



Comparative Life Cycle Assessment of one-way plant trays versus returnable plant trays

PUBLIC REPORT - On behalf of Royal FloraHolland

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Title	Comparative Life Cycle Assessment of one-way plant trays versus returnable plant trays	
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Summary

This comparative Life Cycle Assessment (LCA) study is about **the environmental impacts associated with the use of single use and multiple use plant trays that are used in the horticultural sector**. The LCA methodology is used to quantify the environmental impact of plant trays for multiple impact categories from cradle to grave.

Chapter 2 defines the scope of the study, which includes eight different plant trays, grouped into three different plant tray types:

- Two multiple use plastic trays: Floratino FC 746 and FC 736
- Two single use plastic trays: Normpack® 306 and Normpack® 236
- Four single use cardboard trays: corrugated board – closed bottom, corrugated board – open bottom, paper pulp and solid board

Four different markets are considered for this study which are Berlin (Germany), Paris (France), London (Great Britain) and Arnhem (The Netherlands), to determine if one-way and returnable trays perform similar between the different countries.

Chapter 3 describes the collected data for this study. First, the system boundaries are defined. For this study a so-called cradle-to-grave boundary is chosen. Allocation of multifunctional processes is based on the Circular Footprint Formula proposed by the European Commission. The formula quantifies the credits for using recycled material, recycling trays, heat recovery from plastic incineration and electricity recovery from plastic incineration. Primary data on tray production is collected from various producers to model the production phase properly. Several transportation processes are considered as well as the end-of-life processing of disposed trays at the market location. The disposed trays are recycled, incinerated or landfilled. The modelling is based on country specific statistics.

Chapter 4 shows the results of this study. ReCiPe impact categories are chosen to present the impact category results at mid-point as well as endpoint. In paragraph 4.3, mid-point results show that the environmental impact of multiple use trays is lower than single use trays for the most relevant impact categories climate change and fossil energy depletion for all investigated markets. The endpoint method is used to aggregate all environmental impacts into a single score. Based on the single score results, multiple use plastic trays are the most environmental-friendly way to transport plants to the investigated markets. For single use trays, the cardboard trays perform better than the single use plastic variants.

In chapter 5, contribution analyses are performed to get insights in the main contributors to the environmental impact for each tray type. For multiple use trays, the transportation processes and, where applicable, the cleaning process (applied only for the Floratino tray) are the main contributors. For single use trays, both for plastic and cardboard, the environmental impact is mainly caused by the production of materials and its end-of-life.

Sensitivity analysis shows that deliberately changing some important parameters does not change the overall outcome of the study. These important parameters include: higher recycling rates for disposed plastic and lower triprates for Floratino FC 746.

The discussion addresses the main choices, assumptions and consequences of the study. One of the important choices is to use the Circular Footprint Formula to solve the problem of multifunctional processes. The Circular Footprint Formula uses substitution as allocation method, this is especially beneficial for single use trays since more plastic is incinerated per functional unit than for multiple use trays. Another important choice is the substitution of electricity based on the market mix of the specific countries. Some countries, like Germany, have a relatively filthy electricity mix, meaning that a lot of filthy emissions are avoided when electricity is produced from the waste in the end of life. This explains the negative emissions for some impact categories.

Figure 1 below gives an overview of the relative environmental impact per type of tray. The environmental impact of different multiple use plastic trays are averaged and compared with the average impact single use plastic and single use cardboard trays.

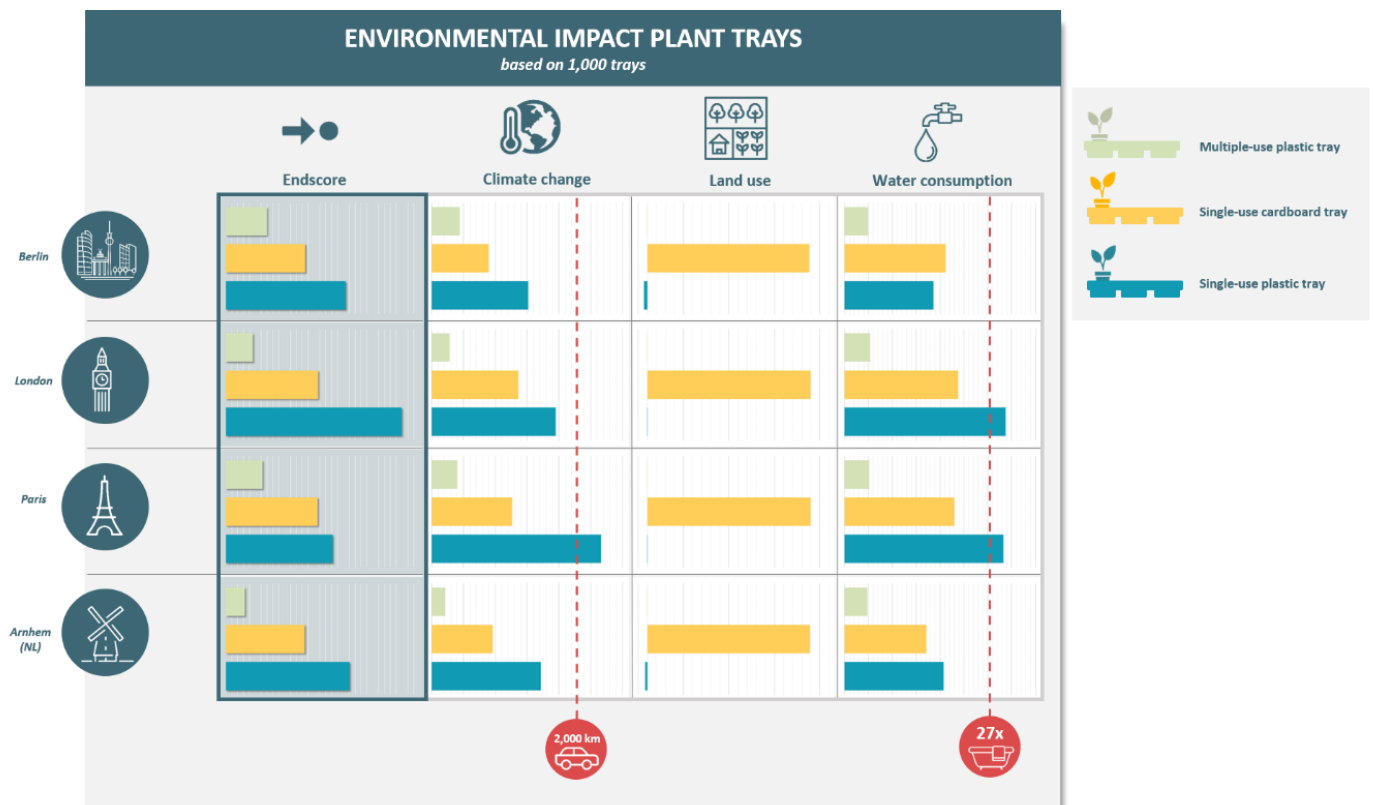


Figure 1: Environmental impact of different plant tray types to different markets

Even though the allocation method and the choice of substitution is more beneficial for single use (plastic) trays, **multiple use plastic trays have the best environmental performance of all the trays types considered in this study. Second best alternative for all markets are the single use cardboard trays over single use plastic trays.**

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Abbreviations

B2B	Business-to-business
B2C	Business-to-consumer
CFF	Circular footprint formula
CH	Switzerland
DE	Germany
ELCD	European reference Life Cycle Database
EoL	End of Life
FR	France
GB	Great Britain
GLO	Global
HDPE	High density polyethylene
kWh	kilowatt hour
LCA	Life cycle assessment
LCI	Life cycle inventory
LCIA	Life cycle impact assessment
LF	Load factor
LHV	Lower heating value
ISO	International organization for standardization
MSW	Municipal solid waste
NCV	Net caloric value
NL	Netherlands
PEF	Product Environmental Footprint
PEFCR	Product Environmental Footprint Category Rules
PS	Polystyrene
PP	Polypropylene
ReCiPe	<i>This is not an abbreviation but a name of a life cycle impact assessment method</i>
RER	Europe
RoW	Rest of World
TR	Triprate

Definitions

Allocation: A step in the inventory analysis in which the inventory model is refined and the input and output flows of multifunctional processes are partitioned to the functional flows of these processes.

Functional unit: The quantified function provided by the product system(s) under study, for use as a reference basis in an LCA

Life Cycle Assessment (LCA): Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle (ISO, 2006a).

Life Cycle Impact Assessment (LCIA): Stage of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product (ISO, 2006a).

Primary packaging: Primary Packaging constitutes the packaging designed to come into direct contact with the product (The Consumer Goods Forum, 2011).

Reference flow: Measure of the outputs from processes in a given product system required to fulfil the function expressed by the functional unit (ISO, 2006a).

Secondary data: Secondary data refers to data not from specific process within the supply-chain of the company applying the PEFCR. This refers to data that is not directly collected, measured, or estimated, but rather sourced from a third-party life-cycle-inventory database or other sources. Secondary data includes industry-average data (e.g., from published databases, government statistics, literature studies, and industry associations), financial data, proxy data, and other generic data. Company-specific data that go through a horizontal aggregation step are considered as secondary data (based on WRI-WBCSD, 2011).

1. Introduction

Royal FloraHolland aims to facilitate a more sustainable logistic system for horticultural products. But the organization lacks the know-how in quantifying the environmental impacts associated with the use of plant pot trays. Therefore, Royal FloraHolland approached Blonk Consultants to quantify the environmental impact of plant trays in a fair comparative way. Hereby Royal FloraHolland aims to gain more insight in the environmental impacts of plant pot trays. This resulted in a comparative screening Life Cycle Assessment (LCA) study, finalized in 2016. That specific study concluded that the multiple-use tray (based on Floratino FC746) showed, a better environmental performance over the single-use tray (based on Normpack® 306) on four environmental impact categories. Royal FloraHolland could not use the results externally, since this requires an external review of the study.



Therefore, in 2017, an ISO 14040 / 14044 compliant study of plastic tray alternatives was carried out, concluding multiple use trays have the best environmental performance. Royal FloraHolland could use this study to communicate externally.

Cardboard tray update

Additionally, Royal FloraHolland was also interested in the environmental performance of cardboard trays. Therefore, in 2019 an update of the study followed, including four different cardboard trays. This study is mostly based on the previous studies. Additionally, some general changes and updates have been implemented:

- Review/update of all Circular footprint formula (CFF) formula and parameters that have been communicated by the European Commission in March 2018 (PEF Packaging Working Group, 2018).
- Review/update of all transportation load factors for all tray types by including pallet type and the number of trays that fit on a pallet.

In most cases, the text of this report has been (partly) rewritten during the update to include information regarding the cardboard trays. Besides that, additional paragraphs have been added starting with “**Cardboard tray update**”. In this way the reader knows what was included in the 2017 study and what had been added or changed in the 2019 study.

1.1 Methodology

The LCA methodology is used to study the environmental performance of one-way plastic and one-way cardboard and returnable plastic trays. Most important advantage of the methodology is that it is product based and all relevant life-cycle processes can be included. This means the environmental impacts of products from cradle-to-grave can be studied. Another important feature of LCA is that the environmental impacts can eventually be translated into different impact categories, like climate change, stratospheric ozone depletion, eutrophication, acidification, water use, land use and many others. This can be used to compare multiple production systems in terms of environmental performance. Besides that, it gives insights in possible burden shifts from certain impact categories to other impact categories.

Main drawback of LCA is that it does not include any social and economic aspects. The LCA study itself will be performed using the four phases which are proposed by ISO 14040 (ISO, 2006a).

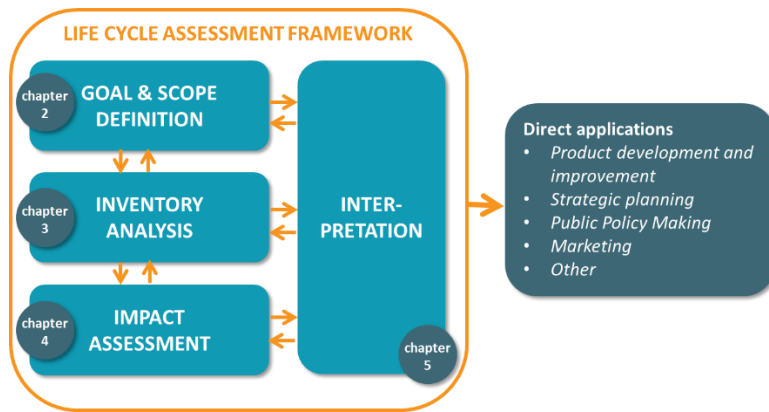


Figure 2: Phases of an LCA and its applications (taken from ISO 14040)

The four steps are:

- **Goal and scope:** description of the product system in terms of system boundaries and functional unit.
- **Inventory analysis:** also called ‘life cycle inventory’ (LCI), estimation of the consumption of resources, quantities of waste flows and emissions caused by (or attributed to) a product’s life cycle.
- **Impact assessment:** also known as ‘life cycle impact assessment’ (LCIA) provides indicators and the basis for analyzing the potential contributions of the resource extractions and emissions in an inventory to several potential impacts.
- **Interpretation:** results of the analysis and evaluation of all choices and assumptions made during the study. And finally, the overall conclusions of the study are drawn.

This report has been critically reviewed by a panel of reviewers, according to the ISO 14040/14044 criteria (ISO, 2006a, 2006b).

1.2 Approach of the study

Previous ISO compliant LCA study

The chronological order of the study follows the same four steps of the LCA methodology. During the whole study an interactive three-step review was performed to comply with the ISO critical review criteria. The first review moment was performed after the goal & scope report at which the methodological part of the study was reviewed. After approval of the review panel, the remaining three phases of the LCA framework was performed resulting in the main report of the study. The second review involved the first draft report including the LCI results and lists of substances for which characterization factors are lacking. This resulted in some adjustments. The third and final review process was a physical meeting, at which the last comments were given to close the review process. After the final review process, some adjustments and additions have been made to the report resulting in the final research report. In short, the phases of the 2017 study were:

- Goal and scope definition
 - 1st review: goal and scope report
- Inventory analysis
- Impact assessment
- Interpretation
 - 2nd review: draft research report
 - 3rd review: final physical meeting to close the review.

Cardboard tray update

For the cardboard tray update study, the same goal and scope definitions were respected as in the previous study. For this reason, no additional 1st review was included for the cardboard tray update. The two reviews after the interpretation phase are included in this cardboard tray update report.

1.3 Type of critical review

This comparative LCA report is compliant to the ISO 14040 series (ISO, 2006a, 2006b). The critical review process is as stated in the ISO 14044 (ISO, 2006b). Royal FloraHolland has chosen the following review panel members for the 2017 study:

- Siem Haffmans from Partners for innovation.
- Harry van Ewijk from SGS Search.
- Stakeholder from Industry

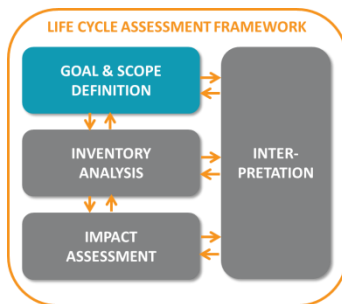
Siem Haffmans also has acted as chair of the review panel.

Cardboard tray update

Royal FloraHolland has chosen the following review panel members for the 2019 carbon tray update study:

- Siem Haffmans from Partners for innovation.
- Harry van Ewijk from SGS Search.
- Marijn Bijleveld from CE Delft.

Two out of three persons were also involved in the 2017 study. Siem Haffmans again acted as chair of the review panel.



2. Goal and scope definition

The first phase of the LCA framework determines the initial choices of the working plan of the entire LCA (Guinée et al., 2002). The goal of the study is formulated in a research question. Also, the target audience, intended application and other report specific aspects are defined. The scope deals with the temporal, geographical and technological coverage of the study. Finally, the trays are defined in function, functional unit and reference flows.

2.1 Goal definition

The first step of goal and scope definition involves the stating and justification of the whole study. First, the goal of the study is explained, together with its primary intentions. This is followed by the intended audience and the involved parties of the study.

2.1.1 Goal of the study

The goal of the study is to compare the environmental performance of different plastic and cardboard single-use and plastic multiple-use trays. The trays are used to transport horticultural products from production location to their markets. After use the single use trays can be landfilled, incinerated or recycled as raw material. Multiple-use trays can be reused up to 70 times, these trays are heavier than single-use trays and require additional transportation and some varieties require additional cleaning.

The main objective of the study is to understand the environmental impacts associated with the use of plastic and cardboard trays and select the most environmental favorable type of tray. Therefore, the main research question of this study is:

Which tray type (one-way plastic vs one-way cardboard vs returnable plastic) has best environmental performance?

The environmental performance of different tray types will be compared to those only of similar size. Different export countries and markets are investigated to see if country specific parameters influence the overall results. Country specific parameters include transportation distances, plastic and cardboard recycling ratios, thermal and electric efficiency of incineration facilities, et cetera.

2.1.2 Intentions of Royal FloraHolland

Main reason for Royal FloraHolland to perform this study is to improve the environmental performance of trays that are used for transporting horticultural products. Hereby Royal FloraHolland would like to facilitate a more sustainable horticultural distribution system. Also, the company aims to gain more knowledge environmental performance studies, like LCA. This bolsters internal capacity regarding environmental themes, which will be useful for future studies and strategic decision making.

2.1.3 Intended audience

The results of the LCA study can be used for external communication by Royal FloraHolland. The target audience are the Dutch government, users of plastic trays (e.g. growers, distributors, traders, etc.), plastic trays producers, non-governmental organizations, consumers and others. The results will be communicated by Royal FloraHolland in form of a public report. The complete report, excluding the technical and company sensitive information, will be disclosed to the public.

2.1.4 Involved parties

The first involved party is Royal FloraHolland as initiator of this study. Blonk Consultants acts as the performer of the whole study. Company specific data from six different companies are used in this report. Three are plastic tray producers, which are three plastic tray producers that remain anonymous throughout the study. Four are cardboard tray producers and two other tray producers that remain anonymous throughout the study. Primary data for plastic tray cleaning is collected at Anonymous7. At last, there is a review panel consisting of three

members: Siem Haffmans (from Partners for innovation, both reports), Harry van Ewijk (from SGS Search, both reports), Anonymous (from anonymous, review of the first report only) and Marijn Bijleveld (from CE Delft, review of the second report only).

2.2 Scope definition

The scope definition phase establishes the main characteristics of the whole study. First the eight different trays of the study are introduced. Followed by an explanation of the comparison is explained and system boundaries.

2.2.1 The tray products of the study

Four different plastic trays are selected for this study, of which two are single-use trays and two are multiple-use trays. There are numerous tray sizes available, for this study trays with the same characteristics and which are commonly used are selected. The two single use trays that are investigated are Normpack® 306 and Normpack® 236. According to Royal FloraHolland, trays with 56x31 cm dimensions are for 60% of Normpack® 306 trays, and therefore included in this study (Wensveen, 2016). The Normpack® 236 is somewhat smaller and less often used but is selected as second single use tray. The Floratino FC746 and FC736 are included in the study as multiple use plastic trays. The FC736 is commonly used and has similar size as the Normpack® 236 tray. The Floratino FC746 gains more significant market share and has a similar size as the Normpack® 306 tray (Wensveen, 2016). Main characteristics of these four specific trays are listed in Table 1 below.



Figure 3: FC736 multiple-use plastic tray and Normpack 236 single use plastic tray, both 40 x 28 cm in size



Figure 4: Normpack 306 single-use plastic tray and Floratino FC746 multiple-use plastic tray, both 56 x 31 cm in size

Table 1: Specifications of the four plastic tray alternatives considered in this study

	Normpack® 306	Normpack® 236	Floratino FC 746	FC 736
Type	Single use	Single use	Multiple use	Multiple use
Plant capacity	6	6	6	6
Pot size (cm)	17	12/13	13/17	12/13
Size (cm x cm)	56 x 31	40 x 28	56 x 31	40 x 28
Color	Black	Red/Black	Black	Red
Triprate	1	1	70	70
Weight (gram)	177	103	396	400
Material	Polystyrene (PS)	Polystyrene (PS)	HDPE	Polypropylene (PP)
Recycled content	>90%	>90%	0%	100%
Transport unit	Block pallet	Block pallet	CC container	CC container
Amount per unit	1400	2400	320	400

These four different trays were selected since these are all comparable in terms of size and plant capacity. The triprate of both returnable trays is based on the information of Royal FloraHolland's deposit system on the FC 736 tray. This FC 736 tray is already in use for a long time and since there is no data available for the relatively new Floratino FC 746 yet, triprate information of the FC 736 is applied to both returnable trays. Each returnable tray is used on average 70 times before it is disposed. Please note that the triprate will be reduced to 40 and 10 in the sensitivity analysis to investigate the influence of this important parameter (see 5.4).

Cardboard tray update

Four additional cardboard trays are added to this study in 2019. Currently, there are no multiple use cardboard trays available. Therefore, multiple use cardboard trays are not in scope of this study. Specifications of the cardboard trays are presented in Table 2.

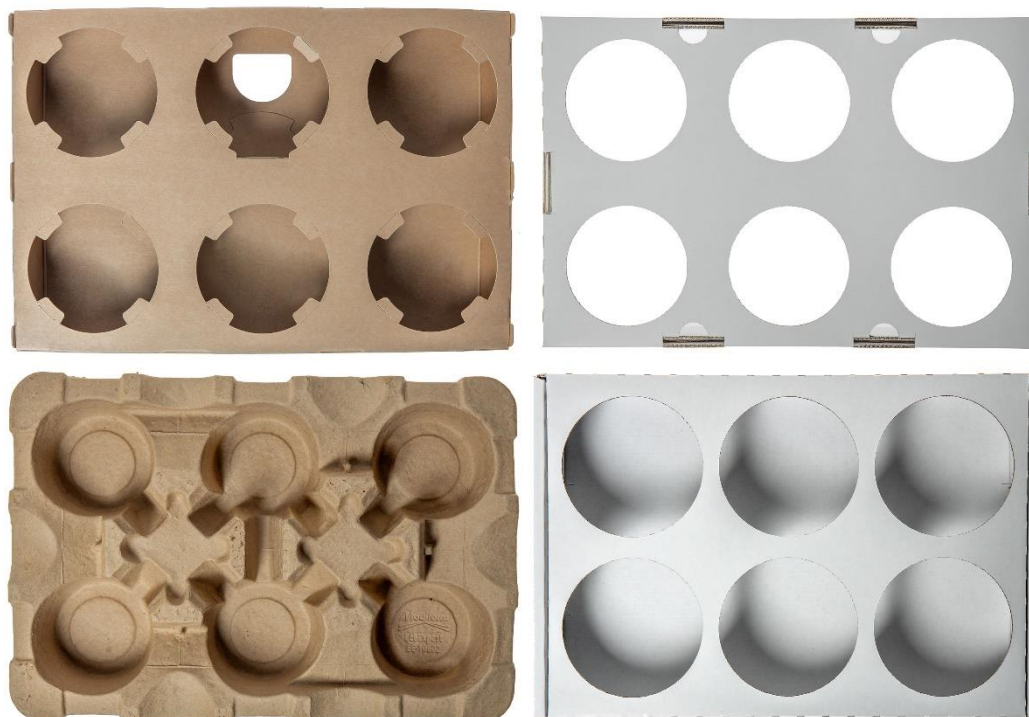


Figure 5: Different cardboard trays. Solid board– closed bottom (upper left), Corrugated board – open bottom (upper right), Paper pulp tray (lower left), Corrugated board – closed bottom (lower right).

Table 2: Specifications of the four additional cardboard alternatives that are included in 2019

	Paper pulp	Solid board – closed bottom	Corrugated board – open bottom	Corrugated board – closed bottom
Type	Single use	Single use	Single use	Single use
Plant capacity	6	6	6	6
Pot size (cm)	12/13	12/13	12/13	12/13
Size (cm x cm)	40 x 28	40 x 28	40 x 28	40 x 28
Color	Beige	White/brown	White/brown	White/brown
Triprate	1	1	1	1
Weight (gram)	154	187	185	257
Material	Paper/cardboard	Kraft/testliner	Kraft/testliner	Kraft/testliner
Recycled content	99%	92%	18%	40%
Transport unit	Block pallet	Block pallet	Euro pallet	Euro pallet
Amount per unit	768	3360	1000	1040

2.2.2 Function, functional unit and reference flows

The function of all trays is to facilitate the transportation of horticultural products. The functional unit is 6000 transported plants from Aalsmeer to the different markets. All trays have a plant capacity of 6, which means it requires 1000 trays to transport 6000 plants for all tray types. The three biggest export markets based on sales and home market are considered for this study. Transport from Aalsmeer is chosen in this study since this is the largest auction location of Royal FloraHolland. The main exporting countries are: Germany (27.9%), United Kingdom (16.6%) and France (13.5%), covering 58% of the Royal FloraHolland's export value (Royal FloraHolland, 2016). For each export country it is assumed that products are transported to the capital cities, which are Berlin, London and Paris. The capitals represent the largest market share within the respective countries. For the home market (The Netherlands) 100 transport kilometers from Aalsmeer are assumed, which is the transportation distance between Aalsmeer and Arnhem. As mentioned earlier, eight different tray alternatives are considered in the study. An overview of the reference flows, functional unit, alternatives and markets are given in Table 3 below.

