Life Cycle Assessment of metal packaging in Europe

Executive Summary

Metal Packaging Europe

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Glossary

Allocation Partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems. Allocation refers to the partition of inputs and/or outputs of a process between several products produced together.

Background data or dataset The background system consists of processes on which no or, at best, indirect influence may be exercised by the decision-maker for which an LCA is carried out. Such processes are called "background processes".

A background dataset refers to a document or file with life cycle information of a specified product or other reference (e.g., site, process), covering descriptive metadata and quantitative life cycle inventory.

Closed-loop A closed-loop allocation procedure applies to closed-loop product systems. It also applies to open-loop product systems where no changes occur in the inherent properties of the recycled material. In such cases, the need for allocation is avoided since the use of secondary material displaces the use of virgin (primary) materials.

Comparative assertion Environmental claim regarding the superiority or equivalence of one product versus a competing product that performs the same function.

Cradle-to-gate This term is used to define the system boundaries. It addresses the environmental aspects and potential environmental impacts (e.g. use of resources and environmental consequences of releases) throughout a product's life cycle: from raw materials acquisition up to the gate of the container manufacturing sites.

Cradle-to-grave This term is used to define the system boundaries. It addresses the environmental aspects and potential environmental impacts (e.g. use of resources and environmental consequences of releases) throughout a product's life cycle: from raw materials acquisition through production, use, End-of-Life treatment, recycling and final disposal. Note that in this study, the use phase and reuse have been excluded from the analysis.

Cradle-to-cradle This term is used to define the system boundaries. It addresses the environmental aspects and potential environmental impacts (e.g. use of resources and environmental consequences of releases) throughout a product's life cycle: from raw materials acquisition through production, use, End-of-Life treatment, recycling and final disposal. Note that in this study, the use phase and reuse have been excluded from the analysis.

Critical review Process intended to ensure consistency between a life cycle assessment and the principles and requirements of the International Standards on life cycle assessment. The principles are described in ISO 14040. The requirements are described in ISO 14044.

Cut-off criteria Specification of the amount of material or energy flow or the level of environmental significance associated with unit processes or product system to be excluded from a study.

Downstream chain or process Downstream chain refers to customers of the foreground activity. In case of metal can making process, downstream chain refers to container filling, distribution, use and End-of-Life.

Final energy consumption	Final energy consumption is the amount of energy consumed on site in the form of usable energy (e.g. electricity, steam) and energy carriers (e.g. natural gas, heavy fuel oil) calculated based on net calorific values and gate-to-gate approach. Final energy can be a synonymous of direct energy; in this report, final energy and direct energy are the same concept.
Elementary flow	Material or energy entering the system being studied that has been drawn from the environment without previous human transformation, or material or energy leaving the system being studied that is released into the environment without subsequent human transformation.
End-of-Life	End-of-Life (EoL) refers to the stage of the product life cycle where the product undergoes activities such as recycling, incineration or disposal.
Foreground data and processes	The foreground system consists of processes which are under the control of the decision-maker for which an LCA is carried out. They are called foreground processes.
Functional unit	Quantified performance of a product system for use as a reference unit.
Gate-to-gate	This term is used to define the system boundaries. It addresses the environmental aspects and potential environmental impacts (e.g. use of resources and environmental consequences of releases) but only refers to impact from foreground process. Upstream and downstream activities are not accounted for.
Impact category	Class representing environmental issues of concern to which life cycle inventory analysis results may be assigned.
Impact category indicator	Quantifiable representation of an impact category.
Input	Product, material or energy flow that enters a unit process. Products and materials include raw materials, intermediate products and co-products.
Intermediate product	Output from a unit process that is input to other unit processes that require further transformation within the system.
Life cycle	Consecutive and interlinked stages of a product system; from raw material acquisition or generation from natural resources to final disposal.
Life Cycle Assessment (LCA)	Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle.
Life Cycle Inventory analysis (LCI)	Phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle. A LCI consist in the list of inputs and outputs flows (e.g. carbon dioxide emitted to air, COD emitted to water) of the product system.
Life Cycle Impact Assessment (LCIA)	Phase 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.
Life cycle interpretation	Phase of life cycle assessment in which the findings of either the inventory analysis or the impact assessment, or both, are evaluated in relation to the defined goal and scope to reach conclusions and recommendations

Open-loop	An open-loop allocation procedure applies to open-loop product systems where the material is recycled into other product system and the material undergoes a change to its inherent proprieties.
Output	Product, material or energy flow that leaves a unit process. Products and materials include raw materials, intermediate products, co-products and releases.
Primary data	Also called site-specific data. Data determined by direct measurement, estimation or calculation from the original source.
Raw material	Primary or secondary material that is used to produce a product. Secondary material includes recycled material.
Recycling rate	The term has different usages; most widely, including in industry statistics, is the use for the share of the product that is entering the recycling.
Reference flow	Measure of the outputs from processes in each product system required to fulfil the function expressed by the functional unit.
Secondary data	Non-specific data coming either from literature or from databases providers.

Executive Summary (Short)

Background

Metal Packaging Europe commissioned RDC Environment which is an independent consultancy based in Belgium with extensive experience in conducting LCA studies and facilitating critical stakeholder review processes. RDC Environment provided Metal Packaging Europe and member companies with an LCA study which has been conducted according to the requirements of the international standard ISO 14040/44.

Goals

The goals of the study are the following:

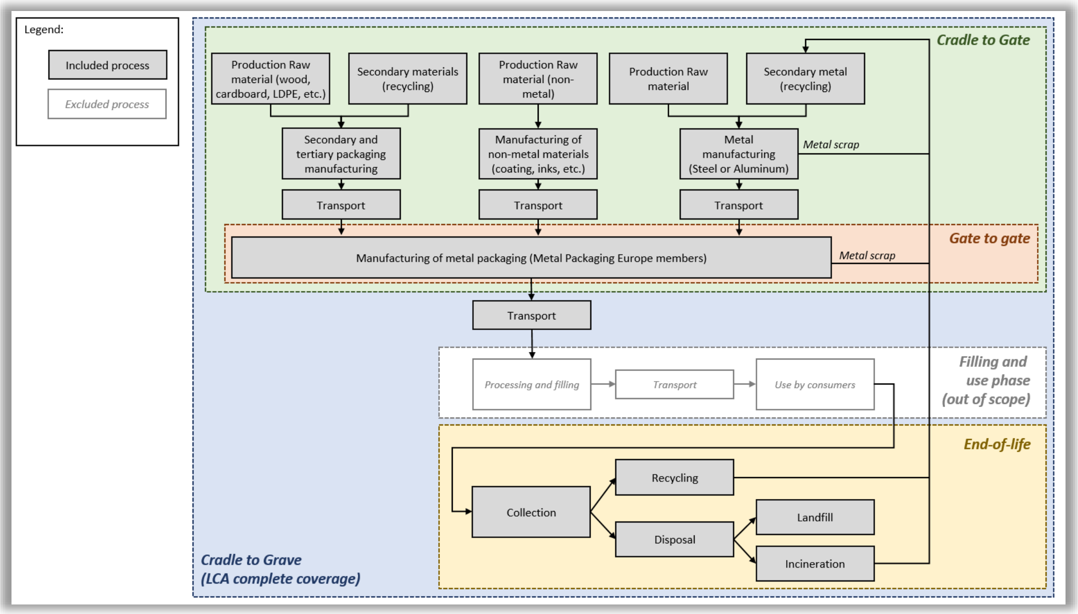
- To determine the environmental impacts and benefits along the life cycle of the average metal packaging produced in Europe.
- To track performance of the average metal packaging production in Europe by comparing the foreground data of production year 2013 with those ones of the production year 2008, 2006 and 2000, which were used to perform the previous Metal Packaging Europe's LCA study (published in 2012).
- To generate Life Cycle Inventories (LCIs) of the average metal packaging produced in Europe.

Functional Unit

In accordance with the general goal of this study, the functional unit is defined as:

One unit of packaging required to protect and decorate one standard unit of content for each of the 6 sectorial packaging types: steel food cans, steel general line cans, steel aerosol cans, steel closure, speciality packaging and aluminium food cans.

Systems boundaries



Main limitations of the study

Limitation due to potential methodological inconsistencies between background databases: most of the background datasets used in the study come from EcoInvent v2.2 database and few other ones come from other databases (such as Gabi).

As a rough estimation, the influence of this limitation on the results is assumed to be lower than 10%.

Limitation due to the use of EcoInvent v2.2 database: most of the background datasets (e.g., for energy, raw materials, transport, etc.) used in the study come from EcoInvent v2.2 database which was updated for the last time in 2010

The influence on the results is assumed to be lower than 5% for all impact categories, excluding ionizing radiation and toxicity

It is assumed that the influence on the results of the other limitations has an order of magnitude of one percent.

Main assumptions

The allocation rules for the recycling benefits follow the "0-100 allocation".

The recycling rates are assumed to be 75.1% for steel and 71.3% for aluminium.

Data collection

The representativeness of the data collection reaches about 57% of the European steel packaging production and 47% of the European aluminium packaging production excluding beverage packaging.

Several members participating to the study covering 74 plants.

With 10 companies involved, the 2013 update has the highest participating rate of Metal Packaging Europe members.

European coverage of the study

Life Cycle Interpretation

Results are complete and consistent.

Completeness checks were carried out at gate-to-gate system boundaries, analysing the completeness of process steps as regards primary data provided by the metal packaging manufacturers and also the energy, input materials as well as emissions from metal packaging manufacturers. Note that in case where no data were available, average from other plants or data from literature has been used

Regarding consistency, the plausibility of the results and main source of impacts were assessed having a critical view on data quality. Consistency has been also done through comparison with results from the previous Metal Packaging Europe LCA.

I. Introduction

Metal Packaging Europe is the European federation of metal packaging makers. Metal Packaging Europe brings together more than 200 manufacturers, suppliers and their national associations, to promote the benefits of rigid metal packaging. Metal Packaging Europe supports more than 65,000 employees in 23 European countries. Each year, they use 5 million tonnes of steel and aluminium to produce in excess of 85 billion units, which reach consumers every day.

Metal Packaging Europe promotes the common interests of its members throughout Europe and is actively engaged in dialogue with European stakeholders and NGOs.

Consequently, Metal Packaging Europe must rely on the most current environmental life cycle information on metal packaging production in order to promote continuous improvement of the environmental sustainability performance of metal packaging.

To accomplish this, Metal Packaging Europe commissioned RDC Environment which is an independent consultancy based in Belgium with extensive experience in conducting LCA studies and facilitating critical stakeholder review processes. RDC Environment provided Metal Packaging Europe and member companies with the present LCA study which has been conducted according to the requirements of the international standard ISO 14040/44.

II. Goal and scope of the study

II.1. Goal of the Study

The goals of the study are the following:

- To determine the environmental impacts and benefits along the life cycle of the average metal packaging produced in Europe, assessed on the cradle-to-cradle approach.
- To track performance of the average metal packaging production in Europe by comparing the foreground data of production year 2013 with those ones of the production year 2008, 2006 and 2000, which were used to perform the previous Metal Packaging Europe's LCA study (published in 2012).
- To generate Life Cycle Inventories (LCIs) of the production stages and some selected further life cycle stages of the average metal packaging produced in Europe according to the following system boundaries:
    - Cradle-to-grave (excluding any specific application of the packaging).
    - Cradle-to-gate.
    - Gate-to-gate.

The scope cradle-to-grave is equivalent to the scope cradle-to-cradle. The "cradle-to-cradle" terms allow to emphasis the recycling by incorporating end-of-life material into new production.

The study is compliant with the international standard ISO 14040-44 and provides LCIs and LCA report of the metal packaging produced in Europe as average across the industry and various technologies. Therefore the intended applications of the study are:

- Internally to Metal Packaging Europe: to increase the knowledge and to provide Metal Packaging Europe members with objective and reliable information about the environmental impacts and benefits connected with the life cycle of the average metal packaging produced in Europe; to provide to Metal Packaging Europe members with objective and reliable information about the performance of the average metal packaging production in Europe in 2013 compared to 2008, 2006 and 2000.

- Externally to Metal Packaging Europe: to communicate to external stakeholders the environmental impacts and benefits connected with the life cycle of the average metal packaging produced in Europe; to share the report and the LCIs with LCA practitioners willing to include metal packaging in their LCA applications.

- The study is not intended to support comparative assertions intended to be disclosed to the public. The use of Metal Packaging Europe study results in further comparative studies is under the responsibility of the LCA practitioner, including to check ISO requirements regarding communication of comparative results to the public.

The intended audience of the study includes Metal Packaging Europe and its members, the manufacturers of metal packaging, government, customers and retailers, non-governmental organizations and LCA practitioners. The LCA report was developed in compliance with the international standard ISO 14040-44 for reporting to third party. Any confidential information is provided in the annexes of the report, which are available only to Metal Packaging Europe members.

The study does not include the associated benefits or impacts of the use of the metal packaging compared with functional equivalent alternative scenarios such as 'tinned foods' compared to fresh food, stored in a fridge or a frozen equivalent and the associated operating impacts and food waste.

A third party critical reviewer was engaged to ensure that the highest level of compliance with the ISO 14040-44 standards was met.

II.2. Scope of the Study

This section describes the scope of the study in order to achieve the above stated goals:

- The product system and its function, the definition of the functional unit and the system boundaries.
- The data requirements including cut-off criteria and limitations.
- The data quality requirements and the allocation procedures.
- The LCIA methodology to be used.
- The type of critical review performed.

II.2.1. Product System description

Figure 1 shows the life cycle flow diagram for the system analysed. Each box is a life cycle stage of the metal packaging.

Three scopes are highlighted on this figure:

- Gate-to-gate scope (orange box): the manufacture of the product at the Metal Packaging Europe members.
- Cradle-to-gate scope (green box): extended system due to the upstream processes;
- Cradle-to-grave (blue box): complete system with close loop recycling and end-of-life scenarios. The filling and processing phase and the use phase are not covered in this study.

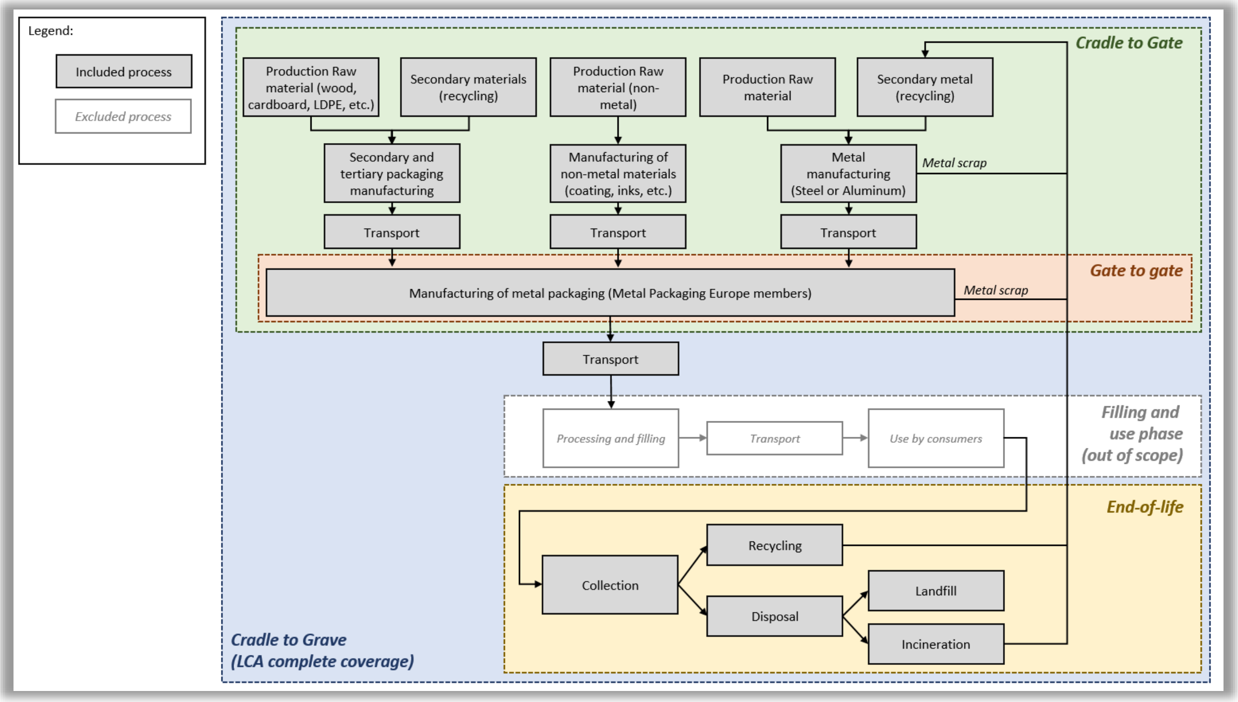


Figure 1 – Life cycle flow diagram for the system analysed

The white area in dotted line arrows indicate processes excluded from the product system analysed in the study and which are related to the specific applications of the packaging. Such applications would include, among others, the filling of the packaging, its distribution to the market, the use of the packaging.

Regarding the distribution, is assumed that the weight of the packaging is much lower than the weight of the transported content, the influence of the packaging weight on the transport impact is assumed to be negligible.

These processes and applications are excluded from the study in accordance with its goal (generating LCI's of product stages and some further selected life cycle stages) and because of lacking information about those stages.

Warning: The future users of Metal Packaging Europe LCI's must be aware of the exclusion of filling, distribution and use phases. Those stages must be accounted additionally for a complete life cycle assessment of the metal packaging.

II.2.2. Representative products

The weight of packaging units selected for this study are defined for a standard unit existing on the packaging market. The beverage cans are not included in this report; a separate beverage LCA study is currently conducted to evaluate the footprint of the beverage sector.

In order to analyse the evolution of impacts in the packaging manufacturing industry, some data and results of this study will be compared with the previous study "*LCA model metal packaging*" realised for Metal Packaging Europe by TNO (2012). To ensure a concordance for the comparisons, the same standardized volumes were retained.

The improvement in light weighting packaging comparing to the previous years (2000, 2006 and 2008) can be observed in the annual evolution of data (See section III.2.9).

II.2.3. Functional Unit

In order to provide an LCI usable by LCA experts, it is necessary to precisely and quantitatively define the "functional unit", i.e. the functions fulfilled by the system.

In accordance with the general goal of this study, the functional unit is defined as:

One unit of packaging required to protect and decorate one standard unit of content for each of the 6 sectorial packaging types: steel food cans, steel general line cans, steel aerosol cans, steel closure, speciality packaging and aluminium food cans.

II.2.4. System boundaries

System boundaries define all steps that are included in the selected scope.

As shown on Figure 1, the **study includes** (cradle-to-cradle scope):

- upstream processing and production of raw materials and primary metal;
- upstream production of secondary and tertiary packaging;
- transport to the metal packaging manufacturer;
- manufacturing of metal packaging and infrastructure;
- transport to processing and filling;
- end-of-life disposal/incineration or recycling including sorting and waste collection.

The following **steps are not included** in the study:

- maintenance and operation of support equipment;
- filling and grouping;
- packaging of final products;
- transport to warehouse and to final customer;
- product use.

Justification for exclusion of some steps of the life cycle of the product:

The steps of filling, transport to stores and consumption are mainly defined by the content and the manufacturer of the content. Besides, regarding the distribution, is assumed that the weight of the packaging is much lower than the weight of the transported content, the influence of the packaging weight on the transport impact is assumed to be negligible. Those steps are not included because of lack of information.

II.2.5. Cut-off criteria

In LCA practice, it is not always possible to achieve data for each flow or process of the life cycle due to lack of information, time or resources. Some flows or processes were excluded from the study in accordance with ISO 14044:2006, which defines criteria on the basis of mass, energy and environmental significance in order to assess whether or not a flow or process can be neglected.

An exclusion threshold of 5% has been established in the study. This means that the sum of all elementary flows belonging to the excluded processes must be less than 5% of the contribution in terms of mass, energy and environmental significance of the whole life cycle. This threshold is a compromise between precision and feasibility (especially data availability). In this study, the process excluded according to the cut-off criteria are linked to the maintenance and operation of support equipment.

These excluded processes are not expected to contribute to more than 5% to any of the three criteria, as detailed below.

- Mass criteria: Based on expert judgement, the process of maintenance and operation of support equipment are not expected to contribute to more than 4% to the mass criteria.
- Energy criteria: Based on expert judgement, the process of maintenance and operation of support equipment are not expected to contribute significantly to the energy criteria.
- Environmental significance: no calculation was performed to assess precisely how much would the excluded processes contribute to the total impact for each impact category. From expert judgement, they are not expected to contribute to more than 5% to each impact category assessed in the study.

There are two level of cut-off process:

- Cut off level 1: Process that are not accounted in the study. See the system boundaries at *II.2.4* where the excluded stages are listed.
- Cut off level 2: Components that are accounted but without upstream model (as the impact of their production or their transport for example). For the specific study, all the components included are modelled with their upstream model.

II.2.6. Data quality requirements

Temporal validity

Primary data were collected on steel packaging manufacturing for the year 2013. The year 2013 was a normal year for the operations of steel packaging manufacturing. Electrical data were obtained from IEA database (year 2012) and secondary datasets come from EcoInvent database V2.2. The most recent version, EcoInvent 3.2, was released in November 2015 when the present LCA was already started; for this reason and due to some technical constraints, it was not possible to use Ecoinvent 3.0. EcoInvent v2.2 database may generate uncertainty due to its limited time representativeness. Because there is no major technological evolution underway for the production operation, the time validity of this study is 3 – 5 years.

Representativeness of the study

APEAL (Association of European Producers of steel for packaging) and EAA (European Aluminium Association) was consulted to estimate the total production of steel and aluminium packaging in Europe (EU28 and Turkey) for the year 2013.

The European production of steel for packaging (Tinplate & Electrolytic Chromium Coated Steel) was estimated for 2013 by *Eurofer* as equal to ≈4 200 kt of steel. Around 26% of this production was exported out of Europe and *Eurofer* considers that ≈500 kt of steel for packaging was imported in Europe in 2013. The amount of steel aimed to be transformed by the European Packaging manufacturers is then estimated to ≈3 600 kt in 2013. APEAL considers that 15% of this production is used for beverage cans (not part of the packaging covered in this study) and 3% are actually not used for packaging production (2006 data published in *APEAL Sustainability report*, 2014). The **European production of steel for packaging (excluding beverage) is then assumed to be ≈3 000 kt in 2013**.

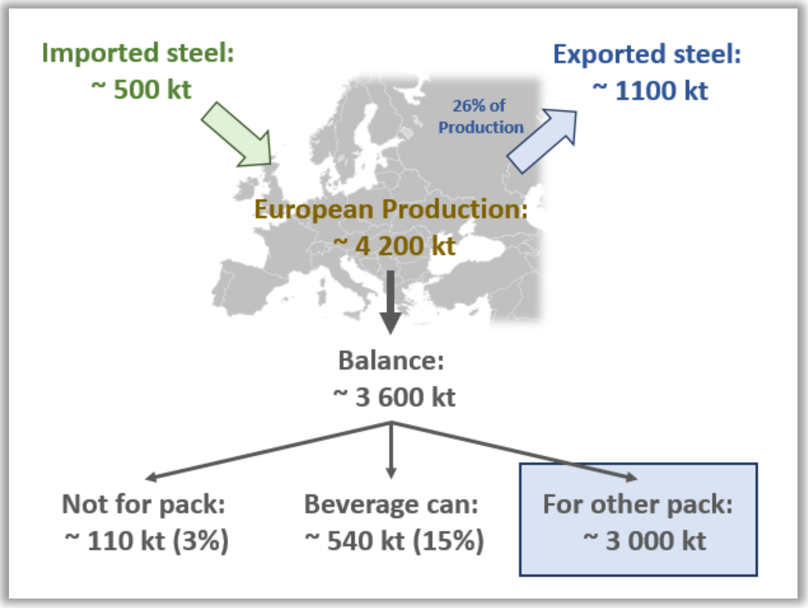


Figure 2 - Estimation of Steel consumption for packaging (excluding beverage can) in 2013.

The estimation from EAA for the **European production of aluminium for food cans is between 65 and 70 kt**.

Technology coverage

In the study, site-specific data are representative of current technology used in Europe for steel packaging manufacturing and aluminium packaging manufacturing excluding beverage packaging (respectively 57% and 47% of the total European production) for the reference year 2013.

This collection corresponds to 74 manufacturing plants (distributed between 10 companies) and more than 1.5M tons of steel packaging and 27 400 tons of aluminium packaging sold.

Geographical coverage

The geographical coverage is metal packaging produced in the EU 27 and in Turkey excluding the production of beverage packaging. Table 1 shows the country share based on the tonnages sold. It also gives the number of plants (for which RDC collected data) in each country.

Table 1 - Geographical coverage: representativeness by country

Metal component	Country	# plants	Repres. of sold tons [%]
Steel	France	11	*17.8%*
	United Kingdom	8	*17.5%*
	Germany	10	*13.4%*
	Italy	10	*12.5%*
	Netherlands	5	*12.0%*
	Turkey	8	*8.4%*
	Czech Republic	3	*4.5%*
	Hungary	2	*3.6%*
	Denmark	1	*3.3%*
	Others	13	*7.0%*
Total		**71**	**100%**
Aluminium	France	2	*71.6%*
	Denmark	1	*19.2%*
	Hungary	1	*9.2%*
Total		**4**	**100%**

Precision

As regards the data collected at the metal packaging plants, the precision of these data is considered very good for bill of materials, energy and water consumption, emissions of CO_2 and particulate matter. This is due to the fact these information are under control of the metal packaging manufacturers and that a high share of plants answering to the questionnaire indicated their data as precise (it is assumed that the margin of error is under 5%). As regards the data collected for other emissions to air and effluents, the precision of these data is considered fair, due to the fact that a limited number of plant answered to the questionnaires (it is assumed that the margin of error is under 30%).

As regards EcoInvent v2.2 and GaBi 5 databases, the precision of these databases is considered as fair to good, depending on the specific dataset. For further details, see EcoInvent v2.2 and GaBi 5 documentation.

As regards the elementary flows that influence land occupation and transformation, estimations were used for the foreground level and generally, they are of little precision in background databases. The precision for these flows is considered as low.

Completeness

All relevant, specific processes were considered in the study. As regards the emissions at the metal packaging plants, beside the tracked emissions reported in the questionnaire, other emissions associated to fossil fuels combustion were assessed based on secondary databases.

As regards EcoInvent v2.2 and GaBi 5 databases, the completeness of these databases is considered as good to very good, depending on the datasets. For further details, see EcoInvent v2.2 and GaBi 5 documentation.

Consistency

Consistency of the study has been considered through three different aspects:

- As regards the primary data, plausibility checks of each data were done through cross-checks and comparison to average. See further for details on primary data validation.
- As regards the methodological consistency, most of the background datasets come from the same database (EcoInvent v2.2) and few processes come from other database. Hence methodological deviation between processes belonging to different databases are plausible.
- As regards the consistency of the LCA model, cross-checks regarding mass and energy flows were carried out.

Reproducibility

As far as possible, all considered assumptions and data are detailed in the LCA report to allow reproducibility and transparency. An external audience may not be able to reproduce all life cycle phases, however experienced LCA practitioners should find key data and assumptions in the current study.

Uncertainty of the information

Uncertainty of the results were considered through two different aspects:

- As regards the primary data, precision assessment were carried out while collecting data from the plants. Uncertainty is very low for the bill of material composition, energy and water consumptions as well as direct emissions of carbon dioxide and dust. Uncertainty is medium to high regarding other emissions (such as nitrogen oxide, sulfur oxide and VOC).
- As regards the background databases, uncertainty is considered as low except for elementary flows contributing to Ozone layer depletion, Toxicity (human and ecotoxicity) and Resources depletion for which the uncertainty is considered as high.

Allocations

Heat surplus

Export of heat surplus from plant: the heat surplus (heat produced but not used by the furnaces) can be sold to external grid. In this case, the sold heat was modelled via a substitution approach because it avoids an equal heat production somewhere else (based on the energy content).

