-life Subtotal	TOTAL
AP	kg SO_2-eq	17.0%	80.6%	2.4%	100%
EP	kg Phosphate-eq.	9.1%	89.2%	1.7%	100%
GWP	kg CO_2-eq.	24.5%	70.3%	5.2%	100%
ODP	kg R11-eq.	2.0%	95.4%	2.7%	100%
POCP	kg Ethene-eq.	50.2%	48.7%	1.1%	100%
AVOIDED (INCORPORATED)					
AP	kg SO_2-eq.	0.0%	0.0%	100.0%	100%
EP	kg Phosphate- eq.	0.0%	0.0%	100.0%	100%
GWP	kg CO_2- eq.	0.0%	0.0%	100.0%	100%
ODP	kg R11-eq.	0.0%	0.0%	100.0%	100%
POCP	kg Ethene-eq.	0.0%	0.0%	100.0%	100%

Table 7. Results of contribution of energy consumption by stages in the life cycle of PLASTIC BOXES

ACRONYM	UNIT	Production Subtotal	Service life Subtotal	End-of-life Subtotal	TOTAL
CONSUMPTIONS					
PE-R+PE-NR	MJ	43.6%	53.9%	2.5%	100%
PE-NR	MJ	46.2%	51.9%	1.9%	100%
PE-R	MJ	15.4%	76.2%	8.4%	100%
SAVINGS					
PE-R+PE-NR	MJ	0.0%	0.0%	100.0%	100%
PE-NR	MJ	0.0%	0.0%	100.0%	100%
PE-R	MJ	0.0%	0.0%	100.0%	100%

As can be seen from the results, in the case of **plastic boxes** most of the emissions and thus **environmental impacts are concentrated in the service life stage**, followed by that of the production of boxes. As regards the **savings**, these are concentrated in the **end-of-life stage** for all impact categories.

With regard to energy consumption, total renewable and non-renewable energy consumptions are concentrated in the production stages (44%) and service life (54%). As for savings, these are all concentrated in the end-of-life stage.

Cardboard boxes

Tables 8 and 9 display the results of the contribution of each of the life cycle stages of disposable cardboard boxes.

Table 8. Results of the contribution of environmental indicators by stages in the life cycle of CARDBOARD BOXES

EMISSIONS	UNIT	Production Subtotal	Service life Subtotal	End-of-life Subtotal	TOTAL
AP	kg SO_2-eq	82.8%	2.9%	14.3%	100%
EP	kg Phosphate-eq.	90.1%	2.2%	7.7%	100%
GWP	kg CO_2-eq.	38.2%	0.4%	61.4%	100%
ODP	kg R11-eq.	99.8%	0.0%	0.2%	100%
POCP	kg Ethene-eq.	93.0%	1.6%	5.4%	100%
AVOIDED (INCORPORATED)					
AP	kg SO_2-eq.	0.7%	0.0%	99.3%	100%
EP	kg Phosphate- eq.	0.4%	0.0%	99.6%	100%
GWP	kg CO_2- eq.	56.9%	0.0%	43.1%	100%
ODP	kg R11-eq.	0.1%	0.0%	99.9%	100%
POCP	kg Ethene-eq.	2.6%	0.0%	97.4%	100%

Table 9. Results of contribution of energy consumption by stages in the life cycle of CARDBOARD BOXES

ACRONYM	UNIT	Production Subtotal	Service life Subtotal	End-of-life Subtotal	TOTAL
CONSUMPTIONS					
PE-R+PE-NR	MJ	95.0%	0.8%	4.2%	100%
PE-NR	MJ	88.3%	2.2%	9.5%	100%
PE-R	MJ	98.5%	0.1%	1.4%	100%
SAVINGS					
PE-R+PE-NR	MJ	1.5%	0.0%	98.5%	100%
PE-NR	MJ	1.9%	0.0%	98.1%	100%
PE-R	MJ	0.0%	0.0%	100.0%	100%

As can be seen from the results, in the case of **cardboard boxes**, except for GWP, **most of the environmental impacts** for the other categories **are concentrated in the production stage of the boxes**. In the case of GWP, 38% of the impact is spread in the production stage and 61% in the end-of-life stage. As for **savings**, except in the case of GWP, in which there is a greater saving in the production stage of the boxes (due to the absorption of CO_2 from biological sources), for the other impacts **practically all of the savings are associated with the end-of-life stages**.