Table 3: The 32 different reference flows for this study

Reference flow	Functional unit + market	Plastic Alternative	Cardboard Alternative
1 & 17	6000 plants transported to Berlin (Germany)	Normpack 306	Paper pulp tray
2 & 18		Normpack 236	Solid board – closed bottom
3 & 19		Floratino FC746	Corrugated – open bottom
4 & 20		FC 736	Corrugated – closed bottom
5 & 21	6000 plants transported to Paris (France)	Normpack 306	Paper pulp tray
6 & 22		Normpack 236	Solid board – closed bottom
7 & 23		Floratino FC746	Corrugated – open bottom
8 & 24		FC 736	Corrugated – closed bottom
9 & 25	6000 plants transported to London (Great-Britain)	Normpack 306	Paper pulp tray
10 & 26		Normpack 236	Solid board – closed bottom
11 & 27		Floratino FC746	Corrugated – open bottom
12 & 28		FC 736	Corrugated – closed bottom
13 & 29	6000 plants transported to Arnhem (Netherlands)	Normpack 306	Paper pulp tray
14 & 30		Normpack 236	Solid board – closed bottom
15 & 31		Floratino FC746	Corrugated – open bottom
16 & 32		FC 736	Corrugated – closed bottom

These 32 reference flows or independent scenarios will be the basis of comparison between the different alternatives. Keep in mind that it is only fair to compare trays;

- Which are transported to the same market. Otherwise the comparison would be inconsistent, since different transportation routes and waste processing systems are involved.
- Which have the same tray size. Which are:
 - Normpack 306 & Floratino FC746 (both are 56 x 31 cm in size)
 - Normpack 236, FC736, paper pulp tray, solid board, corrugated board – open bottom & corrugated board – closed bottom (all six are 40 x 28 cm in size)

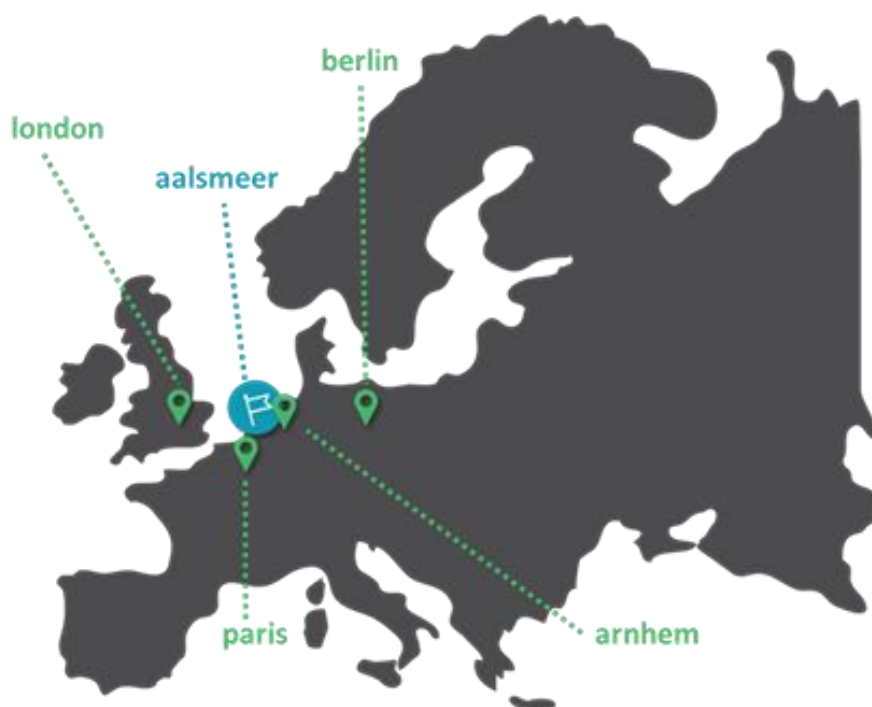


Figure 6 Overview selected markets

2.2.3 Data quality requirements

ISO 14044 requires an extensive data quality assessment for comparative assertions intended to be disclosed to the public. This paragraph provides the data quality requirements for the study.

2.2.3.1 Time-related coverage

Primary data on production, cleaning processes, recycling rates, etc. are based on most recent data and preferably not older than 3 years. For background data the most recent data, from Ecoinvent and Agri-footprint are used in order to simulate present-day impacts.

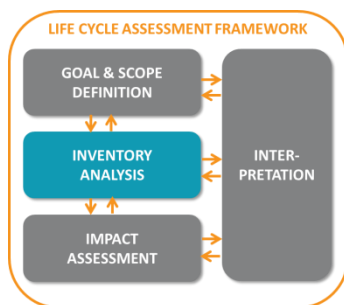
Primary data for Normpack 306, Normpack 236, Floratino FC 746, FC 736 and tray cleaning processes were collected in 2016 and 2017. Primary data for the four different cardboard trays were collected in 2019.

2.2.3.2 Geographical coverage

Mainly country-specific and also region-specific data are used for this study. European production data for raw materials, like plastic granulates, is used to model the upstream environmental impacts of materials. Background data for energy inputs for tray production will be based on country-specific data. End-of-life processing of plastic trays is based on country-specific data on plastic recycling, energy recovery of incinerators and landfilling.

2.2.3.3 Technical coverage

The obtained production data for trays is representative for the most applied production technology. For all other life cycle stages average technologies for waste processing, electricity generation and heat generation for the various countries are considered.



3. Life cycle inventory

The life cycle inventory (LCI) stage estimates the consumption of resources and quantifies the waste flows and emissions caused or attributable to the tray's life cycle. This is done by defining the system boundaries, constructing a flow diagram with all relevant unit processes, collecting data for these unit processes and describing the allocation procedure for multi-functional processes. Main result for all reference flows will be the inventory table, which will be the input for the impact assessment phase. Each step of the LCI is discussed below.

3.1 System boundaries

According to the Handbook of Life Cycle Assessment: "In LCA, each and every flow should be followed until its economic inputs and outputs have all been translated into environmental interventions. The term 'environmental interventions' refers to flows entering the product system which have been drawn from the environment without prior human transformation, or flows leaving the product system which are discarded into the environment without subsequent human transformation" (Guinée et al., 2002). Flows entering the product system are usually natural resources. For plastics this would be crude oil, for electricity this is a wide pallet consisting of fossil fuels, renewables and biofuels, for example. The flows leaving this system are referred as emissions, examples are exhaust emissions during transportation or emissions that are a result of plastic incineration. By describing the system boundaries, a complete picture of the economy-environmental system boundary will arise that will be used for all plastic tray and cardboard product systems used in this study. As a rule of thumb all processes in which humans have control are regarded as processes belonging to the economic system.

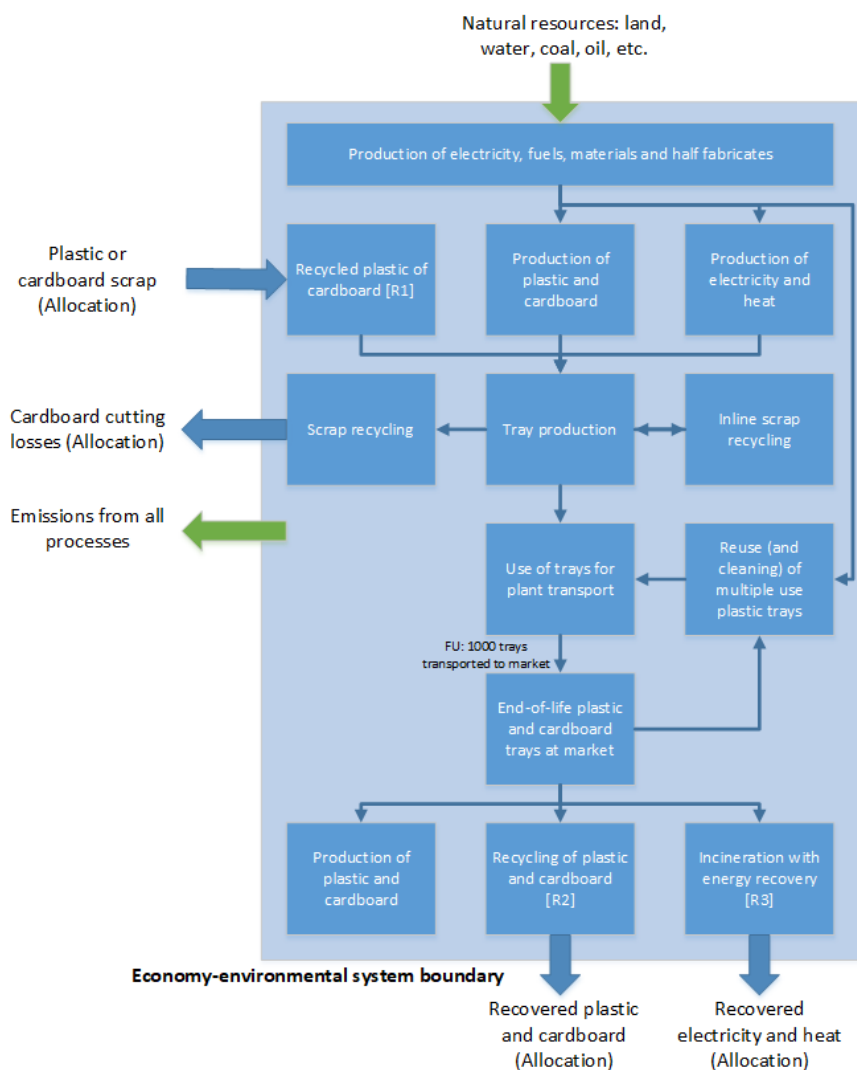


Figure 7: Economy-environment system boundary of plastic and cardboard trays

3.1.1 Boundary between product system and the environmental system



A so-called cradle-to-grave system boundary is chosen for plastic and cardboard trays, meaning that all relevant processes related to the life cycle of the tray are studied. Most important life cycle processes for all trays are: raw material production, production of the trays, transportation and end-of-life processing. End-of-life processing consists of a fraction recycling, fraction landfilling and a fraction incineration. These fractions differ in each country. Plastic recycling and plastic incineration also provide economic products (electricity & heat) which are used in other product systems. Allocation is required to solve the problem of multi-functional processes (more on this in 3.1.3). Landfills in European countries are considered to be controlled environments, meaning that this is regarded as an economic process from which emissions take place.

Main difference between one-way and returnable trays is that the life cycle of multiple-use trays has additional processes. These include extra transportation (return transportation to Aalsmeer) and cleaning process for Floratino FC 746 trays (including additional transportation to the cleaning facility). Because the trays are reused, the production, fraction of landfilling, incineration and recycling are considerably lower per functional unit compared to single-use trays. This is because the emissions associated with production, landfilling and incineration are distributed over the number of trip-rates.

3.1.2 Cut-off boundary

This part discusses the processes that are irrelevant or not taken into consideration during the whole LCA study. In principle all processes are included since a cradle-to-grave approach will be used for this study. However, some processes and flows are not included, these are: packaging materials, tray labels, manufacture, maintenance and decommissioning of capital goods (e.g. injection molding machines, trucks, incinerators, etc.) and additional operations (e.g. lighting, heating, maintenance, etc.). An overview of processes that are included or excluded are shown in Table 4.

Table 4: Overview of included and excluded operations

Item	 Included	 Excluded
Materials	Upstream processes Capital goods Transport of raw materials and recycled materials	
Tray production, reuse and recycling	Energy requirements Additives Cleaning of plant trays (only for Floratino FC 746)	Additional packaging materials Coating & printing Barcode Capital goods
Transport	Load factors of shipped plastic trays from producer to customer Emissions from fuel combustion	Capital goods Infrastructure
Use phase		Plant cultivation
Waste-processing	Transport of disposed trays Emissions from combustion/landfilling Heat credit during incineration Electricity credit during incineration Recycling processes + credits	Capital goods

Coating and printing information for the different cardboard trays could not be determined and could therefore not be considered in the main results of the study. During the sensitivity analysis, the impact of coating and printing cardboard trays is studied to estimate the environmental impact of these processes (see chapter 5.4.5).

3.1.3 Allocation

Besides transporting horticultural products to their main markets, the whole product system for one-way and returnable trays provide four additional functions (See Figure 8). These are:

1. Recycling of plastic and cardboard scrap from other product systems into trays, at production.
2. Recycling of plastic and cardboard from trays for other product systems, at end-of-life.
3. Recovery of heat from plastic and cardboard incineration, at end-of-life.
4. Recovery of electricity from plastic and cardboard incineration, at end-of-life.

An appropriate allocation procedure is required to determine the amount of emissions that are assigned to the tray product system. The circular footprint formula (CFF) is used to solve the problem of allocation for all multi-functional processes in this study. The formula and its parameters are shown in Figure 8.

The diagram illustrates the circular footprint formula (CFF) for material, energy, and disposal, with arrows linking descriptive text to specific parts of the formula.

Material:

$$= (1 - R_1)E_V + R_1 \times \left(AE_{recycled} + (1 - A)E_V \times \frac{Q_{Sin}}{Q_P} \right) + (1 - A)R_2 \times \left(E_{recyclingEoL} - E_V^* \times \frac{Q_{Sout}}{Q_P} \right)$$

- Life Cycle Inventory (LCI) of primary material:** Points to $(1 - R_1)E_V$.
- LCI associated to secondary material input:** Points to $R_1 \times \left(AE_{recycled} + (1 - A)E_V \times \frac{Q_{Sin}}{Q_P} \right)$.
- LCI of the material recycling (or part/product reuse) process minus the credit for avoided primary material:** Points to $(1 - A)R_2 \times \left(E_{recyclingEoL} - E_V^* \times \frac{Q_{Sout}}{Q_P} \right)$.

Energy:

$$+ (1 - B)R_3 \times (E_{ER} - LHV \times X_{ER,heat} \times E_{SE,heat} - LHV \times X_{ER,elec} \times E_{SE,elec})$$

- LCI of the energy recovery process minus the credit for avoided primary energy:** Points to the entire energy term.

Disposal:

$$+ (1 - R_2 - R_3) \times E_D$$

- LCI of the disposal of remaining waste:** Points to $(1 - R_2 - R_3) \times E_D$.

Figure 8: The circular footprint formula, from European Commission (2018)

Small description of the formula is given below. More technical details about CFF are included in Appendix III.

3.1.3.1 Material: allocating secondary material in- and output

The circular footprint formula for material consists of three different parts. Most important variable for the CFF for materials is the allocation factor of burdens and credits between supplier and user of recycled materials (given as 'A' in the equation). An allocation factor of 0.5 is given for plastic and 0.2 for cardboard/paper by the European Commission (PEF Packaging Working Group, 2018) hereby a proportion of the burdens and credits of recycling are assigned to trays in the production as well in the recycling process.

The first two parts (containing the R1 parameters) deal with the emissions associated with the use of materials. The R1 parameter itself is the proportion of material in the input to the production that has been recycled from previous systems. R1 values are based on primary data of plastic tray producers (see chapter 3.2.1). The R1 parameters are used to quantify the impact of tray production appropriately.

The third part of the equation (containing the R2 parameters) addresses "burdens and benefits related to secondary output". This part of the CFF will be used to quantify the emissions related to materials of the tray product system at end-of-life stage. The R2 values represent the amount of plastic and cardboard that is recycled after end-of-life. These R2 values differ between the different markets and will be based on country specific statistics on plastic recycling rates. For cardboard, there are no country specific R2 values available and therefore a European average is used for all countries in scope.

3.1.3.2 Energy: allocating recovered heat and electricity from plastics and cardboard

The circular footprint formula for energy recovery consists of three different parts. Most important component for all three parts is the allocation factor of the energy recovery process (given as 'B' in the equation). An allocation factor of 0 is required by the European Commission (PEF Packaging Working Group, 2018) hereby all of the burdens and credits of energy recovery are assigned to the tray life cycle.

The first part is about the emissions associated with the incineration of plastic and cardboard. Based on the allocation factor, all the emissions are assigned to the tray product system.

Second part of the formula calculates the amount of recovered energy from plastic and cardboard. This is based on the lower heating value (LHV) of the specific type of plastic and cardboard and the heat efficiency of the incineration process (more on this in Annex III). Again, the allocation factor (B) determines that all of the recovered heat should be assigned to the tray product system. This is done by substituting the impact of heat from the product system. Substitution solves the allocation problem of recovered heat.

Third part determines the amount of substituted electricity recovered from plastic incineration in a very similar approach as used for heat recovery. This approach will be used to solve the fourth and last multi-functional process of the product system.

3.1.3.3 Disposal of plastics and cardboard

The disposal part of the CFF does not concern allocation, but calculates the emissions associated with plastic and cardboard disposal, which are also considered in this study. Because there is no additional function of landfilling besides waste processing of plastic and cardboard, all the emissions associated with landfilling are fully assigned to the tray product.

3.2 Data sources

Primary and secondary data are used to model the environmental impact of plastic and cardboard trays over its whole life cycle. Table 5 below gives an overview of what data is required and which sources are used. Some of the required data is already collected during the screening study or in the 2017 study. Information regarding cardboard trays has been added for the 2019 study. More detailed information is presented in the following paragraphs.

Table 5: Overview of data requirements, sources and additional comments

Data requirement:	Data source:	Remarks:	Values:
Production data for Normpack 306	Anonymous5 (2017)	Primary data based on location average	Confidential
Production data for Normpack 236	Anonymous5 (2017)	Primary data based on location average	Confidential
Production data for Floratino FC746	Anonymous	Primary data	Confidential
Production data for FC 736	Anonymous2	Primary data based on similar tray	Confidential
Production data for paper pulp tray	Anonymous6 (2019)	Primary data	Confidential
Production data for solid board tray	Anonymous3 (2019)	Primary data	Confidential
Production data for corrugated board – open bottom	Anonymous4 (2019)	Primary data	Confidential
Production data for corrugated board – closed bottom	Anonymous4 (2019)	Primary data	Confidential
Cleaning process data	Anonymous7 (2017)	Primary data	Confidential

Transportation distances	Google maps Sea-distances.org	For truck transport For ferry transport	See 3.2.2
Trip rates multiple-use trays	Royal FloraHolland (Wensveen, 2016)	Based on deposit system of FC 736 tray, also applied for FC 746	70 for returnable trays
Fraction disposed plastic & cardboard to recycling [R2]	PEF Packaging Working Group (2016)	Based on packaging material. Country specific data, trays assumed to be fully recyclable. For cardboard no country specific data available, therefore European average is used.	Plastic: France 19%, United Kingdom 29% Cardboard: European Union 75%
Fraction disposed cardboard to recycling [R2]	Royal FloraHolland internal study	For Netherlands and Germany 50% plastic recycling is used instead of European default (which is 33% and 35% for the respective countries)	Plastic: Germany 50%, Netherlands 50%
Fraction disposed plastic and cardboard to incineration [R3]	PEF Packaging Working Group (2018)	$R3 = (1 - R2) * \text{fraction incineration}$	Fraction incineration: Germany 99%, France 64%, UK 38%, NL 97%
Fraction disposed plastic and cardboard to landfilling	PEF Packaging Working Group (2018)	Calculated value: $(1 - R2 - R3)$	
Efficiency energy recovery	CEWEP (2013)	Based on efficiency of MSW (including UK). Country specific data on heat and electricity	See Appendix IV: Energy recovery at incineration
Energy density of disposed plastic	Ecoinvent background data	Energy density based on lower heating value	PS 38.67 MJ/kg HDPE 42.47 MJ/kg PP 40.34 MJ/kg Cardboard 16.04 MJ/kg
Allocation factor 'A'	(PEF Packaging Working Group, 2018)		0.5 for plastic 0.2 for cardboard
Allocation factor 'B'			0
Quality indicators plastic		For Q_{sin}/Q_p and Q_{sout}/Q_p	0.9 for plastics, 0.85 for cardboard
Remaining parameters of the CFF	Ecoinvent APOS	3.5 See Appendix V: Background data	

Instead of the European recycling rates for plastic in Germany (35%) and The Netherlands (33%), it was chosen to use 50% recycling rate of plastic for both countries. The value is based on a study performed by Royal FloraHolland in which they quantified the recycling rate of their own facilities. Since the trays are used for business-to-business it is easier to collect and reuse plastic.

All quality indicators for plastic are proposed to be 0.9, meaning that some degradation of the plastic is considered in the model. For paper and cardboard there are two default values available, one which includes degradation of the material (0.85) and one without degradation of the material (1). It was chosen to use the degradation default (0.85) in order to make the comparison more fair. For most of the cardboard trays there are either additives, glues and/or coatings used (see following paragraphs), which supports the idea that there is some form of degradation of the material.

3.2.1 Primary data on tray production and cleaning (for reviewers only)

Nine different primary datasets have been obtained for the whole LCA study. These include the production data of the four plastic trays, production data of the four cardboard trays and cleaning process data for Floratino trays. Overview of the different primary data sets are only available for reviewers.

3.2.2 Transportation processes

All transportation processes throughout the study are based on large trucks (except sea transport to Great Britain). Transportation distances of trucks are based on Google maps data between various locations, sea transport distance is based on sea-distances.org¹. Although Royal FloraHolland has multiple auction locations, only the largest auction location is used throughout the study. All transportation distances from tray production facilities, to greenhouses and to markets will be based on this location. The largest auction location of Royal FloraHolland is Aalsmeer, with 50.1% of sold market value of Royal FloraHolland for 2015 (Royal FloraHolland, 2016).

An important parameter in the quantification of environmental impact of transportation processes is the inclusion or exclusion of return processes. In case trucks return empty, the impacts of the return process should be allocated to the plastic tray system. But when trucks pick up other goods at point of delivery, the impact of the return trip should be allocated to the other product system. For this study is assumed that return processes from factories, landfills and incinerators are empty. For transportation processes between greenhouses, Aalsmeer and the three different markets is assumed that other goods are picked up for the way back.

Multiple-use trays are returned to Aalsmeer from the different market and cleaned (Floratino FC 736 only) before it is send-off to the greenhouses to be reused again. An overview of the transportation distances and how these are modelled (empty return or default) are given in Table 6 below.

Table 6: Overview of all transportation distances that are used throughout the study

From	To	Distance	Remarks	Modelled as:
Virgin materials	Tray producers	100 km	Default value, for granulates and additives	Empty return
Anonymous	Aalsmeer	125 km	Based on google maps data. Production location Floratino FC746	Empty return
Anonymous2	Aalsmeer	150 km	Based on google maps data. Production location FC 736	Empty return
Anonymous5	Aalsmeer	75 km	Based on google maps data. Production location Normpack	Empty return
Anonymous3	Aalsmeer	125 km	Production location of Solid board	Empty return
Anonymous4	Aalsmeer	250 km	Production location of corrugated board types	Empty return
Anonymous6	Aalsmeer	300 km	Transport distance from production location to Aalsmeer	Empty return
		200 km		Default
Aalsmeer	Greenhouses	50 km	Within range of Aalsmeer, Oostland & Westland	Default
Greenhouses	Aalsmeer	50 km	Same transportation distance as to greenhouses	Default
Aalsmeer	Germany	700 km	Based on google maps data. Based on transport to Berlin	Default
Aalsmeer	Great Britain	200 km	Based on truck distance to London	Default
		200 km	Based on ferry Hoek van Holland – Harwich	
Aalsmeer	France	500 km	Based on transport to Paris	Default
Aalsmeer	Netherlands	100 km	Based on transport to Arnhem	Default
Market	Incineration	100 km	Default value	Empty return
Market	Landfill	100 km	Default value	Empty return
Market	Aalsmeer		Same transport distance as from Aalsmeer to market. Only considered for returnable trays	Default
Aalsmeer	Anonymous7	50 km	Based on google maps data. Cleaning facility location, only used for FC746 tray	Default
Anonymous7	Aalsmeer	50 km	Same transport distance as from Aalsmeer to cleaning facility	Default

¹ <http://www.sea-distances.org/>

Other transportation processes are not considered in this study. No transport is assigned to recycling of plastic and cardboard from market place to recycling, since this is covered in the substitution process, see 3.1.3.

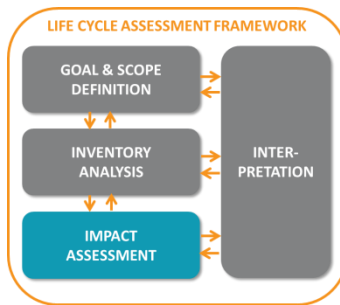
Load factors for produced trays transport till greenhouses

Some trays can be stacked more easily/efficient than others from the production facility to the greenhouses. Higher load factors lead to lower impact for transportation, since it makes use of the load capacity more efficiently. From the greenhouses onwards, the load factor for the different tray types are assumed to be similar. This is because the limiting factor for these stages are the horticultural products. In these stages it is assumed that the same number of trays do fit in a truck. The only variable that still be considered is the mass of the tray. Average load factors for big trucks is 26 tons.

Tray type	Mass tray (gram)	Amount per unit	Layers	Unit	Mass including pallet (kg)	Load factor	Modelled As:
Normpack 306	177	1400	1	Block	7015	27%	20%
Normpack 236	103	2400	1	Block	7000	27%	20%
Floratino FC 746	396	320	1	CC container	6463	25%	20%
FC 736	400	320	1	CC container	6519	25%	20%
Paper pulp tray	154	768	1	Block	3647	14%	20%
Solid board – closed bottom	187	3360	1	Block	16908	65%	50%
Corrugated board -open bottom	185	1000	1	Euro	6699	26%	20%
Corrugated board – closed bottom	257	1040	1	Euro	9414	36%	20%

Some assumptions:

- Size of standard semi-trailer: 2.44 m x 13.6 meter
- Size of blockpallet: 120 x 100 cm (22 kg), or 26 pallets in a standard truck
- Size of Europallet: 120 x 80 cm (18 kg), or 33 pallets in a standard truck
- Size of CC container: 135 x 56.5 cm (23.6 kg), or 43 CC's in a standard truck



4. Life cycle impact assessment

During the life cycle impact assessment (LCIA) the inventory tables from the LCI are used to determine the environmental impact of trays for different impact categories. This is done by first selecting the impact categories that are considered for this study. Then the environmental interventions are classified and characterized to quantify the impact of each tray alternative for each impact category, which is the main result of the impact assessment.

4.1 Selection of impact categories

First the impact categories are selected which are used to present the results for the various tray alternatives. To evaluate the environmental impact of various tray alternatives, it is essential to have appropriate indicators (Brenttrup, Küsters, Kuhlmann, & Lammel, 2004). Some studies focus only on a single impact category, like global warming. This study focusses on more environmental impact categories to better understand the environmental impacts associated with the use of trays and to detect a so-called 'burden-shift' from one impact category to another.

For this study the 18 different impact categories from ReCiPe (version 1.1) are considered based on hierarchical version. It is chosen to present the results at mid-point level and at end-point level. This is because mid-point results are more certain and detailed. End-points results are also used to present the environmental impact of the reference flows in a single score. More information about the mid-point and end-point level results and impact categories, see Appendix VIII: Explanation of the LCA methodology.

Although there are concerns regarding plastic waste and the plastic soup phenomena, the LCA methodology is not capable of determining the contribution to plastic soup for various reference flows. This is because there is no robust method available to quantify this in LCA.

Cardboard tray update

During the cardboard tray update the whole LCIA was performed again. Instead of 10 different impact categories, it was chosen to focus on the most relevant impact categories only. Impact results of all other impact categories of the method except toxicological impact categories are available in Appendix VI, but not analyzed in detail. Most relevant impact categories are: climate change and fossil energy depletion for packed water (Technical secretariat of PEF packed water, 2018). This PECFR comes closest to plastic and cardboard tray production in terms of function. Additionally, land use, water use are included. Only these four impact categories are analyzed in more detail in the paragraphs below.

4.2 Interventions for which characterization factors are lacking

Not all interventions from the inventory table are assigned to one or more impact categories. This means that these quantified interventions do not have any environmental impact for the selected ten ReCiPe impact categories. These substances are mentioned briefly to discuss the possible consequences. For example, for trays to Germany 675 out of 1879 substances could not be characterized by one of the impact categories. These usually involve small amounts of substances which are not harmful in any way to the environment (e.g. O₂ or N₂).

4.3 Results at mid-point

Using the ReCiPe2016 method the LCIA results are shown for the four most important impact categories. Results are shown separately for the different markets. This makes the information flow from the results more digestible and allows to make country specific comments on the results. In this chapter the results are presented relatively (0% to 100%). The absolute values are presented for all ReCiPe impact categories are presented in Appendix VI: Absolute LCIA results at mid-point.

Remember that it is only fair to compare trays of similar size. The first two trays, the Floratino and Normpack tray are 31 x 56 cm in size. All others are trays are 40 x 28 cm in size.

4.3.1 Mid-point results for trays use to Berlin (Germany)

The environmental impact of trays used for transporting 6000 plants to Berlin (700 km transport by truck) for all eight tray alternatives are shown for the most relevant impact categories.