Recycling allocation

In the case of the steel packaging, the allocation chosen a “0-100 allocation” or a “incorporator allocation”. Steel can be so called a “permanent” material. In this case, the demand for secondary material is higher than supply. Additional recycling will only occur if an additional amount of material to be recycled is made available, namely at product end-of-life. Incorporating recycled material in an application corresponds to an increase in demand for secondary materials, which cannot be satisfied without forcing another user to use virgin material. Hence, the incorporation of recycled material has to be modelled by the production of virgin material and environmental impacts are independent of the recycled content.

The same allocations rules are applied for the other materials (aluminium and other materials used for secondary and tertiary packaging).

Warning: the future users must be aware that the recycling benefits are already included in the LCI’s. They should *not* be accounted additionally. Besides, these LCI’s do not follow the recommendations of the PEF, advising to use a “20-80 allocation” for metals.

Background dataset

Most of the background datasets used in the study apply allocation rules. No change was made to these allocation rules, which are thus following the general approach of EcoInvent v2.2 and GaBi 5 databases. A sets of specific processes requires attention as their allocation rules can influent the results of the study.

Allocation of impacts deriving from energy production. The background datasets used in the study for energy production (from natural gas and fuel oils) come from EcoInvent v2.2 database. The allocation approach applied in those processes is based on the energy content.

II.2.7. Selection of life cycle impact assessment methods

The choice of the LCIA methods aims at giving an overall view of environmental impacts of metal packaging production in Europe. Total results are presented for all the 14 impact categories recommended by the PEF (product Environmental Footprint by the European Commission) as edited at the moment of redaction of the study (2014).

The list of those impact categories are listed in the Table 2. The 14 impact categories are described in details in the annex.

Table 2 - LCIA methods applied in the study

Impact categories	Units	Impact assessment model	Source
Climate change	*kg CO2 eq.*	Bern model – Global Warming Potential over a 100 year horizon	Intergovernmental Panel on Climate Change, 2013
Ozone depletion	*kg CFC-11 eq.*	EDIP model based on the ODPs of the World Meteorological Organization (WMO) over an infinite time horizon	WMO 1999
Human toxicity	*CTUh, c*	USEtox 2.0	USEtox 2.0
Ecotoxicity for aquatic freshwater	*PAF*m³*day*	USEtox 2.0	USEtox 2.0
Particulate matter/ respiratory inorganics	*kg PM2.5 eq*	RiskPoll model	Humbert, 2009
Ionizing radiations	*kBq U235 eq*	Human Health effect model	Dreicer et al., 1995
Photochemical ozone formation	*kg NMVOC eq*	LOTOS-EUROS model	Van Zelm et al., 2008 as
Acidification	*mol H+ eq.*	Accumulated Exceedance model	Seppälä et al., 2006;
Terrestrial eutrophication	*mol N eq.*	Accumulated Exceedance model	Posch et al., 2008
Freshwater eutrophication	*kg P eq.*	EUTREND model	Seppälä et al., 2006;
Marine eutrophication	*kg N eq.*	EUTREND model	Posch et al., 2008
Land use	*kg C deficit*	Soil Organic matter (SOM) model	Struijs et al., 2008
Resource depletion water	*m³ of water-eq*	Swiss Ecoscarcity model	Struijs et al., 2008
Resource depletion-mineral, fossil	*kg Sb eq.*	CML 2002 model	Milà I Canals et al.,

The list of impact categories chosen for the study is based on ILCD handbook[1] and takes into account recent method development:

- Climate change was assessed using IPCC 2013 characterization factors, while ILCD handbook refers to IPCC 2007. As IPCC 2013 is an update of the 2007 method, the most recent one was considered as more robust.
- Human toxicity and freshwater ecotoxicity were assessed using USEtox 2.0 characterization factors, while ILCD handbook refers to USEtox 1. As the version 2.0 is an update of the first version, the most recent one was considered as more robust.

[1] ILCD Handbook – Recommendations for life cycle impact assessment in the European context

The details results by life cycle stages and the sensitivity analysis are only presented for 6 impact categories identified as the most relevant categories for the metal packaging sector from the expert judgement:

- Climate change;
- Abiotic resource depletion;
- Water depletion;
- Air acidification;
- Photochemical ozone formation;
- Particulate matter/ respiratory inorganics.

II.2.8. Critical review

As the study is intended to be used for communication purpose to third party and the LCIs could be used in other studies (including comparative assertion), the critical review was performed by the LCA expert: Philippe Osset, Chairman of Solinnen.

The critical review process ensured that:

- The methods used to carry out the LCA are consistent with this International Standard ISO 14040-44:2006.
- The methods used to carry out the LCA are scientifically and technically valid.
- The data used are appropriate and reasonable in relation to the goal of the study.
- The interpretations reflect the limitations identified and the goal of the study.
- The study report is transparent and consistent.

The critical review report is available in annex as for further detailed references of the peer reviewer.

II.3. Limitations of the study

II.3.1. General LCA methodology limitations

As preliminary warning, general LCA limitations are reminded:

- Limitations inherent in the LCA methodology (ISO 14040:2016, 5.4.3)

  The LCIA addresses only the environmental issues that are specified in the goal and scope. Therefore, LCIA is not a complete assessment of all environmental issues of the product system under study. LCIA cannot always demonstrate significant differences between impact categories and the related indicator results of alternative product systems. This may be due to:

  - Limited development of the characterization models, sensitivity analysis and uncertainty analysis for the LCIA phase,
  - Limitations of the LCI phase, such as setting the system boundary, that do not encompass all possible unit processes for a product system or do not include all inputs and outputs of every unit process, since there are cut-offs and data gaps,
  - Limitations of the LCI phase, such as inadequate LCI data quality which may, for instance, be caused by uncertainties or differences in allocation and aggregation procedures, and
  - Limitations in the collection of inventory data appropriate and representative for each impact category.

The lack of spatial and temporal dimensions in the LCI results introduces uncertainty in the LCIA results. The uncertainty varies with the spatial and temporal characteristics of each impact category. There are no generally accepted methodologies for consistently and accurately associating inventory data with specific potential environmental impacts. Models for impact categories are in different stages of development.

- Limitations inherent in the LCA methodology (ISO 14044:2016, 4.4.5)

  An LCIA that is intended to be used in comparative assertions intended to be disclosed to the public shall employ a sufficiently comprehensive set of category indicators. The comparison shall be conducted category indicator by category indicator. 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 limitations in the LCIA. Value-choices, exclusion of spatial and temporal, threshold and dose-response information, relative approach, and the variation in precision among impact categories are examples of such limitations. LCIA results do not predict impacts on category endpoints, exceeding thresholds, safety margins or risks. Category indicators intended to be used in comparative assertions intended to be disclosed to the public shall, as a minimum, be;

  - Scientifically and technically valid, i.e. using a distinct identifiable environmental mechanism and/or reproducible empirical observation, and;
  - Environmentally relevant, i.e. have sufficiently clear links to the category endpoint(s) including, but not limited to, spatial and temporal characteristics.

Category indicators intended to be used in comparative assertions intended to be disclosed to the public should be internationally accepted. Weighting, as described in 4.4.3.4, shall not be used in LCA studies intended to be used in comparative assertions intended to be disclosed to the public. An analysis of results for sensitivity and uncertainty shall be conducted for studies intended to be used in comparative assertions intended to be disclosed to the public.

II.3.2. Specific limitations from this study

In this study the main limitations are related to the quality of the background datasets and the approach to average the information collected from the involved members. The list of limitations is detailed below.

- **Limitation due to the use of EcoInvent v2.2 database:** most of the background datasets (e.g., for energy, raw materials, transport, etc.) used in the study come from EcoInvent v2.2 database which was updated for the last time in 2010. The most recent version, EcoInvent 3.2, was released in November 2015 when the present LCA was already started; for this reason and due to some technical constraints, it was not possible to use Ecoinvent 3.0. EcoInvent v2.2 database may generate uncertainty due to its limited time representativeness.

  Warning: Some users may request an update of the LCI's by using EcoInvent 3.2. It has been decided that the present LCI's would not be updated as it is planned to publish updated versions of the LCI's (with 2016 data) in 2018 and the most updated version of EcoInvent will be used.

  The limitation due to the use of EcoInvent has a variable influence on results, depending on the impact categories considered.
  - For most of the impact categories, the influence on the results is assumed to be lower than 5%.
  - For the ionizing radiation, the land occupation and transformation, the influence is estimated to be lower than 50%.
  - For the toxicity categories, the influence could be higher than 100%. Nevertheless, the toxicity categories are dedicated to provide indicative information on toxicity and their results must be considered on a logarithmic scale.

- **Limitation due to potential methodological inconsistencies between background databases:** most of the background datasets used in the study come from EcoInvent v2.2 database and few other ones come from other databases (such as Gabi). The use of different background databases can lead to inconsistencies due to different methodological rules applied in the databases. For example, electricity mix is modelled differently between EcoInvent and Gabi databases.

  As a rough estimation, the influence of this limitation on the results is assumed to be lower than 10%.

- **Limitation due to the approach to average the information collected from the different members**: when modelling the average production occurring at different sites, two approaches can be used:
  - Horizontal averaging, which consists in weighting each collected primary data (e.g., amount of primary steel, amount of natural gas, etc.) according to the sales volume of the plant, and then averaging them in order to produce a virtual plant. The LCIs and LCIA are then calculated based on the

virtual average plant. This approach was used in the study because it is the best compromise between quality of the results and time and resource availability. It is a less accurate approach than the vertical averaging (for instance, in case of regionalized methods, there could be a loss of accuracy in locating the emissions).

- Vertical averaging, which consists in calculating each LCI per plant based on its specific data and then averaging the LCIs based on the sales volume per plant. This approach gives more precise results but it is time and resources consuming as more than 70 plants have to be modelled separately.

In both cases, the weighting applied is the sold volume of metal packaging.

It is assumed that the influence of this limitation on the results has an order of magnitude of one percent.

- **Limitation due to filling missing data:** when empty cells were found in the filled questionnaires, they were assumed to be a "no data entry" (instead of a "zero value") and the average value was calculated including the empty cells. This approach can maximize the bill of materials and the energy consumption and therefore can overestimate the overall environmental impacts. Hence, the results of the study can be considered as conservative.

  It is assumed that the influence of this limitation on the results has an order of magnitude of one percent.

- **Limitation due to simplified modeling for some minor raw materials:** Solvents, inks and sealing are modelled considering average compositions of solvent, solid substances and water. This proxy is used as these raw materials are not available in the background database used.

  It is assumed that the influence of this limitation on the results has an order of magnitude of one percent.

- **Limitations due to the use of average recycling rate:** The recycling rate for steel (from APEAL) and aluminum (from EAA) are average post consumption recycling rate. They do not stand for the specific packaging types modelled.

  For aluminium, it corresponds to the aluminium can recycling rate, including the beverage packaging. It is assumed that as a rigid type of packaging, the specific food can has a similar recycling rate.

For steel, the recycling rate corresponds to the full scope of steel packaging formats under the category of municipal waste (including general lines, aerosols, closures and food cans which are covered by this study but also beverage cans and a small part of non-packaging). It is assumed that the formats covered in this study have a similar recycling rate.

It is assumed that the influence of this limitation on the results has an order of magnitude of one percent.

- **Limitations due to the geographical scope:** the study refers to the average European production (including Switzerland and Turkey). However, differences between countries exist regarding emissions norms, electricity mix and also the surrounding environment. The average value is thus not reflecting any individual country and the reader should keep in mind that the LCA of the metal packaging production in a specific country/plant might lead to different results compared with this study. This limitation is also due to the fact that data collected from the plants were anonymized due to confidential reasons.

  Besides the European average is used for the steel packaging recycled content. The recycled content specific to the members participating to the study was not asked in the questionnaire.

- **Limitations due to lack of data for representativeness calculation:** the calculation of the total production of metal packaging excluding beverage is based on assumptions. This value is used to estimate the representativeness for steel.

III. Inventory analysis

III.1. Data collection and quality

This section describes the process followed by RDC Environment to collect the data used in the study. Data concern the gate-to-gate processes (tinplate printing and packaging manufacturing) and the upstream transport.

III.1.1. Data sources

The representativeness of the data collection reaches about 57% of the European steel packaging production and 47% of the European aluminium packaging production excluding beverage packaging.

Several members participating to the study covering 74 plants.

Some plants answered the questionnaire but were excluded from the analysis:

- Two plants were excluded from the analysis as only the first part of manufacturing (tinplate printing) occurs in those plants.
- Two plants were excluded from the analysis as their production does not correspond to one of the 6 sectorial packaging types.

III.1.2. Questionnaires

A questionnaire was sent to the participating members. It was developed based on a discussion with Metal Packaging Europe and one of its members.

The questionnaire concerns the data related to the manufacturing plant. Six sectorial types of packaging were clearly identify: Steel Food can, Steel Aerosol can, Steel General line, Steel Closure, Steel Speciality and Aluminium food can. Two kinds of plants were identified:

- Single sectorial production. Only one type of the sectorial types of packaging is manufactured in the plant (65 plants).
- Multiple sectorial production. Several types of packaging are produced in the plant (9 plants).

As the members could not distinguish the activity parameters by type of packaging in the multiple sectorial plants, their data were not used to produce the average results by type of packaging. For the aggregated average (for all types of packaging), the data from all the plants were used.

III.1.3. Data validation

Several checks were made in order to validate the data received from the metal packaging manufacturing plants. When questionable data were identified, an email was sent to the metal packaging manufacturing plant to validate the data. More than 20 correction responses from members helped to ensure that data collection was of high quality. Figure 3 shows an example of a question sent to a member.

Subject	File - Rows	Description	Answer
Amount of cans produced	[illegible] Rows 32	The number of units is mentioned as [illegible] cans + ends (sum of [illegible] and [illegible]) but the comment mention [illegible] ends instead of the [illegible] Considering the production of your other sites, we would think that the right value is [illegible] and not [illegible] Can you confirm which value is the right one?	

Figure 3 – Discussion with member about questionable data

Three types of data quality tests were performed as part of the data validation process. These tests are presented in this section along with a list of examples. These lists are non-exhaustive.

Logical tests

These tests aim to check the consistency of data provided by each member:

- $Total\ waste = \sum(individual\ wastes)$?
- $\sum(raw\ materials) > Total\ output$?

Comparison tests

These tests aim to check whether the data of one specific issue (energy, waste, water…) are in a range of acceptable values. When data is out of range, it is important to find the reason (technological reason for example):

- Comparison of energy consumption "GJ/ton" for each plant
- Comparison of water consumption "m^3/ton" for each plant

Value tests

After validating data per member (logical tests) and data per issue for all members (comparison tests), the average values weighted by volumes were calculated and value tests were performed. These tests aim to check whether average values are in line with the range of values commonly used and the standards:

- Are atmospheric emissions in the ranges observed in the previous Metal Packaging Europe study?
- Are water consumption values (in & out) consistent with bibliography?
- Are emissions in natural environment acceptable regarding European directive?

III.1.4. Data averaging

A horizontal averaging approach was performed to average data across the 74 manufacturing plants. The horizontal averaging approach consists in weighting each collected primary data (e.g., amount of steel, amount of natural gas, etc.) according to the sales volume of the plant, and then averaging them in order to produce a virtual plant. A vertical averaging approach would be more accurate but it also requires to model all 74 plants separately (and then average them on the basis on their sales volume). In particular, when applying the regionalized indicators (water resource depletion, acidification and terrestrial eutrophication) the real repartition of emissions per country would have been kept by using the vertical averaging approach; by using the horizontal averaging approach, the average emissions were distributed according to sales volumes.

III.1.5. Filling data gaps

In the questionnaires it was clearly stated to answer the questions by differentiating between "no data entry" and "zero value". As a consequence, when empty cells were found in the filled questionnaires, they were assumed to be a "no data entry" and the average value was calculated including the empty cells. This approach mainly concerns secondary and tertiary packaging accounting together for 2% in mass of the average packaging. Raw materials, energy and water consumptions have a very high coverage in terms of answers of the questionnaires.

A different approach was used to fill in the data gap related to transport modes, as there were clear reasons to think that some of the empty cells actually correspond to zero values:

- In case of a questionnaire partially filled in but presenting also empty cells as regards all transport modes, the empty cells were considered as "zero value".
- In case of a questionnaire completely empty as regards all transport modes, the cells were considered equal to the average of the answers of other questionnaires.

III.1.6. Foreground data quality assessment

In the questionnaire, it was required to the compiler to encode an estimation of the quality for each provided data, according to three ranges of data quality (see the next table where "X" represents the uncertainty of the encoded value). RDC associated respectively the values 1, 2 and 3 to the ranges in order to calculate an "average data quality". Data quality is then weighted by the sold volume of metal packaging.

Category	Ranges available for the member	Value associated by RDC	Comments
Cat 1	X < 5%	1	Very low uncertainty
Cat 2	5%< X < 15%	2	Medium uncertainty
Cat 3	X > 15%	3	Large uncertainty

Table 3 – Data quality in the questionnaire

Quantified estimation of the uncertainty by the manufacturing plant is judged of limited reliability; however, the qualitative estimation is considered as giving a good insight to assess the precision and the representativeness of the data.

Data quality is weighted by the production of steel packaging (volume in tons). In addition, RDC calculated one percentage of response to each main parameter. For a given parameter, this percentage represents the ratio of steel packaging volume accounted for the members which gave a value for this parameter divided by the total volume of steel packaging produced by all members involved in the study.

Based on the assessment of the provided data (see annex), the main inputs and outputs of the manufacturing plant can be classified as following:

- **Data with low uncertainty**
  - Raw material to produce the metal packaging were answered by most of the furnaces (76% to 100%) and producers assessed the uncertainty for these materials as very low.
  - Electricity and Natural gas consumptions have a very good coverage (100%) and producers assessed a very low uncertainty.
  - Water consumption has a very good coverage (99%) and producers assessed a low uncertainty.
  - Atmospheric emissions of CO_2 have a good coverage (51%) and producers assessed a low uncertainty.
  - Water emissions have a very low coverage (under 20%) but a very low uncertainty.

- **Data with medium uncertainty**
  - Secondary and tertiary packaging data have a low coverage (19%) and a medium to high uncertainty.
  - Other atmospheric emissions have a very disparate coverage (3% to 95%) and producers assessed medium to high uncertainty.

- **Data with high uncertainty**
  - Consumption of other energy sources (heavy fuel, light fuel, liquid gas, propane) have a very high coverage (100%) and producers assessed a high uncertainty.
  - Transports of raw materials to the furnaces are considered of high uncertainty as around half of the production volumes are tracked. Producers were not asked to assess data quality in this case.

III.1.7. Background data quality assessment

Background datasets used in the study mostly come from EcoInvent v2.2 and some other ones from Gabi 5 and RDC models based on COPPERT 4. The following table assesses the data quality of the background datasets by considering the influence on results (based on contribution to LCIA results) and the data quality (based on expert judgement).

Legend

Influence on the results		Data quality	
+	Low influence	+	Low quality data
++	Medium influence	++	Fair quality data
+++	High influence	+++	Good quality data

Data	Influence on results	Data quality	Comments
Energy carrier			
Natural gas supply	+++	++	Datasets from EcoInvent v2.2 with a good geographical and technological representativeness but low time representativeness
Heavy fuel supply	+++	++	
Electricity from hard coal, at power plant	+++	++	
Electricity from nuclear at power plant	++	+/++	
Electricity from natural gas at power plant	++	++	
Electricity from oil at power plant	+	++	
Raw materials production			
Steel production	+++	++	Dataset from APEAL 2012 with a good geographical and technological representativeness. Time representativeness is lower, this mainly concerns electricity production that has changed since then.
Aluminium	+++	++	Dataset from EAA 2010 with a good geographical and technological representativeness. Time representativeness is lower, this mainly concerns electricity production that has changed since then.
Lacquers, coatings, varnishes	+	++	Datasets from EcoInvent v2.2 with a good geographical. Technological representativeness and Time representativeness is lower.
Printing inks	+	++	
Sealing compounds	+	++	

Data	Influence on results	Data quality	Comments
Transports			
Truck emissions	+	++	Datasets produced by RDC based on COPPERT 4, taking into account truck classes, pollution norm, real payload, etc.
Diesel production	+	++	Datasets from EcoInvent v2.2 with a good geographical and technological representativeness but low time representativeness
Train	+	++	Model based on Ecotransit from 2014
Ship	+	++	Model based on Ecotransit from 2014. Consumptions are from Base Carbone v11.0
Infrastructure			
Metal Working Factory	+++	+	Process highly influent on a limited number of impact categories: Human toxicity, Ecotoxicity, Abiotic resources depletion, Land use. The quality of these impact categories is seen as limited, leading to a high uncertainty for these indicators.
Waste and wastewater treatment			
Hazardous and non-hazardous waste disposal	+	+	Generic process for waste treatment from EcoInvent v2.2.
Treatment of wastewater rejected to the grid treatment	+	+	Mostly refers to the electricity consumption of the WWTP. Model of the process is based on RDC knowledge, and infrastructure comes from EcoInvent v2.2.

III.2. Life cycle model description

III.2.1. Categories

Eight categories are used to present the data:

- Five types of steel packaging sectors were identified. Most of the plants participating to the study produce a single type of steel packaging (61 plants). Those steel sectors correspond to the five first categories.
- Few plants had a multiple sectorial production (10 plants). A sixth category is therefore identified as the multi-packaging sector.
- The average for steel packaging is created from those six categories. The average data are weighted by the production of the manufacturing plants.
- Finally, the aluminium food can sector is identified as the only category to calculate the average for aluminium packaging.

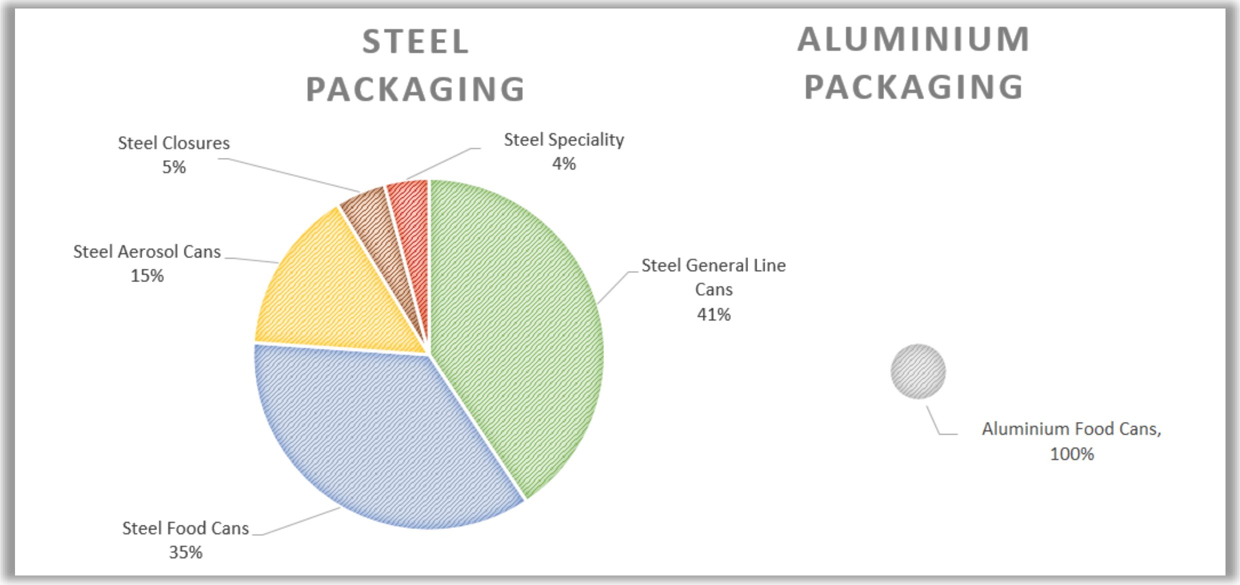
The next table presents the eight categories created to present the data and assumptions.

Table 4 - Categories for data and assumptions presentation.

Category	Description	Use of the data	Use of the results
1	Steel General line cans	*Production of results and average for Steel packaging*	*Presentation in the LCA report*
2	Steel food cans	*Production of results and average for Steel packaging*	*Presentation in the LCA report*
3	Steel aerosol cans	*Production of results and average for Steel packaging*	*Presentation in the LCA report*
4	Steel closures	*Production of results and average for Steel packaging*	*Presentation in the LCA report*
5	Steel speciality	*Production of results and average for Steel packaging*	*Presentation in the LCA report*
6	Multi-packaging sector	*Average for Steel packaging*	-
7	Steel packaging (based on categories 1 to 6)	Production of results	*Presentation in the LCA report and LCI publication*
8	Aluminium packaging (based on aluminium food cans)	Production of results	*Presentation in the LCA report and LCI publication*

III.2.2. Packaging production

Production of packaging is expressed in tons. The next figure gives the repartition in the different sectors (from the data received by the participating members).



III.2.3. Raw materials for primary packaging

Data collected

Consumption of raw material was calculated in g by kg of packaging produced from members' data. The average data are weighted by the production of the manufacturing plants.

Raw material *g / kg prod.*	Steel General line Cans	Steel Food Cans	Steel Aerosol Cans	Steel Closures	Steel Speciality	Multi-Packaging	Steel Packaging Average	Aluminium Food Cans
Steel	1 147.8	1 113.1	1 080.7	1 295.6	1 106.0	1 181.9	**1 136.4**	**0.0**
Aluminium	3.6	0.9	0.0	0.0	0.0	6.2	**2.5**	**1 149.4**
Lacquers, coatings, varnishes	22.8	22.8	10.7	59.7	13.4	31.2	**23.0**	**58.0**
Printing inks	0.3	0.1	0.3	1.5	0.3	1.5	**0.4**	**1.3**
Sealing compounds	3.9	2.2	1.4	14.1	0.4	13.9	**4.7**	**9.4**
% loss	17.8 %	13.9 %	9.3 %	37.1 %	12.0 %	23.5 %	**16.7 %**	**21.8 %**

Assumption on coatings

Coatings and lacquers are assumed to be 50% water based and 50% solvent based. The coatings are assumed to be similar in composition for both steel and aluminium packaging.

III.2.4. Secondary and tertiary packaging

Data collected

Around one fifth of the participating members gave data for secondary and tertiary packaging. All the information was treated as a single set associated to the global metal packaging manufacturing (steel and aluminium). It is assumed that secondary and tertiary packaging are similar no matter the type of packaging (aluminium or steel), this is validated by Metal Packaging Europe. Seven materials were included in the questionnaire to encode the data, see table below.

One of the materials was not used at all by answering members (steel frame). Two of them were gathered to a category "other" (Plastic pallet and PPA) as they represent a very small part of the total weight encoded for secondary and tertiary packaging. The data encoded for the wooden pallet was not used due to lack of robust data. Assumptions were made to evaluate the number of pallets required for the transport to the filler. Those take into account the volume of standard units and the maximal volume available in trucks during the transport.

Assumptions

The transport of empty packaging to the filler is constraint by the volume available in the truck (except for the transport of closures, in this case, the transport is constraint by the weight). The number of cans on a pallet is therefore also limited.

The secondary and tertiary packaging are assumed to start their end-of-life at a European industrial stage. It was assumed that 100% of the material were sent to recycling.

III.2.5. Energy data

Consumption data were calculated from members' data for both consumption of electricity and consumption of heat.

Electrical mixes

The consumption of electricity for the **production of raw material** is included in the LCI's of production (sources: APEAL, EAA, PasticsEurope and Ecoinvent, see section *III.2.3 Raw materials for primary packaging*).

For the **manufacturing of packaging,** participating members encoded the total consumption of electricity consumed during a full year of production (2013). The members could choose to select the average national mix or to encode a specific mix of electricity. The average national mix is the consumption mix[2] coming from IEA 2012.

The average mix was calculated from the data of all participating members. The next figure gives the final electrical mix estimated for the metal packaging production, it is decomposed by its description, its locations and its sources.