With regard to energy consumption, 95% of the total renewable and non-renewable energy consumptions are concentrated in the production stage and 4% in the end-of-life stage, the contribution to this indicator from the service life stage being only 1%. As for savings, 98.5% are concentrated in the end-of-life stage and 1.5% in that of production.

3.1.4 Contribution of production processes of cardboard boxes

Since the process making the greatest contribution to environmental impact and energy consumption of cardboard boxes is that of manufacturing the boxes, an analysis of the contribution made by the subprocesses included in this was performed in greater detail. In particular, the following subprocesses were analysed:

- (1) sylviculture and wood supply
- (2) manufacture of paper pulp and obtaining secondary raw materials. This subprocess includes both the manufacture of semi-chemical pulp and Kraft paper as well as obtaining recycled paper and sawmill waste.
- (3) production of cardboard boxes.

The results of this analysis are shown in Table 10. The process with least contribution in the production of the boxes in all impact categories can be seen to be sylviculture and wood supply. On the other hand, the process with greatest contribution in all cases is the one including obtaining paper pulp. As for energy consumption, making paper pulp is the part contributing most to non-renewable energy consumption (81%) and sylviculture to that of renewable energy (64%).

Table 10. Contribution of the processes included in manufacturing cardboard boxes

IMPACT CATEGORIES	UNIT	Sylviculture and wood supply	Manufacture of paper pulp and obtaining secondary raw materials	Production of cardboard boxes	TOTAL
AP	kg SO_2-eq.	6.4%	84.4%	9.2%	100%
EP	kg Phosphate-eq.	4.3%	85.6%	10.0%	100%
GWP*	kg CO_2-eq.	1.5%	93.2%	5.3%	100%
ODP	kg R11-eq.	0.0%	80.0%	20.0%	100%
POCP	kg Ethene-eq.	10.3%	78.8%	10.9%	100%
ENERGY					
PE-R+PE-NR	MJ	45.0%	46.8%	8.2%	100%
PE-NR	MJ	3.3%	80.8%	15.9%	100%
PE-R	MJ	64.0%	31.4%	4.7%	100%

* Only fossil origin CO_2 was considered for this analysis; biological CO_2 was not taken into consideration.

3.1.5 Relevance of the different parameters and influence on results

A sensitivity study was carried out in this study in order to observe the effect on the results of some of the parameters (and mean or default values) which have been used. The aim of this phase is to determine how robust the results are and find out if any of the variables may modify the tendency in the results obtained or not.

The parameters that have varied were the ones identified in Table 11 as the main parameters affecting the overall results of the study and the production and end-of-life stages. These parameters varied with the values shown in the same table, which displays the value of the basic scenario and of the variation.

Table 11. Parameters and values on which sensitivity analyses have been made

Ref.	Sensitivity analysis performed	Base scenario	Variation
	FOR CARDBOARD BOXES		
P.1	Percentage of (*semi-chemical*) virgin fluting in the cardboard box	63%	10%
P.1	Percentage of virgin liner (*Kraftliner*) in the cardboard box	37%	21%
P.1	Percentage of recycled fluting (*Wellenstoff*) in the cardboard box	0%	33%
P.1	Percentage of recycled liner (*Testliner*) in the cardboard box	0%	33%
P.2	Percentage of cardboard boxes recycled at the end of their useful lives	80%	100%
P.3	Value of secondary paper fibres in respect of *Wellenstoff*	90%	100%
	FOR PLASTIC BOXES		
P.4	Percentage of recycled plastic used in making the boxes	0%	30%
P.5	Percentage of virgin HDPE used in making the boxes	57%	100%
P.6	Percentage of virgin PP used in making the boxes	43%	100%
P.7a	Losses of granulate during the production of the boxes	2.75%	1.5%
P.7b	Losses of granulate during the production of the boxes	2.75%	6%
P.8a	Breakage index of the plastic boxes during their service life	0.51%	0.2%
P.8b	Breakage index of the plastic boxes during their service life	0.51%	0.70%
P.9	Percentage of plastic boxes recycled at the end of their useful life	100%	50%
P.10	Value of the secondary plastic material in respect of the primary material	70%	100%
P.11a	Number of rotations/year	10	12
P.11b	Number of rotations/year	10	8