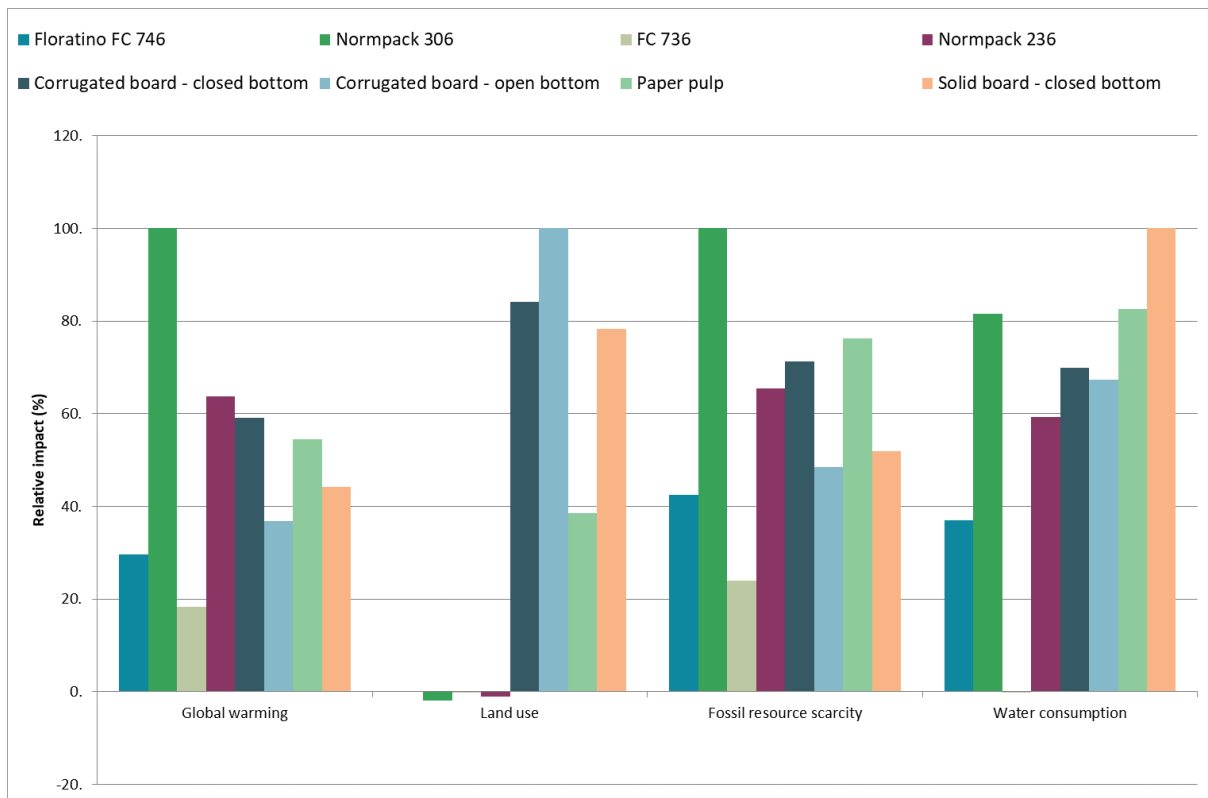


Figure 9: Relative impact category results for the impact of trays used for transporting plants to Berlin (Germany)

In terms of carbon footprint, the cardboard trays perform better than single use plastic trays but worse than multiple use plastic trays for the German market. For land use, all cardboard trays perform worse than all plastic alternatives. This makes sense, since cardboard is made from wood products, whereas plastic is usually made from oil which does not require land. For the plastic variants the land use is slightly negative due to credits of produced electricity and heat from plastic incineration. Land use for the “open” cardboard type exceeds that of the “closed” variant, despite the lower mass of the tray. This is because the “closed” uses material with a higher recycled material content compared the “open” version which heavily relies on virgin materials. In other words, the recycled content of the product heavily influences the land use impact indicator for cardboard trays. For fossil energy use, multiple use trays perform best against other tray types. The “open” cardboard tray and solid board tray perform better than the Normpack 236, whereas the “closed” cardboard and paper pulp tray perform worse than the single use plastic tray type. For the closed cardboard this can be explained by the larger mass of the tray. For the paper pulp tray due to the high energy use during the production of the trays (See chapter 5.3 for more detailed information). Water consumption of the cardboard trays is somewhat higher compared to the plastic alternatives.

4.3.2 Mid-point results for trays use trays to Paris (France)

The environmental impact of trays used for transporting 6000 plants to Paris (500 km transport by truck) for all eight tray alternatives are shown for the most relevant impact categories.

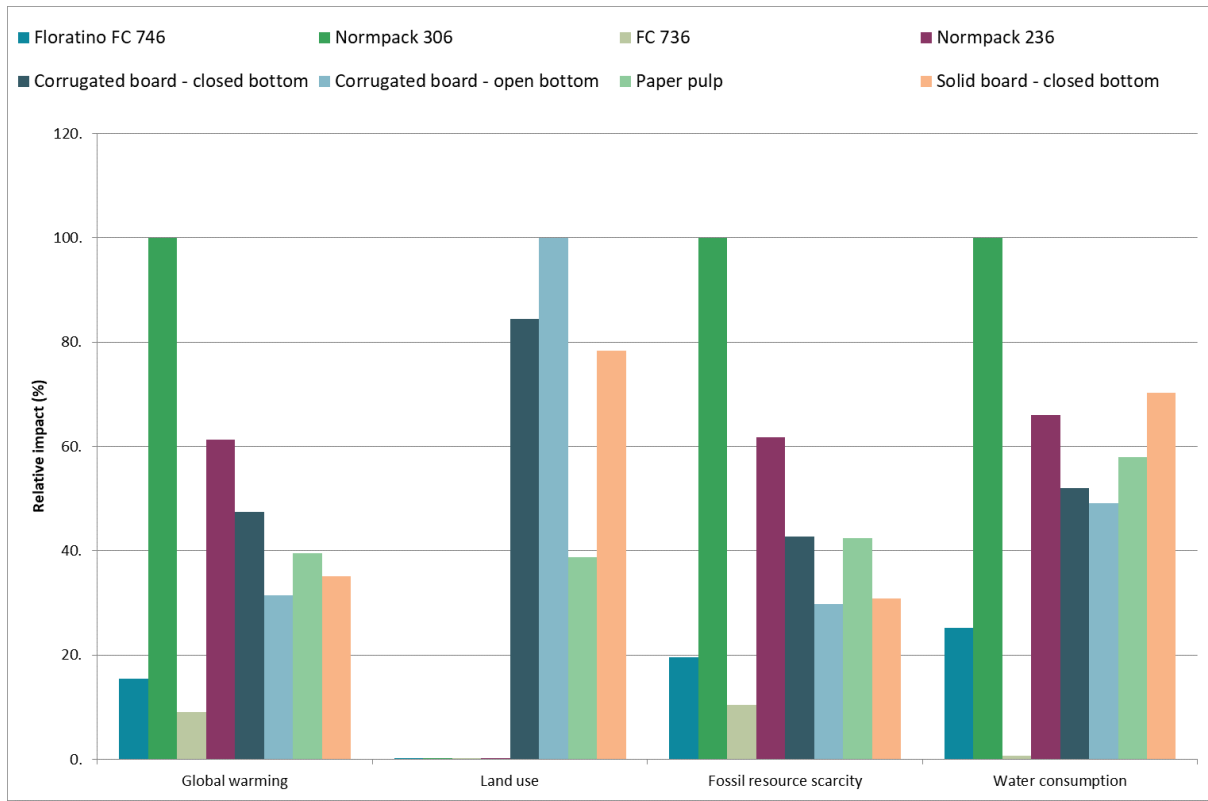


Figure 10: Relative impact category results for the impact of trays used for transporting plants to Paris (France)

Multiple use plastic trays have the best environmental performance for the French market, similarly as in Germany. The relative impact of single use trays is similar to the results of the German market, but there are some differences. The environmental impact of cardboard trays in France is relatively better than single use plastic trays compared to the results in Germany. For global warming, the cardboard alternatives perform even better since there are less credits assigned in the French market. Also, the electricity of mix of France is less carbon intensive compared to the German mix, which means less impact is substituted in France per kWh than in Germany. For land use, there are still credits assigned to all tray alternatives. But the amount of credit for land use does not exceed the total impact, therefore there is no negative land use for plastic trays on the French market. Less credits are also assigned to the fossil resource scarcity indicators, for the same reason as mentioned before. This explains why all cardboard variants perform better than single use plastic for the impact category fossil energy depletion.

4.3.3 Mid-point results for trays use to London (Great Britain)

The environmental impact of trays used for transporting 6000 plants to London (200 km transport by truck and 200 km by ferry) for all eight tray alternatives are shown for the most relevant impact categories.

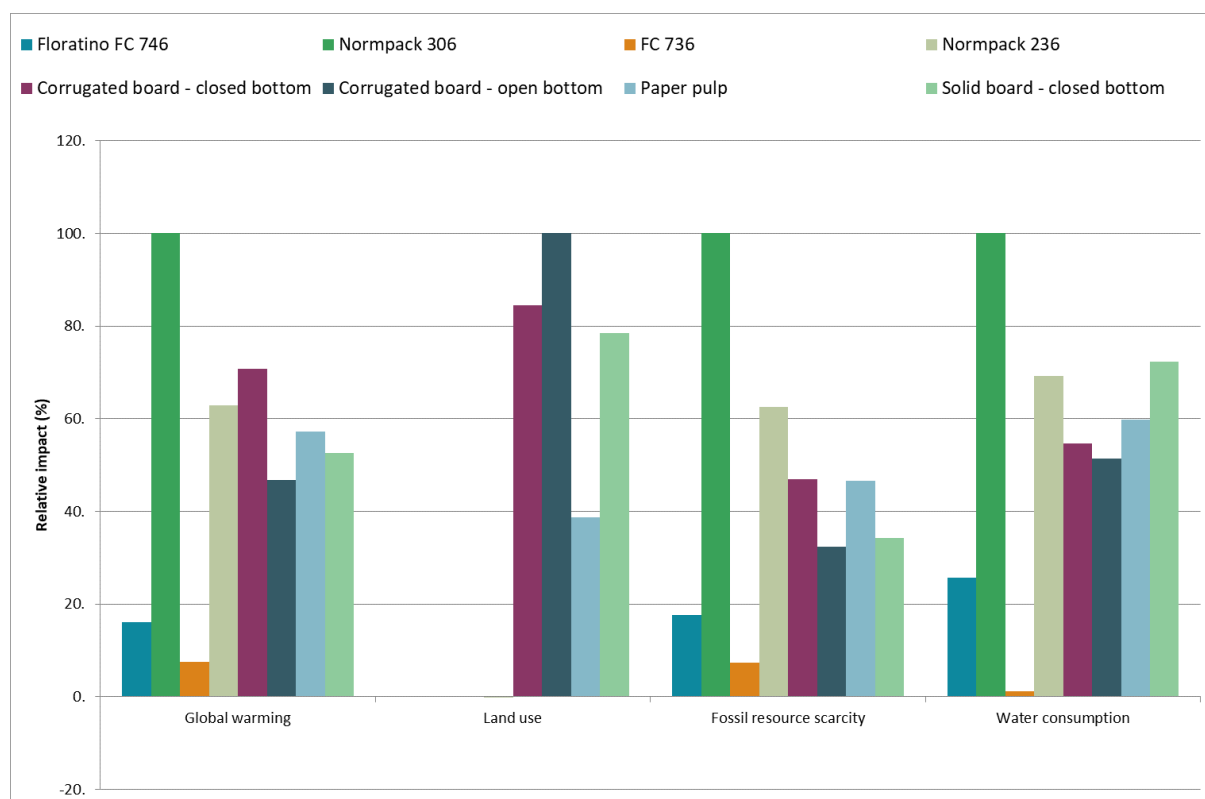


Figure 11: Relative impact category results for the impact of trays used for transporting plants to London (Great Britain)

For the British market the multiple use plastic tray performs best of all alternatives. The relative carbon footprint impact of cardboard trays is somewhat higher than in France or Germany since a large proportion of cardboard is landfilled in the United Kingdom. Landfilling causes significant methane emissions which is a potent greenhouse gas. Landfilling of cardboard causes more methane emissions than for plastic trays. Because of the larger share of landfilling residual waste, the carbon footprint of the “closed” cardboard tray is higher than the single use plastic tray of similar size. For land use, all cardboard trays score worse than the plastic which should not come as a surprise. For fossil resource scarcity, all cardboard trays perform better than single use plastic trays. This differs from the German market, where a larger proportion of the plastic is incinerated providing more credits to the plastic alternatives. Water consumption between the single use alternatives are more or less similar.

4.3.4 Mid-point results for trays use trays to Arnhem (Netherlands)

The environmental impact of trays used for transporting 6000 plants to Arnhem (100 km transport by truck) for all eight tray alternatives are shown for the most relevant impact categories.

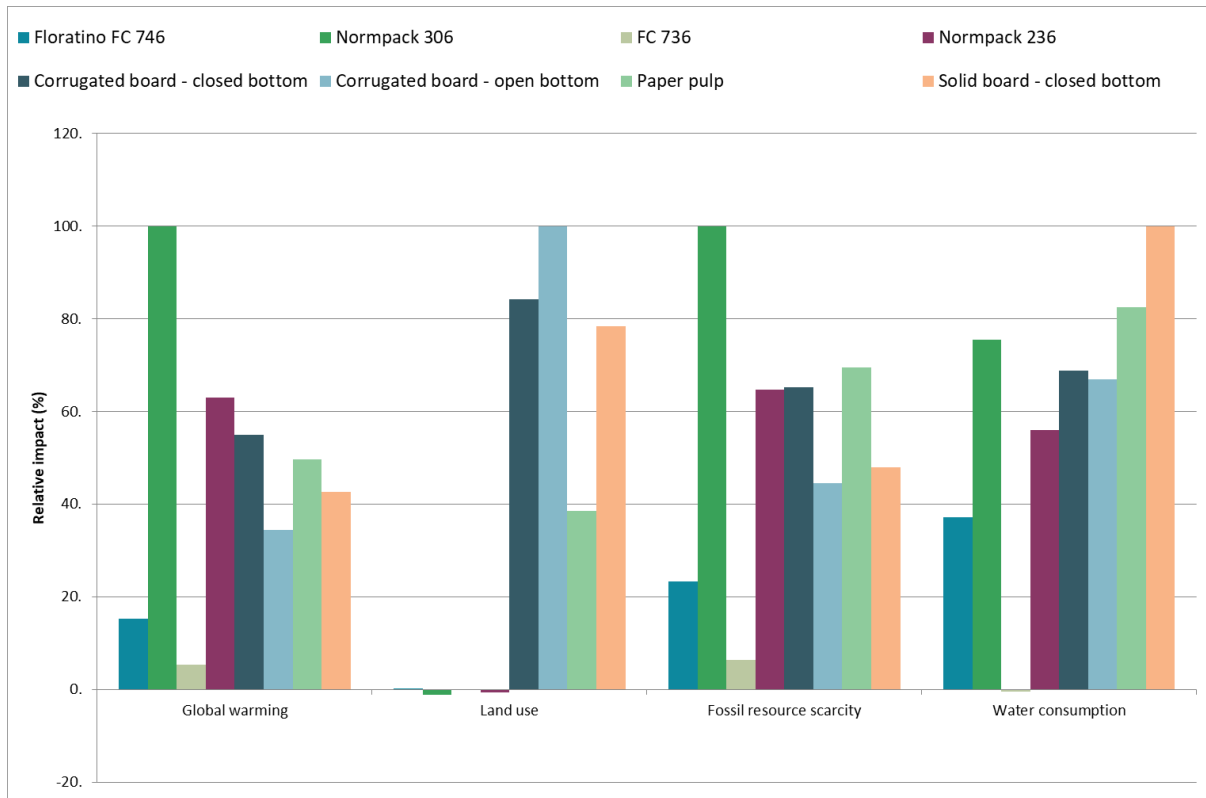


Figure 12: Relative impact category results for the impact of trays used for transporting plants to Arnhem (The Netherlands)

For the Dutch market, multiple use trays have the best environmental performance for all four impact categories. For single use trays, the cardboard alternatives have lower carbon footprint, but a higher land footprint and water footprint compared to single use plastic trays. For fossil resource scarcity two cardboard alternatives perform better than the Normpack 236 and two cardboard variants perform worse than the single use plastic tray.

4.3.5 Overview of the mid-point results

An overview of all mid-point results are shown in the heat-map tables below, in which the environmental performance of the trays is shown in relative percentage (ranging from 100% to -2%) and corresponding color. Red color indicates worst possible performance (= 100%), green indicates the best possible performance (= -2%). Results are based on the relative impact of the four trays from that specific market and country. It is therefore unfair to compare the results among countries. Remember that it is only fair to compare the environmental performance of trays used in the same market which are similar in size.

Table 7: Heat-map results for trays to Germany and France for the four selected impact categories

	Berlin (Germany)								Paris (France)							
Tray size	56 x 31 cm		40 x 28 cm						56 x 31 cm		40 x 28 cm					
Impact categories	Flora-tino	Norm pack 306	FC 736	Norm pack 236	Corrugated board closed	Corrugated board open	Paper pulp	Solid board closed	Flora-tino	Norm pack 306	FC 736	Norm pack 236	Corrugated board closed	Corrugated board open	Paper pulp	Solid board closed
Climate change	30	100	18	64	59	37	54	44	15	100	9	61	47	31	40	35
Land use	0	-2	0	-1	84	100	39	78	0	0	0	0	84	100	39	78
Fossil depletion	42	100	24	65	71	49	76	52	20	100	10	62	43	30	42	31
Water depletion	37	81	0	59	70	67	83	100	25	100	1	66	52	49	58	70

Table 8: Heat-map results for trays to Great Britain and The Netherlands for the four selected impact categories

	London (Great Britain)								Arnhem (The Netherlands)							
Tray size	56 x 31 cm		40 x 28 cm						56 x 31 cm		40 x 28 cm					
Impact categories	Flora-tino	Norm pack 306	FC 736	Norm pack 236	Corrugated board closed	Corrugated board open	Paper pulp	Solid board closed	Flora-tino	Norm pack 306	FC 736	Norm pack 236	Corrugated board closed	Corrugated board open	Paper pulp	Solid board closed
Climate change	16	100	7	63	71	47	57	53	15	100	5	63	55	34	50	43
Land use	0	0	0	0	84	100	39	78	0	-1	0	-1	84	100	39	78
Fossil depletion	18	100	7	63	47	32	47	34	23	100	6	65	65	44	69	48
Water depletion	26	100	1	69	55	51	60	72	37	75	0	56	69	67	83	100

Remember that the first four trays are the plastic trays, in which the Normpack types are the single use alternatives. The remaining last four trays are single use cardboard trays. These results tell us:

- Multiple-use trays perform well on all four impact categories considered. These trays perform better on climate change, fossil energy depletion and water depletion than single-use plastic and cardboard trays in all of the studied markets. They perform very well on land use as well, but since single-use plastic achieve negative land use due to the substitution of energy at plastic incineration, single-use Normpack trays perform better on this impact category.
- When comparing single-use plastic with single-use cardboard:
 - Cardboard trays perform better on climate change in all markets except Great Britain. In Great Britain the “closed” cardboard tray performs worse than its plastic variant of similar size due to the higher mass and large fraction of cardboard that is landfilled, causing methane emissions.
 - On land use, cardboard trays perform worse than single-use plastic trays. This is because cardboard is based on a natural resource which requires land to grow. Plastic is an oil-based product which requires little land.
 - For fossil energy depletion plastic trays score worse than the cardboard alternatives in France and Great Britain. For the German and Dutch market there is not a clear winner between the single-use trays. In those two markets, single-use plastic trays receive more credits because more plastic is recycled and a higher fraction of the plastic is incinerated. Therefore, the

environmental performance of plastic trays approaches cardboard trays on this impact category.

- For water use, plastic single-use trays perform better in Germany and the Netherlands. In France and Great Britain cardboard trays perform better than the single-use plastic alternative when it comes to water use.

More hints and clues why certain tray types perform better than others are discussed in the contribution analysis of the various trays (see chapter 5.3).

4.4 Single score results

Using the ReCiPe Endpoint method, hierarchist version (Goedkoop et al., 2013), a single score for the environmental impact of each tray alternative is presented for all markets. **Please note that it is not allowed to present solely these figures for external communication**, since:

“An LCIA shall not provide the sole basis of comparative assertion intended to be disclosed to the public of overall environmental superiority or equivalence, as additional information will be necessary to overcome some of the inherent limitation in the LCIA” (ISO, 2006b).

Besides the single score of reference flow, the contributing impact categories are shown. More information about the mechanism between midpoint and endpoint, see .Appendix VII: Absolute LCIA single score results presenting results in LCA studies. More detailed information about the underlying calculation method see Goedkoop et al. (2013). The contributing impact categories are hard to interpret due to the amount of colors to present each category endpoint. Quantitative information about each impact category is given in

Appendix VII: Absolute LCIA . Main findings about single scores for each market are presented separately.

4.4.1 Single score of the environmental impact of tray use for transport to Berlin

Single scores for trays to Berlin are shown in Figure 13 below.



Figure 13: Absolute endpoint results for the impact of trays used for transporting 6000 plants to Berlin (Germany)

Using an aggregate single score result based on the ReCiPe method reveals that multiple-use trays are the most environmentally favorable way of transporting plants to Berlin. As shown earlier, it performs best on the most relevant impact categories, which are global warming (lower blue bar) and fossil resource scarcity (top pink bar). For single-use trays, the cardboard alternatives perform better than the plastic alternative. Although cardboard trays score worse on a variety of impact categories, of which fine particulate matter formation, human toxicity and land use are the most important impact categories. On average cardboard trays still perform better when considering a total end-point score of all product systems. Although the environmental impact of corrugated board – open bottom type and the paper pulp tray have similar but slightly less environmental impact than the Normpack 236 tray.

4.4.2 Single score of the environmental impact of tray use for transport to Paris

Single scores for trays to Paris are shown in Figure 14 below.

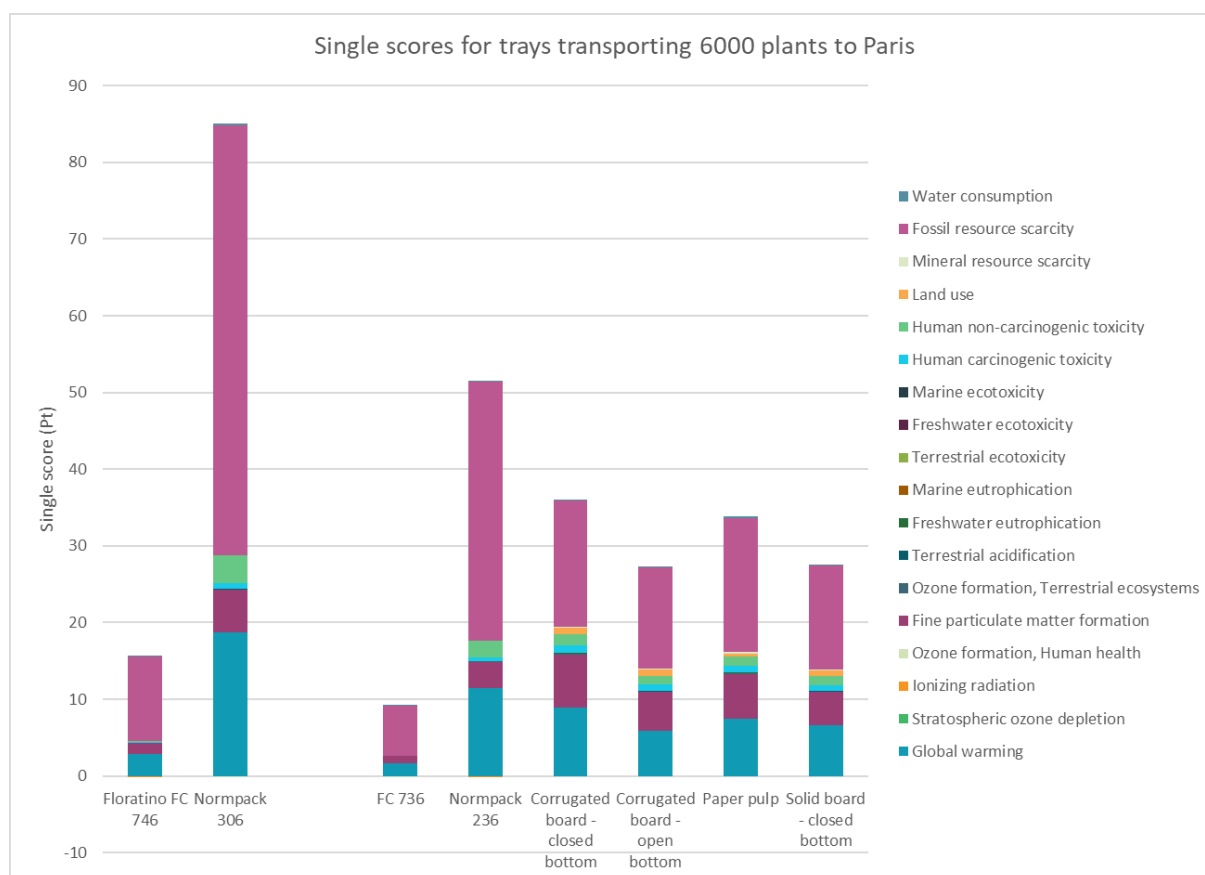


Figure 14: Absolute endpoint results for the impact of trays used for transporting 6000 plants to Paris (France)

For the French market multiple use trays are also the most environmentally friendly option. Second best alternative are the single-use cardboard trays. The environmental performance of single-use plastic and cardboard trays have widened compared to the German results. This is mainly because less credits are awarded to the plastic trays systems because less plastic is assumed to be recycled on the French market. In addition, less credits are awarded per kg of incinerated plastic because French incinerators are less efficient as the German once, meaning less credit in the form of substituted heat and electricity. Last factor is that per kWh of electricity less impact can be substituted in the French market. This is because a large part of the French electricity grid is based on nuclear power which have considerably lower carbon footprint and fossil energy use. This means that substituting 1 kWh electricity in France will give less credit than in Germany. A combination of these factors leads to deterioration of environmental impact of single use plastic trays compared to plastic single use trays on the German market.

4.4.3 Single score of the environmental impact of tray use for transport to London

Single scores for trays to London are shown in Figure 15 below.



Figure 15: Absolute endpoint results for the impact of trays used for transporting 6000 plants to London (Great Britain)

The shape of Figure 15 is quite similar to Figure 15. Again, the plastic multiple-use tray performs best of all alternatives. Best alternative for single-use trays would be the cardboard type. The single-use plastic trays have higher environmental impact compared to single use cardboard trays mainly because of the lower recycling rate for plastic compared to cardboard.

4.4.4 Single score of the environmental impact of tray use for transport to Arnhem

Single scores for trays to Arnhem are shown in Figure 16 below.