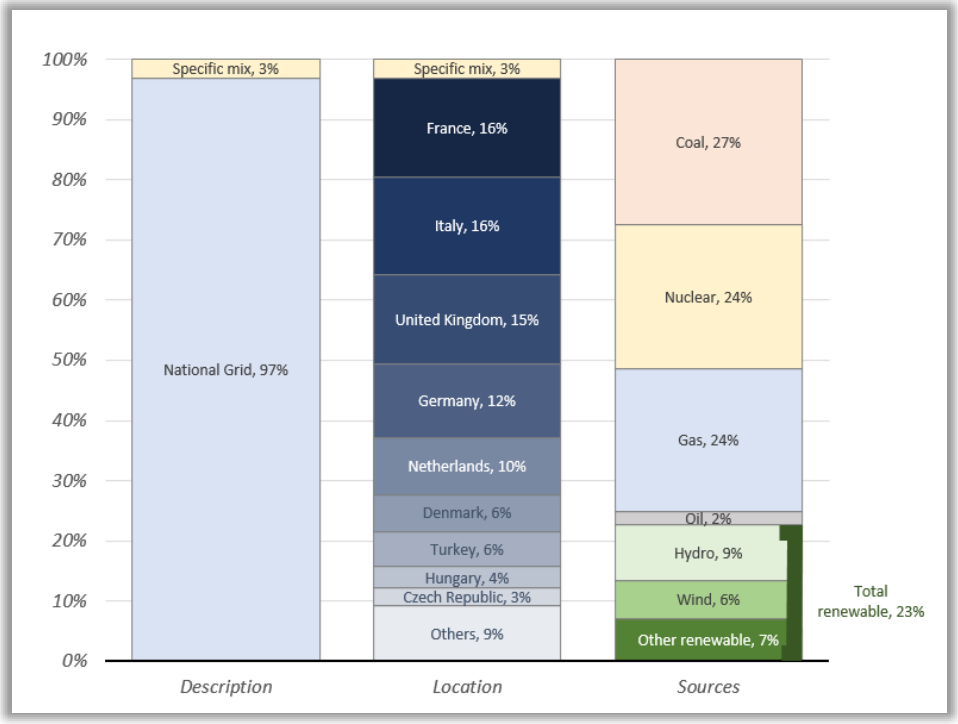


Figure 4 - Composition of electrical mix used for manufacturing production (Members' data).

Finally, the mix of electricity used for the **end-of-life process** is the European average mix of consumption from IEA 2012.

See section *II.3 Limitations of the study*.

[2] Consumption mix is used instead of production mix in order to be consistent with ILCD / PEF.

Recovered Energy

During the year 2013, some metal packaging manufacturers sold energy to the grid. This energy was taken into account in the model and represents a benefit for the process.

The value of **0.006 kWh / kg produced steel packaging** was recovered in 2013. It represents 0.9% of the total consumption of heat for the Steel packaging average.

No energy recovery was modelled at incineration stages, neither for steel, nor for aluminium.

III.2.6. Water consumption and effluent

Water consumption

The average volumes of water required per kg of finished metal packaging are **0.48 l** and **0.72 l** respectively for steel and aluminium packaging.

The waste water output are **0.29 l** and **0.55 l** per kg of, respectively steel and aluminium packaging. The net water consumptions are then equal to **0.19 l** and **0.17 l** per kg of, respectively steel and aluminium packaging.

It is assumed that the water output is rejected in the same place from which it has been taken.

Water emissions

The waste water output volume may be released either to the natural environment or to a public water system. Regarding the total water releases of all participating members, 61% is released to a water system and 39%, directly to the environment.

The next table shows the measurements of waste released in the water. Two sets of data are presented for the part of water released into water systems, the data measured by Metal Packaging Europe members and the estimation of concentrations after Waste Water Treatment Plant (WWTP). Abatement rates come from Degrémont sa (Water treatment solutions).

Table 5 shows the waste measurements in water after passing through WWTP.

Table 5 – Key analyses concentrations in water discharged

Waste	To Environment	To Public Water System	
	mg/l (measured)	*mg/l (measured)*	*mg/l (after WWTP)*
SS (Suspended Solids)	36.8	252	20
COD (Chemical Oxygen Demand)	73.0	1769	195
BOD (Biological Oxygen Demand)	26.5	524	31
Total hydrocarbons	0.0	9	1

III.2.7. Transport

Transport includes three stages of the life cycle:

- Transport of raw materials to the manufacturing plant;
- Transport from manufacturing plant to the filler;
- Collection transport and transport to recycler at end-of-life stage.

Modes of transportation

Transport by truck

Fuel consumptions and airborne emissions from trucks are obtained from the COPERT 4 methodology (version 5.0). More details about this methodology are presented in Annex.

The trucks considered in this study:

- Have a payload of 24 Tons;
- Are "Articulated 34-40 Tons" (framework);
- Have an impact when they are empty that represents around 70% of those when trucks are fully loaded (the factor 70% is a coarse average value derived from the Copert 4 methodology by considering a set of trucks of various gross vehicle weights for both speed used respectively for rural and urban transportation); the 30% remaining varies linearly with the ratio of load to maximum payload (the hypothesis of linearity comes from Copert 3 methodology).

The empty return rate (part of the trip that the truck must achieve empty before being reloaded) is assumed to be 29% (European average published by Eurostat, 2008).

For the transport of raw material, trucks are assumed to be fully loaded.

For the transport of empty packaging (from manufacturing site to filling site), the payload is assumed to be under 100%. Indeed, the filling of the truck is constraint by the volume of empty packaging rather than their weight. The total weight of loaded pallets are presented in the section *III.2.4 Secondary and tertiary packaging*.

Transport by train

Two types of traction are modelled: either electric or diesel.

In this study all transports by train are modelled by a "train Europe".

Environmental impacts of trains comprise direct emissions and emissions linked to the production and supply of fuel or to electricity production.

Transport by boat

Impacts of transport by transoceanic boat are calculated per container. This allows taking into account the loading rate of the containers. Indeed, the number of containers required for a transport depends on this loading rate.

Emissions due to transport by transoceanic boat are calculated as ton*km. The boat is assumed to be a handymax bulk carrier, based on information from Ecotransit. Fuel consumption is assessed based on "Base carbone – Documentation des facteurs d'émissions de la Base Carbone ® - version 11.0". The report gives consumption per km and average load rate as well as empty return rate. Emissions due to heavy fuel oil (HFO) production, boat infrastructure and maintenance are based on EcoInvent v2.2 background datasets. Emissions due to HFO combustion are based on Ecotransit data and other elementary flows are based on EcoInvent v2.2 background datasets.

Distances

Distances are calculated from members' data (raw material and transport to filler) or estimated based on literature.

III.2.8. End of life

End of life after the manufacturing stage

The loss and scrap of metal during the manufacturing stage is assumed to be 100% recycled. Non-hazardous waste is modelled as municipal waste. It is assumed to be either incinerated or landfilled according to answers from members. Hazardous waste is assumed to be incinerated in a hazardous incinerator.

End of life after the delivery to fillers

The secondary packaging (e.g. pallet or cardboard) is assumed to be 100% recycled at the filler.

End of life post-consumption

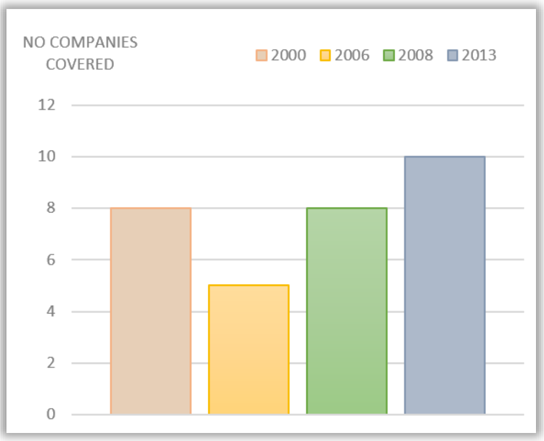
The European average recycling rates published by APEAL are used for steel (75.1%, 2013 data) and data from EAA was used for aluminium (71.3% for aluminium can, 2013 data) packaging.

III.2.9. Data – Annual evolution

The previous study "*LCA model for metal packaging*" realised for Metal Packaging Europe by TNO in 2012 showed the evolution of results from 2000 to 2008 by covering three years of production: 2000, 2006 and 2008. In order to follow the evolution of environmental performances of Metal Packaging Europe members, the **data** presented in the TNO study was reused in this document to produce evolutionary graphical representations. The same work is done for the evolution of the **results**.

Representativeness - Number of companies and countries covered by the study

With 10 companies involved, the 2013 update has the highest participating rate of Metal Packaging Europe members.



Unfortunately, no information is accessible to evaluate the number of countries involved in the previous study. The next figure shows a European map identifying the countries of production of the participating plants for the 2013 update.

Figure 5. European coverage of the actual study.

Packaging weight

The weight of packaging is a key factor as all the results are expressed by unit (can). This is also a key issue for the manufacturers. As it can be seen in the next figure, the individual weights of the standard packaging are slightly reduced year after year, except for the aerosol cans.

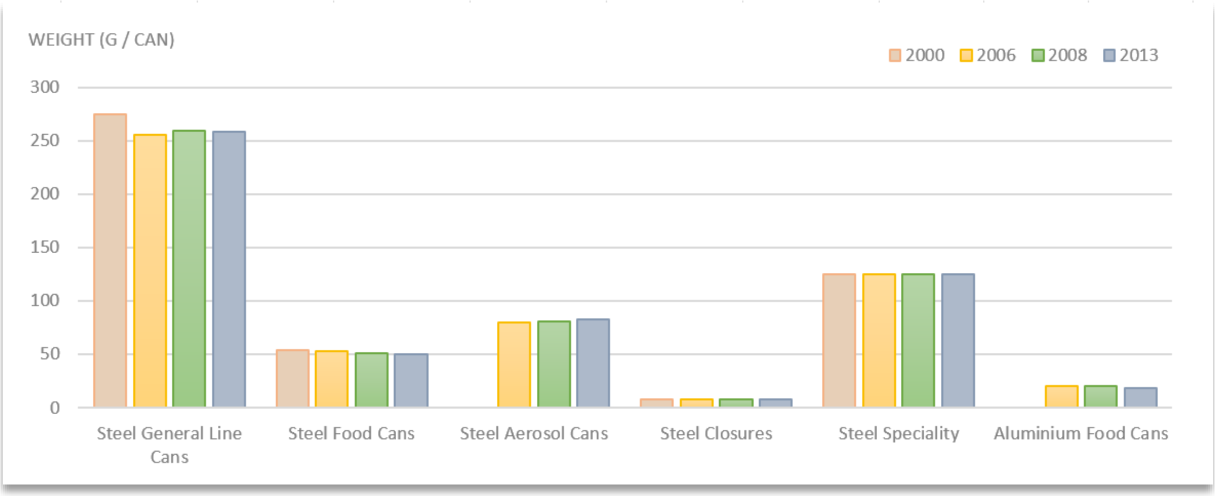


Figure 6 - Weight of the standardized units of packaging. Comparisons with previous study (TNO 2012)

The weight diminution is the results of the compromise between reducing the amount of used material and ensuring the same performance of the products. The can manufacturers would use several ways to reduce the weight of their packaging and this is kept as confidential information. The reasons explaining this willingness to produce more lightweight packaging are multiple:

- Reducing the costs throughout the supply chain (e.g transportation costs);
- Preventing waste production;
- Ensuring a better resource efficiency;
- Remaining competitive;
- Reducing the environmental foot print.

IV. Life Cycle Impact Assessment (LCIA)

IV.1. System considered and methodology

IV.1.1. System considered

Figure 7 shows the system considered for the cradle-to-gate with end-of-life LCA. The results are calculated for the 6 sectors of packaging (5 steel packaging and 1 aluminium packaging). Total results are presented for the 14 impact categories recommended by the PEF. Detailed results (by life cycle stages) are then analysed for six selected categories. Those results are compared to the previous results made in the TNO study (for 2000, 2006 and 2008). This shows the annual evolution of results by impact categories.

Sensitivity analysis was assessed for three key parameters: the recycling rate, the weight of packaging and the part of green sourced energy at the manufacturing stage. Those are achieved for the *climate change* indicator.

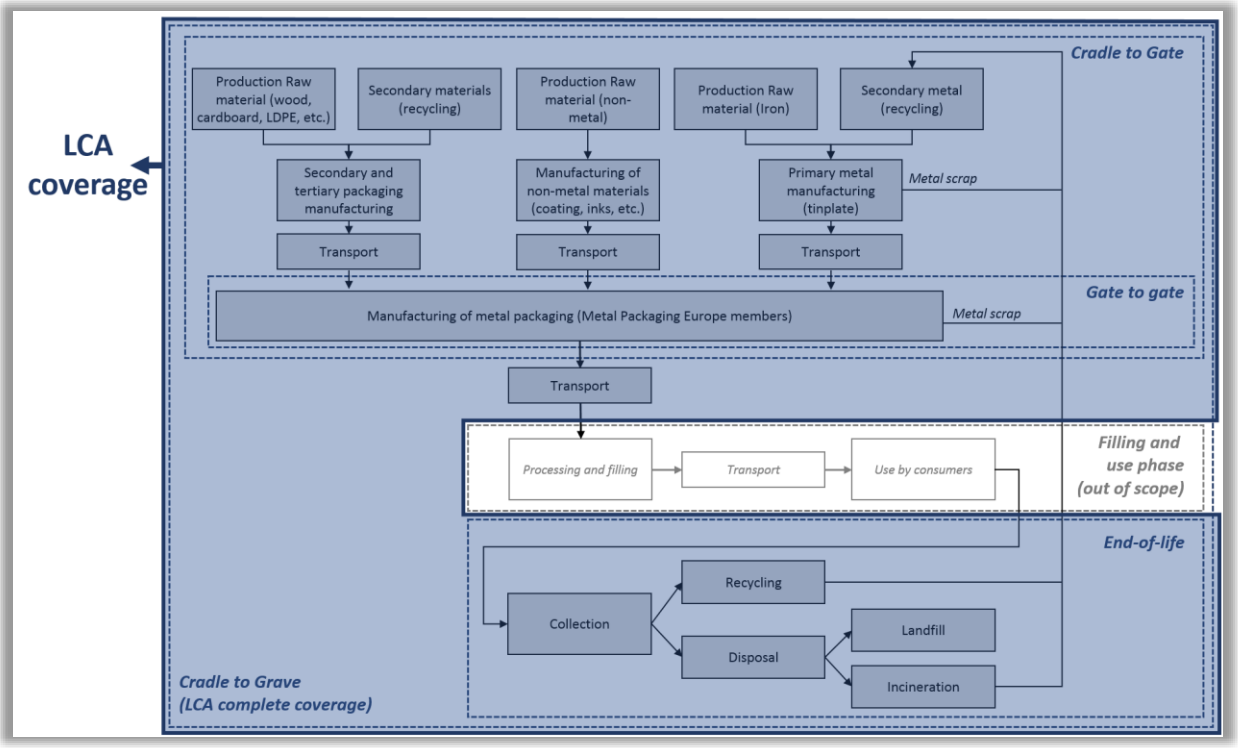


Figure 7 – LCA system boundaries

IV.1.2. Methodology: main assumptions

The allocation rules for the recycling benefits follow the "0-100 allocation".

The recycling rates are assumed to be 75.1% for steel and 71.3% for aluminium.

IV.2. Annual evolution comparisons

IV.2.1. Similar methodologies for valid comparisons

All of the results could not be compared with the ones from the previous study. The main reason is the difference of methodologies retained for the calculation of the impact categories. Indeed, the LCA community is constantly improving the methodology used to calculate the environmental indicators. The consensus for many LCA experts is now to follow the PEF recommendations for the choice of environmental impacts categories. Those are different than the ones selected in the previous report.

14 PEF impact categories were then retained in this present study. Amongst them, six categories were identified as key-issues for the metal packaging manufacturing and were analysed in detail. The next table presents those six categories, their equivalent from the previous study (if exists) and whether a comparison is possible or not.

Impact categories retained in the present study	Equivalent category in the previous study	Comparison of methodology	Can be compared?
Climate change (kg eq. CO_2)	Climate change	*Seems coherent*	*Yes*
Abiotic resource depletion (kg Sb eq.)	*Metal depletion*	Metal depletion is expressed in kg Fe eq. and no conversion exists between the two calculation methodologies.	*No*
Water depletion (m^3 eq.)	Water depletion	*Seems coherent*	*Yes*
Air acidification (kmol H^+ eq.)	*Terrestrial Acidification*	*Terrestrial Acidification* is expressed in kg SO_2 eq. and no conversion exists between the two calculation methodologies.	*No*
Photochemical oxidant formation (kg NMVOC eq.)	Photochemical oxidant formation	*The category retained by TNO appears to follow a different methodology as the one recommended by the PEF. Indeed the results show a 20% higher impact with the PEF category with exact same inputs as in the previous study.*	*No*
Particulate matter (kg PM2.5 eq.)	*Particulate matter*	In the TNO study, *Particulate matter* is expressed in kg of PM10 equivalents and no conversion exists between the two calculation methodologies.	*No*

Besides the differences regarding the choice of impact categories, it must be noticed that **the comparisons of results must be interpreted with caution as the results for 2000, 2006 and 2008 (produced by TNO) are not based on the same model than the ones for 2013 (produced by RDC Environment). Although RDC tried to follow a similar methodology as the one presented in the TNO report, several differences between the two studies may occur.** Amongst them, the following can be identified:

- The precise list of LCI's used to model the life cycle is not available in the TNO study. The choice made by RDC Environment of some processes may therefore be different than the ones made by TNO.
- The judgement of LCA experts may be different regarding the best source for some parts of the model (e.g. Coppert is preferred by RDC Environment instead of Ecoinvent for transport model).

V. Life Cycle Inventories (LCI)

There are two kinds of packaging, steel packaging and aluminium packaging, and two scopes identified for the LCI production. It means that 4 LCI's are eventually produced:

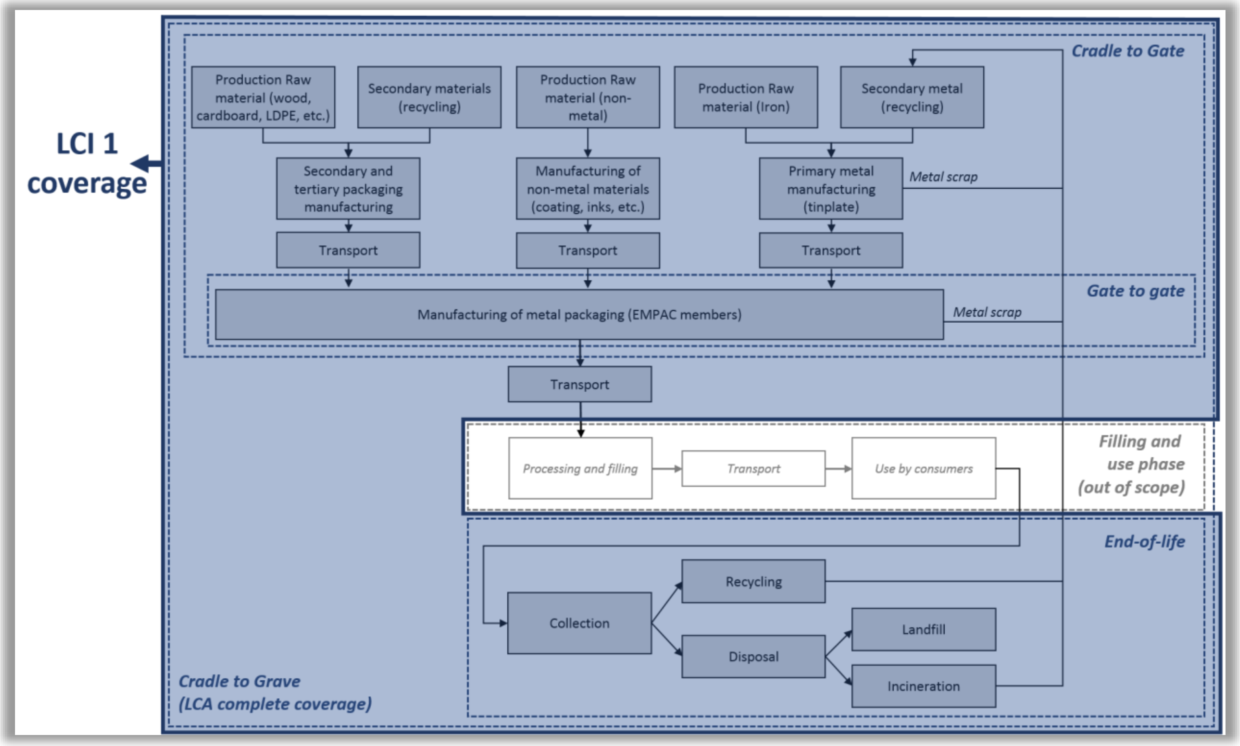
- Cradle-to-gate with End-of-life LCI for steel packaging
- Cradle-to-gate with End-of-life LCI for aluminium packaging
- Gate-to-gate with End-of-life LCI for steel packaging
- Gate -to-gate with End-of-life LCI for aluminium packaging

The LCI's are expressed by kg of packaging (the previous results presented for the LCIA are expressed by unit of packaging). The two kinds of LCI's respond to different modes of use:

- The cradle-to-gate with End-of-life LCI's must be used for LCA studies analysing the global European production of metal packaging (excluding beverage packaging).
- If an LCA practitioner wishes to evaluate the result for a specific European country, the gate-to-gate LCI's must be used and associated with the APEAL LCI's (for steel production and recycling) and the EAA LCI's (for aluminium production and recycling). This will allow to model a specific recycling rate for the packaging.

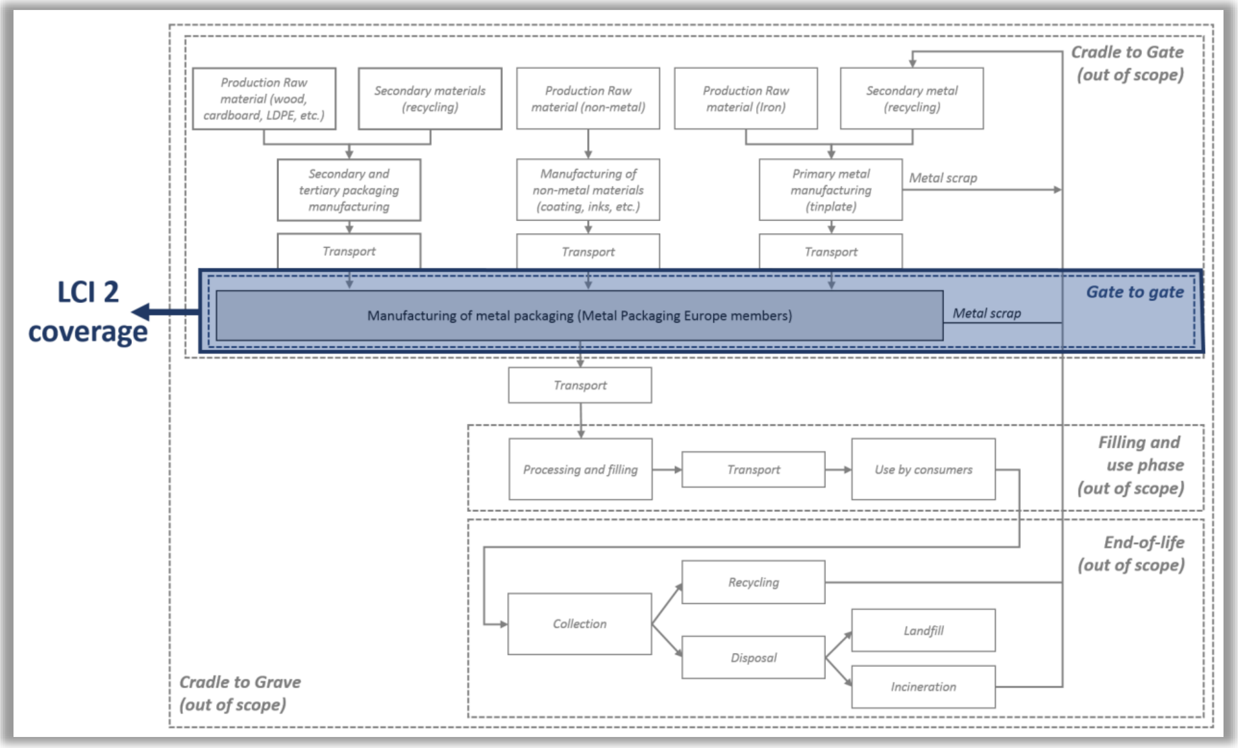
V.1. Cradle-to-gate with End-of-life LCI's

V.1.1. Scope: Cradle to gate with end-of-life



V.2. Gate-to-gate LCI's

V.2.1. Scope: Gate to Gate



V.3. Sensitivity analysis on average results

Two sets of average results were calculated:

- The steel packaging average expressed by kg of packaging.
- The aluminium packaging average expressed by kg of packaging.

The software used to calculate the result is RangeLCA. RangeLCA software, developed by RDC Environment, has innovative characteristics that improve the reliability (and consequently, the credibility) of the results of an LCA.

The basic concept is that the results must reflect the diversity of individual cases (instead of being limited to an average of possible cases and a few alternative scenarios) and thus automatically integrate the sensitivity analysis of the parameters.

From a mathematical point of view, this concept is expressed by the use of random variables instead of fixed values (known as "typical" values). In a model, there can be two types of parameter variability:

- Variation of the situations; these express non-concurrent alternative situations (for example: choice X or Y for fume treatment).
- Data uncertainty; this is expressed by probability distributions around the average value of the parameters (for example, a transport distance described by a normal distribution); the probability distributions can be uniform, normal, log-normal, etc.

This software automatically calculates the results obtained for each combination of parameters (3000 combinations in this study); these results can be summarized in graphical form according to the value of one of the variables in the model; these so-called "Range" graphs make it possible to assess the sensitivity of the results in relation to the

Three parameters were analysed in the sensitivity analysis. The purpose of the analysis is to evaluate the influence of these parameters on the results. The sensitivity analysis was led only for the impact on the climate change. This impact category was chosen to illustrate the variation of impact on the environment. The 3 parameters are the following:

- A factor of reduction of the weight of packaging from 0 to 15%.
- The part of green energy used in the electrical mix from 0 (no green energy) to 100% (only green energy).
  The "green energy" terms relate to the production of electricity from a mix of renewable resources (solar, thermal, wind and biomass) The mix is calculated using the European mix of electricity consumption excluding the non-renewable resources.
- An additive factor of recycling rate from 0 (the recycling rate is not changed) to 10% (the recycling rate is ten percent higher).