Table 12 displays the results of the sensitivity analysis of all the parameters analysed. The table identifies the analysis scenarios and the environmental impact indicators, stressing which of the two options (reusable plastic boxes or disposable cardboard boxes) are better in each of the cases, with a degree of confidence of 25%. This means that the environmental impact of the boxes for any given impact category is 25% greater or lesser than the other option. This has been considered a sufficiently broad to be able to contain any effects due to the uncertainty of the data used in the inventory.

Table 12. Result of the sensitivity analysis of variables on disposable cardboard boxes

	AP	EP	GWP	ODP	FOFP	PE-R+PE-NR
Base scenario	Similar options	Best option plastic	Best option plastic	Best option plastic	Best option plastic	Best option plastic
P1	Best option cardboard	Best option cardboard	Best option plastic	Best option plastic	Similar options	Best option cardboard
P2	Best option cardboard	Best option plastic	Best option plastic	Best option plastic	Best option plastic	Similar options
P3	Similar options	Best option plastic	Best option plastic	Best option plastic	Best option plastic	Best option plastic
P4	Similar options	Best option plastic	Best option plastic	Best option plastic	Best option plastic	Best option plastic
P5	Similar options	Best option plastic	Best option plastic	Best option plastic	Best option plastic	Best option plastic
P6	Similar options	Best option plastic	Best option plastic	Best option plastic	Best option plastic	Best option plastic
P7a	Similar options	Best option plastic	Best option plastic	Best option plastic	Best option plastic	Best option plastic
P7b	Similar options	Best option plastic	Best option plastic	Best option plastic	Best option plastic	Best option plastic
P8a	Similar options	Best option plastic	Best option plastic	Best option plastic	Best option plastic	Best option plastic
P8b	Similar options	Best option plastic	Best option plastic	Best option plastic	Best option plastic	Best option plastic
P9	Similar options	Best option plastic	Best option plastic	Best option plastic	Best option plastic	Best option plastic
P10	Similar options	Best option plastic	Best option plastic	Best option plastic	Best option plastic	Best option plastic
P11a	Similar options	Best option plastic	Best option plastic	Best option plastic	Best option plastic	Best option plastic
P11b	Similar options	Best option plastic	Best option plastic	Best option plastic	Best option plastic	Best option plastic

Best option plastic > 25% (yellow)
Similar options (<>25%) (grey)
Best option cardboard > 25% (blue)

4. Conclusions

- The results of the study clearly display that **reusable plastic boxes give a better environmental performance than disposable cardboard ones**.

- This occurs **for all the impact categories and renewable and non-renewable energy consumption indicators considered, except for Acidification Potential (AP) for which**, taking into account a security margin of 25% in the results in order to take into account the uncertainty of the model and the data used, **both types of boxes may be considered to have a similar impact**.

- In the case of **DISPOSABLE CARDBOARD BOXES**, the **greater environmental impact is associated with the stage of manufacturing the boxes** (sylviculture, supply of raw materials and production), while the **savings are concentrated in the end-of-life stages**, mainly associated with the recovery of secondary paper fibres.

- In the case of **REUSABLE PLASTIC BOXES**, the **greatest environmental impact is associated with the useful life of the boxes**, including returning the boxes from the shops to the distribution centres, the inspection and hygienisation processes and also transporting the boxes back to the manufacturers of fruit and vegetables, followed by the production stage of the granulated polymer in its manufacturing. As regards the **savings**, these are also **concentrated** in the end-of-life stage due to the recovery of recycled plastic chips.

- **The sensitivity analysis made on all the parameters continues to display a clear preference for reusable plastic boxes in comparison with disposable cardboard boxes**. Except for AP, EP and the consumption of energy in two of the cases analysed, for the other categories and variations of parameters, the plastic boxes always have 25% less impact than those of cardboard.

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