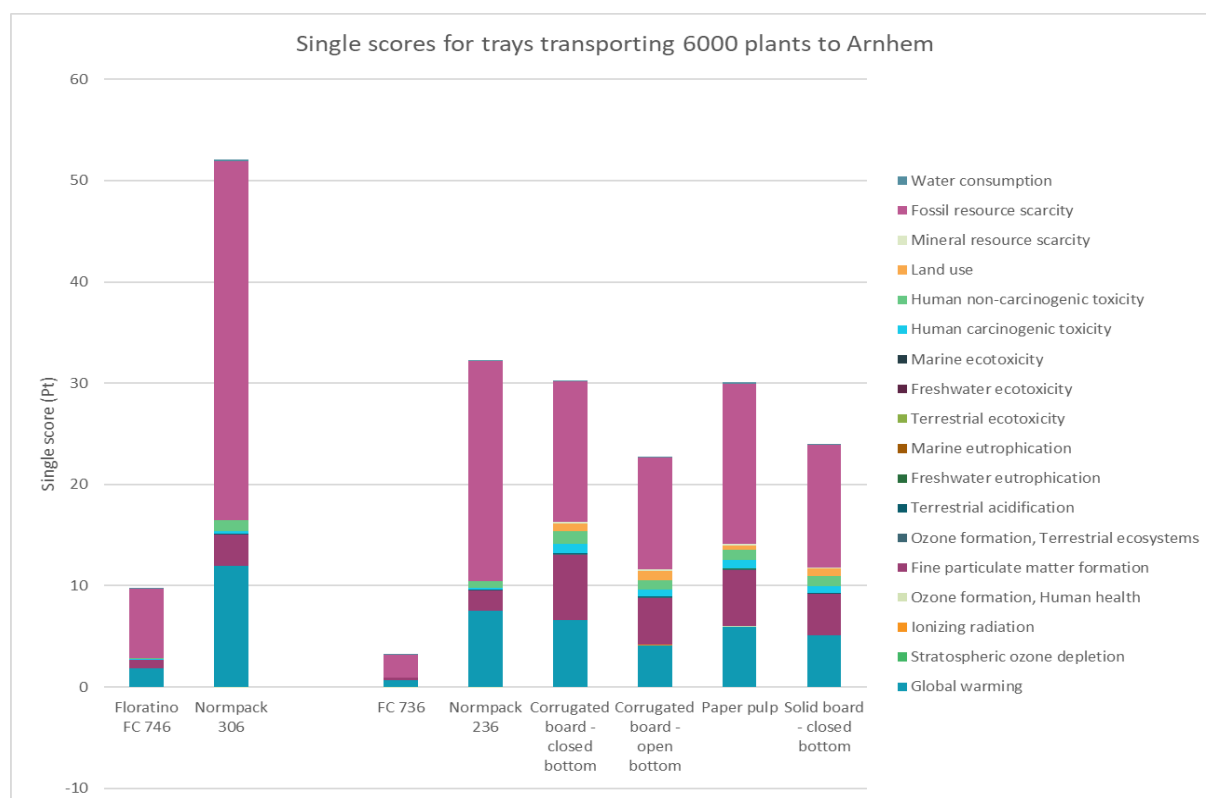


Figure 16: Absolute endpoint results for the impact of trays used for transporting 6000 plants to Arnhem (Netherlands)

Multiple-use trays are from an endpoint point of view the best way to transport plants in the Netherlands. For single-use trays, the cardboard alternative is more favorable, although some cardboard trays have just a marginal advantage compared to the Normpack 236 tray of similar size.

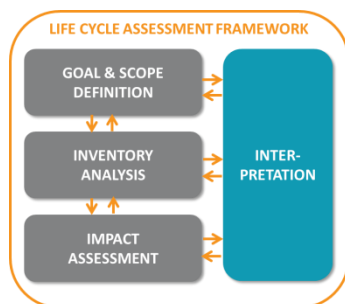
4.4.5 Overview and comments on single score results

Overview of the single score results based on ReCiPe endpoint method is given in Table 9 below. In this table the environmental performance of the tray is shown in relative percentage for each country (ranging from 100% to 0%). Red indicates worst possible performance (= 100%), green indicates the best possible performance (= 0%). Again, remember that it is only fair to compare the results of trays with similar size.

Table 9: Relative endpoint results per country for the four investigated countries

Tray size	56 x 31 cm		40 x 28 cm					
Tray	Floratino	Normpack 306	FC 736	Normpack 236	Corrugated board – closed bottom	Corrugated board – open bottom	Paper pulp	Solid board – closed bottom
Germany	34	100	21	62	61	46	60	48
France	18	100	11	61	42	32	40	32
Great Britain	17	100	8	61	49	37	45	38
Netherlands	19	100	6	62	58	44	58	46

From Table 9 can be seen that the multiple-use plastic trays have the best end-point performance for all studies markets. For single-use alternatives, all four studied cardboard variants perform better than the Normpack plastic trays in all four markets.



5. Interpretation

The final phase of the LCA discusses the overall result from the previous steps. Interpretation begins with a consistency and completeness check to determine the soundness of the study. The multiple contribution and sensitivity analyses helps to bolster the robustness of the results in preparation of the discussion and conclusion of the report.

5.1 Consistency check

The objective of the consistency check is to determine whether assumptions, methods, models and data are consistent with the goal and scope of the study. This consistency check is performed on all product's life cycles and across various options (Guinée et al., 2002). For this study it is opted to use a checklist to determine the consistency of data sources, data accuracy, technical level, age, geography and functions for each reference flow.

Checkpoint:	Consistency	Remarks
Data sources	High	Same (background)sources are used for various processes for all reference flows. For example: the CFF for EOL modelling. Only the production data of various trays are from different sources, but this is unavoidable.
Data accuracy	High	Same data accuracy for all processes used in all reference flows. Only data for data inventory for production process of trays least consistent. Some production data is based on facility averages (Normpack 306 & 236) or based on similar type of tray produced by that company (Floratino FC 746 & Open cardboard tray).
Technical level	High	Very similar for all alternatives. Technical level can only deviate in the production data.
Age	High	Production data is collected in different time periods: plastic tray production data originate from 2016 or 2017, cardboard tray production data from 2018 2019. Other data and parameters originate from same year for all alternatives.
Geography	High	Geographical data are applied consistent for all markets. Often data based on larger geographical area (e.g. cardboard recycling based on European default) but applied consistent for all reference flows.
Functions	High	Function of plant pot trays are the same. There is a difference in tray sizes, and some might have additional features. But this was part of the scope of the study.

Overall the study is performed consistent for all the different checkpoints.

5.2 Completeness check

The objective of the completeness check is to ensure that the information and data used for this study are available and complete. For this study information for all different unit processes were available and complete, using Figure 7 as tray product system. Minor parts of the product system are not included, like labels, packaging etc. But these economic flows are part of the cut-off (See 3.1.2) that has been applied to all product systems. Furthermore, these cut-offs are considered to have minor impact on the overall result.

The study complies with the data quality requirements set by ISO 14044 regarding time-related coverage, geographical coverage, technology coverage, completeness, representativeness, consistency, reproducibility and sources of data. Only the variance of precision for the primary data values could not be determined, since primary data for all trays were based from single production location.

5.3 Contribution analysis

Contribution analyses to Berlin (Germany) are presented to illustrate the main contributing processes for each impact category. The analysis gives a better understanding of the environmental impact of the different product systems. Furthermore, the information was used to identify the most contributing processes which help to improve the environmental impact of the specific type of trays. Reference flows to Berlin were chosen since this is the largest market of Royal FloraHolland. Since the Normpack® 236 tray is very similar to the Normpack® 306 tray, the former is left out from the contribution analysis. For the contribution analysis results for 13 impact categories are shown, although for the analysis the focus is still on: global warming, land use, fossil energy scarcity and water consumption.

5.3.1 Contribution analysis of transporting plants with Normpack 306 to Berlin

Contribution analysis of the Normpack® 306 tray is shown in Figure 17 below.

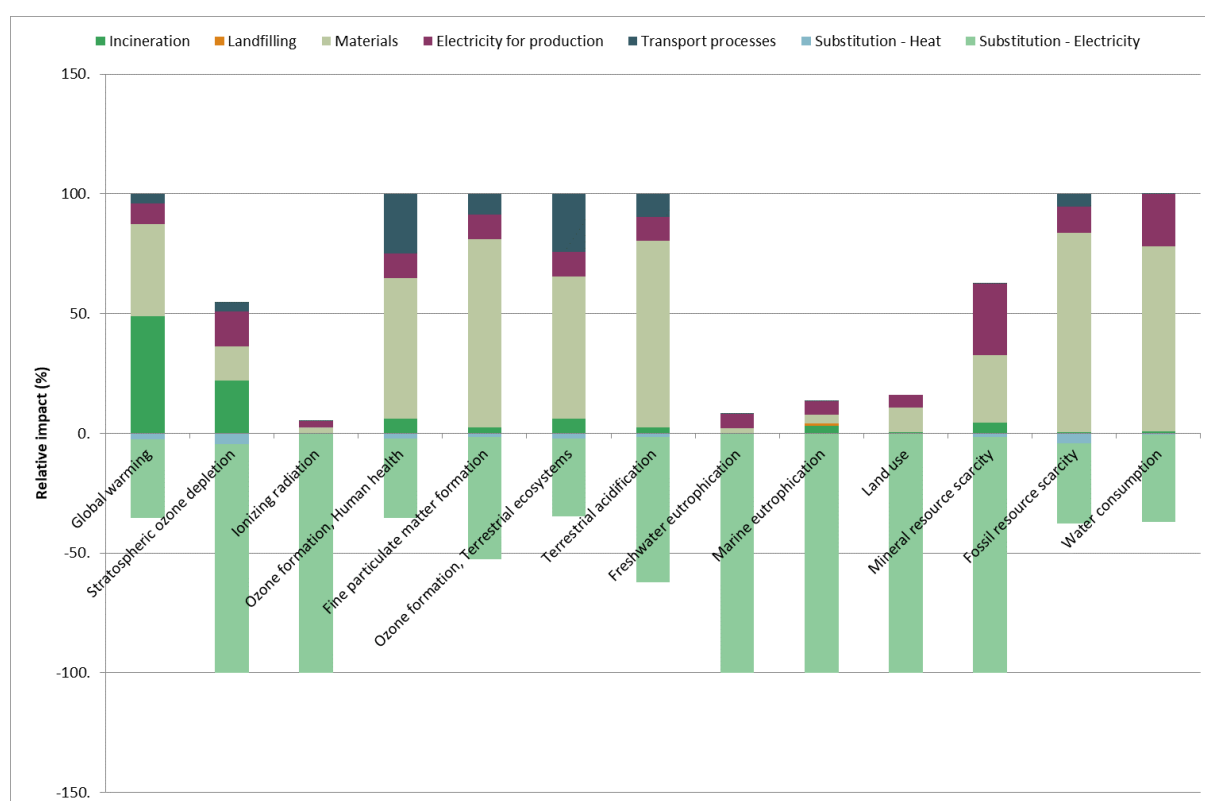


Figure 17: Contribution analysis of the impact of Normpack 306 trays used for transporting plants to Berlin (Germany)

Materials are the largest positive contributor for almost all impact categories. Materials include the production of virgin and secondary material as well as the credits that are given when materials are recycled in the end-of-life stage. For climate change and stratospheric ozone depletion the incineration process of plastic contributes even more than the impact of materials. The impact of both materials and incineration can be reduced when more recycled plastic is used during the production process (higher [R1] value) and more plastic is recycled after use (higher [R2] values).

Although the incineration process has a significant environmental impact, there is also environmental gain from the substitution of heat and electricity. For Germany the credits are more substantial than for other countries due to the higher share of incineration, higher electrical efficiency at incineration and relatively polluted electricity grid mix.

There is a link between the impact of materials and the substitution of electricity: more plastic recycling leads to lower impact for materials but also less credits from electricity generation since there is less plastic available for incineration. During the sensitivity analysis a higher recycling rate was used to study its impacts compared to the scenario that is presented here (see chapter 5.4.1).

A relatively easy way to reduce the impact of the plastic Normpack trays would be to use more renewable electricity in the production phase. This electricity mix used for the production phase includes renewable energy, it is still dominated by fossil-based electricity production techniques.

5.3.2 Contribution analysis of transporting plants with Floratino FC 746 to Berlin

Contribution analysis of the Floratino FC 746 tray is shown in Figure 18 below.

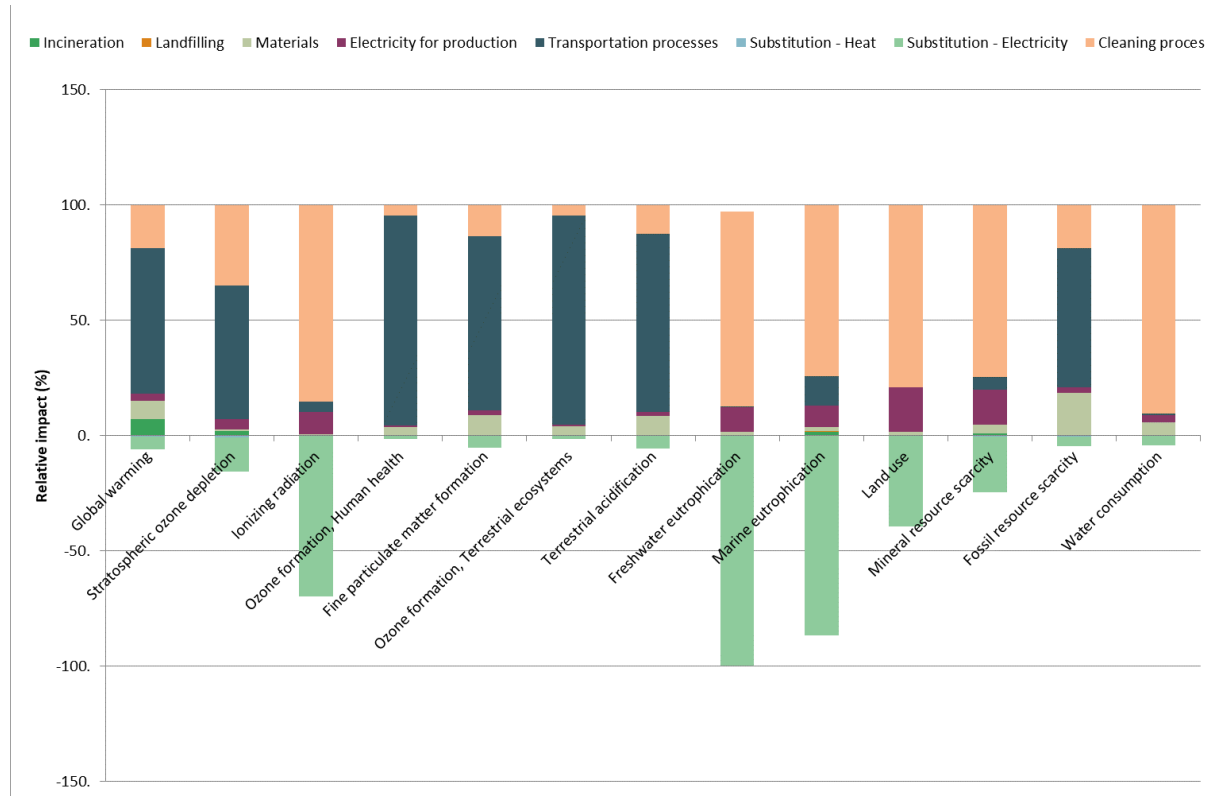


Figure 18: Contribution analysis of the impact of Floratino FC 746 trays used for transporting plants to Berlin (Germany)

Main contributing processes for the Floratino FC 746 tray are the transportation and cleaning processes. Impact of transportation can be reduced when higher load factor is achieved for all transportation processes. Load factor of all transportation processes in this study are assumed to be 20%.

The cleaning process contributes most to ionizing radiation, eutrophication, land use, mineral resource scarcity and water depletion. For ozone depletion this is due to the use of the use of energy inputs (heat and electricity) during the cleaning process. Freshwater eutrophication emissions are mainly a result of electricity use during cleaning.

Compared to the Normpack contribution analysis, materials do have limited impact on the overall system and is explained by the high trip-rate of the trays. The trip-rate of 70 is based on the economics of the deposit system of the FC 736, since there is no data available for the relatively new Floratino FC 746. It might be possible that lower trip-rates are achieved for this type of tray. During the sensitivity analysis a lower trip-rate of 40 and 10 will be used to study its impacts compared to the trip-rate of 70 that is used for this study (see 5.4).

5.3.3 Contribution analysis of transporting plants with FC 736 to Berlin

Contribution analysis of the FC 736 tray is shown in Figure 19 below.

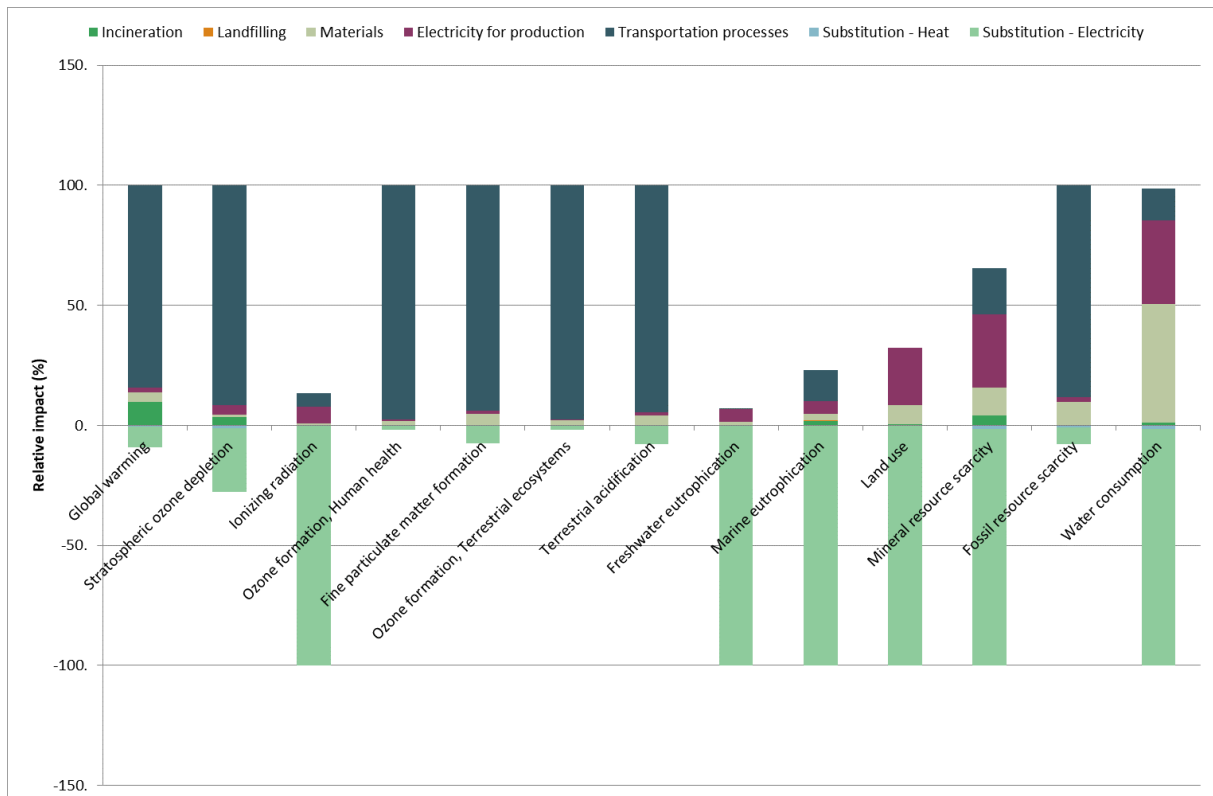


Figure 19: Contribution analysis of the impact of FC 736 trays used for transporting plants to Berlin (Germany)

Main difference between the multiple-use trays is that the Floratino tray is cleaned before it is reused, whereas the FC 736 is not. This means that for the FC 736 the cleaning process and the additional transport to the cleaning facility are not applied which leads to a significant lower impact compared the Floratino tray.

As a consequence, the main contributing processes for this tray are the transportation processes within the whole life cycle. Another influential process are the given credits that are a result of avoided electricity from plastic incineration.

Please keep in mind that the contribution analysis presents the relative results for this reference flow. Since the influence of the FC 736 is low compared to the other tray types, less environmental gain can be achieved in absolute terms.

5.3.4 Contribution analysis of transporting plants with Closed cardboard tray to Berlin

Contribution analysis of the closed cardboard tray is shown in Figure 20 below.

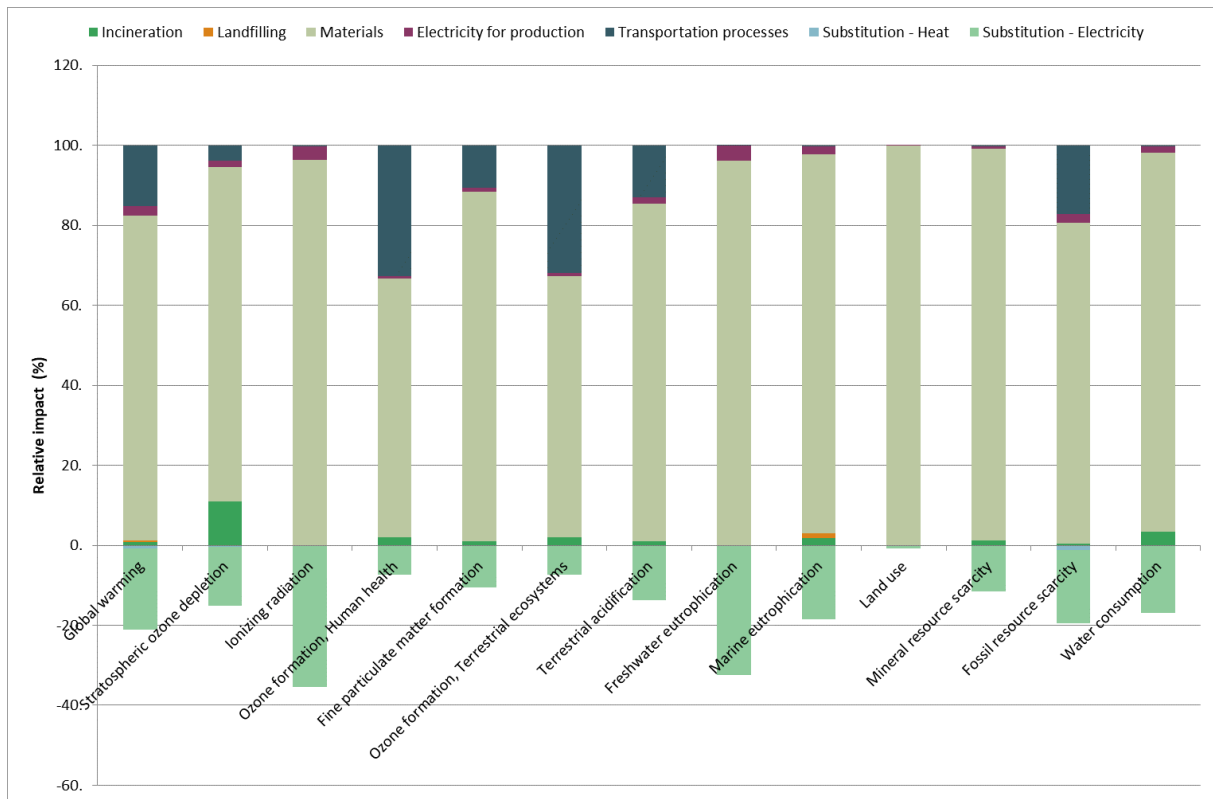


Figure 20: Contribution analysis of the impact of closed cardboard trays used for transporting plants to Berlin (Germany)

For the closed cardboard tray the most important aspect regarding the environmental impact are the materials used. This involves the materials used for producing the trays but also the credits that are awarded when materials are reused after end-of-life.

The incineration process has a relative low impact on global warming compared to plastic trays. This is because the carbon within cardboard is from biogenic origin and the carbon in plastic is from fossil origin. In the impact method the impact of biogenic impact of both the uptake and emissions of CO₂ are not considered. This is an advantage of using cardboard instead of plastic. On the other hand, cardboard has a lower energy density which means that less electricity can be generated per mass of waste and therefore less credits can be awarded.

For optimizing this type of tray, the following aspects could be considered: lowering the mass of the tray & reducing the amount of cutting losses of the tray. Using materials with a higher recycled content does not have similar impacts as for recycling plastics. This is because the recycling cardboard into new cardboard is still an intensive process, whereas recycled plastic granulates can easily be reused.

5.3.5 Contribution analysis of transporting plants with Open cardboard tray to Berlin

Contribution analysis of the open cardboard tray is shown in Figure 21 below.

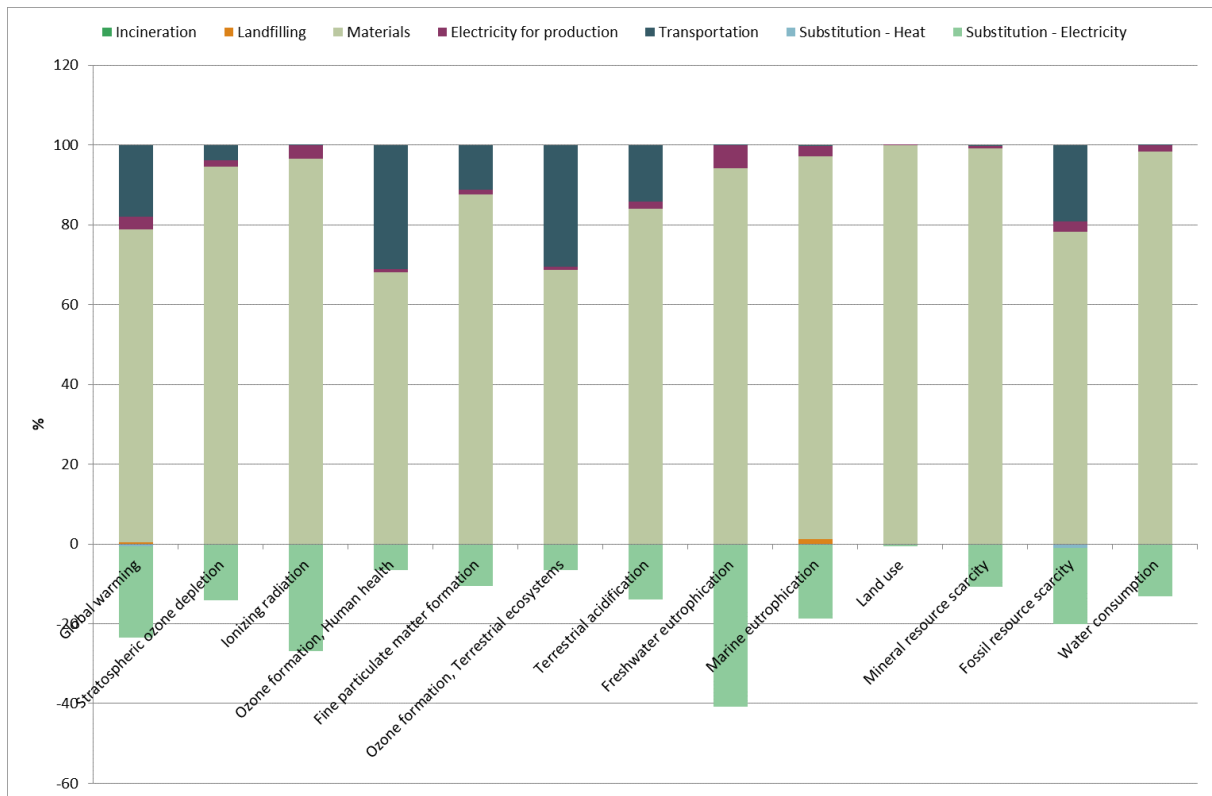


Figure 21: Contribution analysis of the impact of open cardboard trays used for transporting plants to Berlin (Germany)

For open cardboard trays the main contributing aspect for all impact categories are materials, with at least 68% for all impact categories. The above figure looks very similar to the previous cardboard tray. For optimizing this type of tray, the following aspects could be considered: lowering the mass of the tray & reducing the amount of cutting losses of the tray.