V.3.1. Climate change

Weight reduction

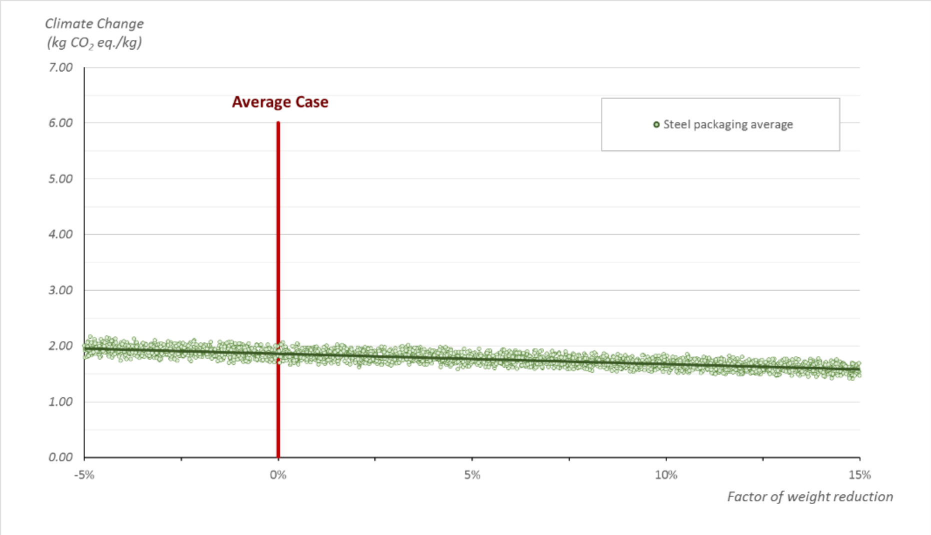


Figure 8 - Sensitive analysis – Steel - Weight reduction (from 0 to 15% of weight reduction)

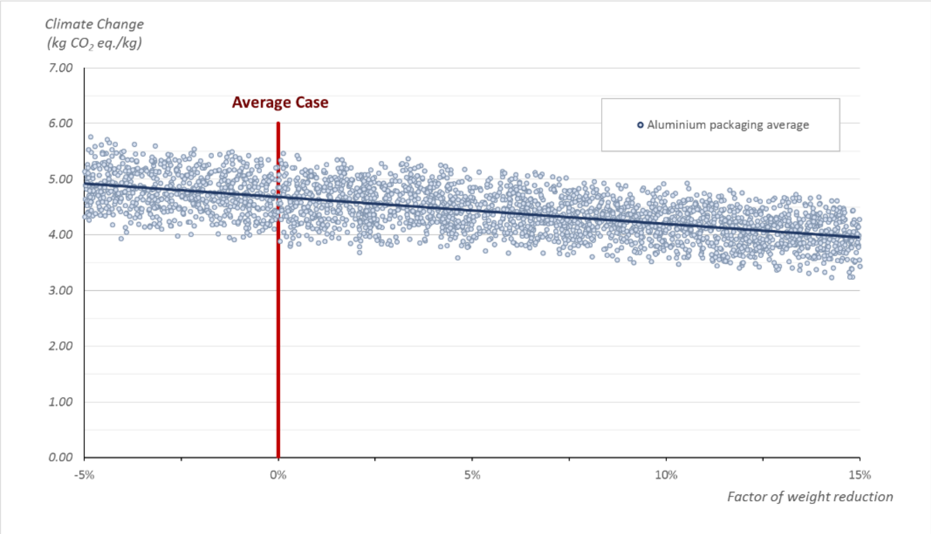


Figure 9 - Sensitive analysis – Aluminium - Weight reduction (from 0 to 15% of weight reduction)

Any reduction of weight of the packaging units will directly be expressed in decrease of the impact on the climate change. For each percentage of weight reduced, the impact would be reduced by one percent.

Increase of recycling rate

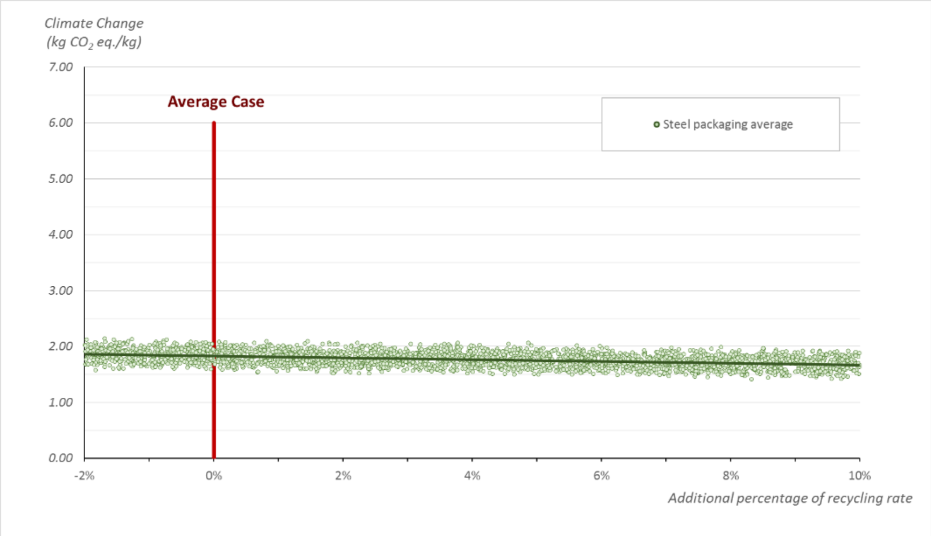


Figure 10 - Sensitive analysis – Steel - Recycling rate increase

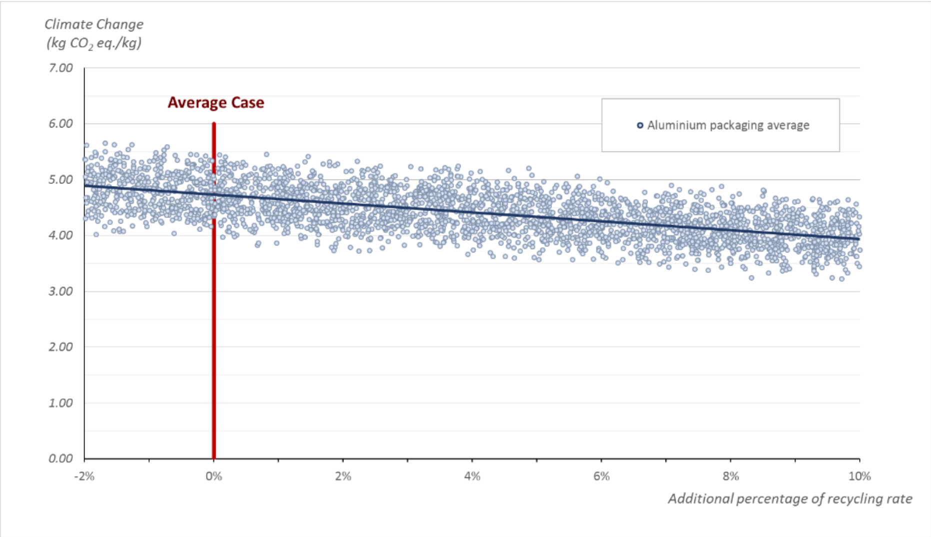


Figure 11 - Sensitive analysis – Aluminium - Recycling rate increase

An increase of 10% of the recycling rate would reduce the average impact on the climate change by 9% for the steel packaging and by 18% for the aluminium packaging.

Part of green energy in the electrical mix

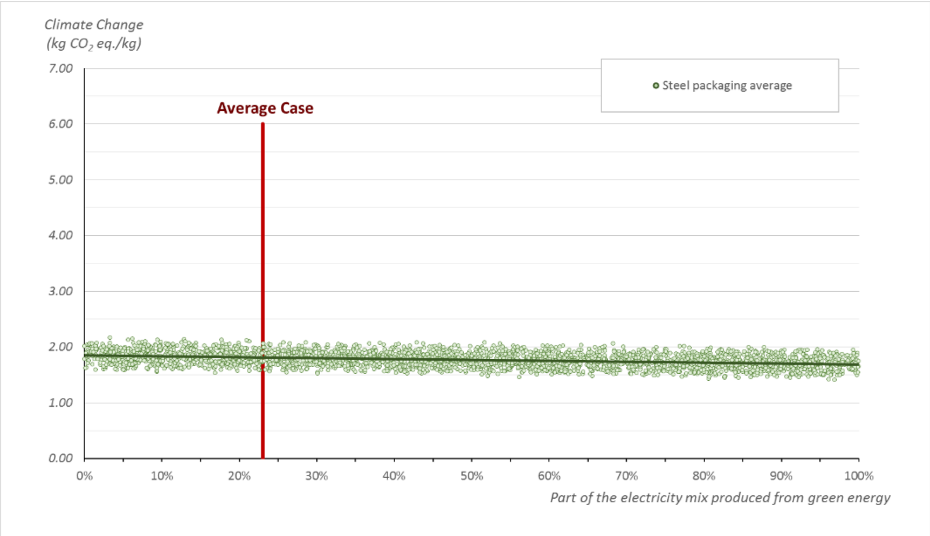


Figure 12 - Sensitive analysis – Steel - Part of green energy in the electrical mix.

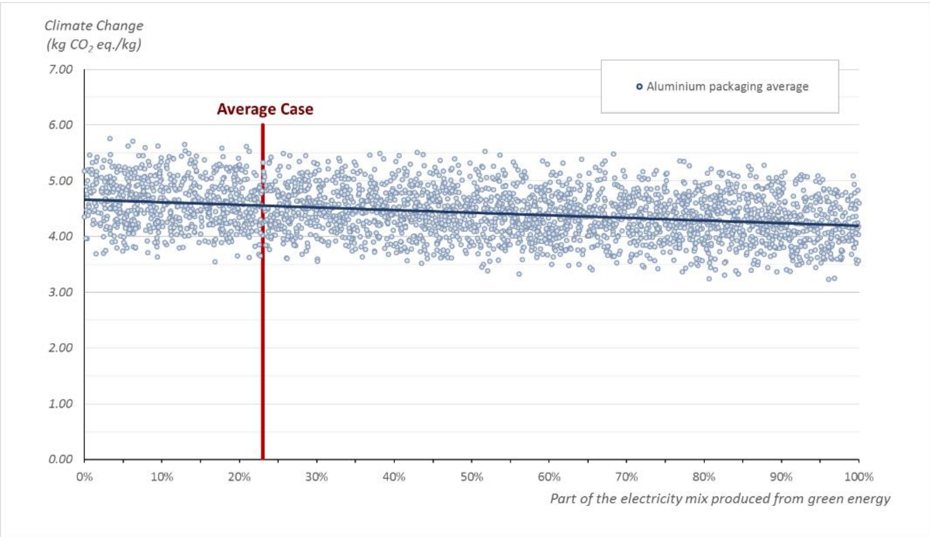


Figure 13 - Sensitive analysis – Aluminium - Part of green energy in the electrical mix.

By choosing a 100% green sourced electricity, a manufacturer could reduce their impact on climate change between 7 and 9%.

V.3.2. Other impact categories

The sensitivity graphs for the 13 other impact categories are presented in annex. The next table show the variation of results expressed in percentage of difference compared to the average case. For the following statements:

- A reduction of weight of 1%.
- An increase of 10% of the recycling rate.
- A choice for a 100% green sourced electricity.

Table 6 - Variation of results from sensitivity parameters.

Impact categories	Steel			Aluminium		
	For a weight reduction of 1%	For a recycling rate rise of 10%	For 100% green sourced electricity	For a weight reduction of 1%	For a recycling rate rise of 10%	For 100% green sourced electricity
Climate change	-1.0%	-8.9%	-7.3%	-1.0%	-17.9%	-8.5%
Abiotic resource depletion	-1.1%	-38.6%	0.0%	-1.0%	-23.5%	-0.5%
Water depletion	-1.0%	1.5%	-17.7%	-1.0%	-25.5%	-23.7%
Acidification	-1.0%	-5.7%	-8.5%	-1.0%	-21.7%	-7.4%
Photochemical oxidant formation	-1.0%	-8.0%	-6.5%	-1.0%	-10.5%	-5.1%
Freshwater eutrophication	-1.0%	0.5%	-29.8%	-1.0%	-18.2%	-11.6%
Particulate matter	-1.0%	-4.0%	-4.7%	-1.1%	-27.8%	-6.9%
Stratospheric ozone depletion	-1.0%	5.4%	-4.8%	-1.0%	-7.0%	-8.2%
Ionising radiation	-1.0%	2.8%	-14.2%	-1.1%	-28.6%	-3.0%
Terrestrial Eutrophication	-1.0%	-7.5%	-7.3%	-1.0%	-10.1%	-5.2%
Marine eutrophication	-1.0%	-6.2%	-6.4%	-1.0%	-9.6%	-4.9%
Land use	-1.1%	-52.2%	0.1%	-1.0%	0.9%	-5.9%
Human toxicity	-1.0%	7.9%	-0.4%	-1.0%	-25.9%	-4.9%
Ecotoxicity	-1.0%	6.3%	-0.9%	-1.0%	-11.3%	-5.3%

VI. Life Cycle Interpretation

VI.1. Completeness and consistency check

VI.1.1. Completeness

Completeness checks were carried out at gate-to-gate system boundaries, analyzing:

- The completeness of process steps as regards primary data provided by the metal packaging manufacturers.
- The energy, input materials as well as emissions from metal packaging manufacturers. Note that in case where no data were available, average from other plants or data from literature has been used.

For more details see chapter II.2.6.

VI.1.2. Consistency

Several checks were made in order to validate the data received from the metal packaging manufacturing plants. When questionable data were identified, an email was sent to the manufacturing plant to validate the data. Three types of data quality tests were performed as part of the data validation process. These tests are presented in this section along with a list of examples. These lists are non-exhaustive.

- Logical tests to check the consistency of data provided by each member.
- Comparison tests to identify if data from one specific furnace (energy, waste, water, etc.) are in a range of plausible values having in mind data from other manufacturers.
- Value tests to check whether average values are in line with range of values commonly used.

As regards results, plausibility of the results and main source of impacts were assessed having a critical view on data quality. Consistency has been also done through comparison with results from the previous Metal Packaging Europe LCA.

VII. Annex

VII.1. Description of the selected impact categories

VII.1.1. Climate change

Each greenhouse gas (GHG) has a different warming potential which affects climate change. This potential is calculated on the basis of a reference, the warming potential of CO_2, and a time-horizon, 100 years here. Each GHG is assigned to a characterization factor, which expresses how many times more important the warming potential of this greenhouse gas is compared to CO_2 (whose characterization factor is by definition equal to 1) when averaged over the time horizon considered. The characterization factors used are taken from IPCC 2013 – 100 years.

The category comprises effects of all greenhouse gases and is expressed in *kg eq.* CO_2.

No credits are associated with temporary (carbon) storage or delayed emissions. In practice, all emissions modelled as occurring within a time span of 100 years are accounted as emitted at time 0 of the assessment, similarly as the carbon capture from the air that has occurred in the past, for example during growth of a tree.

VII.1.2. Mineral & fossil resources depletion

The impact category is based on the CML method. It uses the Abiotic Depletion Potential (ADP), given in kg of antimony equivalents, to be multiplied with the amount of a given resource extracted. For ADP, the annual production of the resource (the extraction rate, DRi in *kg/year*) is divided by the reserves squared (Ri, in *kg*), and the result divided by the same ratio for the reference resource, antimony:

$$ADP_i = \frac{DR_i}{R_i^2} \bigg/ \frac{DR_{Ref}}{R_{Ref}^2}$$

According to the ILCD Handbook,[3] "*the value for reserves is squared to take into account the fact that a simple ratio of annual production over reserve may, in the case of higher production rates corresponding to larger reserves and vice versa, fail to reflect the impact that e.g. 1 kg of resource extraction has on overall scarcity. By including the annual production rate, CML also captures the current importance of a given resource*."

[3] ILCD Handbook: Recommendations for Life Cycle Impact Assessment in the European context, First edition, 2011 ».

The CML mid-point indicator expresses the consumption of both mineral and fossil types of resources, in kg equivalent antimony (*kg eq Sb*).

The sets of characterization factors are the ones from van Oers et al., 2002. In this publication "*fossil fuels are assumed to be full substitutes (both as energy carriers and as materials)*". ADP is hence expressed as *kg eq Sb/ MJ fossil energy*.

Three different types of reserves are considered by van Oers:

- Ultimate reserves: the reserves are based on the concentrations of the elements and fossil carbon in the earth crust
- Reserve base: these reserves are part of an identified resource that meets specified minimum physical and chemical criteria related to current mining practice. They may encompass resources that have a reasonable potential for becoming economically available within planning horizons.
- Economic reserves: reserve that can be economically extracted at the time of determination

The ILCD Handbook recommends the "*reserve base*" approach as indicated in the recommendations for LCIA of 2011, with sensitivity analysis versus ultimate and economic reserves:

"Van Oers et al. (2002) give characterization factors for economic reserves, reserve base, and ultimate reserves. ***The characterization factors given for the reserve base are recommended****, as this reflects a longer time horizon and the possibility of improvement in mining technology, making feasible the exploitation of previously sub-economic deposits. The reserve base includes deposits which meet certain minimal chemical and physical requirements to potentially become economically exploitable within planning horizons (van Oers et al. 2002)."*

For bottles systems studied in this report, the elementary flows contributing the most to each type of indicator differ significantly. They are:

- For "*ultimate reserves*": energetic resources.
- For "*reserve base*": Nickel, indium, uranium, barite, zinc…

The consumption of metals as nickel, indium, zinc, *etc*. was not pointed as an influent issue at the time the common databases (as Ecoinvent 2.0) were created. In most of the processes modelling infrastructures, the amount of metals was roughly estimated without any deep investigation. Now that the van Oers method with "reserve base" must be used as a standard, the metal consumptions are revealed to be overestimated. More specific and accurate data should be found to update those infrastructure processes.

For this reason, results on mineral and fossil resources depletion must be interpreted with caution.

VII.1.3. Acidification

Terrestrial acidification has many consequences, both on nature and on technosphere. Emissions of acidifying pollutants (NOX, SOX) lead to a decrease in rainwater *pH*, which will then affect soils. These acid water rainfalls wash nutrients from soil, moreover they increase metal solubility into soils. Most known natural effects are softwood forest damage in Northern and Eastern Europe.

Impact on technosphere are buildings degradation due to metals as well as limestone corrosion.

This type of pollution is mainly regional, even if it also applies to the global scale. Acidification is expressed in *kmol* H^+.

VII.1.4. Eutrophication, Terrestrial, marine and freshwater

Eutrophication is an impact category that addresses impacts from emission of nitrogen (N) and phosphorus (P) compounds on aquatic ecosystems, such as lakes and oceans, or terrestrial ecosystems, such as forests and grasslands. The emissions can be airborne emissions of N compounds (NOx, NO, NO2) from combustion processes and artificial fertilizers. Such emissions later deposit mainly on terrestrial systems as nutrients for plants and other organisms. There can also be waterborne emissions of N and P containing substances that are nutrients to algae and other aquatic organisms.

The direct effect of the additional nutrients is stimulated growth of some species more than others, resulting in a change in species composition in the ecosystem. Increased algae growth in aquatic systems due to eutrophication can cause reduced penetration of light into the water and oxygen depletion. This obviously has damaging effects on other species.

The ReCiPe method of characterization is used. It is based on the EUTREND model, based on European conditions, that distinguishes freshwater systems (only P-emissions considered) and marine systems (only N- emissions considered). Marine eutrophication is expressed in *kg eq. N*. Freshwater eutrophication is expressed in *kg eq. P*.

For terrestrial eutrophication, the LCIA method used is the Accumulated Exceedance (Seppala et al, 2006 and Posch et al, 2008). It's expressed in *mole eq. N*.

VII.1.5. Water consumption

Water consumption is assessed taking into account local water scarcity. Gross water consumption is measured, which means that any withdrawal except water going through from hydropower plant turbines is accounted as a consumption.

These withdrawal are then weighted based on their location. Based on the water scarcity in each country, water scarcity factors from 0 to 1 are given to each consumption and then summed. These water scarcity factors reflect the ratio between the gross water consumption and the available resource.

The results are expressed in m^3 of water depletion.

Not that the method used was published in 2006 and updated in 2013, but this update came out too late to be integrated in recommended method of the PEF. The main improvement of this update is to consider net water consumption and not gross water consumption. This is a significant change, especially for the present study, since washing step involves a high gross water consumption but only a moderate net water consumption.

VII.1.6. Photochemical ozone formation

The impact category "photochemical ozone formation" designates the impacts from ozone and other reactive oxygen compounds formed as secondary contaminants in the troposphere by the oxidation of the primary contaminants Volatile Organic Compounds (VOC) or carbon monoxide in the presence of nitrogen oxides (NOX), under the influence of light.

The ReCiPe method of characterization is used. It models marginal increase in ozone formation due to emissions of NMVOC or NOX applying the LOTOS-EUROS spatially differentiated model for calculating European factors. Photochemical ozone formation is expressed in *kg eq. NMVOC*.

VII.1.7. Particulate matter/ respiratory inorganics

This impact category assesses the impacts due to primary particulate matter (PM) as well as and secondary PM, formed in the troposphere due to reactions of precursors like including SO_2 and NOX. Such pollutants typically increase mortality (acute and long-term) and morbidity (typically chronic bronchitis and asthmatics).

The RiskPoll method at midpoint is used. It determines the intake fraction. As PM, only the fraction $PM_{2.5}$ is considered as harmful. The impact category is so expressed in *kg eq.* $PM_{2.5}$.

VII.1.8. Human toxicity

The category 'human toxicity' represents potential effects on human health caused by emissions into air, water and soil. The impact pathway between emissions and effects on populations comprises modelling of three steps:

- Fate of the emitted pollutants in the media
- Exposure of human bodies through various intake routes
- Effects of substance intake on human health

The LCIA method recommended by the PEF USEtox. The characterization factors correspond to both carcinogen and non-carcinogen effects. The category uses all available characterization factors, included those reported by the experts as 'interim' (level III as defined by JRC), namely for metals, due to the likely uncertainty of the factors for these substance groups relative to others. The unit of the impact category is CTU, i.e. comparative toxic unit. It corresponds to the number of cases of mortality or morbidity that are supposed to occur per unit of mass of the substance in function of the compartment of emission.

The method USEtox results from a consensus effort between the modellers. It is developed for modelling comparative risks of toxics on human and ecosystems. For human toxicity, it considers carcinogen and non-carcinogen effects (but does not include factors related to respiratory effects). The model accounts for all important parameters of the impact pathway. The underlying principles reflect common and agreed recommendations from these experts, which makes the method more robust than other methods.

The global score of the category should be used with caution for the following reasons:

- Uncertainty in the factors remain large as indicated in Rosenbaum et al (2008) : "The toxicity factors, i.e. characterization factors, presented here must be used in a way that reflects the large variation of ten orders of magnitude between chemical characterization factors as well as the three orders of magnitude uncertainty on the individual factors. This means that contributions of 1%, 5% or 90% to the total human toxicity score are essentially equal but significantly larger than those of a chemical contributing to less than one per thousand or less than one per million of the total score. […]The life cycle toxicity scores thus enable the identification of all chemicals contributing more than, e.g. one thousandth to the total score. In most applications, this will allow the practitioner to identify ten to 30 chemicals to look at in priority and perhaps, more importantly, to disregard 400 other substances whose impacts are not significant for the considered application."

- The emissions contributing to human toxicity create effects at local or regional scales around the source. The resulting impact strongly depends on the location of these emissions and on the properties of the receiving medium, in particular on the population density within the area exposed to the pollutants. In a method like USEtox, although sub-compartments are defined such as 'urban air', characterization factors are based on average (statistical) fate factors of pollutants and exposure but they cannot take site-specific data into account.

- Process inventories are often incomplete, due to the lack of available data, or wrong due to lack of update. Moreover, they do not specify the properties of the receiving medium.

VII.1.9. Ecotoxicity

Assessing the toxicological effects of a chemical emitted into the environment implies a cause–effect chain that links emissions to impacts through three steps:

- Fate: it links the quantity released to the environment to the chemical masses (or concentrations) in a given compartment. It accounts for multimedia and spatial transport between the environmental media.
- Exposure: (for aquatic eco-toxicity) fraction of a chemical that is dissolved (available) in water
- Effect: quantification of the disappearance of species (on the basis of toxicological data such as EC50, i.e. the concentration at which 50% of a population dies in a laboratory test)

The PEF guide recommends the USEtox method, this category is expressed in CTU.

VII.1.10. Ozone Layer depletion potential

Ozone layer depletion potential expresses ability of persistent chemicals containing chlorine or bromine to damage the ozone layer. These substances go up to the ozone layer where chlorine and bromine react with ozone. Their high damage potential is because they act as catalyser, but remains after ozone destruction.

The most known effect is the ozone hole detected over Antarctica in the mid 80's. Absence of the ozone layer let ultraviolet radiation from the sun reaching the earth surface, which affects living cells (such as human skin). Note that Montreal Protocol reduced drastically emission of these pollutants.

Ozone layer depletion potential is expressed in kg CFC11 equivalent.

VII.1.11. Ionising radiation

The impact category Ionising radiation refers to emissions of radioactive substances to air and water, which have an effect on human health through cancer and severe hereditary effects. The modelling of this impact starts with the emissions and calculates the radiative fate and exposure, based on detailed nuclear physics knowledge. The exposure analysis calculates the dose that a human actually absorbs, given the radiation levels that are calculated in the fate analysis. The dose – response relationship quantifies the effect of absorption by humans on human health.

Ionising radiation is expressed in *kg eq. U235*.

VII.1.12. Land use

The impact categories "Land use" reflect the damage land use has on ecosystems. Examples of land use are agricultural production, mineral extraction and human settlement. Land use can be separated in land transformation ad land occupation. Occupation of land can be defined as the maintenance of an area in a particular state over a particular time period. Transformation is the conversion of land from one state to another state, for example from primary forest to arable land for intensive crop production. Land transformation is often followed by land occupation.

Land occupation causes physical changes to flora and fauna, which results in altered species composition and accompanied species loss and possible species extinction. There are also a lot of side-effects thinkable, such as changes in soil quality and reduction of habitat size elsewhere, but they are often not taken into account in LCIA methods. The environmental mechanism of land transformation is more complex, because it has effect not only on physical changes to flora and fauna. Land transformation also has an effect on physical changes to the soil, which also has an effect on species composition.

Another complicating factor for land transformation is that the changes to the soil causes the release of the greenhouse gases carbon dioxide, nitrous oxide and methane, which has a significant contribution to climate change. This mechanism, however, is normally included in the life cycle inventory and therefore excluded from life cycle impact assessment.

VII.2. Waste water treatment

VII.2.1. Council directive

Council Directive 91/271/EEC indicates the permissible concentration (maximum) in waste after passing through a WWTP (see Table 7).

Urban waste water treatment (Council Directive 91/271/EEC)	
Parameters	Concentration
DBO	25 mg/l
DCO	125 mg/l
MES	35 mg/l for an agglomeration of more than 10 000 "population equivalent" (p.e.)
	60 mg/l for an agglomeration of between 2 000 and 10 000 p.e.

Table 7 – Maximum allowable concentrations in waste water discharged from WWTPs

VII.2.2. Abatement rates[4]

Table 8 shows the abatement rates for main waste in water.

Abatement rates	%
DCO	89
DBO	94
MES (SS)	92.2
Hydrocarbons*	92.6

Table 8 – Abatement rates in WWTP

*Abatement rate for hydrocarbons was calculated from members' data (before and after WWTP).

[4] Source: Dégremont

VII.3. Transport details

VII.3.1. Transport by truck

Copert 4 methodology

COPERT 4[5] is an MS Windows software program used to calculate air pollutant emissions from road transport. The development of COPERT has been financed by the European Environment Agency (EEA), in the framework of the activities of the European Topic Centre on Air and Climate Change. In principle, COPERT has been developed for use by National Experts to estimate emissions from road transport to be included in official annual national inventories. However, it is available and free for use in any other research, scientific and academic applications.

The COPERT 4 methodology is also part of the EMEP/CORINAIR Emission Inventory Guidebook. The Guidebook, developed by the UNECE Task Force on Emissions Inventories and Projections, is intended to support reporting under the UNECE Convention on Long-Range Transboundary Air Pollution and the EU directive on national emission ceilings. The COPERT 4 methodology is fully consistent with the Road Transport chapter of the Guidebook. The use of a software tool to calculate road transport emissions allows for a transparent and standardized, hence consistent and comparable data collecting and emissions reporting procedure, in accordance with the requirements of international conventions and protocols and EU legislation.

COPERT 4 estimates emissions of all major air pollutants (CO, NOx, VOC, PM, NH3, SO_2, heavy metals) produced by different vehicle categories (passenger cars, light duty vehicles, heavy duty vehicles, mopeds and motorcycles) as well as greenhouse gas emissions (CO_2, N2O, CH4). Emissions estimated are distinguished in three sources: Emissions produced during thermally stabilized engine operation (hot emissions), emissions occurring during engine start from ambient temperature (cold-start and warming-up effects) and NMVOC emissions due to fuel evaporation. Non-exhaust PM emissions from tyre and break wear are also included. The total emissions are calculated as a product of activity data provided by the user and speed-dependent emission factors calculated by the software.