5.3.6 Contribution analysis of transporting plants with Paper pulp tray to Berlin

Contribution analysis of the paper pulp tray is shown in Figure 22 below.

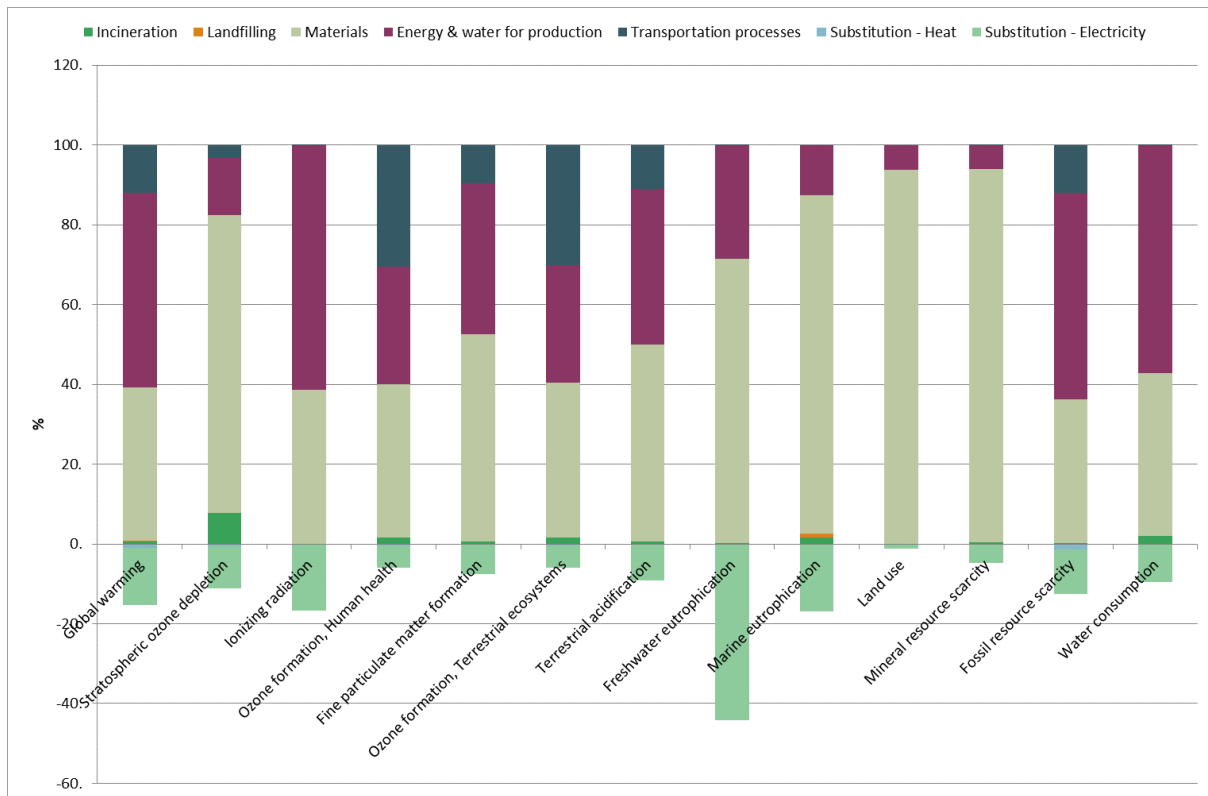


Figure 22: Contribution analysis of the impact of paper pulp trays used for transporting plants to Berlin (Germany)

The paper pulp tray has a different contribution analysis compared to the previous cardboard trays. Next to materials, energy & water for production are the most dominant processes in terms of environmental impact. Reducing energy needs or using renewable energy to produce the paper pulp tray might be a good way to further optimize this tray, next to reducing the mass of the tray itself. Materials cannot be optimized easily, since waste flows are already used to produce paper pulp trays and high recycling rates at end-of-life are already achieved. It is interesting to see what the environmental impact of this paper pulp tray would be if the trays are produced in the Netherlands (more on this in chapter 5.4.3).

5.3.7 Contribution analysis of transporting plants with Solid board tray to Berlin

Contribution analysis of the solid board tray is shown in Figure 23 below.

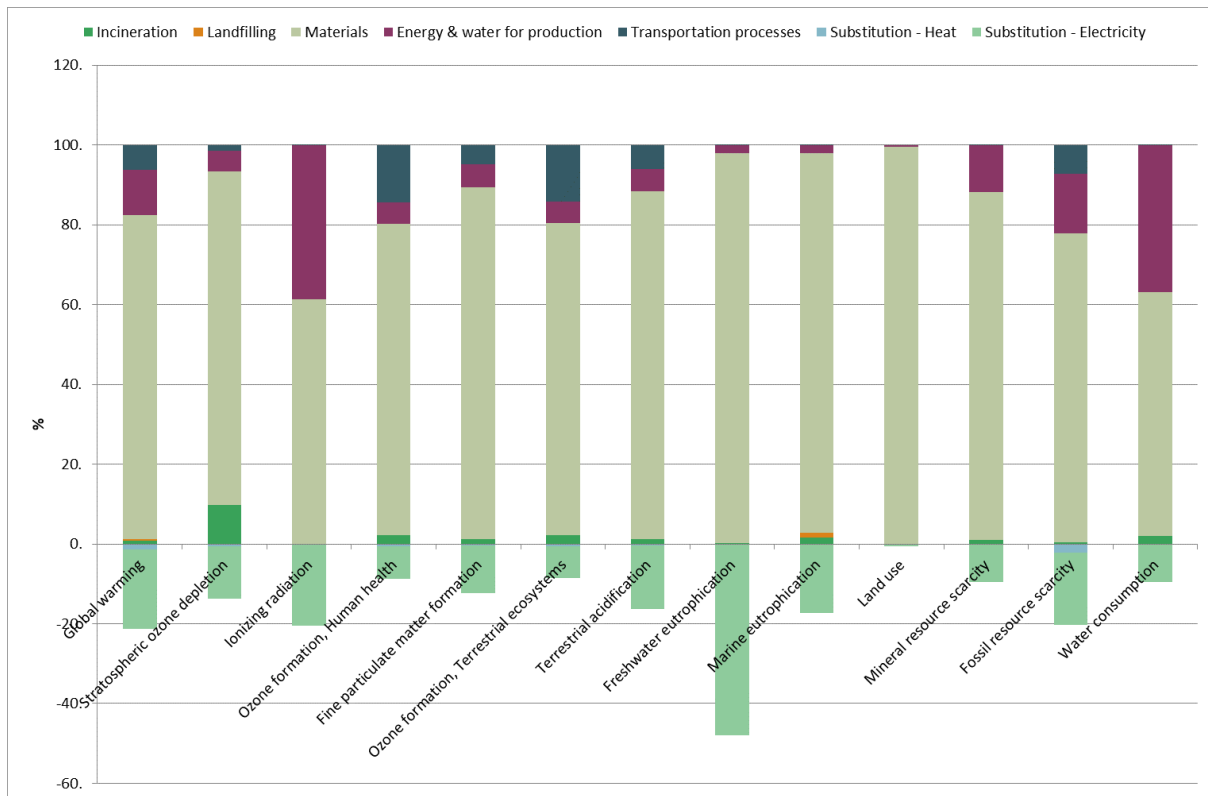


Figure 23: Contribution analysis of the impact of solid board trays used for transporting plants to Berlin (Germany)

The contribution analysis of the solid board tray is sort of an average of the other three cardboard trays. Materials contribute mostly for all environmental impact categories. Energy & water use have moderate impact on the overall result. Especially for ionizing radiation energy use for production has a significant impact, because production is modelled to take place in Belgium, which has a relatively large share of nuclear in its electricity mix.

5.4 Sensitivity analysis

The sensitivity phase assesses the influence on the results of variations in process data, model choices and other parameters. During the sensitivity analysis some of the important parameters are deliberately changed in order to determine the robustness of the results. The identified parameters for a sensitivity analysis are:

- Higher recycling rates [R2] for single use plastic trays
- Lower trip-rates for Floratino FC 746 trays
- Location of paper pulp tray production
- Influence of the cleaning process of multiple-use trays

Each of these aspects are studied in the following paragraphs.

5.4.1 Influence of higher plastic recycling rates [R2]

An important parameter for the environmental performance of the single-use plastic trays is the fraction of disposed plastic that is recycled. The fractions of recycled plastic considered in this study were 50% for Germany, 19% for France, 29% for Great-Britain and 50% for The Netherlands. For France and Great Britain these numbers were based on post-consumer recycling rates for these specific countries. For the Dutch and German markets, the recycling rate of a Royal FloraHolland study was used (50%), which is higher than the numbers from the PEF defaults (which are 33% and 35% Netherlands and Germany respectively). In this sensitivity analysis the recycling rate for plastic is further increased to study its impact.

Only the 40 x 28 cm single-use trays are considered for the sensitivity analysis, all involving the market Berlin. Berlin as market was chosen since it is the largest market of Royal FloraHolland. The current Normpack® 236 tray scenario (with R2 value of 50%) together with the Normpack® 236 tray with recycling rate of 60%, 70% and 80% are compared to the single-use cardboard trays. Results are shown on end-point level in Figure 24 below.

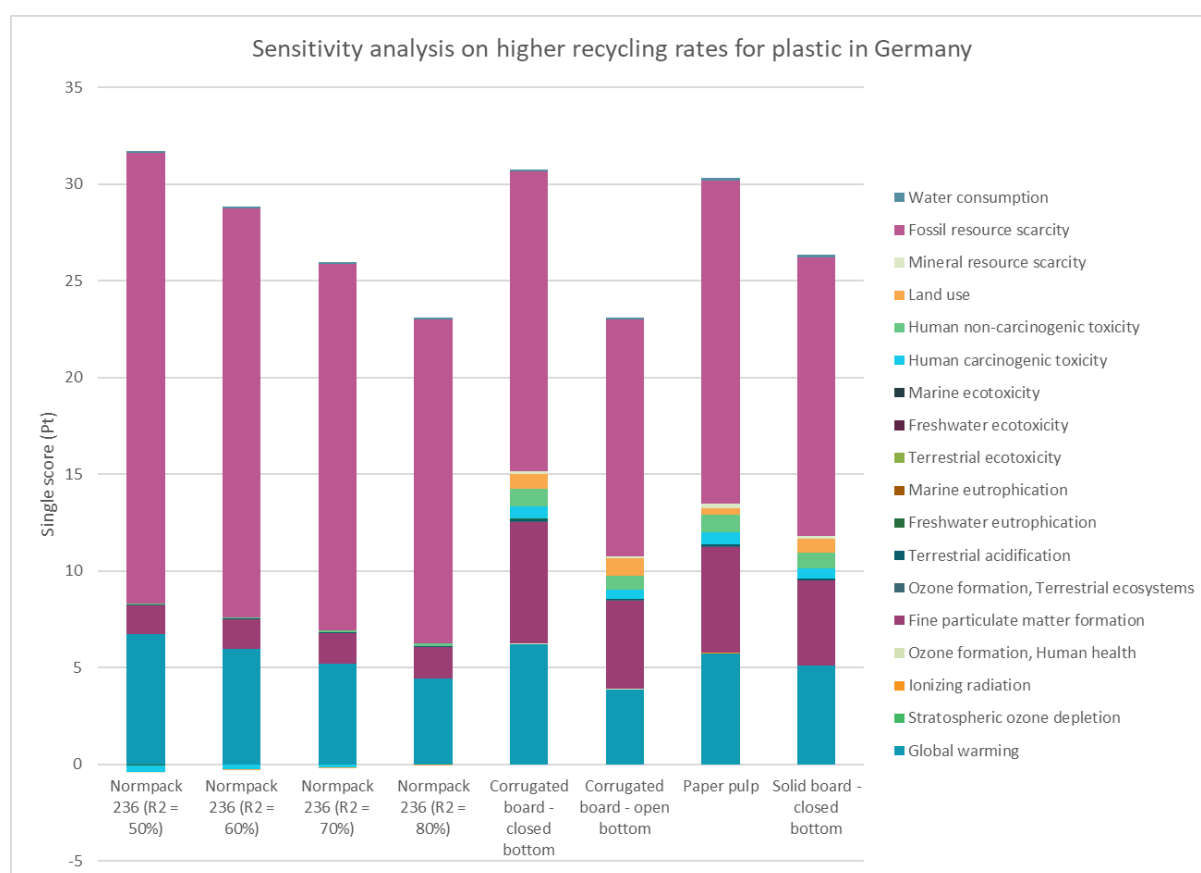


Figure 24: Sensitivity analysis on higher recycling rates of disposed plastic for Normpack 236 versus cardboard trays

As the recycling rate for plastic increases, the environmental impact of single use plastic decreases linearly. In theory, a 'break-even' plastic recycling percentage could be determined for each cardboard tray to after which the plastic single use tray performs better than the cardboard variant. But because of the scope, the amount of primary data that has been collected, assumptions and choices made throughout the study it would not be fair to make these false precision statements.

The important message here is that recycling percentage at end-of-life is an important factor. Considering that the recycled content of the Normpack products already exceed 90% recycled content at production, the recycling rates at end-of-life is one of the few remaining possibilities in reducing the impact of single use plastic trays. It could be questioned if higher recycling rates are achievable. As facilitator Royal FloraHolland could reduce the impact of plastic single-use trays by aiming to improve the recycling rates of plastic at their market locations.

5.4.2 Lower trip-rates for Floratino FC 746 trays

An important variable for multiple use trays is the trip-rate. This was set at 70 for Floratino FC 746. However, this might be too optimistic. The trip-rate of 70 is based on the economics of the deposit system of the FC 736, since there is no data available for the relatively new Floratino FC 746. It could be possible that in the Floratino is reused less often than the FC 736 tray. For this sensitivity analysis the trip-rate is lowered to 40 and 10 to study its impacts compared to the trip-rate of 70 that is used for this study. The environmental impact of the Normpack 306 will be added as a reference, because it is of similar tray size. Endpoint results of the sensitivity analysis are shown in Figure 25.

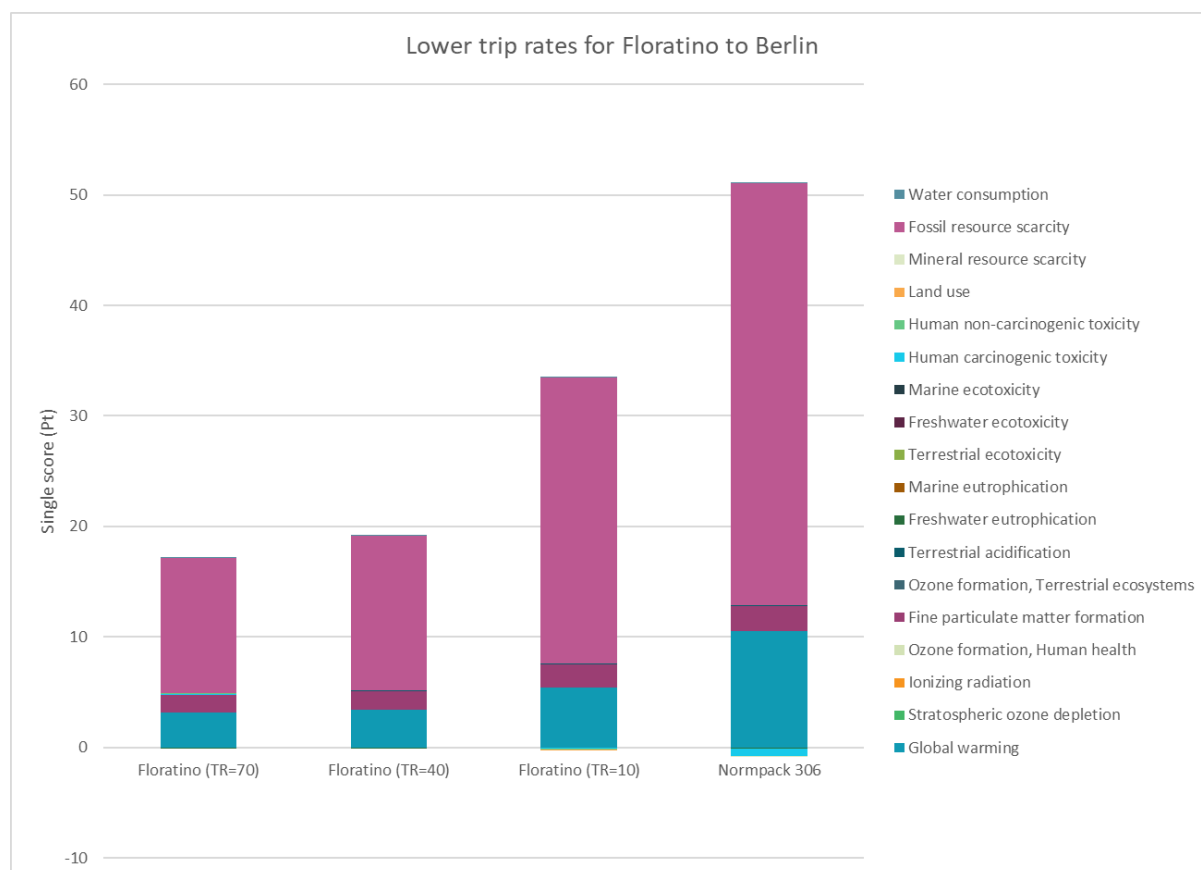


Figure 25: Sensitivity analysis on lower trip rates for Floratino FC 746 trays to Berlin

A reduction of the trip-rate from 70 to 40 will lead to a slight increase in the environmental impact of the multiple-use tray. With a trip-rate of 10 the impact of the multiple-use tray will increase in a more exponential manner. But even with a very pessimistic trip-rate of 10, the Floratino multiple-use tray performs better than the single-use plastic variant. In other words, the trip-rate is an important parameter in the lifecycle of multiple use trays, but even a pessimistic trip-rate of 10 will still lead to more favorable results compared to single-use plastic trays.

5.4.3 Paper pulp tray produced in the Netherlands

Currently the paper pulp tray is produced in the Great Britain. But the producer has plans to open a production location in the Netherlands. This sensitivity analysis investigates the environmental performance of the tray produced in the Netherlands, instead of Great Britain. It is assumed that the production in the Netherlands has the same inputs and materials as has been collected in this study. Only the background data and transportation distances will change. In both scenarios average national energy grids are used as background data, which are specific for each country. Endpoint results of the sensitivity analysis are shown in Figure 26. For comparative reasons the FC 736 and Normpack 236 trays are shown as well.

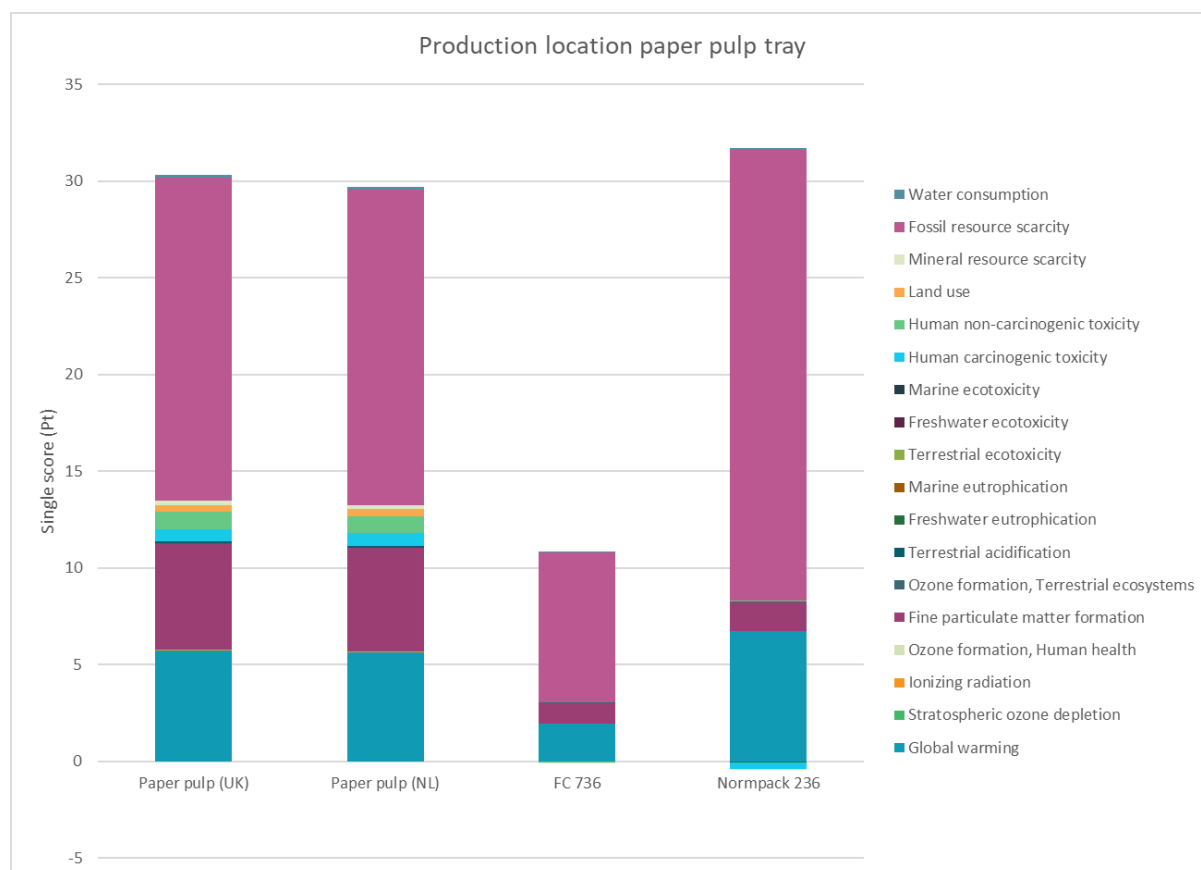


Figure 26: Sensitivity analysis on the production location of the paper pulp tray

Moving the production location from Great Britain to the Netherlands would lead to a marginal gain of environmental performance of the paper pulp tray, considering the whole life cycle. Reducing energy needs during the production stage or using renewable energy will lead to more environmental gain (see chapter 5.3.6).

5.4.4 Influence on cleaning FC 736 multiple use trays

For the trays with size of 40 x 28 cm there is only one multiple-use tray, which is the FC 736. This type of tray is not cleaned before it is reused. In the sensitivity analysis the impact of cleaning the FC 736 is studied. The same inventory data of the cleaning process of the Floratino tray is assumed for the FC 736. Furthermore, a second scenario is created in which the trays are cleaned in a cleaning facility further away from Aalsmeer (175 km instead of 50 km). Endpoint results of the sensitivity analysis are shown in the Figure 27. Other trays of similar size are added for comparison.

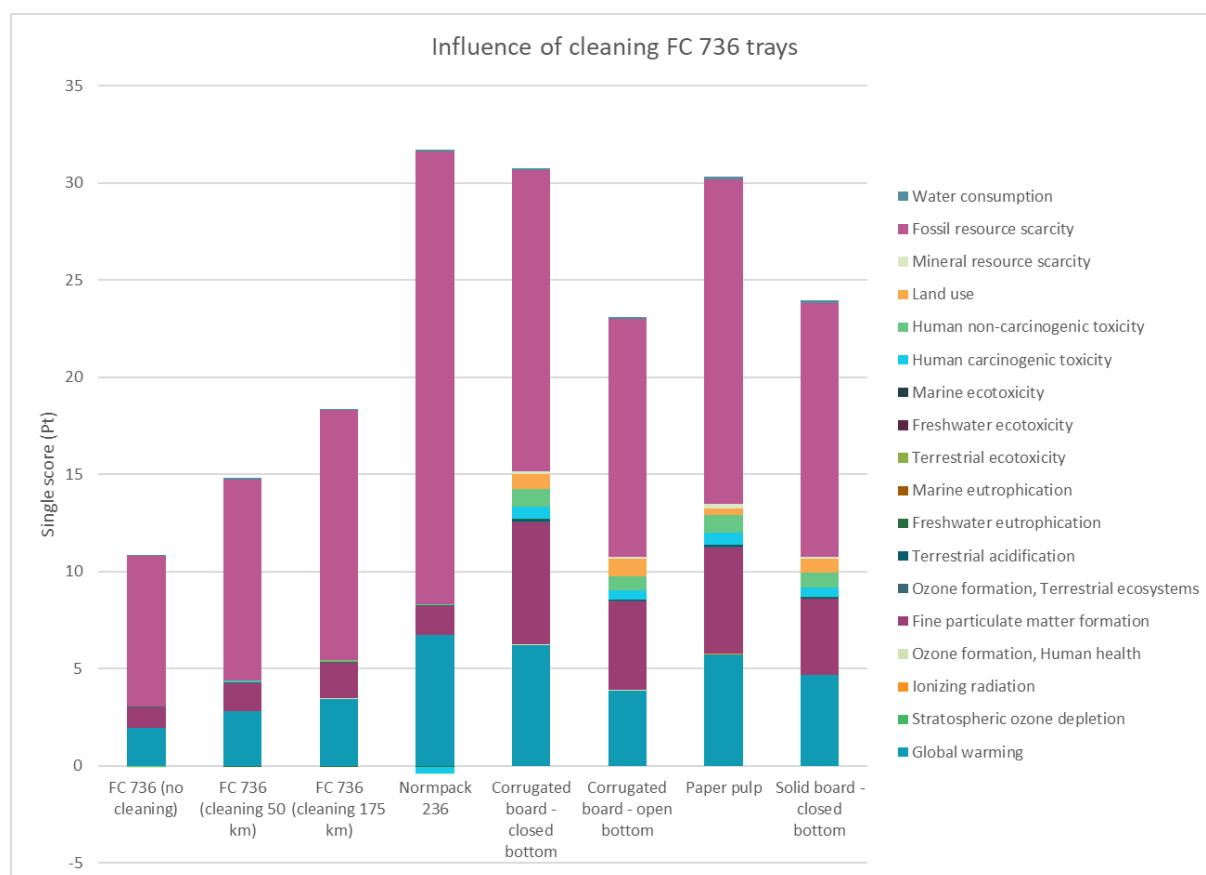


Figure 27: Sensitivity analysis on FC 736 tray with cleaning and additional transportation to cleaning facility

Cleaning the FC 736 tray will result in an increase of the environmental impact, but it is environmentally speaking still superior compared to the single-use tray types. Even if the cleaning facility is further away from Aalsmeer, it is still more beneficial. However, in selecting an appropriate partner for cleaning trays, Royal FloraHolland should consider the transportation distance, since these additional burdens are avoidable.