Activity data are expressed in km driven by a vehicle, i.e., by “vehicle*km” or “vkm”. In GEF, this parameter is calculated by multiplying the one-way distance to be driven by the number of trucks necessary to transport the load associated with the studied functional unit. This number of trucks corresponds to the ratio of the load by FU to be carried to the payload for the selected truck.

COPERT 4 gives pollutant emission rates as a function of four parameters:

- type of vehicle (framework, gross weight, vehicle rating and EURO standard);
- load;
- average speed;
- slope.

[5] Methodological reports and the free software can be downloaded from http://lat.eng.auth.gr/copert/

Euro Standards

EURO Standards are regulating airborne emissions from road transportation vehicles. Because of these standards, emissions of several pollutants dropped significantly, like NOx and particulate matter. Consequently, it is important to know the standard to which used trucks comply.

The default mix (see Table 9) is used as fixed for truck transport in this study.

Euro norm for truck	Default mix value
Euro 3	52%
Euro 4	18%
Euro 5	30%

Table 9 – Euro norm default mix

VII.3.2. Transport by train

Electricity and diesel consumptions

Electricity and diesel consumptions are calculated as a function of "gross ton * km". Working with gross weight allows modelling of a specific empty return rate (ERR).

Values of energetic consumptions used for this study are given in Table 10. They have been calculated on the basis of data provided by SNCF (Source: "Trafics et consommations d'énergie des différentes catégories de trains SNCF par mode de traction en 1999", SNCF, direction de la stratégie, Mission économie). .

Electric traction		Diesel traction
KWh/gross ton * km	kg diesel / gross ton * km	kg diesel / gross ton * km
0.0162	0.00023	0.00416

*Table 10 – Consumptions per gross ton * km*

Values of gross tons are independent of the number of wagons per train but depend on the tare of wagon (fixed at 24 tons) and on the effective load in a wagon. This last parameter is fixed at 36 tons.

Direct emissions

For diesel trains, direct emissions arising from diesel combustion are presented in Table 11.

Emitted pollutant	CO_2	NOx	SO_2	PM 10	NMHC
Unit	g/kg diesel				
Value	3170	42	0.7	1.5	4.7

Table 11 – Direct emissions from diesel

* NMHC = Non-methane hydrocarbons

VII.3.3. Transport by boat

Table 12 shows the fuel consumption details for transoceanic boat transportation.

Parameter	Unit	Value
Typical average capacity of ship	#EVP – TEU	5000
Fuel consumption per day per ship	T of fuel / day	153
Average speed of the corresponding ship	knots	22.5
Average number of kilometres sailed per day	km/day	1000.08
Fuel consumption / TEU / km	**kg fuel / km / TEU**	**0.031**

Table 12 – Fuel consumption for transoceanic boat

Fuel is considered to be bunker oil, as represented by the EcoInvent dataset "heavy fuel oil, at regional storage, RER [#1552]". Combustion of this fuel emits 2882 g CO_2 per kg of fuel.[6] It is considered that there are no receptors of other type of air pollutants for transoceanic transport. Hence only the effect of CO_2 emissions, which is global, is taken into account.

[6] Source: WRI/WBCSD GHG Protocol -Stationary Combustion Guidance : "Calculation tool for direct emissions from stationary combustion, Version 3.0, July 2005" Table 17. Value for residual fuel oil is 2939 in g CO_2/l. Density is 1.02 kg/l)

VII.4. Data Quality

The following table (Table 13) provides information about data quality and answers coverage.

Quality

"→1" refers to data with low uncertainty ("1"= X<5%)

"→2" refers to data with medium uncertainty ("2"= 5 %< X<15%)

"→3" refers to data with large uncertainty ("3"= X>15%)

1.00
1.25
1.50
1.75
2.00
2.25
2.50
2.75
3.00

Answers coverage

The higher is the percentage (→100%), the better is the coverage of the data.

Data	Quality	Coverage	Comments
Raw material			
Steel	1.44	100%	Good quality and high coverage answers. Low uncertainty on main materials of the packaging.
Lacquers, coatings, varnishes (wet mass)	1.55	100%	
Printing inks	1.61	76%	
Sealing compounds	1.59	91%	
Secondary and Tertiary Packaging			
Corrugated board	1.89	19%	Low coverage, only 19% of "positive answers", most of members do not collect information regarding the secondary and tertiary packaging. Besides the quality of data is mostly medium.
Cardboard	2.00	19%	
Wood Pallet	1.90	19%	
Film LDPE	1.85	19%	
Alveolar polypropylene (PPA)	1.61	19%	
Energy			
Electricity	1.02	100%	Maximal coverage answers and very low uncertainty. There is almost no uncertainty about electrical and natural gas consumption.
Natural gas	1.15	100%	
Heavy fuel oil	3.00	100%	Only one member declared a consumption of those kinds of fuel. Very poor quality declared.
Others (light fuel oil, liquid gas, propane)	3.00	100%	
Water consumption and effluent			
Water	1.78	99%	Medium quality and high coverage answers. Process with low uncertainty for members.
SS (after WWTP) – natural env.	1.00	5%	Very few members have information regarding effluent data but when the members collect the data, they a sure about it.
COD (after WWTP) – natural env.	1.00	5%	
BOD (after WWTP) – natural env.	1.00	5%	
Hydrocarbons (after WWTP) – natural env.	1.00	5%	
SS (before WWTP) – public water	1.56	11%	
COD (before WWTP) – public water	1.30	16%	
BOD (before WWTP) – public water	1.00	13%	

Data	Quality	Coverage	Comments
Hydrocarbons (before WWTP) – public water	1.00	9%	
Waste			
Non-hazardous waste incinerated	1.23	34%	Good quality and medium coverage.
Non-hazardous waste landfilled	1.26	37%	
Unspecified	1.00	16%	
Non-hazardous waste recycled	1.40	67%	
Hazardous waste	1.29	67%	
Atmospheric emissions			
Carbon dioxide (CO2)	1.08	51%	High quality and medium coverage.
Nitrogen oxide (Nox)	1.79	16%	Low to medium quality with a poor coverage. Most of members did not share data regarding atmospheric emissions.
Sulfur oxide (Sox)	2.00	10%	
Ammonium (NH3)	-	0%	
Dust (PM 10)	2.00	7%	
Dust (PM 2.5)	-	3%	
Dust (PM unspecified)	1.40	3%	
VOC	2.03	95%	Medium quality and high coverage.
Transport			
Raw Material - Steel	-	46%	No uncertainty information was requested from the member. Answers coverage was medium for these data.
Raw Material - Lacquers, coatings, varnishes	-	28%	
Raw Material - Printing inks	-	26%	
Raw Material - Sealing compounds	-	46%	
Empty bottle (manuf. plant to filler)	-	50%	

Table 13 – Data quality and answers coverage

VII.5. Critical review report

Critical Review of "Life Cycle Assessment of metal packaging in Europe June 2016"

according to ISO 14040, ISO 14044 and ISO/TS 14071

30 of June 2016

for

Metal Packaging Europe

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1 Introduction

RDC Environment has done a LCA study for Metal Packaging Europe. The title of this study was "Life Cycle Assessment of metal packaging in Europe". The study report is dated June 2016.

The goals of the study were the following:

- "To determine the environmental impacts and benefits along the life cycle of the average metal packaging produced in Europe, assessed on the cradle-to-cradle approach.
- To track performance of the average metal packaging production in Europe by comparing the foreground data of production year 2012 with those ones of the production year 2008, 2006 and 2000, which were used to perform the previous METAL PACKAGING EUROPE's LCA study (published in 2012).
- To calculate the Life Cycle Inventories (LCIs) of the average metal packaging produced in Europe according to different system boundaries: Cradle-to-cradle (excluding any specific application of the packaging), Cradle-to-gate and Gate-to-gate".

This study has been done applying ISO 14040:2006 and ISO 14044:2006 recommendations and may be published. It is not a comparative LCA study. Therefore, Metal Packaging Europe & RDC Environment have requested one expert to make a critical review (CR) of this study.

The present report is the "Final CR report" prepared by Solinnen. This CR report, including appendices, is dedicated to be integrated as a whole within the final report of RDC Environment.

2 Presentation of the expert of Solinnen

Dipl. Eng. Philippe Osset, CEO, Solinnen. Mr. Osset has over 20 years of experience of the LCA practice, including CR practice. Mr. Osset has applied the LCA practice to different packaging systems, including made of steel and aluminum.

The choice of the expert has been make to make available competencies which cover the studied topics, i.e. sector specific expertise (steel, aluminum & packaging) and the LCA expertise.

3 Nature of the CR work, CR process and limitations

The expert has worked according to the requirements of ISO 14040:2006 and 14044:2006 concerning CR, and according to the requirements of ISO/TS 14071. According to ISO 14044, the CR process has worked in order to check if:

- the methods used to carry out the LCA are consistent with ISO 14044 requirements,
- the methods used to carry out the LCA are scientifically and technically valid,
- the data used are appropriate and reasonable in relation to the goal of the study,
- the interpretations reflect the limitations identified and the goal of the study, and
- the study report is transparent and consistent.

The first goal of the CR was to provide RDC Environment with detailed comments in order to allow RDC Environment to improve its work. These comments have covered methodology choices and reporting. The expert has checked the plausibility of the data used in the report, through sample tests, including a review of the database within the software used by RDC Environment. Additionally, the present final CR report provides the future reader of the RDC Environment report with information that will help understanding the report.

The CR work has started after the generation of a first full LCA report by RDC Environment. The work has started in May 2016 and ended up in June 2016. During this period, different oral and written exchanges have been held between the expert and RDC Environment, including clarification exchanges regarding the CR comments, and the production of one new final version of the report by RDC Environment. RDC Environment has taken into account most of the comments and significantly modified and improved its report.

The present final CR report is the synthesis of the final comments by the expert. Some detailed comments are provided within this final CR report, together with the full detailed exchanges as appendix (this appendix is made according to Annex A of ISO/TS 14071).

The present CR report is delivered to Metal Packaging Europe and RDC Environment. The expert cannot be held responsible of the use of its work by any third party. The conclusions of the expert cover the full report from RDC Environment "Life Cycle Assessment of metal packaging in Europe – June 2016" and no other report, extract or publication which may eventually been done. The expert conclusions have been set given the current state of the art and the information which has been received. These expert conclusions could have been different in a different context.

4 Conclusions of the review

The CR first set of 60 comments covered the following points:

- Discrepancies (20 key comments),
- Comments for improvement (23 key comments),
- Editorial comments and other miscellaneous comments (17 comments).

Out of these comments, 19 covered ISO issues, 3 about Analysis and Interpretation, 15 about Data and calculations, 2 about General Methodology and 21 about Report Writing.

An exhaustive work has been done by RDC Environment to provide a final report integrating answers to all the CR points, and the final result has improved as compared to the first one.

As a whole, the expert considers that the final report answers to the goals which have been set up, within the scope of the limitations that are mentioned in the report.

At this point, a warning has to be done since different packaging is covered in the report: the conclusions of this LCA report do not support comparative assertions as such. According to ISO 14044, additional work should be done to get a comparative LCA report, together with a CR of this new report by a panel.

5 Detailed comments

The following lines bring some highlights that a reader of the final LCA report may use to assist his reading and understanding of the report. They mainly recap some critical comments which were not addressed, or which were addressed in a way which is different from what the expert expected. The reading of the detailed comments and answers (see appendices) is recommended, since they cover key issues when dealing with the comparison which has been made.

5.1 Consistency of methods used with ISO 14040 and ISO 14044 requirements

The final structure of the report reflects the ISO 14040 and ISO 14044 standard requirements. The methods that have been selected for reference calculations are clearly presented. Incorporation of the comments of the expert has improved the clarity of the report as to methodology and as to the nature and sources of assumptions used in the calculations.

No assessment of the consistency of the methodology applied for the metal production has been done, since these choices have been done by the data providers (primary metal production is used as aggregated data in the present study) and since no comparison between packaging is intended to be done in the present LCA report.

5.2 Scientific and technical validity

The scientific and technical validity of the work is high due to the exhaustive approach which has been followed.

One limitation comes from the fact that the similarity between the nature of coating used for the different metal packaging has not been justified through the use of a reference to a scientific publication (it has been set as an "assumption").

Horizontal averaging (of processes) is commonly used in LCA, and has been used in the study (see III.1.4). Whatsoever, as mentioned, it introduces a bias as compared to the average of production route (vertical).

Assumption concerning secondary and tertiary packaging end of life could have been elaborated a bit more since it is an axis of improvement of the environmental impacts.

5.3 Appropriateness of data used in relation to the goal of the study

The overall data used and the calculations done are adapted to provide the final results in the scope of the goal of the study.

Ecoinvent 3.2 data are available at the date of the report. According to the answer of RDC, these background data have not been used during the process, since the work has started before their release. Whatsoever, integration of alternative background data in future work will be essential for the quality of this future work. This point is transparently mentioned in the limitations of the study.

One can regret that no European data about the boat transportation model have been made available, since they could be of value to strengthen the interpretation of the study results. Whatsoever, the level of influence on the overall results of these models is low.

5.4 *Validity of interpretations in the scope of the limitations of the study*

The conclusions (VI.3.1) presented in the interpretation chapter are adapted to the goal of the study, taking into account the limitations of the study (chapter II.2.6 and VI.3.2), which are adapted and clearly stated: the reader shall take it into account when reading the conclusions – e.g. the limitations have an influence on the level of precision of the improvement which is presented.

5.5 *Transparency and consistency*

The overall level transparency and consistency of the report is high, and in line with the ISO 14044:2006 expectations. The limitations which are mentioned concerning data sources looks in line with the data source used in the report. One can expect that this LCA report will be accompanied by the detailed LCI of the studied products since it is one of the goal of the study.

6 Appendices

The detailed CR tables exchanged during the work are the appendices of the present CR report. They recap the detailed exchanges between the expert and RDC Environment.

VII.6. Peer reviewer reference

Philippe Osset is the CEO and a co-founder of Solinnen since 2010. He is an engineer from the Ecole Centrale de Paris, ECP 92. He has more than 20 years experience in the application of LCA to his clients issues, such as the set up of sustainable development strategies integrating product concerns, processes improvement, ecodesign, environmental product communication (EPD, according to ISO 14020 series and EN 15804), trainings and CRs. He has developed a LCA-based business in Japan. He is the scientific director of SCORE LCA, a non-profit corporation of members aiming at specifying and funding LCA-based research projects. He has participated to different research projects at French and European level (DG Research, ANR), and to projects with European Federation of Industries (see below).

Philippe Osset practices different LCA software (such as SIMAPRO, EIME, TEAM, BEE, BEES), and has managed sub-contractors in charge of the development of LCA software. He possesses a competency covering the different sectors for which he has practiced or managed the LCA-based studies: extractive industries (IMA Europe, Imerys), energy (EDF, ENGIE, Total), water (Lyonnaise des Eaux), building and construction (ADEME, Lafarge, Saint-Gobain, Knauf, Bouygues, Colas, Corstyrène, SNMI, Eurima...), automotive (JAMA, Toyota, Nissan, Renault), electronic products (NEC, Ricoh, FNAC), food (Danone, Nestlé), packaging (ADEME, Nestlé Waters, Nestlé Baby food, Saint-Gobain packaging, COPACEL, APEAL, SIG, Sofrigam), metals (IISI, ICDA, Eurométaux), chemical (ADEME, Dow Chemicals, BASF), detergent and personal care (A.I.S.E., AFISE, P&G, L'Oréal), logistics and end of life (Eco-emballages, Aliapur).

Philippe Osset is an active member of the "Environmental Management" commission of the French Standardization institute AFNOR, and participates to different tasks of the French platform concerning Environmental Labeling. He represents France at ISO TC207 SC3 and SC5. He has leaded two work-groups in charge of redacting a Technical Specification (TS) document concerning the way to apply LCA within organizations (leading to ISO/TS 14072) and the practical way CRs have to be done (leading to ISO/TS 14071). He is also member of the "Sustainable Development within Construction" commission of AFNOR.

He is co-author, with Laurent Grisel, of the book « L'Analyse du Cycle de Vie d'un produit ou d'un service, applications et mise en pratique » published by « AFNOR Éditions ».

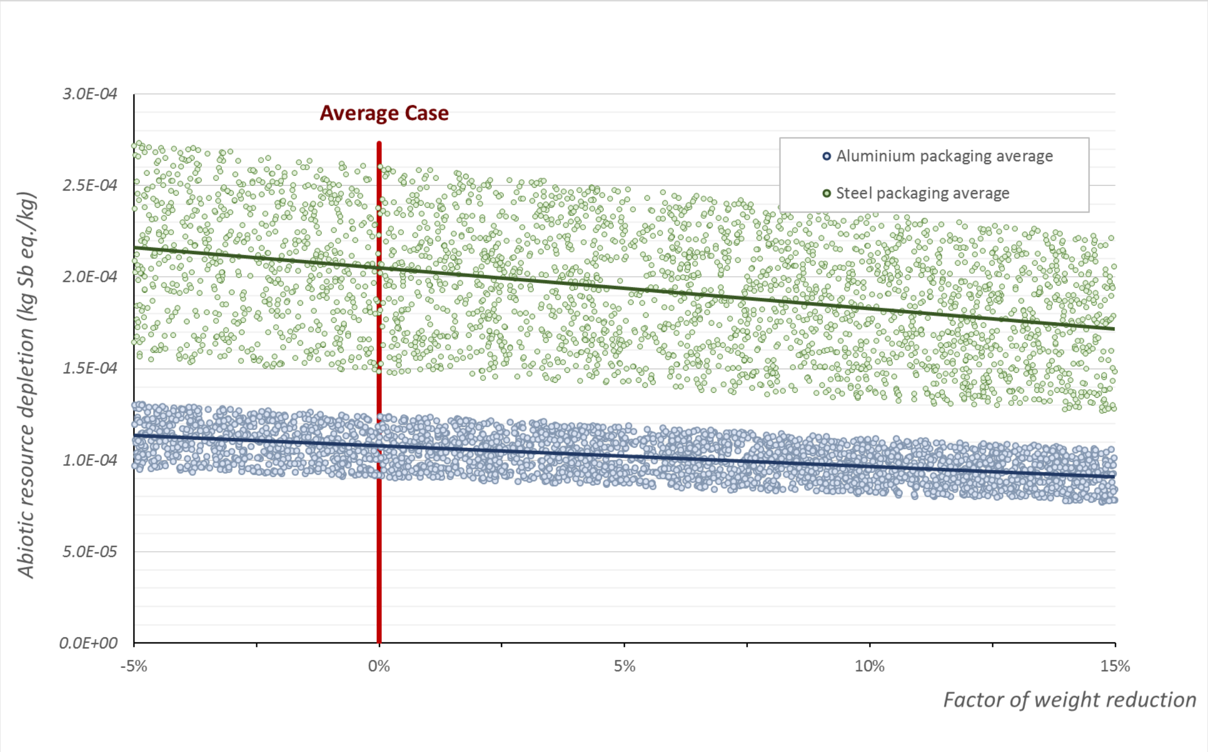
VII.7. Sensitivity analysis for PEF impact categories

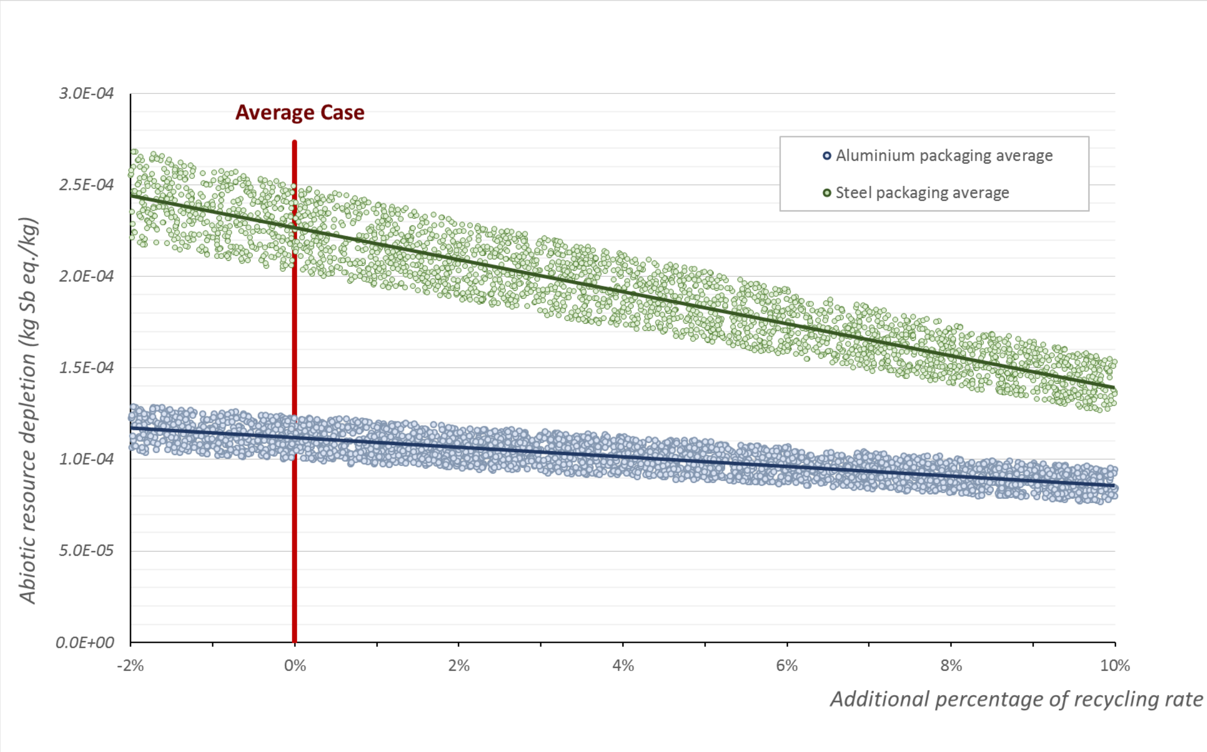
For efficiency reasons, the results of aluminium and steel are presented in the same charts. Nevertheless, the comparisons between the two packaging is not valid.

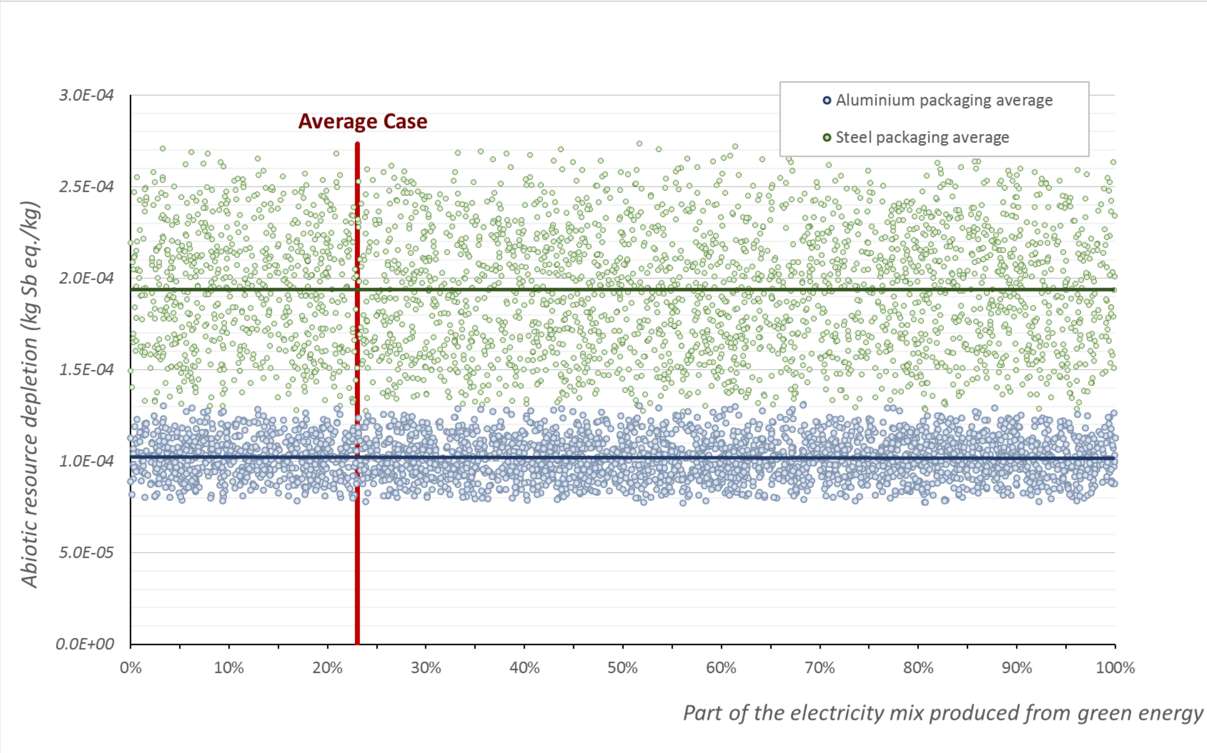
VII.7.1. Climate Change

See figures in section 0.