5.4.5 Influence of coatings and print on cardboard trays

During the data collection phase, it proved to be difficult to cardboard tray producers to estimate the amount of ink and coating material that could be used for the cardboard trays. To get an idea of the environmental impact of printing and coating it was chosen to perform a sensitivity analysis on these processes. In order to quantify the impact of printing information of a printing service process in Ecoinvent is used as a proxy. The information includes the amount of printing ink (18 gram/kg cardboard), solvents (2.2 gram/kg cardboard) and rosin size materials (5.2 gram/kg cardboard) used per kg of printed cardboard, assuming no additional energy requirements or losses of paper. Result of the sensitivity analysis is shown in Figure 28 below. The FC 736 and Normpack 236 plastic trays are added as a reference. Results shown are for the German market.

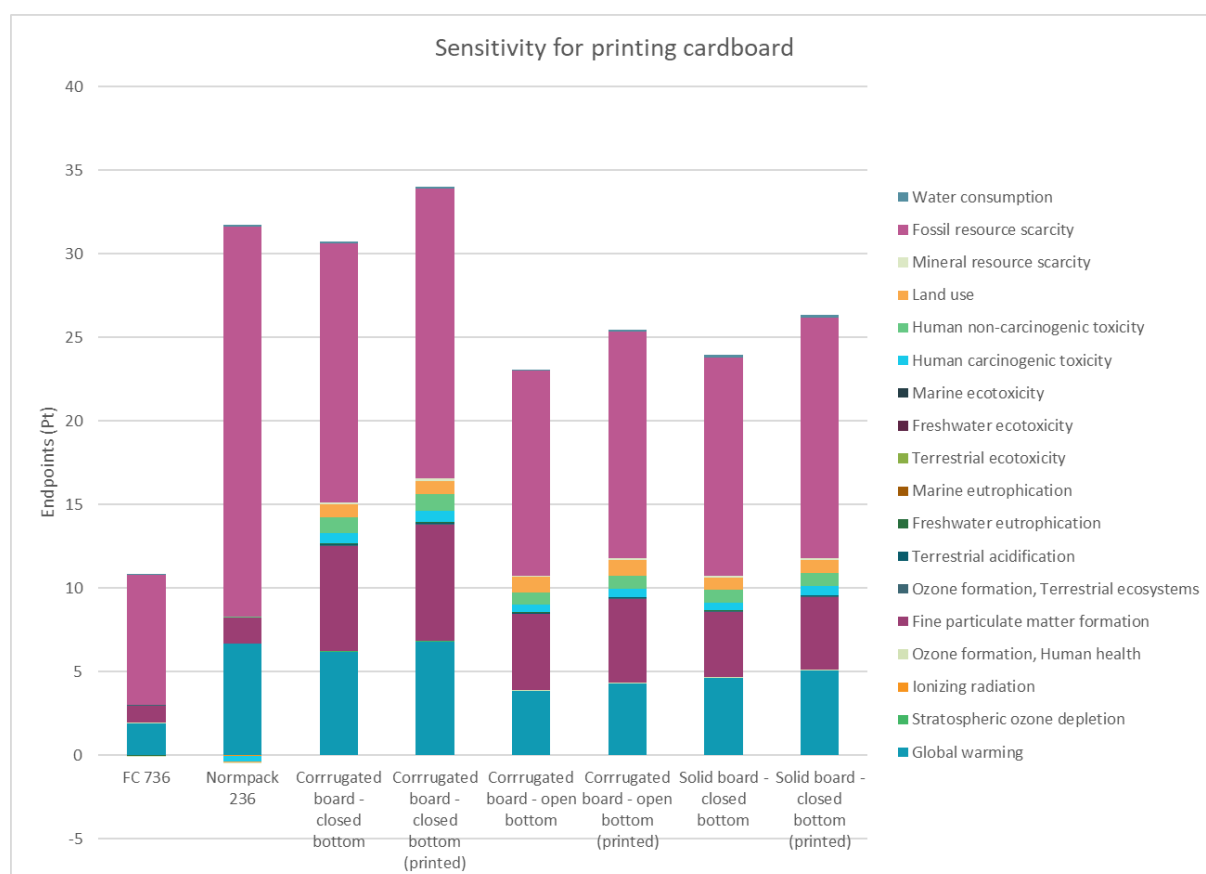


Figure 28: Sensitivity analysis on printing cardboard trays for the market

Assuming the modelled printing process described earlier is representative for the three printed cardboard trays, the impact of the cardboard tray will increase with about 10% considering the whole lifecycle. But making any hard conclusions about printing cardboard is unjustified since the sensitivity analysis does not use any primary data. Results are an indication that the environmental impact of cardboard trays would increase when additional printing is applied.

6. Discussion

The LCA was performed to quantify the environmental footprint of single-use and multiple-use trays. Main advantage of LCA is that it is product-based, includes all relevant process stages and can quantify emissions for multiple impact categories. However, it is not capable to quantify emissions related to the 'plastic soup' phenomena, since there is no method available to determine this. However, it is likely that single-use trays contribute more to this environmental problem than multiple-use trays. Also plant trays are mainly used for business-to-business operations, which means that it is less likely to end-up in the environment than plastics used by consumers.

The study determined the environmental impact of multiple-use plastic trays and single-use trays made from plastic and cardboard based on primary data for eight different trays. It is assumed that these tray types are representative for other type of trays since the production system of other single-use trays and multiple-use trays are quite similar to the products used in this study. For single-use cardboard trays there is more variation in type of materials used. For this reason, four different cardboard trays were selected, each based on different materials, production technology and weight.

The allocation problems in this study are tackled by using the circular footprint formula which is proposed by the European Commission. The formula solves the problem of electricity and heat production by substituting half of the produced electricity from the product system. This is especially beneficial for single-use plastic trays, since a larger proportion of plastic is incinerated per functional unit compared to multiple-use trays. Single-use plastic trays have an edge over single-use cardboard trays since plastic has a higher calorific value, generating more credits per mass of product than cardboard. The type of allocation procedure has always been a controversial topic in the LCA. Another option would be to use economic allocation (Guinée, Heijungs, & Huppes, 2004). Hereby the processes are partitioned based on the economic proceeds of the functional flows. If economic substitution would be applied for this study, single-use plastic trays would perform even worse, since substitution is not applied in economic allocation. Further advantage of economic allocation is that negative emissions are technically not possible. However, since consistency is important aspect in LCA studies, the proposed circular footprint formula of the European Commission was used in this study to solve all allocation problems with one formula.

In the Ecoinvent background database, upstream allocation of petroleum products from the refinery process are based on mass allocation. In our view it would be better if the allocation is based on economic allocation. Main reason is because refining processes largely exist to produce valuable short-chain hydrocarbons like gas, petroleum and diesel and not to produce bitumen. With economic allocation the environmental burdens of oil extraction and processing would be more allocated towards lighter fractions, which are used for plastic granulates. Hereby the environmental impact of materials would increase, and this would have more influence on single use trays since these consume more materials per functional unit. However, since only background data based on mass allocation exists, this had to be applied for this study.

Primary data that has been used in this study all originate from a single source. Ideally, more sources should be used to achieve higher accuracy, but in some cases the trays are produced by a single company only. Still there is room for improvement since some of the primary data is based on facility averages or based on production data of a similar type of tray.

Better data could change the results of the single-use plastic tray, but the contribution analysis showed that the impact of energy to produce single use plastic trays is already marginal. Also, both Normpack trays use more than 90% recycled material, meaning that there is little room for improvement at the production side for single use plastic trays.

For single use cardboard trays energy use between the different types are quite different. The paper pulp tray is relatively energy intensive compared to the other cardboard trays. This also partly because the impact of materials is lower (since it uses mainly waste paper and cardboard as input). For the other tray types, energy use is considerably lower, but these are made from corrugated or solid board material which only have to be folded

and cut in the correct shape. For these tray types, the impact of the materials is relatively high and impact of energy use is relatively low.

The environmental impact of processes like raw materials production, energy production, transport, incineration, landfilling is all based on data from background databases. This means that the quality of the background data is partly responsible of the quality of this report. The quality of the report could be improved by collecting more background data for these processes. For example, collecting primary data of the suppliers of plastic (granulates) or cardboard materials. Because of time and budget reasons it was opted to use background data from the Ecoinvent database, which is a high-quality background database.

The allocation procedure includes credits for electricity generation that results from plastic incineration. The credits are based on the electricity market mix of that specific country. This means that the avoided electricity usually includes significant 'base load' electricity production of coal and nuclear power for some countries. However, it is worth to check if electricity from plastic incineration in practice also replaces nuclear and/or coal electricity production. If plastic incineration does not replace 'base load' power generation but gas fired power plant for example, less credits would be assigned to all tray types, especially for single use trays.

The sensitivity analysis revealed that higher recycling rates of plastic at disposal, lower trip rates for Floratino FC 746, printing cardboard trays and the cleaning process of multiple use trays can have (severe) influence on some tray product systems but this will not lead to a significantly different outcome. Since multiple use trays will always perform better than the single use tray types. Potentially, single use plastic trays can perform better than single use cardboard trays when higher recycling rates are achieved for plastic (60-70%). But it is questionable if this achievable or realistic.

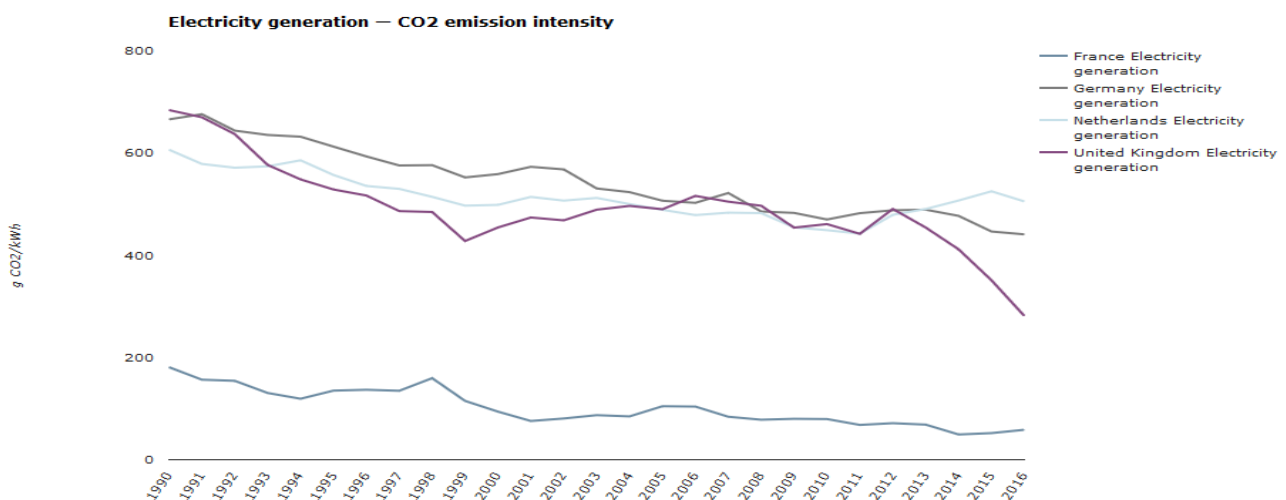


Figure 29: Is electricity production in Europe becoming less carbon intensive? (European Environmental Agency, 2019)

The amount of credits earned for each kWh generated is expected to further decrease over time (European Environment Agency, 2019). This is because European policy is steering towards cleaner grids by implementing more renewable energy in their respective national grids. This means that less impact can be substituted which is least beneficial for single use plastic which gains the most from energy substitution.

7. Conclusion

The main objective of the study was to understand the environmental impacts associated with the use of plastic and cardboard trays and select the most favorite type of tray. The main research question for this study was:

Which tray type (one-way plastic vs one-way cardboard vs returnable plastic) has the best environmental performance?

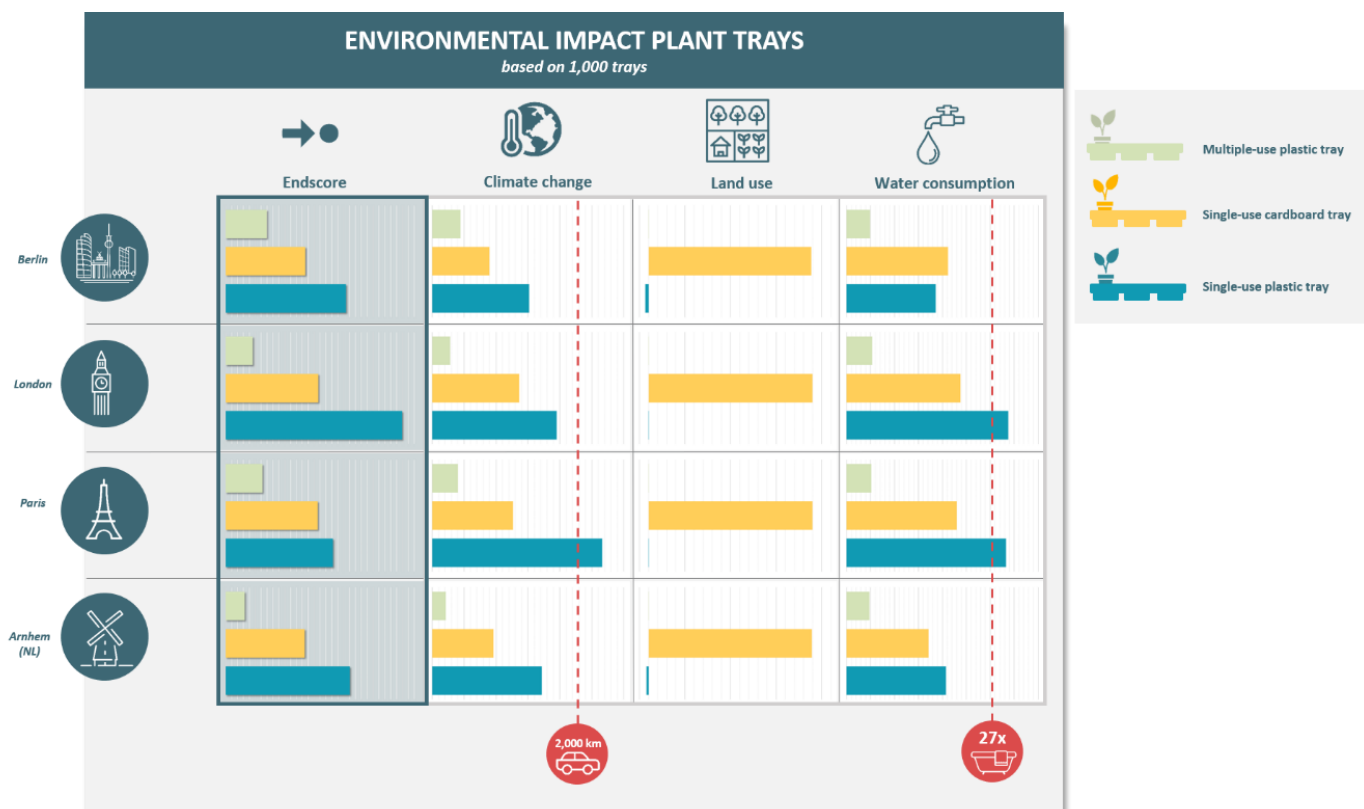


Figure 30: Environmental impact of different plant tray types to different markets

It can be concluded that multiple-use plastic trays have best overall environmental performance for all markets. This type of tray scores best on the most important impact categories (climate change and fossil energy depletion). For some impact categories other tray types might score better (see Appendix VI) than multiple use trays, but these have little influence on the overall single score result.

Second best alternative currently are the single-use cardboard trays. Although the single-use plastic variant scores (see appendix VI) best on most environmental impact categories, it scores worst on the most important impact categories compared to the single-use cardboard variant.

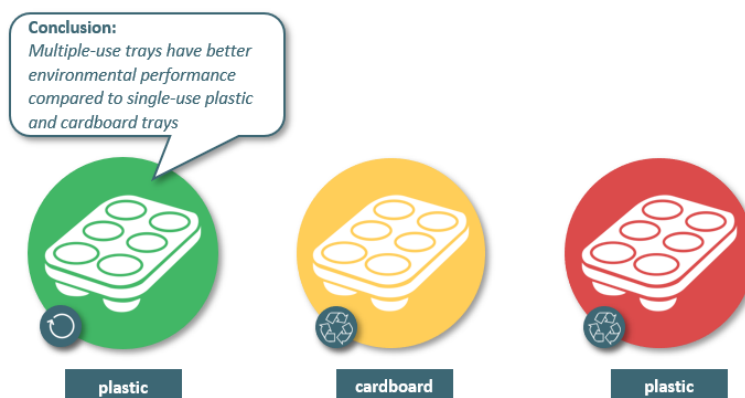


Figure 31 Conclusion: Environmental performance of different plant trays

8. Recommendations

Some recommendation for reducing the environmental impact of different tray types in general, specified for the main important actors in the supply chain and specified per type of tray.

Tray producers:

- Multiple use trays:
 - Make multiple use trays durable (at least Triprate of ~10, but more is always better). Adding more mass to make the trays more durable is eventually more environmentally.
- Single use trays:
 - Reduce the mass of trays.
 - Reduce energy use during production and/or use more renewable energy.
 - Make use of recycled material. This is especially beneficial for plastic trays.
 - Try to produce 'clean' trays:
 - Use ideally one widely available material: which makes recycling easier.
 - Avoid printing & coating of the trays: it adds environmental burden and makes recycling more difficult.

Royal FloraHolland:

- Multiple use trays:
 - Facilitate the use of multiple use trays.
 - Take transport distance to cleaning facility in consideration for next tender.
- Single use trays:
 - Facilitate better recycling of disposed plastic and cardboard.

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Appendix I: Critical review statement

Review statement:

“Comparative Life Cycle Assessment of one-way plant trays versus returnable plant trays”

Commissioned by: Royal FloraHolland

LCA performed by: Blonk consultants

Review team:

Royal Flora Holland has chosen the following review panel members:

- Siem Haffmans (SH) from Partners for innovation (chair),
- Harry van Ewijk (HvE) from SGS Search
- Jeroen Ravensbergen (JR), assisted by Egbert Bok (EB) from Modiform

The review team is composed of an independent chair from a consultancy (Partners for Innovation), a LCA specialist (SGS Search) and an industry specialist (Modiform).

Goal & Scope review

The following feedback is given by the review team on the Goal and Scope report, from 9th December 2016. Only the main comments are listed below, detailed comments are not listed in this table.

Comment review team	Proposal for improvement	Result
First reaction of the review panel is that it is a thorough well executed report and it forms a good basis for the LCA study.	See below...	
1. Introduction		
Second paragraph: ISO 14040 / 14044 compliant study (HvE)	clear	changed
2. Goal and scope definition		
2.2.1. After use can be 'reused' replace by: 'recycled as granular material' (SH) [reuse = product / recycling = material]	clear	changed
2.2.2 The functional unit is 1000 transported trays > Suggestion: The functional unit is 6000 transported plants (SH) [Note: Function of the tray is to transport plants]	Good suggestion	changed
2.2.2. Three countries seems a good choice, but why not also include The Netherlands as home market? (HvE/SH)	Discussed with FloraHolland	added
2.2.2. Why choosing the capital? Seems ok for Germany, but might be too short for FR and UK? (HvE)	Discussed with review team, seems not critical	Not changed
2.3 Trip rate: set as 70 > please give data and calculations for this number (SH) <i>Suggestion: number of trips / year * average years usage * loss percentage</i>	This trip rate is based on numbers from practice from FloraHolland.	Sensitivity analysis done for TR 40 and 10
2.3 Fraction disposed, energy recovery, landfill > <i>might be a higher recycling percentage in Germany (JR) but no data available</i>	No data available. FloraHolland will start a study on this topic to get better data.	Not changed

3. Life Cycle inventory		
EURO4 = very old trucks > standard for this kind of transport is EURO6 and EURO5 (SH)	Good suggestion	Changed to EURO5
80% load factor > <i>is this weight or volume transport?</i> (HvE) ... <i>we think this is volume transport. How is this 80% implemented within the Agri-footprint 2.0 database?</i>	Discussion: It is more volume transport, with the load factor it is possible to adjust the transport to practical situation. Correct load factor needs to be determined.	Not changed in draft report, further research
Different data bases are used (HvE) why? Is the system modelling consistent?	This is the best possible combination	Not changed
Suggestions for Sensitivity analysis		
Different transport scenario's (add also Netherlands)	Discussed with FloraHolland	Done
Recycling percentage of one-way trays (higher percentage might be possible in future)	No data available	Further research
Trip rate: 70 trips > add other trip rates (50 or 40?)	TR might be lower for export	Done
Circular Footprint Formula	Discussed, but no better option found	Not added
Other methods than ReCiPe (PEF or CML)	Discussed, but no better option found	Not added

The following feedback is given by the review team on the Final Draft report, from 27th February 2017. Only the main comments are listed below, detailed comments are not listed in this table.

Comment review team	Proposal for improvement	Result
Why aren't the ReCiPe Midpoint scores presented in absolute terms? This helps for readability for non-experts (SH)	Discussion: Adding absolute midpoint results gives more value to the results	Added
Why aren't the ReCiPe Endpoint scores added to the report? This helps for the readability for non-experts and helps in overall conclusion (SH)	Discussion: Is this allowed in a LCA, according ISO? Yes if the other scores are also presented.	Added
I am not convinced on using the 'circular footprint formula' of the EC, but I understand this choice. An alternative (for the sensibility analysis) is the economical allocation (HvE).	Discussion: Economical allocation also has its constraints.	Not added
3. Life Cycle inventory		
80% load factor > <i>is the load factor of 80% not too optimistic?</i> (HvE)	Discussion: 50% seems a better load factor, although it might be even a little lower, but option 20% is too low.	Changed to 50% in final report
Is only masterbatch used as additive? no other additives? Or are they part of the Masterbatch? (HvE)	Insert brief explanation of Masterbatch	Done
4. Life cycle impact assessment		
By presenting the relative impact, one does not get an understanding of the total impact of a criterion. For example, particulate matter formation could be the criterion with the greatest impact, but from this figure you cannot tell at all as it only presents relative influence. Therefore, this figure does not convey the important message (SH).	See first point	Added

I would suggest to leave out all long-term (>100) emissions from the basic scenario's (by using the SimaPro checkbox) and present >100 as sensitivity analysis (HvE).	This is very much work and will have almost no influence on the final results.	Not changed
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Conclusion of the review team:

The report is adequate, transparent and consistent, and all conclusions have a factual basis.



Siem Haffmans



Harry van Ewijk

Anonymous

Appendix II: Critical review statement update cardboard trays

Review statement

Subject	<p>Comparative Life Cycle Assessment of one-way plant trays versus returnable plant trays</p> <p>Goal: strategic decision making by Royal Flora Holland</p> <p>LCA practitioners: Mike van Paassen, Jasper Scholten; Blonk Consultants</p>
Reviewed by	<p>Siem Haffmans (chair), Partners for Innovation, Amsterdam, The Netherlands</p> <p>Harry van Ewijk, SGS Search, Amsterdam, The Netherlands</p> <p>Marijn Bijleveld, CE Delft, Delft, Netherlands</p>
Review history	<p>First round: 17 February 2020 (Draft report)</p> <p>Panel discussion: 20 February 2020</p> <p>Second round: 2 March 2020 (Final draft report)</p>

We hereby state that the LCA practitioners have performed the comparative LCA study according to the ISO 14040/44 guidelines. In particular:

- Proper definition of the functional unit and scope;
- Proper application of allocation procedures;
- Well-founded scenarios for comparison, including specific and consistent inventory for the respective production systems;
- Well-founded choices for environmental background data;
- Proper execution of sensitivity assessments.

The study outcomes and recommendations therefore are technically valid. The interpretations reflect the limitations identified and the goal of the study.

The full LCA report, as supplied to the review committee for review, is transparent and methodologically complete. All questions and suggestions arising from the draft report were discussed in a very constructive panel meeting and subsequently adequately addressed by the practitioners in the final draft report. With full trust that the few remaining small textual comments will be addressed in the final version, we give our consent to this LCA report.

Siem Haffmans
Amsterdam, 4 March 2020



 Partners for Innovation

Harry van Ewijk
Amsterdam, 4 March 2020



 **SGS** SEARCH

Marijn Bijleveld
Delft, 2 March 2020



 CE Delft

Appendix III: Circular Footprint Formula

The diagram illustrates the Circular Footprint Formula (CFF) for Material, Energy, and Disposal, with arrows linking descriptive text to specific parts of the formula.

Material

Life Cycle Inventory (LCI) of primary material → $(1 - R_1)E_V$

LCI associated to secondary material input → $R_1 \times \left(AE_{recycled} + (1 - A)E_V \times \frac{Q_{Sin}}{Q_P} \right)$

LCI of the material recycling (or part/product reuse) process minus the credit for avoided primary material → $(1 - A)R_2 \times \left(E_{recyclingEoL} - E_V^* \times \frac{Q_{Sout}}{Q_P} \right)$

Energy

→ $(1 - B)R_3 \times (E_{ER} - LHV \times X_{ER,heat} \times E_{SE,heat} - LHV \times X_{ER,elec} \times E_{SE,elec})$

Disposal

→ $(1 - R_2 - R_3) \times E_D$

LCI of the disposal of remaining waste → $(1 - R_2 - R_3) \times E_D$

LCI of the energy recovery process minus the credit for avoided primary energy → $(1 - B)R_3 \times (E_{ER} - LHV \times X_{ER,heat} \times E_{SE,heat} - LHV \times X_{ER,elec} \times E_{SE,elec})$

Figure 32: The circular footprint formula, from European Commission (2018)

The CFF formula applies for materials, energy and disposal, all of these will be applied to quantify the environmental impact of plastic trays. The material and energy part of the CFF are explained in more detail. For all definitions, please see the below overview of parameters (European Commission, 2018):

- A:** Allocation factor of burdens and credits between supplier and user of recycled materials.
- B:** Allocation factor of energy recovery processes: it applies both to burdens and credits.
- Q_{Sin}:** Quality of the ingoing secondary material, i.e. the quality of the recycled material at the point of substitution.
- Q_{Sout}:** Quality of the outgoing secondary material, i.e. the quality of the recyclable material at the point of substitution.
- Q_p:** Quality of the primary material, i.e. quality of the virgin material.
- R1:** It is the proportion of material in the input to the production that has been recycled from a previous system.
- R2:** It is the proportion of the material in the product that will be recycled (or reused) in a subsequent system. R2 shall therefore take into account the inefficiencies in the collection and recycling (or reuse) processes. R2 shall be measured at the output of the recycling plant.
- R3:** It is the proportion of the material in the product that is used for energy recovery at EoL.
- Erecycled (Erec):** Specific emissions and resources consumed (per unit of analysis) arising from the recycling process of the recycled (reused) material, including collection, sorting and transportation process.
- ErecyclingEoL (ErecEoL):** Specific emissions and resources consumed (per unit of analysis) arising from the recycling process at EoL, including collection, sorting and transportation process.
- Ev:** Specific emissions and resources consumed (per unit of analysis) arising from the acquisition and pre-processing of virgin material.

- E*v:** Specific emissions and resources consumed (per unit of analysis) arising from the acquisition and pre-processing of virgin material assumed to be substituted by recyclable materials.
- EER:** Specific emissions and resources consumed (per unit of analysis) arising from the energy recovery process (e.g. incineration with energy recovery, landfill with energy recovery ...).
- ESE,heat and ESE,elec:** Specific emissions and resources consumed (per unit of analysis) that would have arisen from the specific substituted energy source, heat and electricity respectively.
- ED:** Specific emissions and resources consumed (per unit of analysis) arising from disposal of waste material at the EoL of the analysed product, without energy recovery.
- XER,heat and XER,elec:** The efficiency of the energy recovery process for both heat and electricity.
- LHV:** Lower Heating Value of the material in the product that is used for energy recovery.