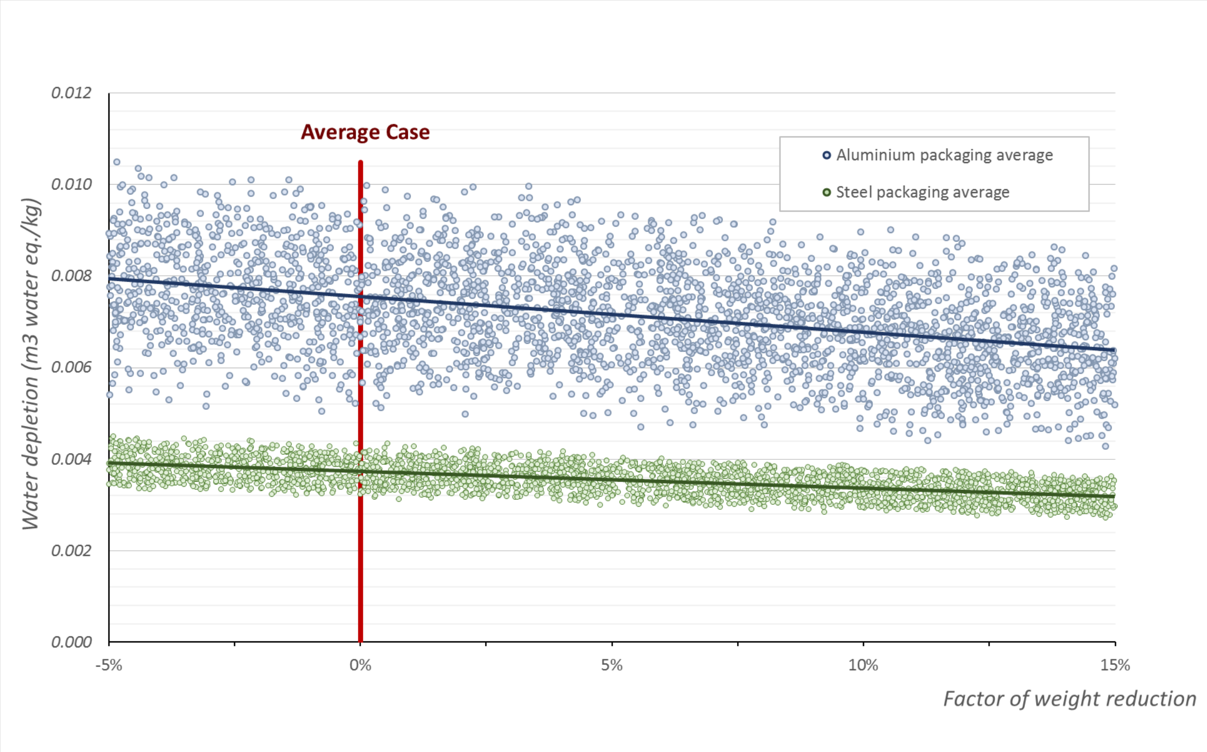
VII.7.2. Abiotic resource depletion

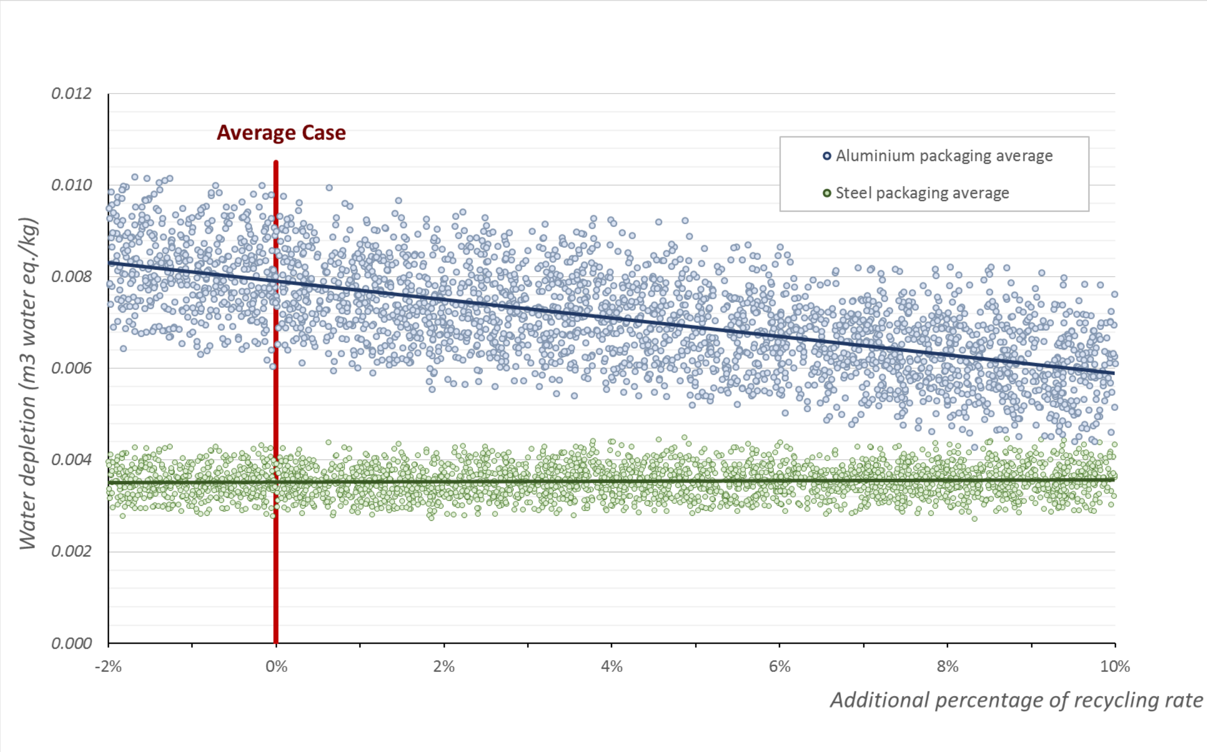


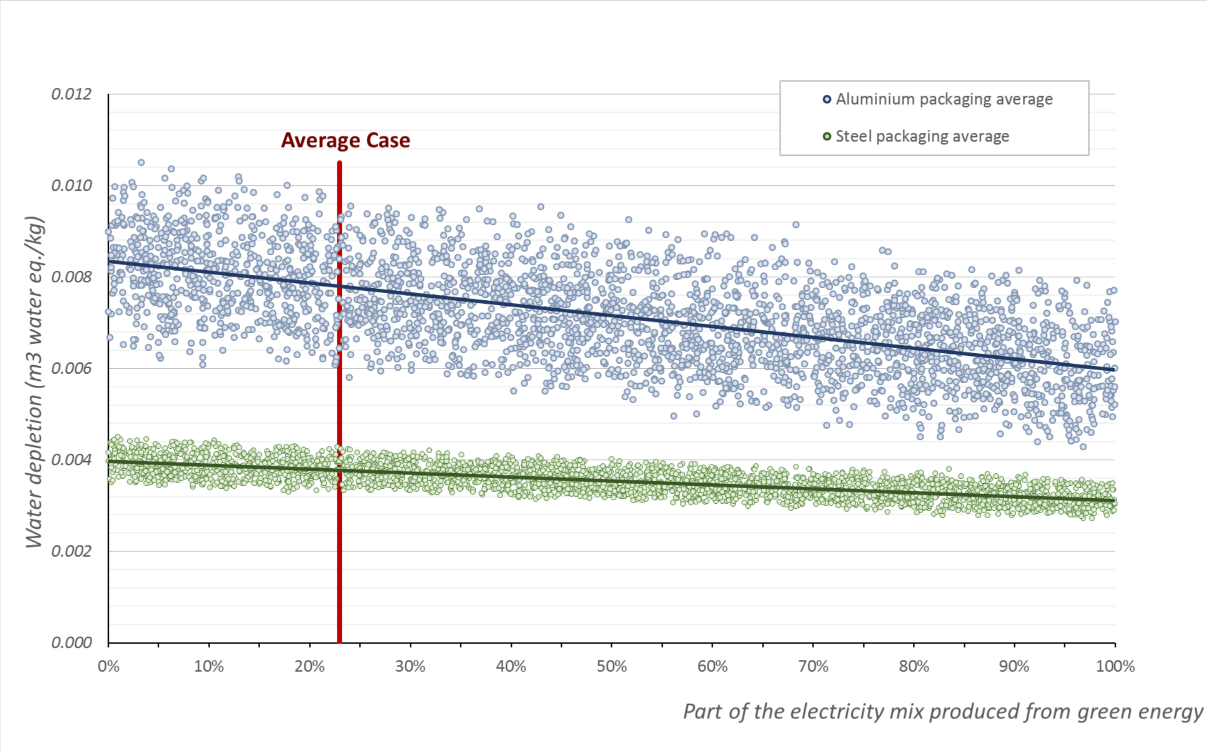

Average Case
Aluminium packaging average
Steel packaging average
3.0E-04
2.5E-04
2.0E-04
1.5E-04
1.0E-04
5.0E-05
0.0E+00
Abiotic resource depletion (kg Sb eq./kg)
-2%
0%
2%
4%
6%
8%
10%
Additional percentage of recycling rate


Average Case
Aluminium packaging average
Steel packaging average
3.0E-04
2.5E-04
2.0E-04
1.5E-04
1.0E-04
5.0E-05
0.0E+00
Abiotic resource depletion (kg Sb eq./kg)
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Part of the electricity mix produced from green energy

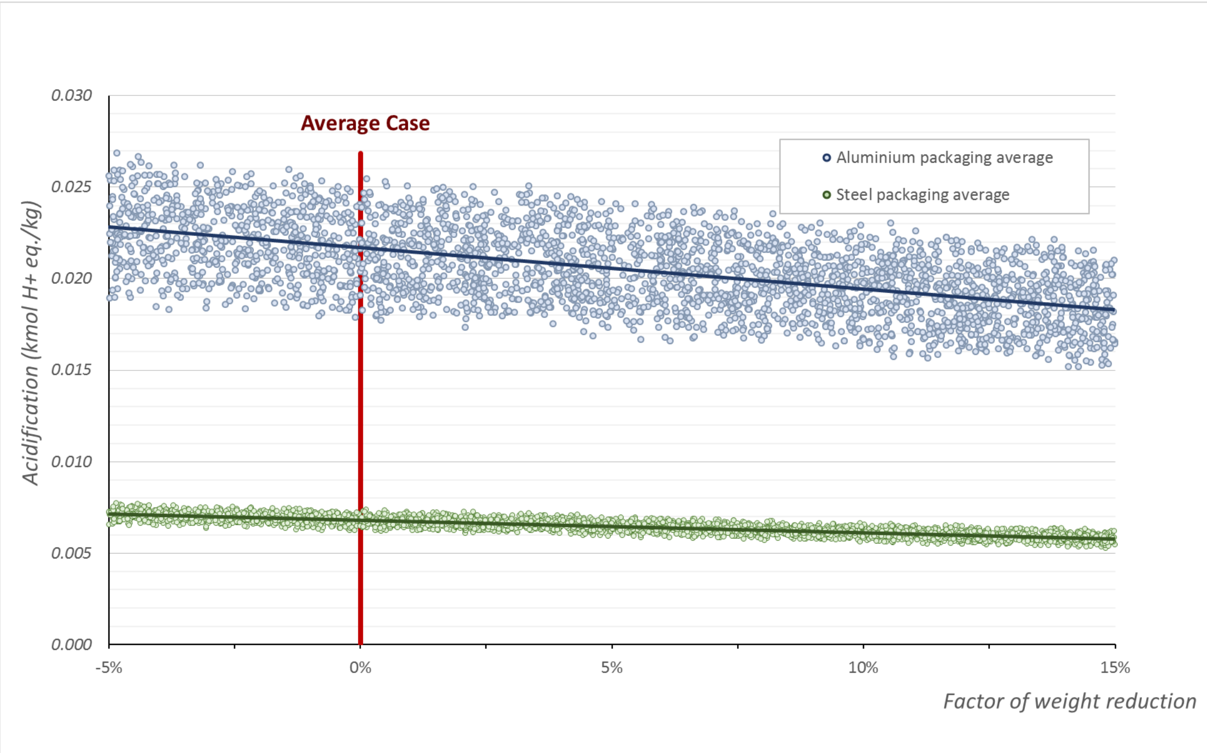
VII.7.3. Water depletion

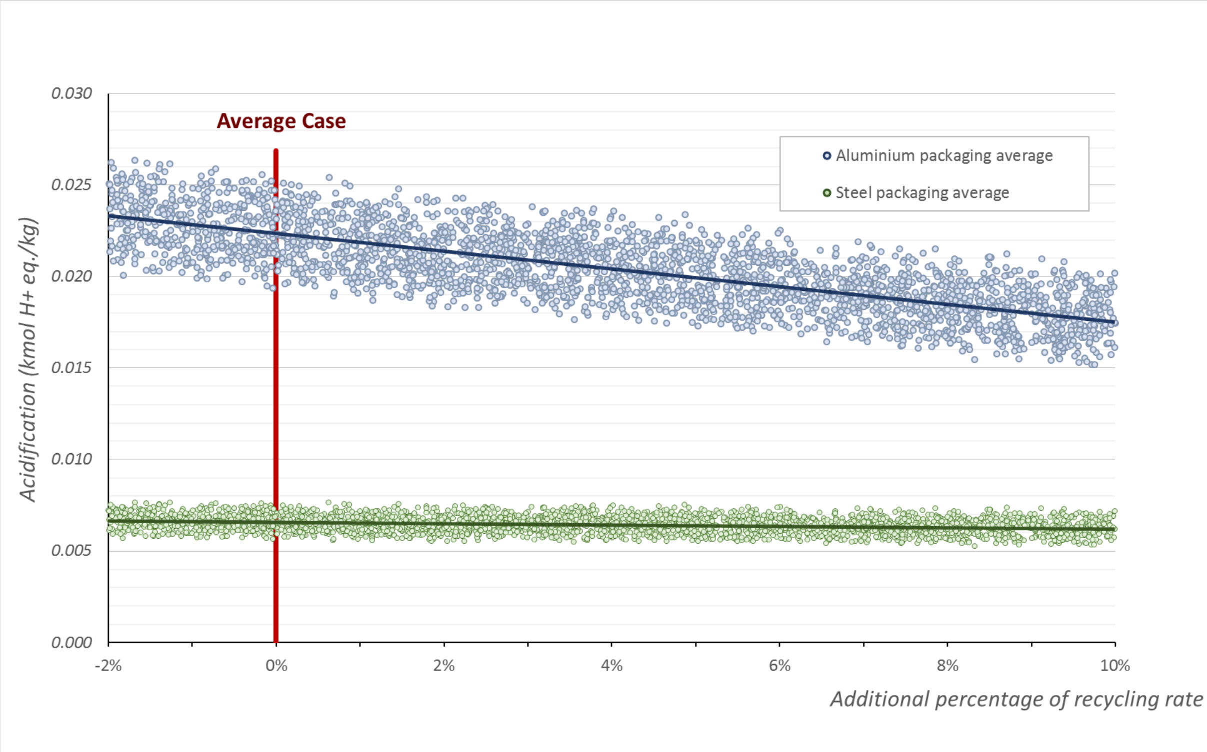


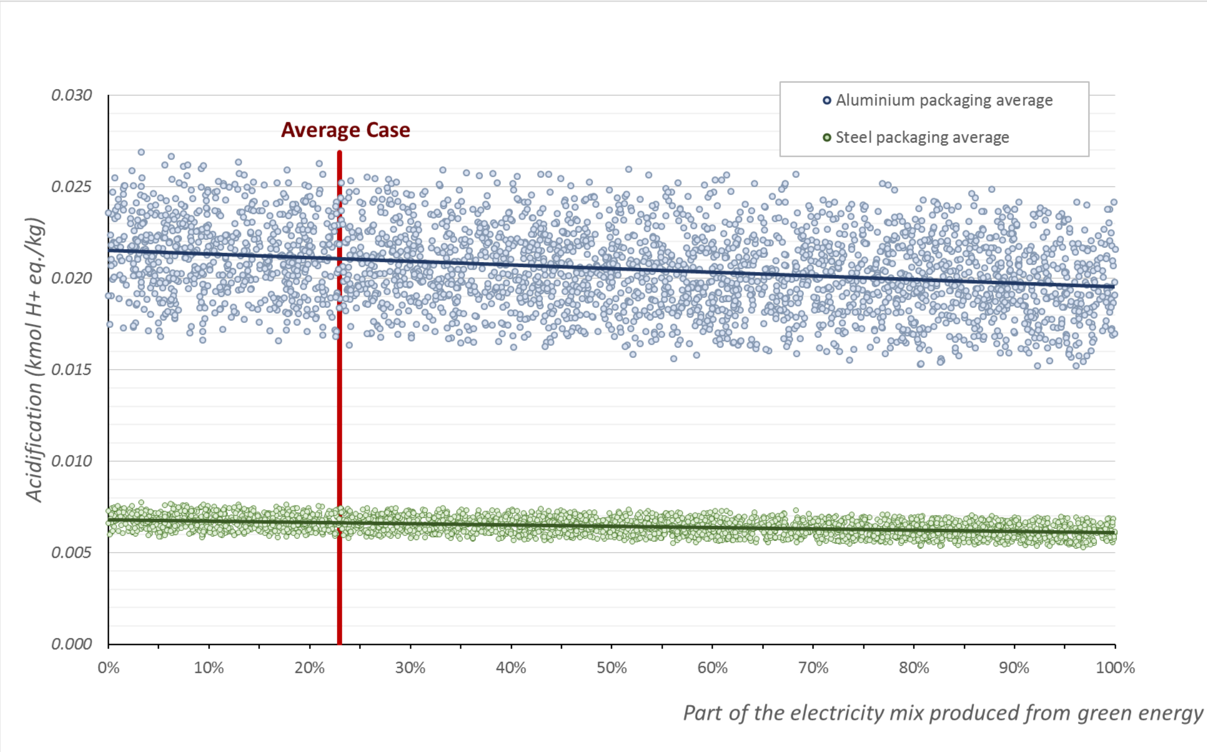




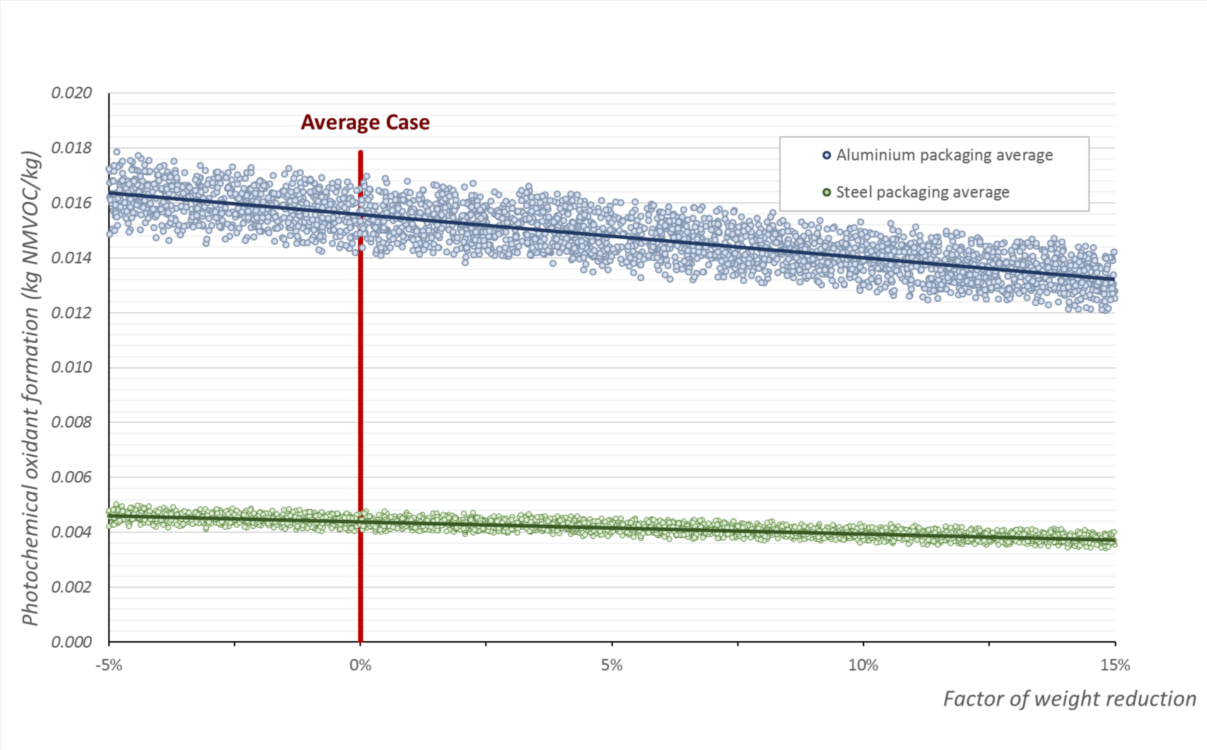
VII.7.4. Acidification

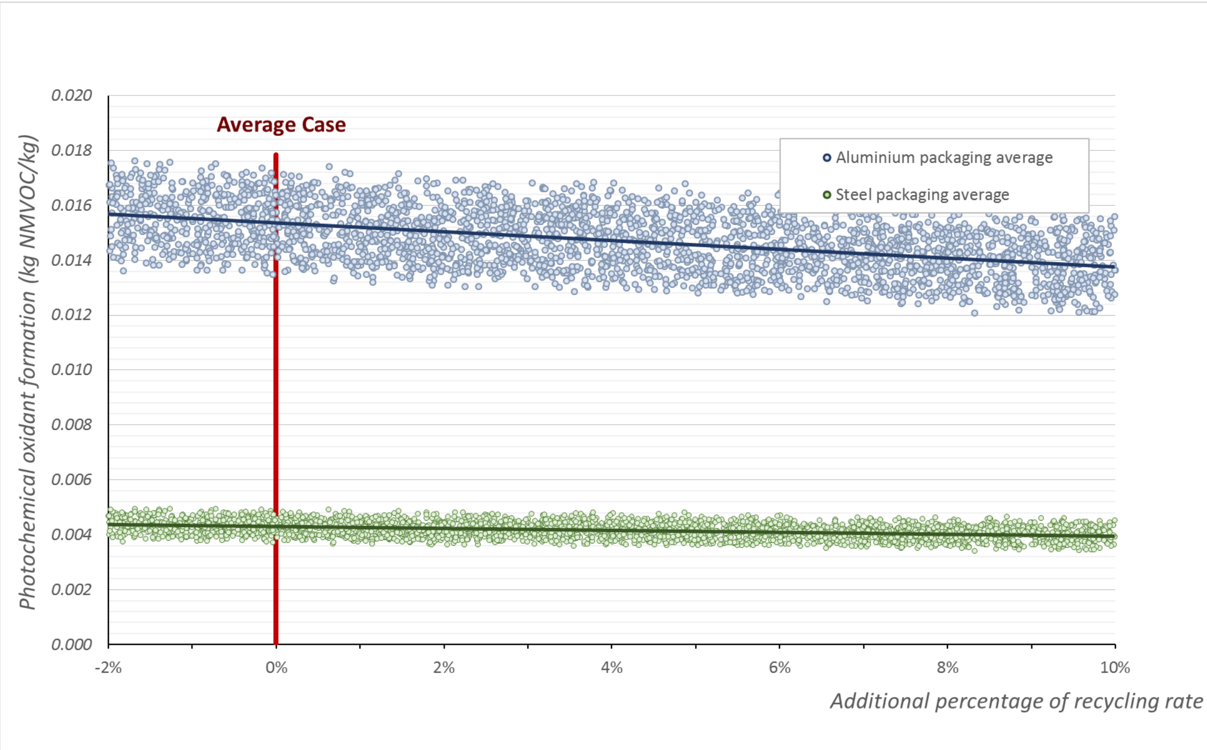


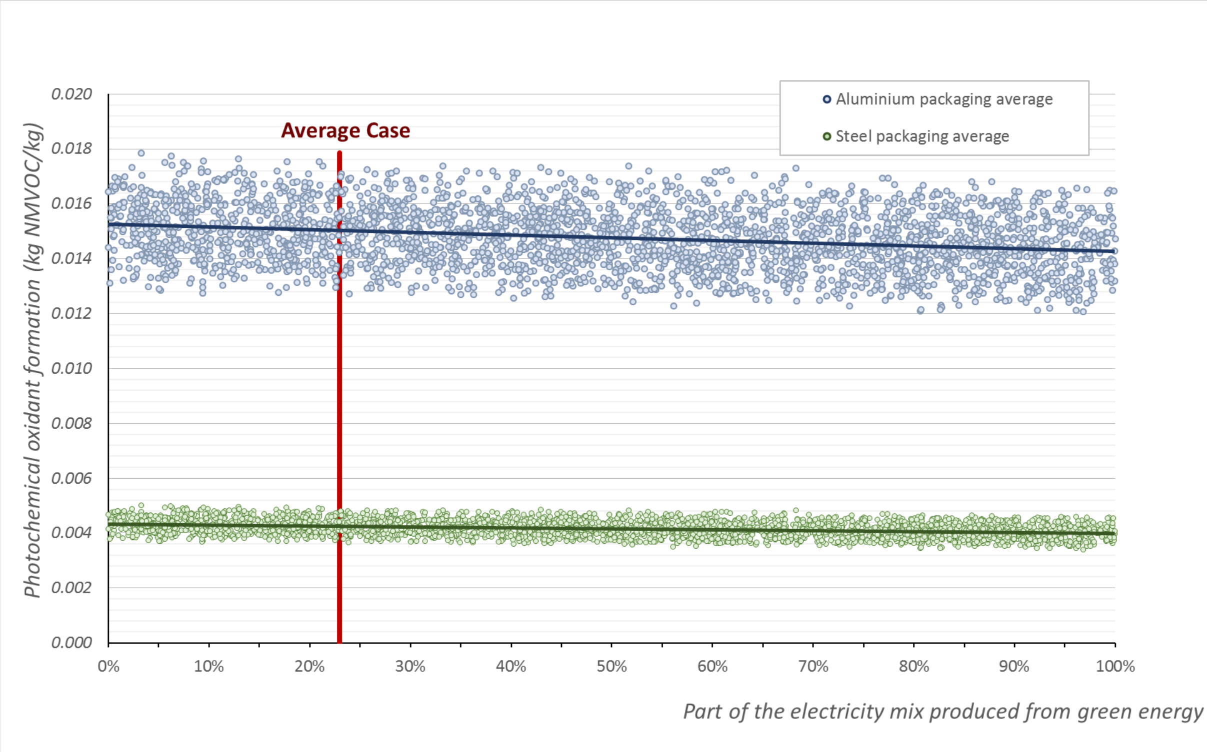

Average Case
Aluminium packaging average
Steel packaging average
Acidification (kmol H+ eq./kg)
0.030
0.025
0.020
0.015
0.010
0.005
0.000
-2%
0%
2%
4%
6%
8%
10%
Additional percentage of recycling rate


Average Case
Aluminium packaging average
Steel packaging average
Acidification (kmol H+ eq./kg)
0.030
0.025
0.020
0.015
0.010
0.005
0.000
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Part of the electricity mix produced from green energy

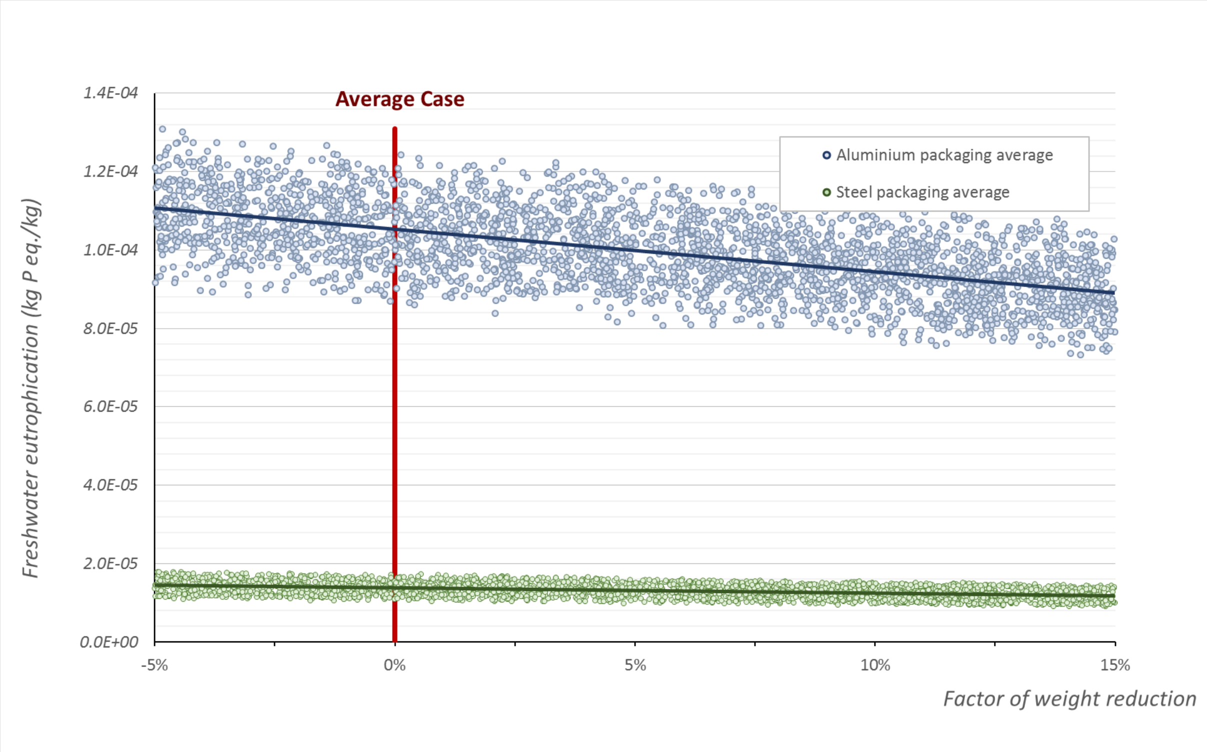
VII.7.5. Photochemical oxidant formation