Material: allocating secondary material in- and output

The circular footprint formula for material consists of three different parts. Most important variable for the CFF formula for materials is the allocation factor of burdens and credits between supplier and user of recycled materials (given as 'A' in the equation).

The first two parts (containing the R1 parameters) deal with the emissions associated with the use of materials. The R1 parameter itself is the proportion of material in the input to the production that has been recycled from previous systems. This equation will be used to quantify the impact of tray production appropriately.

The third part of the equation (containing the R2 parameters) addresses "burdens and benefits related to secondary output". This part of the CFF will be used to quantify the emissions related to materials of the tray product system at end-of-life stage.

Energy: allocating recovered heat and electricity from plastic

The circular footprint formula for energy recovery consists of three different parts. Most important component for all three parts is the allocation factor of the energy recovery process (given as 'B' in the equation). The first part is about the emissions associated with the incineration of plastic. Based on the allocation factor, a certain fraction is assigned to the tray product system. Hereby all the emissions of plastic incineration are partitioned.

Second part of the formula calculates the amount of recovered energy from plastic. This is based on the lower heating value (LHV) of the specific type of plastic and the heat efficiency of the incineration process. Again, the allocation factor (B) determines the fraction of recovered heat assigned to the plastic product system. Finally, the recovered heat assigned to the tray product system is substituted from the system. This will be used to solve the allocation problem of recovered heat.

Disposal of plastic

The disposal part of the CFF does not concern allocation, but calculates the emissions associated with plastic disposal, which are also considered in this study. Because there is no additional function of landfilled plastic besides waste processing of plastic trays, the emissions associated with landfilling are fully assigned to the plastic tray system.

Appendix IV: Energy recovery at incineration

The electrical and heat efficiency of the incineration plants are derived from country specific statistics from the Confederation of European Waste-to-Energy Plants (CEWEP). Using the amount of waste that is incinerated in 2010 for Germany, France, United Kingdom and The Netherlands (CEWEP, 2013) and the amount of heat and electricity that is produced from that same year (CEWEP, 2011) the electrical and heat efficiency from waste could be calculated. These efficiencies are used to determine the amount of avoided electricity for all reference flows in the study. Overview of the statistics and calculation is shown in the table below.

Table 10: Calculation for the electrical and heat efficiency of incineration processes for the different countries, based on CEWEP statistics (CEWEP, 2011, 2013).

Country	Total waste incinerated (Million tonnes)	Total heat generated (Million MWh)	Electricity produced (Million MWh)	Heat produced (Million MWh)	Electrical Efficiency MSWI	Heat efficiency MSWI	Total efficiency MSWI
Germany	20.0	55.6	18.0	8.0	32.4%	14.4%	46.8%
France	13.7	38.1	7.5	3.7	19.7%	9.7%	29.4%
United Kingdom	4.2	11.2	1.0	1.4	8.6%	12.0%	20.6%
The Netherlands	6.5	18.1	4.1	0.8	22.7%	4.4%	27.1%

Appendix V: Background data

The following background datasets are used for this study.

Background data used	Library	Used for	Parameter CFF
Carbon black {GLO} production APOS	Ecoinvent 3.5 - allocation at point of substitution	Additive plastic	
Diesel, burned in agricultural machinery {GLO} diesel, burned in agricultural machinery APOS	Ecoinvent 3.5 - allocation at point of substitution	Heat used in tray production	
Electricity, high voltage {BE} production mix APOS	Ecoinvent 3.5 - allocation at point of substitution	Electricity used in tray production	
Electricity, high voltage {DE} production mix APOS	Ecoinvent 3.5 - allocation at point of substitution	Electricity used in tray production	
Electricity, high voltage {GB} production mix APOS	Ecoinvent 3.5 - allocation at point of substitution	Electricity used in tray production	
Electricity, high voltage {NL} production mix APOS	Ecoinvent 3.5 - allocation at point of substitution	Electricity used in tray production for non-Anonymous5 trays	
Electricity, high voltage {Anonymous5} production mix APOS	Adjusted mix based on company specific information	Electricity used in tray production – specific for Anonymous5 production in NL	
Electricity, low voltage {DE} market for APOS	Ecoinvent 3.5 - allocation at point of substitution	Electricity substitution	Ese,elec
Electricity, low voltage {FR} market for APOS	Ecoinvent 3.5 - allocation at point of substitution	Electricity substitution	Ese,elec
Electricity, low voltage {GB} market for APOS	Ecoinvent 3.5 - allocation at point of substitution	Electricity substitution	Ese,elec
Electricity, low voltage {NL} market for APOS	Ecoinvent 3.5 - allocation at point of substitution	Electricity substitution	Ese,elec
Ethylene vinyl acetate copolymer {RER} production APOS	Ecoinvent 3.5 - allocation at point of substitution	Proxy for glue used	
Fluting medium {RER} production, semichemical APOS	Ecoinvent 3.5 - allocation at point of substitution	Production virgin fluting medium	Ev
Fluting medium {RER} treatment of recovered paper to, wellenstoff APOS	Ecoinvent 3.5 - allocation at point of substitution	Production secondary fluting medium	Erecycled
Heat, district or industrial, natural gas {BE} heat and power co-generation, natural gas, conventional power plant, 100MW electrical APOS	Ecoinvent 3.5 - allocation at point of substitution	Heat used in production	
Heat, district or industrial, natural gas {DE} heat and power co-generation, natural gas, conventional power plant, 100MW electrical APOS	Ecoinvent 3.5 - allocation at point of substitution	Heat substitution	Ese,heat

Heat, district or industrial, natural gas {FR} heat and power co-generation, natural gas, conventional power plant, 100MW electrical APOS	Ecoinvent 3.5 - allocation at point of substitution	Heat substitution	Ese,heat
Heat, district or industrial, natural gas {GB} heat and power co-generation, natural gas, conventional power plant, 100MW electrical APOS	Ecoinvent 3.5 - allocation at point of substitution	Heat substitution	Ese,heat
Heat, district or industrial, natural gas {NL} heat and power co-generation, natural gas, conventional power plant, 100MW electrical APOS	Ecoinvent 3.5 - allocation at point of substitution	Energy used & produced	Ese,heat
Linerboard {RER} production, kraftliner APOS	Ecoinvent 3.5 - allocation at point of substitution	Production virgin linerboard	Ev
Linerboard {RER} treatment of recovered paper to, testliner APOS	Ecoinvent 3.5 - allocation at point of substitution	Production linerboard secondary	Erecycled
Polyethylene, high density, granulate {RER} production APOS	Ecoinvent 3.5 - allocation at point of substitution	Production virgin HDPE granulate	Ev
Polypropylene, granulate {RER} production APOS	Ecoinvent 3.5 - allocation at point of substitution	Production virgin PP granulate	Ev
Polystyrene scrap, post-consumer {GLO} market for APOS	Ecoinvent 3.5 - allocation at point of substitution	Production secondary plastic	ErecycledEol
Polystyrene scrap, post-consumer {GLO} market for APOS	Ecoinvent 3.5 - allocation at point of substitution	Impact substitution plastic when recycled	E*v
Polystyrene, general purpose {RER} production APOS	Ecoinvent 3.5 - allocation at point of substitution	Production virgin polystyrene	Ev
Sodium hydroxide, without water, in 50% solution state {GLO} market for APOS	Ecoinvent 3.5 - allocation at point of substitution	Cleaning trays	
Tap water {Europe without Switzerland} tap water production, conventional treatment APOS	Ecoinvent 3.5 - allocation at point of substitution	Cleaning trays	
Transport, sea ship, 15000 DWT, 50%LF, short, default/GLO Economic	Agri-footprint allocation	5.0 - economic	Transport
Transport, truck >20t, EURO5, 20%LF, default/GLO Economic	Agri-footprint allocation	5.0 - economic	Transport
Transport, truck >20t, EURO5, 20%LF, empty return/GLO Economic	Agri-footprint allocation	5.0 - economic	Transport
Transport, truck >20t, EURO5, 50%LF, default/GLO Economic	Agri-footprint allocation	5.0 - economic	Transport
Transport, truck >20t, EURO5, 50%LF, empty return/GLO Economic	Agri-footprint allocation	5.0 - economic	Transport
Transport, truck >20t, EURO5, 80%LF, default/GLO Economic	Agri-footprint allocation	5.0 - economic	Transport
Transport, truck >20t, EURO5, 80%LF, empty return/GLO Economic	Agri-footprint allocation	5.0 - economic	Transport
Waste paperboard {RoW} treatment of, municipal incineration APOS	Ecoinvent 3.5 - allocation at point of substitution	Incineration cardboard	Eer

Waste paperboard {RoW} treatment of, sanitary landfill APOS	Ecoinvent 3.5 - allocation at point of substitution	Landfilling cardboard	Ed
Waste paperboard, sorted {Europe without Switzerland} treatment of waste paperboard, sorting plant APOS	Ecoinvent 3.5 - allocation at point of substitution	Production cardboard secondary	Erecycled
Waste paperboard, sorted {Europe without Switzerland} treatment of waste paperboard, sorting plant APOS	Ecoinvent 3.5 - allocation at point of substitution	Impact recycling	ErecycledEol
Waste polyethylene {RoW} treatment of waste polyethylene, municipal incineration APOS	Ecoinvent 3.5 - allocation at point of substitution	Incineration PE	Eer
Waste polyethylene {RoW} treatment of waste polyethylene, sanitary landfill APOS	Ecoinvent 3.5 - allocation at point of substitution	Landilling PE	Ed
Waste polypropylene {RoW} treatment of waste polypropylene, municipal incineration APOS	Ecoinvent 3.5 - allocation at point of substitution	Incineration PP	Eer
Waste polypropylene {RoW} treatment of waste polypropylene, sanitary landfill APOS	Ecoinvent 3.5 - allocation at point of substitution	Landilling PP	Ed
Waste polystyrene {RoW} treatment of waste polystyrene, municipal incineration APOS	Ecoinvent 3.5 - allocation at point of substitution	Incineration PS	Eer
Waste polystyrene {RoW} treatment of waste polystyrene, sanitary landfill APOS	Ecoinvent 3.5 - allocation at point of substitution	Landilling PS	Ed
Wood chips, dry, measured as dry mass {RER} market for APOS	Ecoinvent 3.5 - allocation at point of substitution	Impact substitution cardboard when recycled	E*v

Appendix VI: Absolute LCIA results at mid-point

Remember that the results are presented in their functional unit: impact of trays used to transport 6000 transported plants. This requires 1000 trays for all alternatives.

Impact of trays to Germany

Table 11: Absolute midpoint results for trays used for transporting plants to Berlin

Impact category	Unit	Floratio	Normpack306	FC 736	Normpack 236	Closed cardboard	Open cardboard	Paper pulp tray	Solid board
Global warming	kg CO2 eq	1.094E+02	3.705E+02	6.804E+01	2.360E+02	2.186E+02	1.361E+02	2.019E+02	1.636E+02
Stratospheric ozone depletion	kg CFC11 eq	2.507E-05	-5.905E-05	1.151E-05	-2.660E-05	2.152E-04	1.684E-04	1.891E-04	1.793E-04
Ionizing radiation	kBq Co-60 eq	6.171E-01	-3.834E+01	-1.182E+00	-2.182E+01	2.215E+01	2.376E+01	3.618E+01	3.460E+01
Ozone formation, Human health	kg NOx eq	5.517E-01	4.248E-01	4.301E-01	2.732E-01	8.584E-01	6.948E-01	6.726E-01	5.389E-01
Fine particulate matter formation	kg PM2.5 eq	8.613E-02	1.217E-01	5.694E-02	8.153E-02	3.407E-01	2.467E-01	2.967E-01	2.118E-01
Ozone formation, Terrestrial ecosystems	kg NOx eq	5.558E-01	4.430E-01	4.319E-01	2.842E-01	8.786E-01	7.090E-01	6.808E-01	5.515E-01
Terrestrial acidification	kg SO2 eq	2.760E-01	2.842E-01	1.852E-01	1.951E-01	8.784E-01	6.195E-01	8.348E-01	5.273E-01
Freshwater eutrophication	kg P eq	-2.794E-04	-2.558E-01	-8.690E-03	-1.419E-01	1.749E-01	8.700E-02	6.337E-02	6.621E-02
Marine eutrophication	kg N eq	1.014E-04	-1.630E-02	-4.888E-04	-9.028E-03	2.500E-02	1.783E-02	1.681E-02	1.976E-02
Terrestrial ecotoxicity	kg 1,4-DCB	1.477E+02	3.222E+01	1.107E+02	2.549E+01	7.733E+02	5.583E+02	5.272E+02	4.932E+02
Mineral resource scarcity	kg Cu eq	3.361E-02	-1.168E-01	-3.640E-03	-2.911E-02	7.172E-01	5.563E-01	1.114E+00	6.461E-01
Fossil resource scarcity	kg oil eq	3.584E+01	8.450E+01	2.021E+01	5.528E+01	6.024E+01	4.100E+01	6.441E+01	4.381E+01
Water consumption	m3	9.801E-01	2.160E+00	-6.309E-04	1.572E+00	1.855E+00	1.786E+00	2.189E+00	2.651E+00

Impact of trays to France

Table 12: Absolute midpoint results for trays used for transporting plants to Paris

Impact category	Unit	Floratino	Normpack 306	FC 736	Normpack 236	Closed cardboard	Open cardboard	Paper pulp tray	Solid board
Global warming	kg CO2 eq	1.020E+02	6.597E+02	6.001E+01	4.046E+02	3.133E+02	2.074E+02	2.608E+02	2.311E+02
Stratospheric ozone depletion	kg CFC11 eq	2.505E-05	4.525E-05	1.128E-05	3.417E-05	2.407E-04	1.944E-04	2.049E-04	1.976E-04
Ionizing radiation	kBq Co-60 eq	-2.372E+00	-1.229E+02	-4.051E+00	-7.106E+01	1.112E+01	1.582E+01	2.957E+01	2.657E+01
Ozone formation, Human health	kg NOx eq	4.546E-01	7.397E-01	3.308E-01	4.588E-01	9.070E-01	7.520E-01	7.163E-01	5.732E-01
Fine particulate matter formation	kg PM2.5 eq	7.674E-02	2.983E-01	4.707E-02	1.846E-01	3.753E-01	2.749E-01	3.194E-01	2.384E-01
Ozone formation, Terrestrial ecosystems	kg NOx eq	4.588E-01	7.684E-01	3.326E-01	4.759E-01	9.280E-01	7.668E-01	7.250E-01	5.864E-01
Terrestrial acidification	kg SO2 eq	2.465E-01	9.043E-01	1.541E-01	5.570E-01	1.003E+00	7.192E-01	9.157E-01	6.225E-01
Freshwater eutrophication	kg P eq	9.191E-03	1.469E-02	4.261E-04	1.548E-02	2.571E-01	1.462E-01	1.126E-01	1.260E-01
Marine eutrophication	kg N eq	8.610E-04	1.000E-02	2.223E-04	6.280E-03	4.187E-02	3.012E-02	2.692E-02	3.203E-02
Land use	m2a crop eq	1.295E+02	1.786E+02	9.174E+01	1.112E+02	8.307E+02	6.046E+02	5.649E+02	5.317E+02
Mineral resource scarcity	kg Cu eq	1.618E+00	1.512E+01	6.804E-01	9.149E+00	6.694E+00	5.073E+00	5.821E+00	5.375E+00
Fossil resource scarcity	kg oil eq	2.333E+00	2.184E+01	1.069E+00	1.319E+01	9.714E+00	7.343E+00	8.260E+00	7.719E+00
Water consumption	m3	8.788E-01	8.153E+00	1.226E-01	5.244E+00	1.022E+01	7.910E+00	8.977E+00	7.762E+00

Impact of trays to Great Britain

Table 13: Absolute midpoint results for trays used for transporting plants to London

Impact category	Unit	Floratino	Normpack 306	FC 736	Normpack 236	Closed cardboard	Open cardboard	Paper pulp tray	Solid board
Global warming	kg CO2 eq	7.717E+01	4.786E+02	3.576E+01	3.012E+02	3.389E+02	2.236E+02	2.739E+02	2.519E+02
Stratospheric ozone depletion	kg CFC11 eq	2.086E-05	3.979E-05	7.094E-06	3.492E-05	2.367E-04	1.962E-04	2.020E-04	1.952E-04
Ionizing radiation	kBq Co-60 eq	1.671E+00	-1.091E+00	-1.731E-01	-3.621E+00	3.243E+01	3.117E+01	4.234E+01	4.208E+01
Ozone formation, Human health	kg NOx eq	3.644E-01	6.534E-01	2.407E-01	3.995E-01	8.946E-01	7.291E-01	6.943E-01	5.676E-01
Fine particulate matter formation	kg PM2.5 eq	7.201E-02	2.816E-01	4.246E-02	1.642E-01	3.750E-01	2.730E-01	3.172E-01	2.367E-01
Ozone formation, Terrestrial ecosystems	kg NOx eq	3.682E-01	6.795E-01	2.422E-01	4.152E-01	9.157E-01	7.438E-01	7.030E-01	5.808E-01
Terrestrial acidification	kg SO2 eq	2.311E-01	8.323E-01	1.391E-01	4.840E-01	9.989E-01	7.106E-01	9.070E-01	6.150E-01
Freshwater eutrophication	kg P eq	9.089E-03	5.464E-03	3.186E-04	1.389E-02	2.564E-01	1.458E-01	1.122E-01	1.256E-01
Marine eutrophication	kg N eq	1.002E-03	1.626E-02	3.435E-04	1.012E-02	5.088E-02	3.670E-02	3.232E-02	3.859E-02
Land use	m2a crop eq	4.410E-01	2.453E-01	8.344E-03	-2.470E-01	2.011E+02	2.384E+02	9.227E+01	1.869E+02
Mineral resource scarcity	kg Cu eq	4.207E-02	1.314E-01	4.410E-03	1.330E-01	7.995E-01	6.198E-01	1.163E+00	7.060E-01
Fossil resource scarcity	kg oil eq	2.699E+01	1.534E+02	1.117E+01	9.598E+01	7.195E+01	4.957E+01	7.142E+01	5.256E+01
Water consumption	m3	1.025E+00	3.994E+00	4.409E-02	2.764E+00	2.181E+00	2.055E+00	2.384E+00	2.889E+00

Impact of trays to Netherlands

Table 14: Absolute midpoint results for trays used for transporting plants to Arnhem

Impact category	Unit	Floratino	Normpack 306	FC 736	Normpack 236	Closed cardboard	Open cardboard	Paper pulp tray	Solid board
Global warming	kg CO2 eq	6.403E+01	4.215E+02	2.313E+02	2.214E+01	2.657E+02	1.452E+02	2.095E+02	1.794E+02
Stratospheric ozone depletion	kg CFC11 eq	1.602E-05	-6.634E-06	2.292E-04	2.278E-06	3.905E-06	1.789E-04	1.975E-04	1.900E-04
Ionizing radiation	kBq Co-60 eq	1.447E+00	-1.306E+01	2.976E+01	-3.883E-01	-7.109E+00	2.923E+01	4.074E+01	4.014E+01
Ozone formation, Human health	kg NOx eq	2.338E-01	4.018E-01	8.144E-01	1.089E-01	2.599E-01	6.634E-01	6.462E-01	5.150E-01
Fine particulate matter formation	kg PM2.5 eq	4.476E-02	1.666E-01	3.490E-01	1.506E-02	1.077E-01	2.527E-01	3.017E-01	2.191E-01
Ozone formation, Terrestrial ecosystems	kg NOx eq	2.369E-01	4.200E-01	8.345E-01	1.097E-01	2.709E-01	6.775E-01	6.544E-01	5.275E-01
Terrestrial acidification	kg SO2 eq	1.415E-01	4.801E-01	9.203E-01	4.896E-02	3.091E-01	6.498E-01	8.599E-01	5.618E-01
Freshwater eutrophication	kg P eq	6.607E-03	-5.888E-02	2.342E-01	-2.085E-03	-2.733E-02	1.297E-01	9.890E-02	1.094E-01
Marine eutrophication	kg N eq	5.142E-04	-2.639E-03	2.967E-02	-9.674E-05	-1.077E-03	2.120E-02	1.961E-02	2.466E-02
Land use	m2a crop eq	8.084E+01	1.576E+02	8.033E+02	4.300E+01	9.846E+01	5.799E+02	5.452E+02	5.168E+02
Mineral resource scarcity	kg Cu eq	1.183E+00	3.009E+00	5.193E+00	2.970E-01	2.099E+00	3.834E+00	4.920E+00	4.336E+00
Fossil resource scarcity	kg oil eq	1.680E+00	5.033E+00	7.720E+00	4.888E-01	3.407E+00	5.698E+00	7.060E+00	6.344E+00
Water consumption	m3	6.937E-01	2.534E+00	9.054E+00	-5.091E-02	1.975E+00	6.915E+00	8.275E+00	6.915E+00

Appendix VII: Absolute LCIA single score results

Remember that the results are presented in their functional unit: impact of trays used to transport 6000 transported plants. This requires 1000 trays for all alternatives.

Impact of trays to Germany

Table 15: Absolute single score results for trays used for transporting plants to Berlin

Impact category	Unit	Floratino	Normpack 306	FC 736	Normpack 236	Closed cardboard	Open cardboard	Paper pulp tray	Solid board
Global warming	Pt	3.110	10.532	1.934	6.710	6.216	3.869	5.739	4.651
Stratospheric ozone depletion	Pt	0.000	-0.001	0.000	0.000	0.003	0.003	0.003	0.003
Ionizing radiation	Pt	0.000	-0.010	0.000	-0.005	0.006	0.006	0.009	0.009
Ozone formation, Human health	Pt	0.015	0.011	0.011	0.007	0.023	0.019	0.018	0.014
Fine particulate matter formation	Pt	1.588	2.241	1.050	1.501	6.276	4.545	5.464	3.902
Ozone formation, Terrestrial ecosystems	Pt	0.031	0.025	0.024	0.016	0.049	0.040	0.038	0.031
Terrestrial acidification	Pt	0.026	0.026	0.017	0.018	0.081	0.057	0.077	0.049
Freshwater eutrophication	Pt	0.000	-0.075	-0.003	-0.041	0.051	0.025	0.019	0.019
Marine eutrophication	Pt	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Terrestrial ecotoxicity	Pt	0.001	0.000	0.001	0.000	0.004	0.003	0.003	0.002
Freshwater ecotoxicity	Pt	0.000	-0.002	0.000	-0.001	0.001	0.001	0.001	0.001
Marine ecotoxicity	Pt	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Human carcinogenic toxicity	Pt	0.037	-0.669	-0.034	-0.341	0.605	0.473	0.640	0.472
Human non-carcinogenic toxicity	Pt	0.065	-0.028	-0.011	0.033	0.921	0.704	0.889	0.764
Land use	Pt	0.001	-0.018	0.000	-0.010	0.772	0.917	0.353	0.718
Mineral resource scarcity	Pt	0.006	-0.022	-0.001	-0.005	0.135	0.105	0.208	0.122
Fossil resource scarcity	Pt	12.245	38.185	7.752	23.340	15.502	12.226	16.728	13.061
Water consumption	Pt	0.064	0.158	0.001	0.100	0.096	0.089	0.138	0.158
Single score result	Pt	17.188	50.354	10.741	31.321	30.741	23.083	30.328	23.976

Impact of trays to France

Table 16: Absolute single score results for trays used for transporting plants to Paris

Impact category	Unit	Floratino	Normpack 306	FC 736	Normpack 236	Closed cardboard	Open cardboard	Paper pulp tray	Solid board
Global warming	Pt	2.899	18.756	1.706	11.504	8.908	5.897	7.415	6.572
Stratospheric ozone depletion	Pt	0.000	0.001	0.000	0.001	0.004	0.003	0.003	0.003
Ionizing radiation	Pt	-0.001	-0.031	-0.001	-0.018	0.003	0.004	0.007	0.007
Ozone formation, Human health	Pt	0.012	0.020	0.009	0.012	0.024	0.020	0.019	0.015
Fine particulate matter formation	Pt	1.414	5.494	0.868	3.400	6.914	5.065	5.883	4.392
Ozone formation, Terrestrial ecosystems	Pt	0.026	0.043	0.019	0.027	0.052	0.043	0.041	0.033
Terrestrial acidification	Pt	0.023	0.084	0.014	0.051	0.093	0.066	0.085	0.058
Freshwater eutrophication	Pt	0.003	0.004	0.000	0.005	0.075	0.043	0.033	0.037
Marine eutrophication	Pt	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Terrestrial ecotoxicity	Pt	0.001	0.001	0.000	0.001	0.004	0.003	0.003	0.003
Freshwater ecotoxicity	Pt	0.000	0.005	0.000	0.003	0.002	0.002	0.002	0.002
Marine ecotoxicity	Pt	0.000	0.001	0.000	0.001	0.000	0.000	0.000	0.000
Human carcinogenic toxicity	Pt	0.086	0.794	0.012	0.510	0.995	0.770	0.874	0.756
Human non-carcinogenic toxicity	Pt	0.145	3.544	0.063	2.112	1.437	1.096	1.199	1.139
Land use	Pt	0.002	0.002	0.000	0.002	0.779	0.922	0.357	0.723
Mineral resource scarcity	Pt	0.007	-0.002	0.000	0.006	0.145	0.112	0.214	0.129
Fossil resource scarcity	Pt	10.971	56.003	6.447	33.739	16.423	13.208	17.526	13.569
Water consumption	Pt	0.065	0.258	0.002	0.158	0.102	0.095	0.142	0.162
Single score result	Pt	15.653	84.977	9.139	51.514	35.960	27.349	33.803	27.600

Impact of trays to Great Britain

Table 17: Absolute single score results for trays used for transporting plants to London

Impact category	Unit	Floratino	Normpack 306	FC 736	Normpack 236	Closed cardboard	Open cardboard	Paper pulp tray	Solid board
Global warming	Pt	2.194	13.607	1.017	8.564	9.638	6.359	7.790	7.163
Stratospheric ozone depletion	Pt	0.000	0.001	0.000	0.001	0.004	0.003	0.003	0.003
Ionizing radiation	Pt	0.000	0.000	0.000	-0.001	0.008	0.008	0.011	0.010
Ozone formation, Human health	Pt	0.010	0.017	0.006	0.011	0.024	0.019	0.019	0.015
Fine particulate matter formation	Pt	1.327	5.186	0.783	3.023	6.908	5.030	5.843	4.361
Ozone formation, Terrestrial ecosystems	Pt	0.021	0.038	0.014	0.023	0.051	0.042	0.040	0.033
Terrestrial acidification	Pt	0.021	0.077	0.013	0.045	0.092	0.066	0.084	0.057
Freshwater eutrophication	Pt	0.003	0.002	0.000	0.004	0.075	0.043	0.033	0.037
Marine eutrophication	Pt	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Terrestrial ecotoxicity	Pt	0.000	0.001	0.000	0.001	0.004	0.003	0.003	0.003
Freshwater ecotoxicity	Pt	0.000	0.006	0.000	0.003	0.002	0.002	0.002	0.002
Marine ecotoxicity	Pt	0.000	0.001	0.000	0.001	0.000	0.000	0.000	0.000
Human carcinogenic toxicity	Pt	0.084	0.625	0.011	0.416	0.985	0.774	0.868	0.748
Human non-carcinogenic toxicity	Pt	0.147	3.990	0.064	2.386	1.487	1.146	1.228	1.176
Land use	Pt	0.002	0.001	0.000	-0.001	0.778	0.921	0.357	0.722
Mineral resource scarcity	Pt	0.008	0.025	0.001	0.025	0.151	0.117	0.217	0.133
Fossil resource scarcity	Pt	8.537	50.552	4.003	30.684	16.060	12.670	17.063	13.557
Water consumption	Pt	0.066	0.261	0.002	0.162	0.107	0.100	0.145	0.166
Single score result	Pt	12.420	74.390	5.914	45.347	36.374	27.303	33.706	28.186

Impact of trays to The Netherlands

Table 18: Absolute single score results for trays used for transporting plants to Arnhem

Impact category	Unit	Floratio	Normpack 306	FC 736	Normpack 236	Closed cardboard	Open cardboard	Paper pulp tray	Solid board
Global warming	Pt	1.820	11.982	0.629	7.554	6.576	4.129	5.955	5.101
Stratospheric ozone depletion	Pt	0.000	0.000	0.000	0.000	0.004	0.003	0.003	0.003
Ionizing radiation	Pt	0.000	-0.003	0.000	-0.002	0.007	0.007	0.010	0.010
Ozone formation, Human health	Pt	0.006	0.011	0.003	0.007	0.022	0.018	0.017	0.014
Fine particulate matter formation	Pt	0.825	3.069	0.278	1.983	6.430	4.657	5.557	4.038
Ozone formation, Terrestrial ecosystems	Pt	0.013	0.024	0.006	0.015	0.047	0.038	0.037	0.030
Terrestrial acidification	Pt	0.013	0.044	0.005	0.029	0.085	0.060	0.079	0.052
Freshwater eutrophication	Pt	0.002	-0.017	-0.001	-0.008	0.068	0.038	0.029	0.032
Marine eutrophication	Pt	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Terrestrial ecotoxicity	Pt	0.000	0.001	0.000	0.000	0.004	0.003	0.003	0.003
Freshwater ecotoxicity	Pt	0.000	0.001	0.000	0.001	0.002	0.001	0.001	0.001
Marine ecotoxicity	Pt	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Human carcinogenic toxicity	Pt	0.068	0.247	-0.005	0.192	0.881	0.673	0.806	0.673
Human non-carcinogenic toxicity	Pt	0.092	1.089	0.015	0.683	1.245	0.939	1.083	1.009
Land use	Pt	0.001	-0.011	0.000	-0.006	0.774	0.919	0.355	0.720
Mineral resource scarcity	Pt	0.006	-0.020	-0.001	-0.004	0.136	0.105	0.208	0.122
Fossil resource scarcity	Pt	6.817	35.412	2.272	21.726	13.921	11.089	15.781	12.064
Water consumption	Pt	0.064	0.169	0.001	0.107	0.099	0.092	0.140	0.161
Single score result	Pt	9.727	51.998	3.202	32.277	30.301	22.771	30.064	24.033

Appendix VIII: Explanation of the LCA methodology

Life Cycle Assessment (LCA) is a method to evaluate and quantify the environmental impact of a product or service. Life Cycle Assessment captures the whole supply chain (from cradle to grave) with its individual stages. From raw-material production, production, distribution, transportation, use and disposal of a specific product (or service). Different environmental impacts are assessed, for instance greenhouse gas emissions, water consumption and fossil depletion.

The goal of an LCA is to get insights in the environmental impacts of a product or service, by quantifying all inputs and outputs of material flows. The results of an LCA can be applied for product development, strategic planning, marketing and communication towards customers.



Figure 33: Example of life cycle approach

Why measure the impact?

There are different motives to assess the impact of a product. Some examples are: decouple environmental impact from growth, reduce resource depletion and create novel products (for example alternative protein sources, energy efficient solutions), establish cost reduction, raise public awareness and involvement (for example regarding deforestation, sustainable fishing, healthy and sustainable nutrition), adaptation of healthy lifestyles.

Steps of an LCA

In order to review all the inputs and outputs and calculate the environmental impacts various steps need to be undertaken. The International Organisation for Standardisation (ISO) provides guidelines related to LCA (ISO 14040 and 14044 (ISO, 2006a, 2006b)). Four different steps are proposed, each of them are explained in more detail.

1. Goal & Scope definition

The first step of goal and scope definition involves the stating and justification of the whole study. First, the goal of the study is explained, together with its primary intentions, followed by the intended audience and the involved parties of the study. In order to define the goal of the study the following questions need to be answered: 'What is the reason for carrying out the study?', 'What is the intended application?' and 'What is the targeted audience of the deliverables?'.

The scope definition phase establishes the main characteristics of the whole study. What to analyse and how? The product system is introduced and the scope of the analysed product system is explained (e.g. cradle-to-grave or cradle-to-gate). Hereby, the following items are important to outline: function, functional unit, alternatives and reference flow(s) of the product(s). Eventually, the results and comparison will be based on the reference flow(s).

2. Inventory analysis: Data collection

The life cycle inventory (LCI) stage estimates the consumption of resources and quantifies the waste flows and emissions caused or attributable to the tray's life cycle. LCA, each and every flow should be followed until its economic inputs and outputs have all been translated into environmental interventions (=emission or resource), from economy to environment or vice versa. To do this, three different system boundaries need to be defined:

- Economy-environmental system boundary: describes which processes belong to the economy and environment.
- Cut-off: discusses the processes that are irrelevant or not taken into consideration during the whole LCA study.

- Allocation: assigning the environmental impacts of multifunctional systems. Three different multifunctional processes exist: coproduction, recycling and combined waste processing. In each of the scenarios the environmental impacts need to be allocated over the different functional flows. The allocation method can either be based on physical properties of the flows (mass or energy content), economic value or substitution (avoided product).

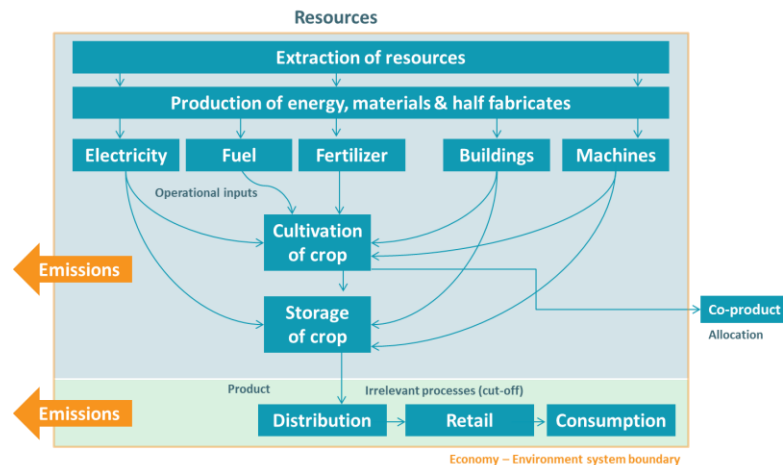


Figure 34: Example of the cradle-to-gate system boundaries that is applied for agricultural products.

At this stage data needs to be collected and modelled. This forms the main part of the LCA studies. It gives inputs for the Life Cycle Impact Assessment and gives feedback to the initial scope setting. The collected data consists preferably of primary data for the most important processes, the so-called fore-ground processes. Economic flows of these foreground processes are connected to so-called background processes to include inventory data from up- and downstream processes. Background databases can be used for this purpose, examples include Agri-footprint®, ELCD and Ecoinvent database. Result of the LCI is the inventory table, an extensive list of environmental interventions.

3. Impact Assessment

During the life cycle impact assessment (LCIA) the inventory tables from the LCI are used to determine the environmental impact of reference flows for different impact categories. This is done by first selecting the impact categories that are relevant for the study. This depends on the type and goal & scope of the study. More information about impact categories, in the next paragraphs.

Next step is to translate the inventory table into impact indicator results (impact categories). This is usually performed using specialized software, like Simapro. The following steps are performed to get from the inventory table to impact category results. This can be best explained using the impact category “climate change” as example, but works similarly for all impact categories.

- Classification – the software classifies the emitted greenhouse gasses from the inventory table. Hereby all, non-greenhouse gasses are left out from the analysis for this impact category.
- Characterisation – the impact of each greenhouse is calculated based on the mass and potency of the greenhouse gas in respect to the indicator unit. The indicator unit for global warming at mid-point level is kg CO₂-equivalents. Each kg of emitted carbon dioxide is 1 kg CO₂-eq., however methane is a more potent greenhouse gas and each kg of emitted methane is equivalent to 25 kg of CO₂. The potency of the greenhouse gasses or “characterisation factors” for greenhouse gasses are derived from IPCC and updated from time to time.
- Normalisation – this is an optional step to compare the significance of the footprint to the total impact of the world or European region. This can give an idea about the significance of the category impact.
- Weighting - this is an optional step to aggregate indicator results of various impact categories into a single score. However, weighting has always been a controversial issue in LCA studies (Finnveden, Eldh, & Johansson, 2006) and is therefore usually not performed.

4. Interpretation

The final phase of the LCA discusses the overall result from the previous steps. Interpretation begins with a consistency and completeness check to determine the soundness of the study. The contribution and sensitivity analysis helps to bolster the robustness of the results in preparation of the discussion and conclusion of the report. Each of the four optional steps are discussed in more detail.

- Consistency check: the objective of the consistency check is to determine whether assumptions, methods, models and data are consistent with the goal and scope of the study.
- Completeness check: ensure that the information and data used for this study are available and complete.
- Contribution analysis: illustrates the main contributing processes for each impact category. This helpful in understanding the product system(s) better.
- Sensitivity analysis: assesses the influence on the results of variations in process data, model choices and other variables. During the sensitivity analysis some of the important parameters are deliberately changed in order to determine the robustness of the results.

What follows is the discussion and the conclusion of the main research question for the study.

Presenting results in LCA studies

LCA results can be shown in multiple ways, at midpoint and at endpoint level. Midpoint are considered to be a point in the environmental cause-effect chain mechanism of a particular impact category (See Figure 34), prior to the endpoint at which characterization factors can be calculated to reflect the relative importance of an emission or extraction in a life cycle inventory (Bare, Hofstetter, Pennington, & Haes, 2000). Both midpoint and endpoint level indicators have complimentary merits and limitations. Results at mid-point indicators are argued to be more certain but can have lower relevance for decision support. Whereas endpoint indicators are considered to have higher relevance but lower certainty.

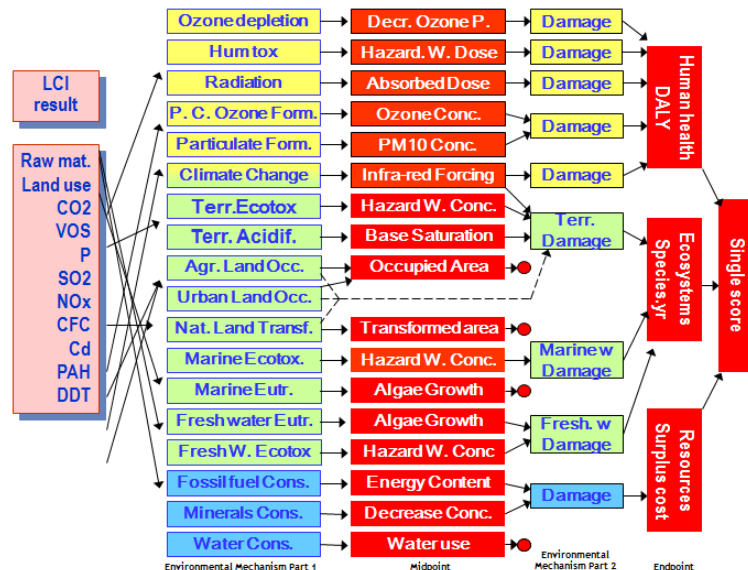


Figure 35: Graphic illustration of basic differences between the midpoint and the endpoint results (Goedkoop et al., 2013)

Because end-points have lower certainty and involves the controversial process of weighting different impact categories, mid-points are always used to present results of LCA studies performed by Blonk Consultants. As default, impact categories from ReCiPe (version 1.13) are used to present results, using the hierarchical version. ReCiPe is chosen, since it is the most recent and harmonized indicator approach available in life cycle impact assessment. Optionally the mid-point results can be aggregated into a single score end-point result using the ReCiPe endpoint method.

Definitions used in LCA

Following LCA definitions are derived from the LCA handbook (Guinée et al., 2002)

Impact category: a class representing environmental issue of concern to which environmental interventions are assigned, e.g. climate change, loss of biodiversity.

Category indicator: A quantifiable representation of an impact category, e.g. infrared radioactive forcing for climate change.

Category unit: Unit to express the category indicator.

Characterization factor: a factor derived from a characterization model for expressing a particular environmental intervention in terms of a common unit of the category indicator.

Characterization method: a method for quantifying the impact of environmental interventions with respect to a particular impact category; it comprises a category indicator, a characterization model and characterization factors derived from the model.

Characterization unit: used to express the indicator result which is the numerical result of the characterization step for a particular impact category, e.g. 12 kg CO₂-equivalents for climate change.

Impact categories

An LCA evaluates the environmental impact of a product or service. There are various impact categories, such as climate change, fresh water eutrophication and agricultural land occupation. Table 19 gives an overview of the impact categories, defined by ReCiPe methodology. In order to transform the extensive list of life cycle inventory results into a limited number of indicator scores the ReCiPe methods has been developed. These indicator scores express the relative severity on an environmental impact category.

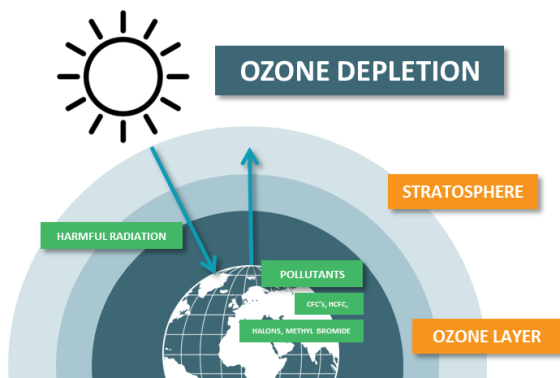
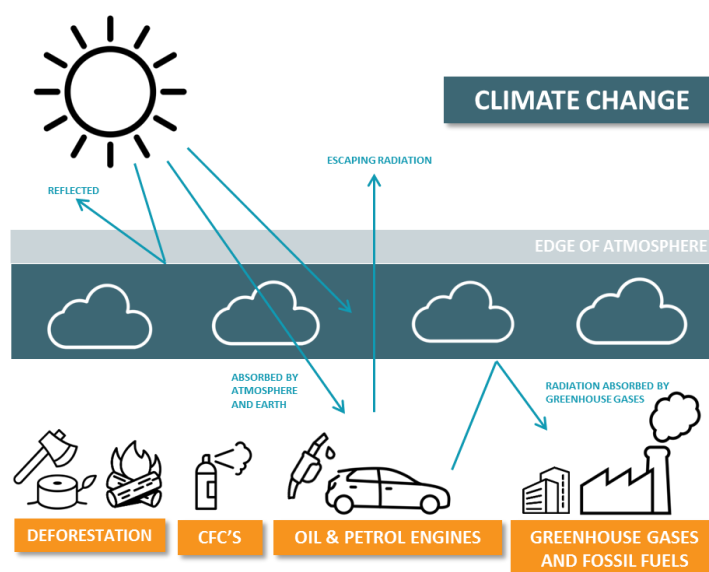
Table 19: category indicators, units, characterization factors, indicators results for 18 ReCiPe impact categories

Impact category	Category indicator	Indicator unit (mid-point)	Characterization factor (mid-point)	Indicator unit (mid-point)	End-point	Indicator unit (end-point)
Climate change	infra-red radiative forcing	W*yr/m ²	GWP ₁₀₀	kg CO ₂ eq.	✓ (2x)	DALY + species/yr
Ozone depletion	Stratospheric ozone concentration	ppt*yr	ODP	kg CFC-11 eq.	✓	DALY
Terrestrial acidification	base saturation	yr*m ²	TAP	kg SO ₂ eq.	✓	species/yr
Freshwater eutrophication	phosphorus concentration	yr*kg/m ³	FEP	kg P eq.	✓	species/yr
Marine eutrophication	nitrogen concentration	yr*kg/m ³	MEP	kg N eq.		
Human toxicity	hazard-weighted dose	m ² *yr	HTP	kg 1,4-DB eq.	✓	DALY
Photochemical oxidant formation	photochemical ozone concentration	kg	POFP	kg NMVOC	✓	DALY
Particulate matter formation	PM ₁₀ intake	kg	PMFP	kg PM10 eq.	✓	DALY
Terrestrial ecotoxicity	hazard-weighted dose	m ² *yr	TETP	kg 1,4-DB eq.	✓	species/yr
Freshwater ecotoxicity	hazard-weighted dose	m ² *yr	FETP	kg 1,4-DB eq.	✓	species/yr
Marine ecotoxicity	hazard-weighted dose	m ² *yr	METP	kg 1,4-DB eq.	✓	species/yr
Ionizing radiation	absorbed dose	man*Sv	IRP	kBq U235 eq.	✓	DALY
Agricultural land occupation	occupation	m ²	ALOP	m ₂ annually	✓	species/yr
Urban land occupation	occupation	m ²	ULOP	m ₂ annually	✓	species/yr
Natural land transformation	transformation	m ²	NLOP	m ₂	✓	species/yr
Water depletion	amount of water	m ³	WDP	m ₃		
Metal depletion	grade decrease	kg ⁻¹	MDP	kg Fe eq.	✓	\$
Fossil depletion	upper heating value	MJ	FDP	kg oil eq.	✓	\$

Most ReCiPe mid-point impact categories can be translated to end-point result. First, the environmental impact are grouped into three different domains: human health, ecosystems and resources. Reference unit at endpoint are DALY, species lost per year and surplus cost for each domain respectively. These results can then be further aggregated into a single score (points). A short description of the impact categories and their main mechanisms are explained for 13 most impact categories hereafter.

Climate change

Climate change refers to the change in weather patterns. Climate change heats up the earth slowly and is often called global warming. These changes have an impact on the quality of life on earth. Climate change is caused by various factors, such as biotic processes, plate tectonics, variations in solar radiation received by the earth, volcanic eruptions. Besides that, human activities have significant influence on climate change. Examples are fossil fuel combustion, agriculture and deforestation. These processes result in higher concentration of greenhouse gases (GHG's) in the atmosphere. CO₂ is one of the greenhouse gases (GHG) that has an impact on climate change. Besides that, there exist other greenhouse gases that contribute to global warming, for instance methane and nitrous oxide. These other gases, with an impact on climate change, are also included and expressed in equivalents with the same impact as CO₂. For results at mid-point, carbon dioxide is taken as reference unit, therefore 1 kg of CO₂ is 1 kg CO₂ equivalents. More potent greenhouse gasses include methane (25 kg CO₂-eq/kg) and nitrous oxide (298 kg CO₂-eq/kg). Within LCA studies, for the impact category climate change only human activities are taken into account. At end-point results for global warming are presented in human health effects (DALY) and effects on the environment (species lost per year).

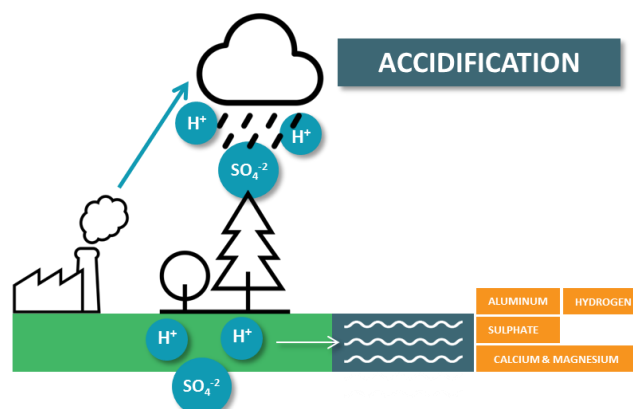


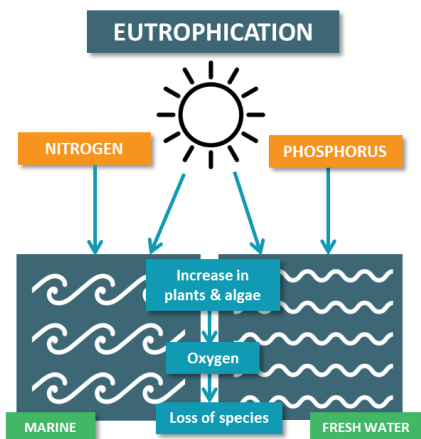
Ozone depletion

Ozone is a naturally occurring molecule containing three oxygen atoms. These molecules form a gaseous layer in the atmosphere (stratosphere). This layer encircles the earth and protects our planet from harmful radiations (solar ultraviolet UV-B radiation) that comes from the sun. However, human activities affect the ozone layer and results into depletion of stratospheric ozone. These ozone depleting substances are able to destroy ozone in the stratosphere. Their potency is expressed in ozone depletion potential using CFC-11 as a reference unit. At end-point, ozone depletion has impact on the human health domain.

Terrestrial acidification

Changes in acidity of the soil are caused by atmospheric deposition of acidic substances. Serious changes are harmful for specific species. In the ReCiPe methodology three acidifying emissions are taken into account. These emissions are: NO_x, NH₃ and SO₂. NO_x is mainly formed during combustion processes. Agriculture is the main source for NH₃. And energy combustion (coal) counts mainly for SO₂ emissions. The characterization unit for this impact category is SO₂ equivalents, which is 2.45 for nitrogen oxides and 0.56 for ammonia. Terrestrial acidification has impact on ecosystems in end-point results.



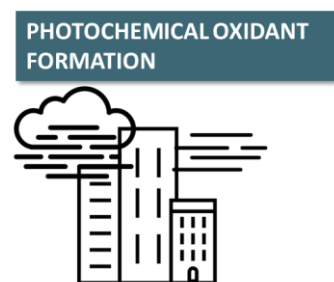


Freshwater & Marine eutrophication

Eutrophication is the enrichment of a water body with nutrients, usually an excess amount of nutrients that induces growth of plants and algae to the biomass load. The extreme growth may result in oxygen depletion of the water body and cause species to suffocate. Freshwater and marine eutrophication both have their distinct nutrients which cause excessive growth of plants and algae, since the limiting growth factor is different in both waterbodies. For freshwater waterbodies the limiting factor are phosphorus containing substances, usually from fertilizers or phosphorus containing detergents. Therefore for reference unit for freshwater eutrophication is kg phosphor equivalents. For marine waters the limiting factor is nitrogen and therefore marine eutrophication potential is expressed in kg nitrogen equivalents. Only freshwater eutrophication is considered at end-point result for ecosystems domain.

Photochemical oxidant formation

Other names for photochemical oxidant formation are urban smog or photochemical air pollution. Smog refers to air pollution, which consists of smoke and fog. This kind of visible air pollution composes of nitrogen oxides, sulfur oxides, ozone, smoke, carbon monoxide and CFCs. Anthropogenic smog is usually derived from coal combustion, vehicle emissions, industrial emissions, forest fires and other photochemical emissions. Reference unit at mid-point level is kg non-methane volatile organic compounds (NMVOCs) and end-point result belong to human health domain.



PARTICULATE MATTER FORMULATION



Particulate matter formation

Particulate matter refers to all solid and liquid particles suspended in air many of which are hazardous. It includes organic and inorganic particles, for instance ammonia, sulfur dioxide and particulate matter. One of the main sources of particulate is the combustion of diesel fuel in vehicles, but also other combustion processes and fireplaces. At mid-point level the reference unit is PM10 equivalents and at end-point the emissions belong to the human health domain, since the impact category has large impact on respiratory organs, in which the impact is expressed in DALYs.

Ionising radiation

Ionising radiation is radiation which is released by atoms, which travels as electromagnetic waves or particles. When the atom has sufficient energy it can cause ionisation or remove electrons from an atom. Ionizing radiation can be dangerous. When living cells become ionised they can die or mutate incorrectly and become cancerous. Radioactive substances exist naturally, examples are rocks and soil, however these levels are rather low. Most common source of ionising radiation is the extraction and use of radioactive materials for nuclear power generation. Reference unit for ionising radiation is kBq Uranium²³⁵ equivalents. At end-point the impact category belong to the human health domain.

IONISING RADIATION



LAND USE



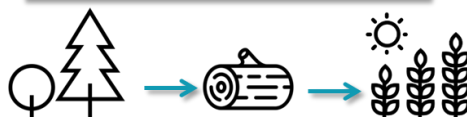
Land use

The area of land on the globe available for cultivation is limited. Land use refers to the area of rural or urban land that is occupied for a certain time period. Reference unit at mid-point is occupation of square meters annually. Lowering the impact means minimizing the number of square meters (m²) per year used to produce a certain product, this will have positive impact on the ecosystems domain in the end-point results in less species lost.

Natural land transformation

Closely related to land use is natural land transformation. For some production systems the land is reclaimed and occupied at the expense of other types of land. Most problematic examples are the reclamation of forests in Brazil and Indonesia for the production of soybeans and palm oil respectively. The emissions of reclaiming land (e.g. burning of forests) are allocated to the product systems over a certain time period. Reference unit is transformed land expressed in square meters. End-point results are included to the ecosystems domain, expressed in lost species per year.

LAND TRANSFORMATION



WATER DEPLETION



Water Depletion

For water depletion it is important to make a clear distinction between water use and water depletion. If water evaporates or is used as an input for the production of concrete or other chemicals, the water is lost from that area. But if the water is consumed but also released near the point of consumption, it may be argued that the water is not lost and does not cause water shortages. Example of this is the use of cooling water in power stations, where the majority of the water is discharged in the same water body it originates from. Mid-point reference flow is cubic meter of water consumed. No End-point modelling is available at the moment.

Metal depletion

Metal is a non-renewable resource, which means that consumption of this resource can lead to depletion. Results at mid-point are expressed in the relative scarcity of metals in iron equivalents, for 20 different metals. At end-point the results are presented as \$ per kg extraction. Extracting one kilo of iron will cost the society 7 cents, uranium \$ 8.76 and platinum a staggering 11 thousand dollar. Metal depletion belongs to the mineral surplus domain.

METAL DEPLETION



FOSSIL DEPLETION



Fossil depletion

Fossil depletion refers to the depletion of resources that contain hydrocarbons. This group of hydrocarbon include coal, oil and natural gas, which are all considered for results mid-point. The ReCiPe mid-point method is very similar to metal depletion, in a way that it includes the scarcity of these resources based on the reserves of these fossil fuels. Fossil fuel depletion is given in kg oil equivalents. At end-point the fossil depletion impact category is aggregated to surplus costs to society.

Blonk Consultants helps companies, governments and civil society organisations put sustainability into practice. Our team of dedicated consultants works closely with our clients to deliver clear and practical advice based on sound, independent research. To ensure optimal outcomes we take an integrated approach that encompasses the whole production chain.

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