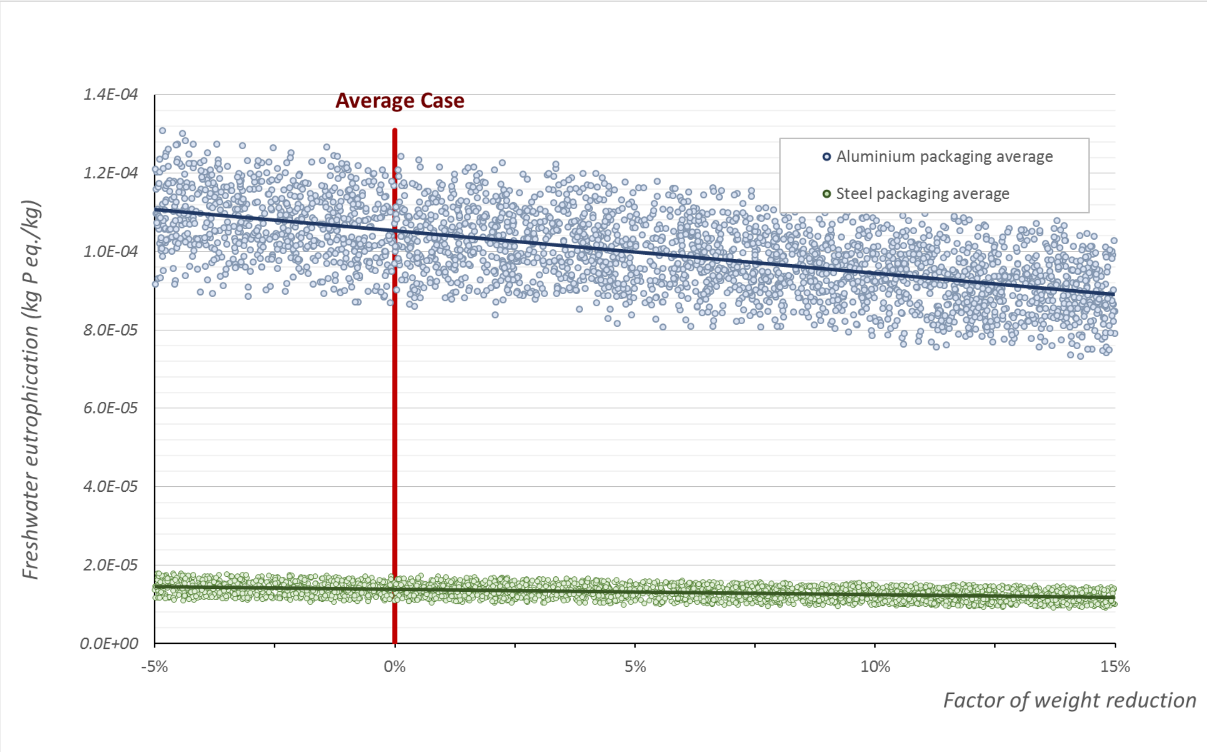


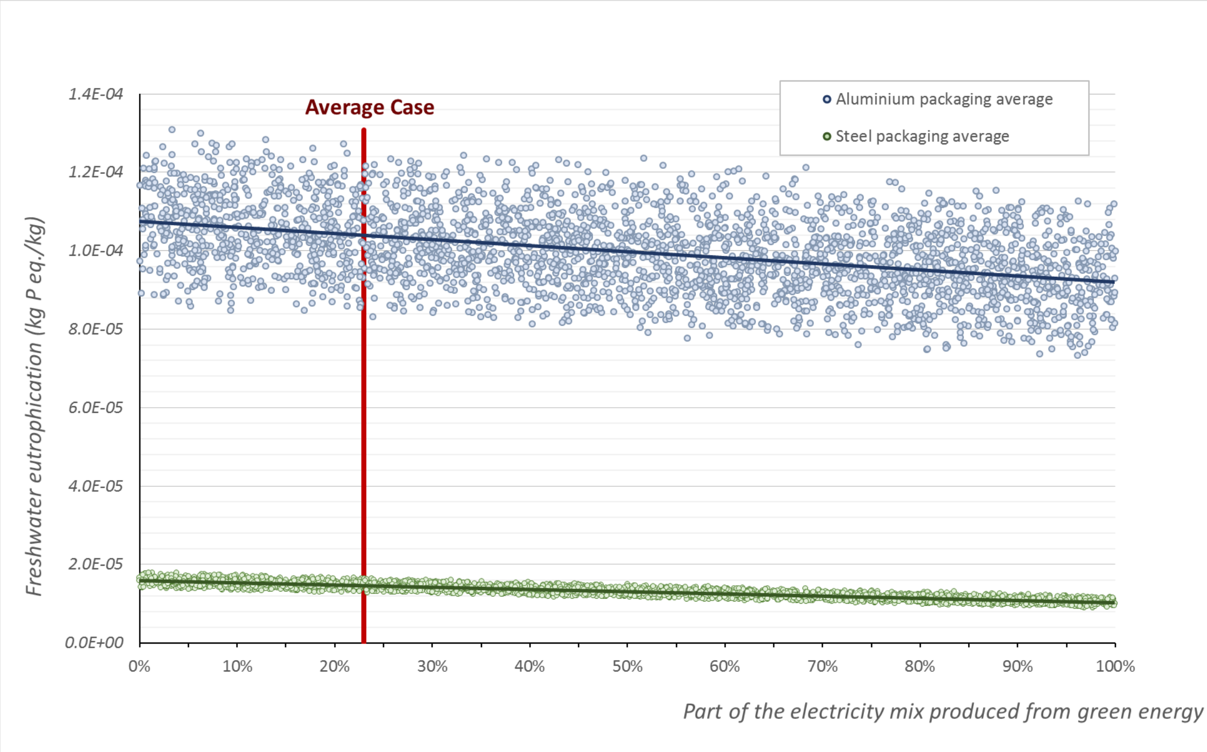



Aluminium packaging average
Steel packaging average
Average Case
Photochemical oxidant formation (kg NMVOC/kg)
0.020
0.018
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Part of the electricity mix produced from green energy

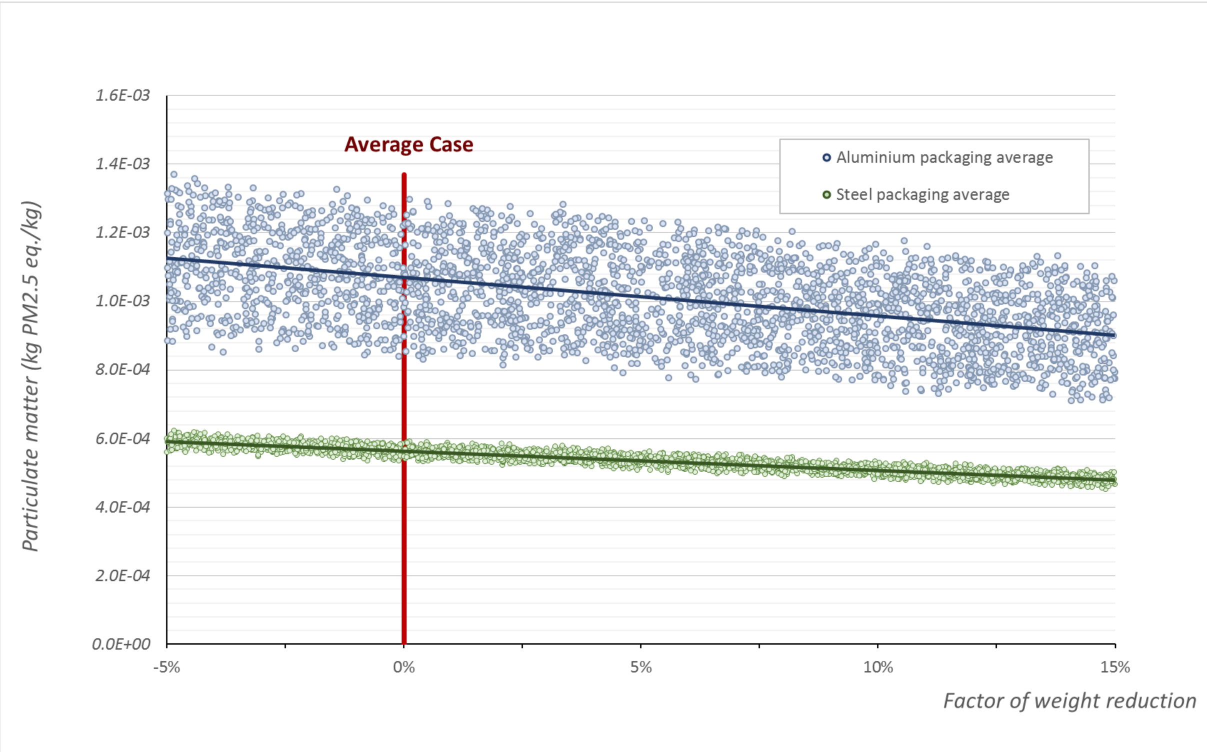
VII.7.6. Freshwater eutrophication

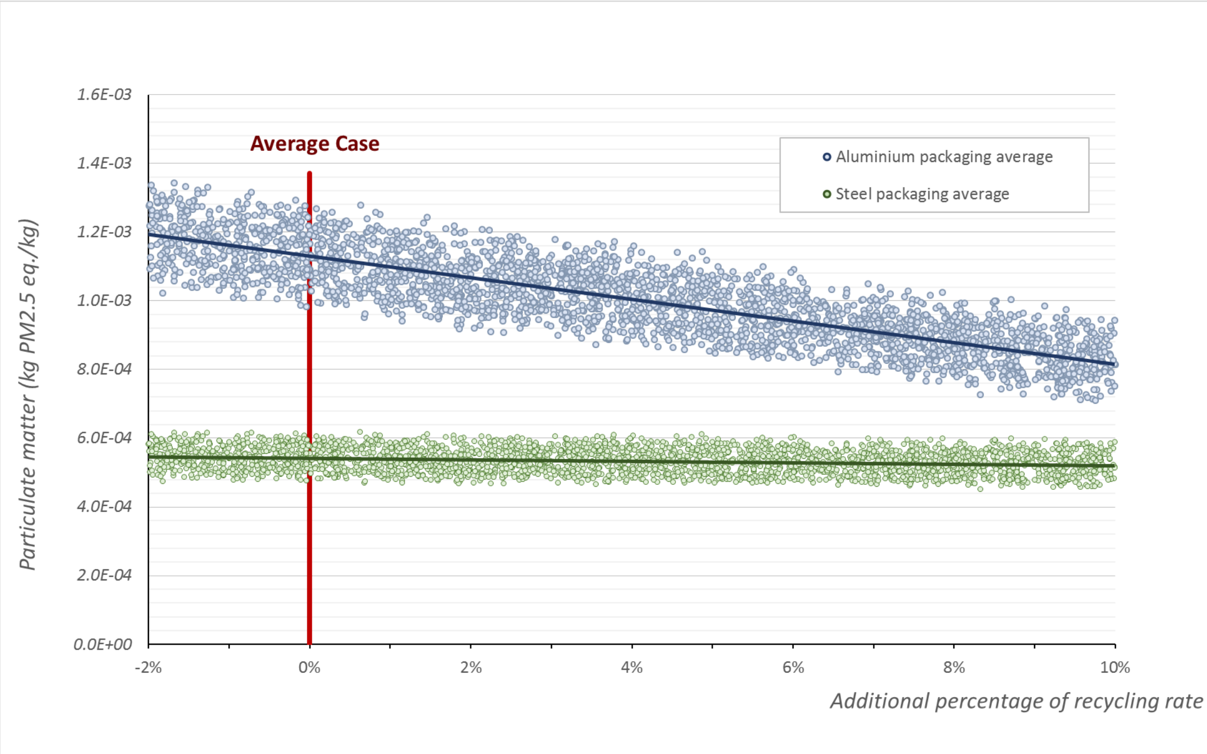


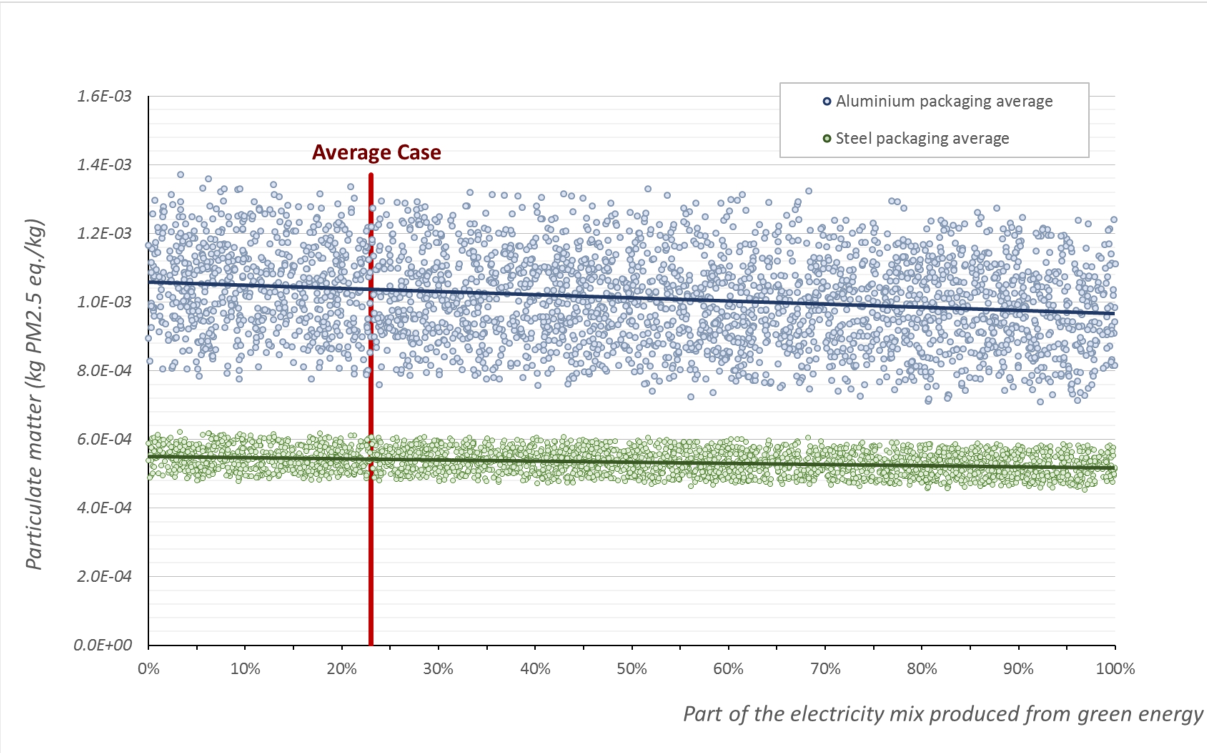




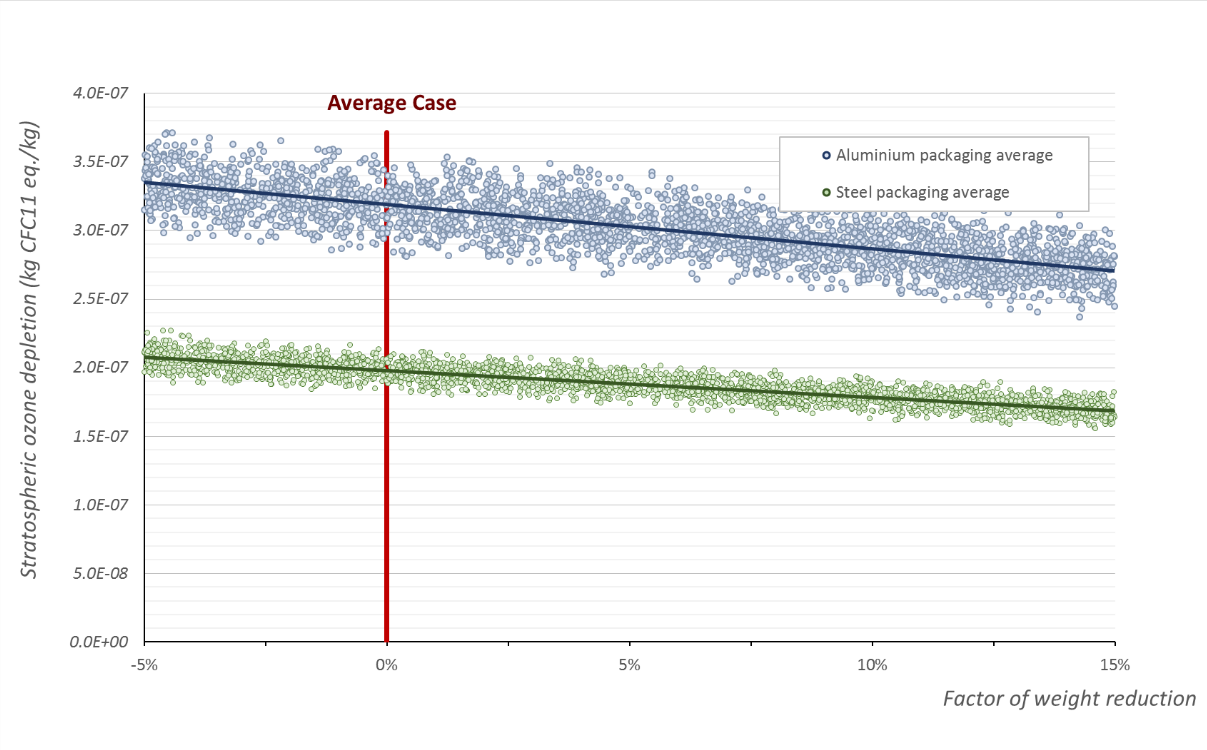
VII.7.7. Particulate matter

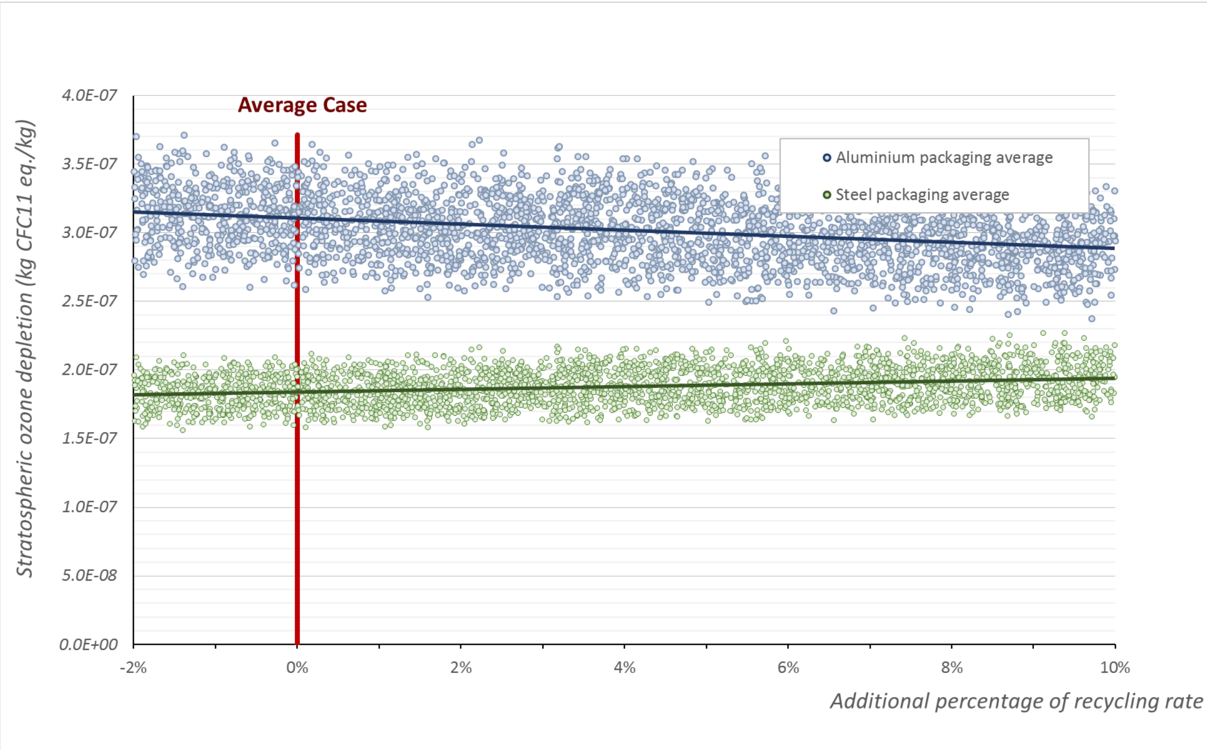


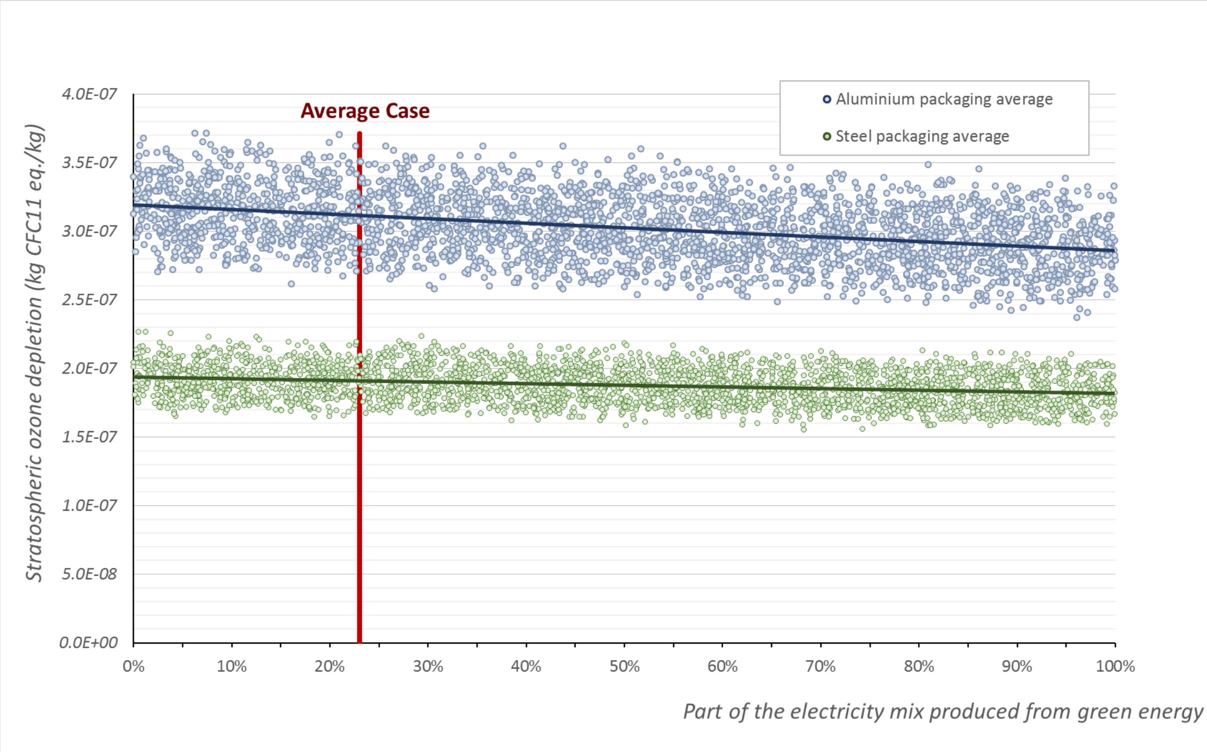

Average Case
Aluminium packaging average
Steel packaging average
Particulate matter (kg PM2.5 eq./kg)
1.6E-03
1.4E-03
1.2E-03
1.0E-03
8.0E-04
6.0E-04
4.0E-04
2.0E-04
0.0E+00
-2%
0%
2%
4%
6%
8%
10%
Additional percentage of recycling rate


Aluminium packaging average
Steel packaging average
Average Case
Particulate matter (kg PM2.5 eq./kg)
1.6E-03
1.4E-03
1.2E-03
1.0E-03
8.0E-04
6.0E-04
4.0E-04
2.0E-04
0.0E+00
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Part of the electricity mix produced from green energy

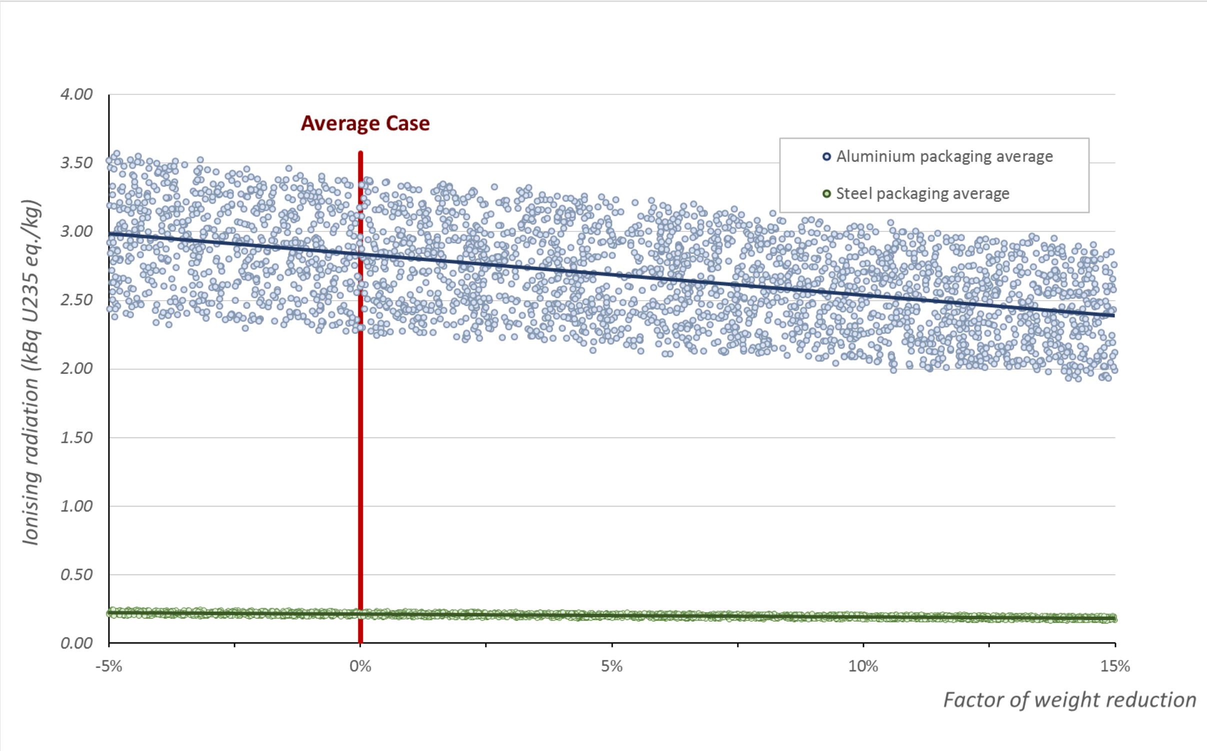
VII.7.8. Stratospheric ozone depletion

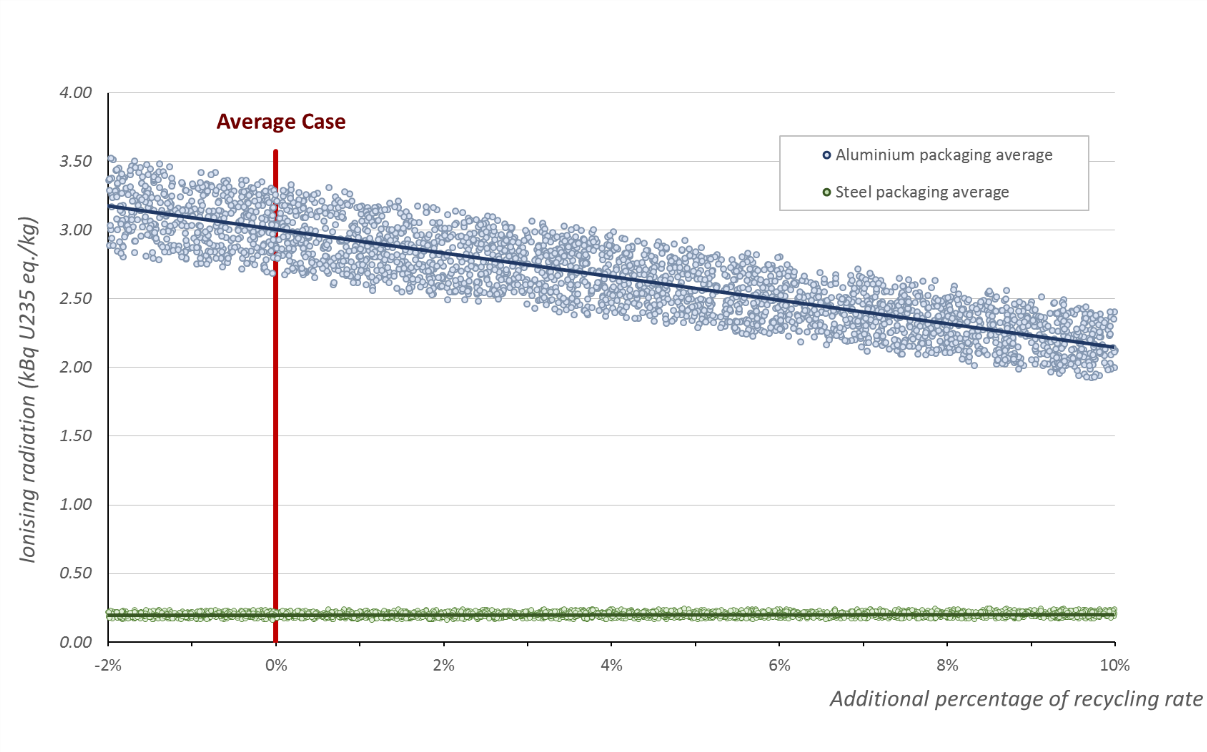


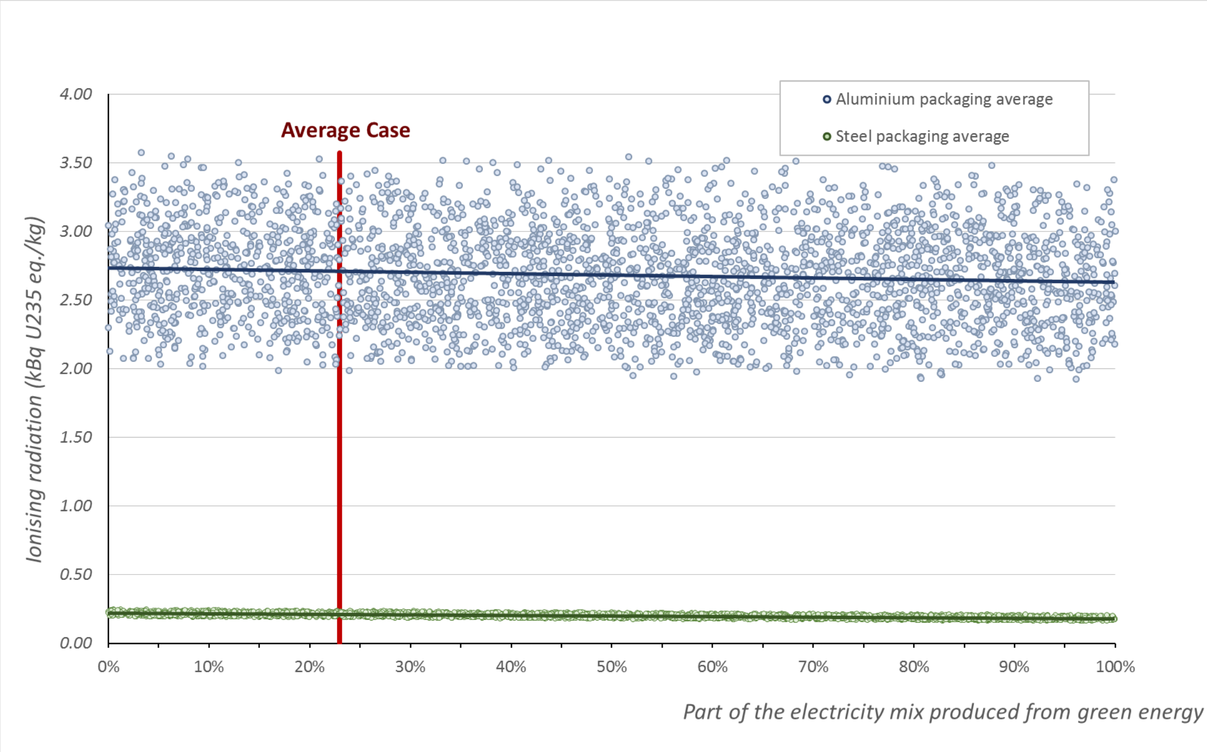




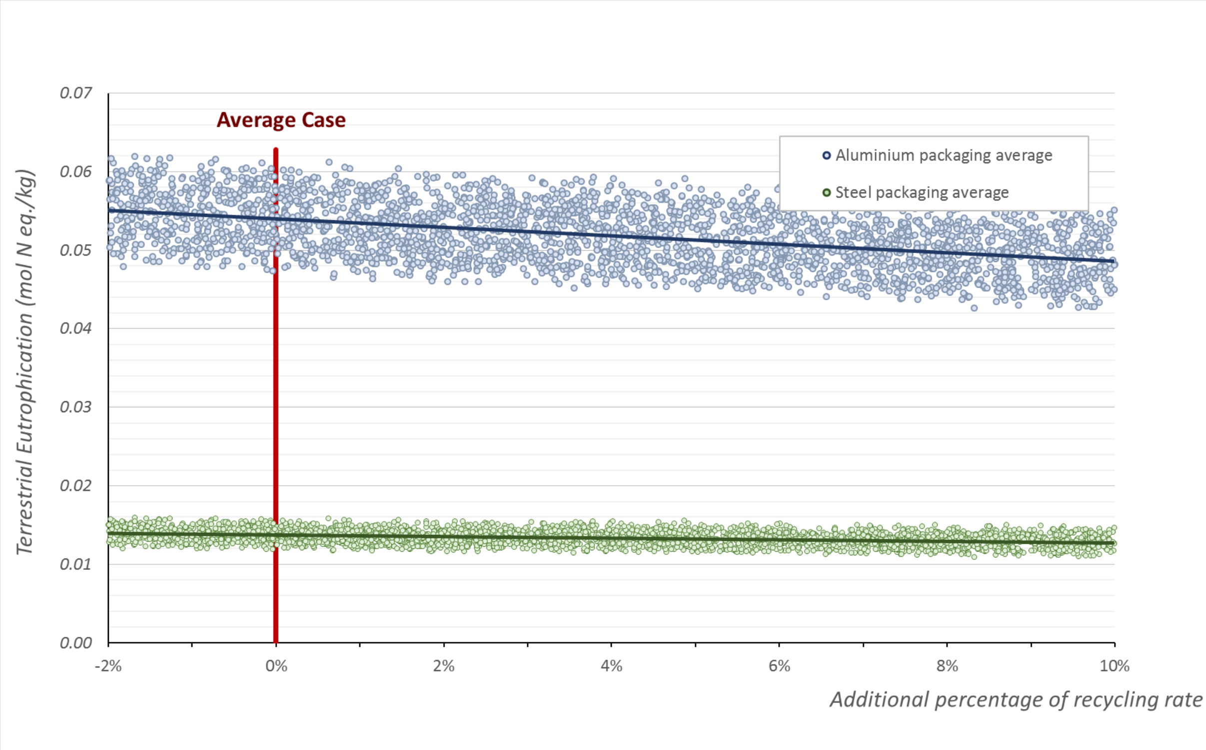
VII.7.9. Ionising radiation

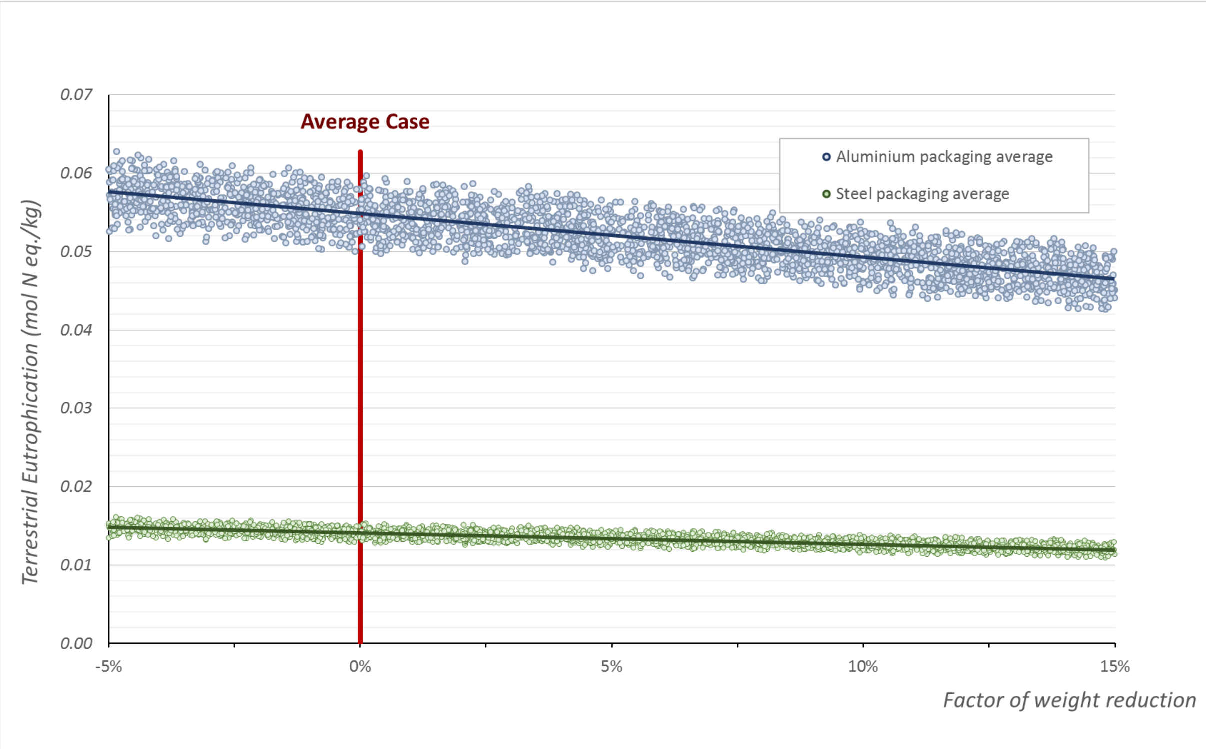


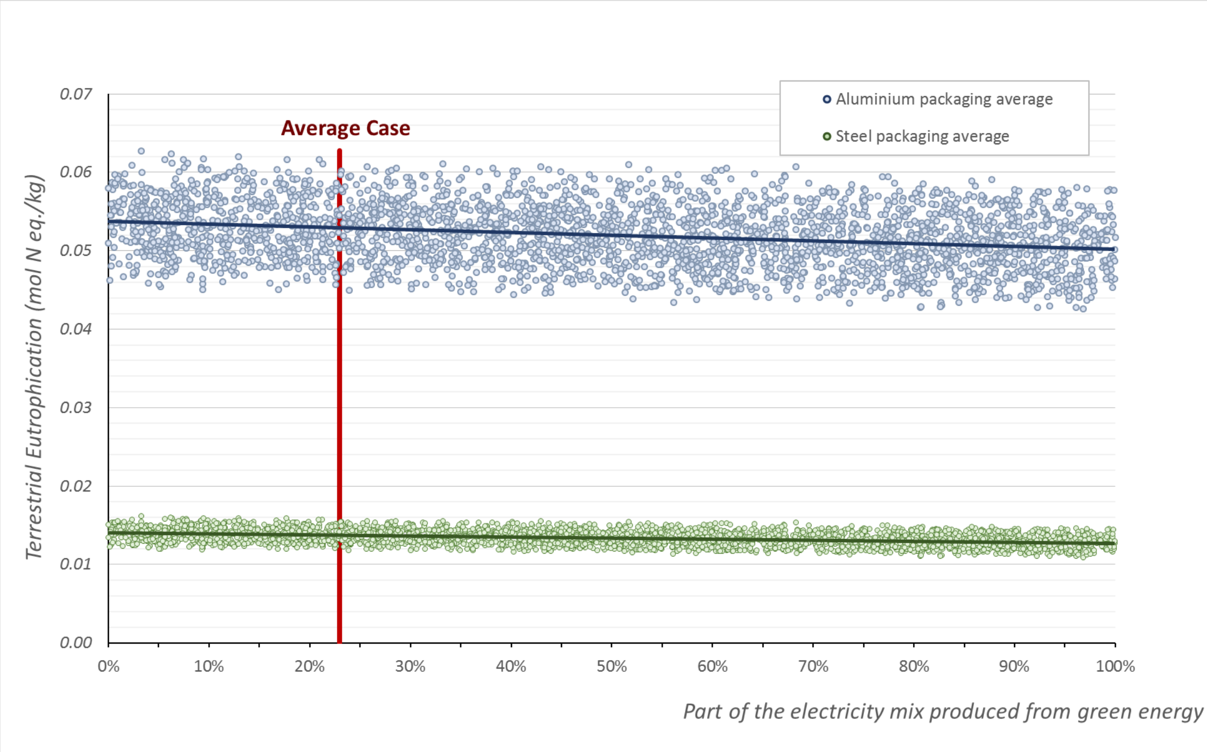

Average Case
Aluminium packaging average
Steel packaging average
Ionising radiation (kBq U235 eq./kg)
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
-2%
0%
2%
4%
6%
8%
10%
Additional percentage of recycling rate


Average Case
Aluminium packaging average
Steel packaging average
Ionising radiation (kBq U235 eq./kg)
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Part of the electricity mix produced from green energy

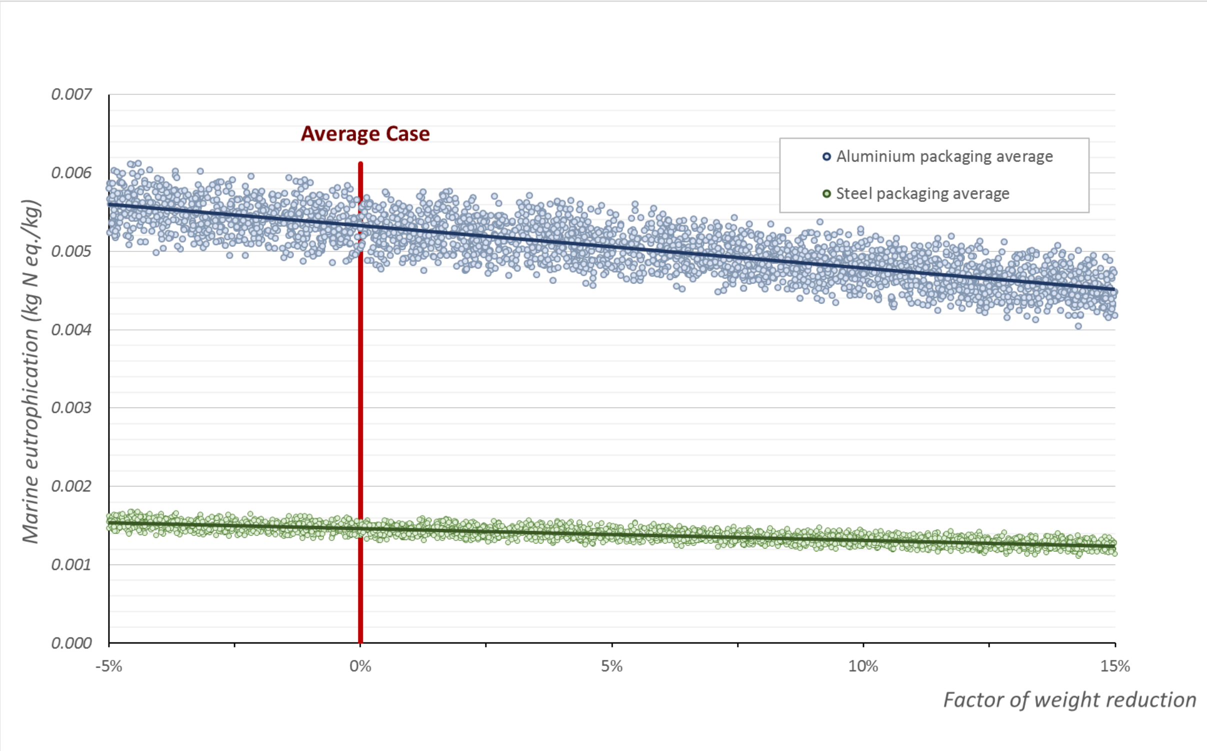
VII.7.10. Terrestrial Eutrophication

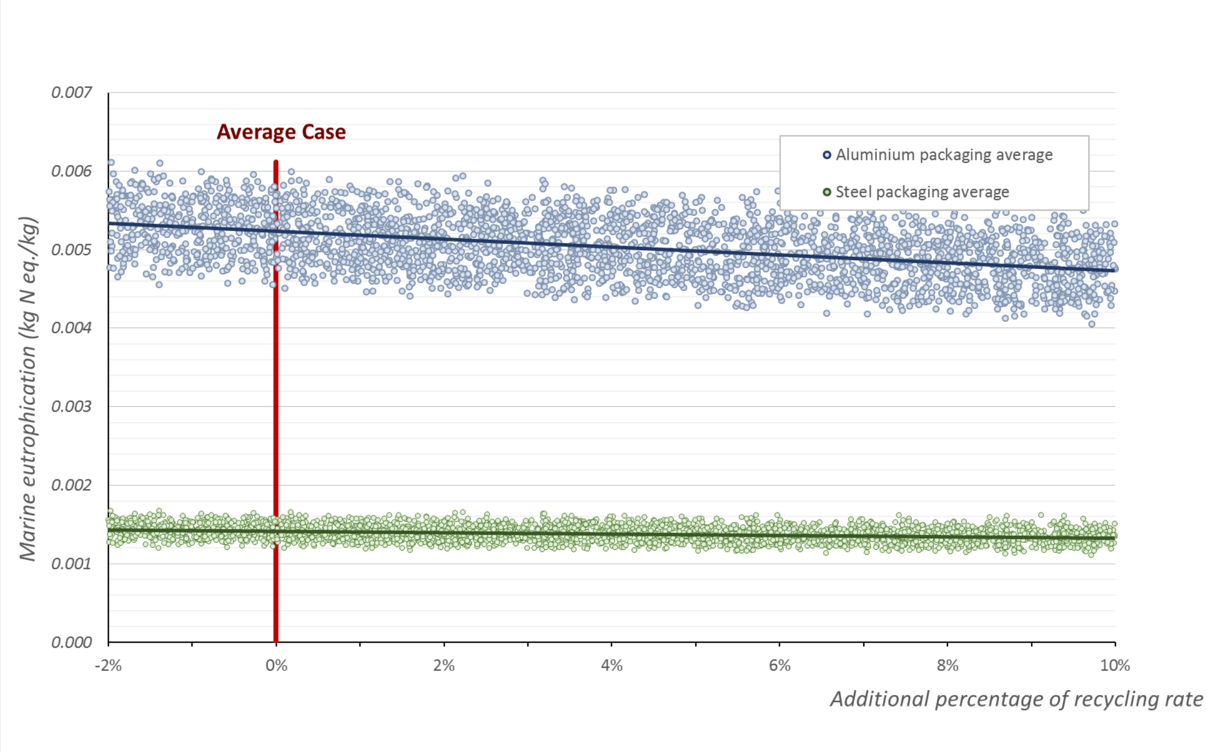


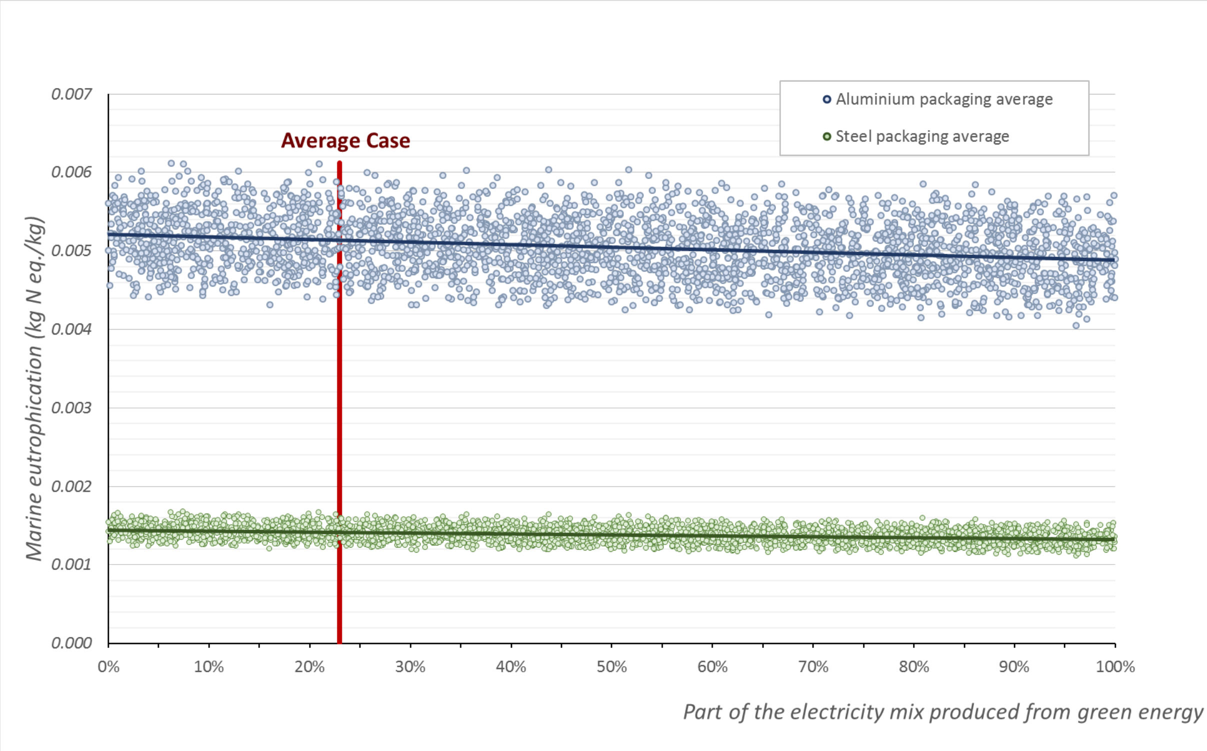




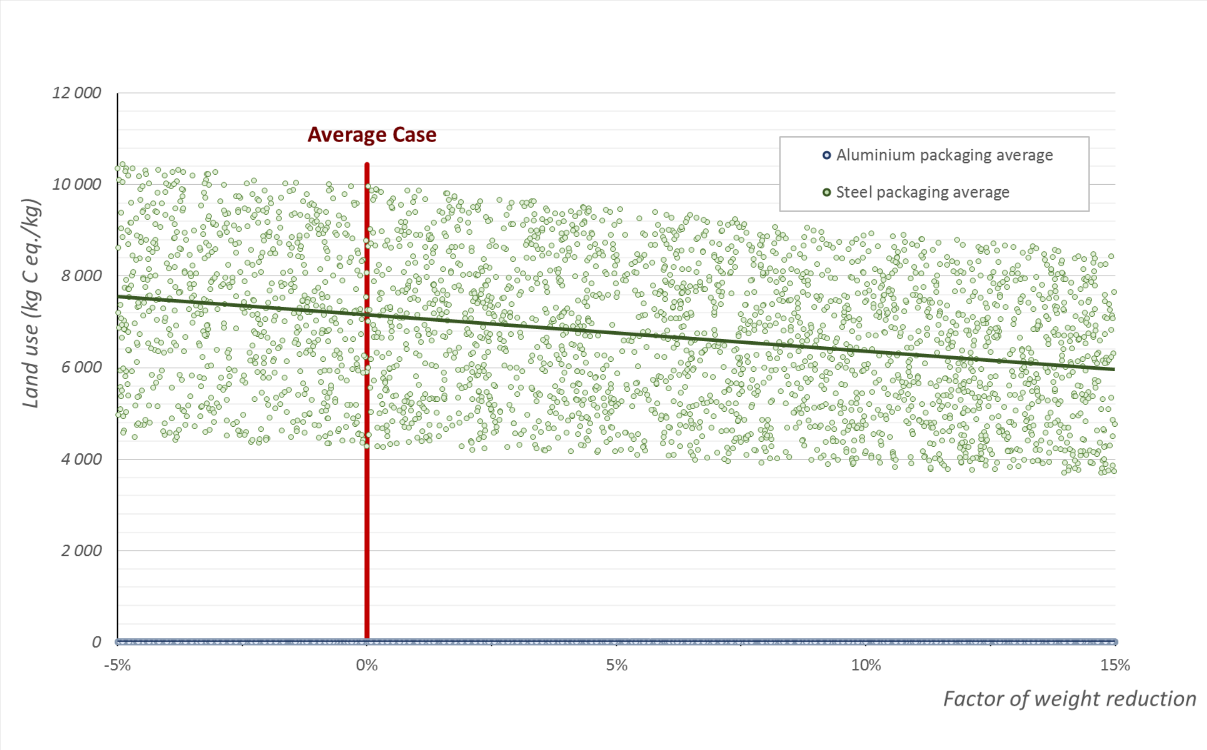
VII.7.11. Marine eutrophication

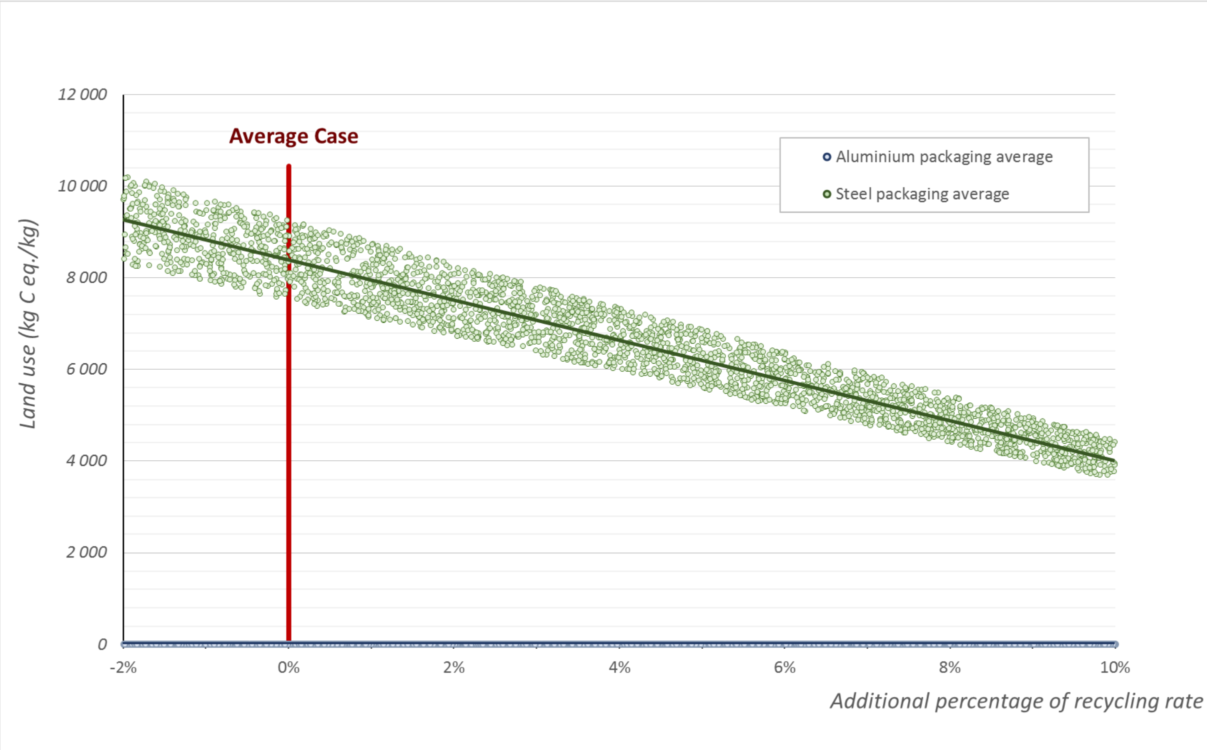


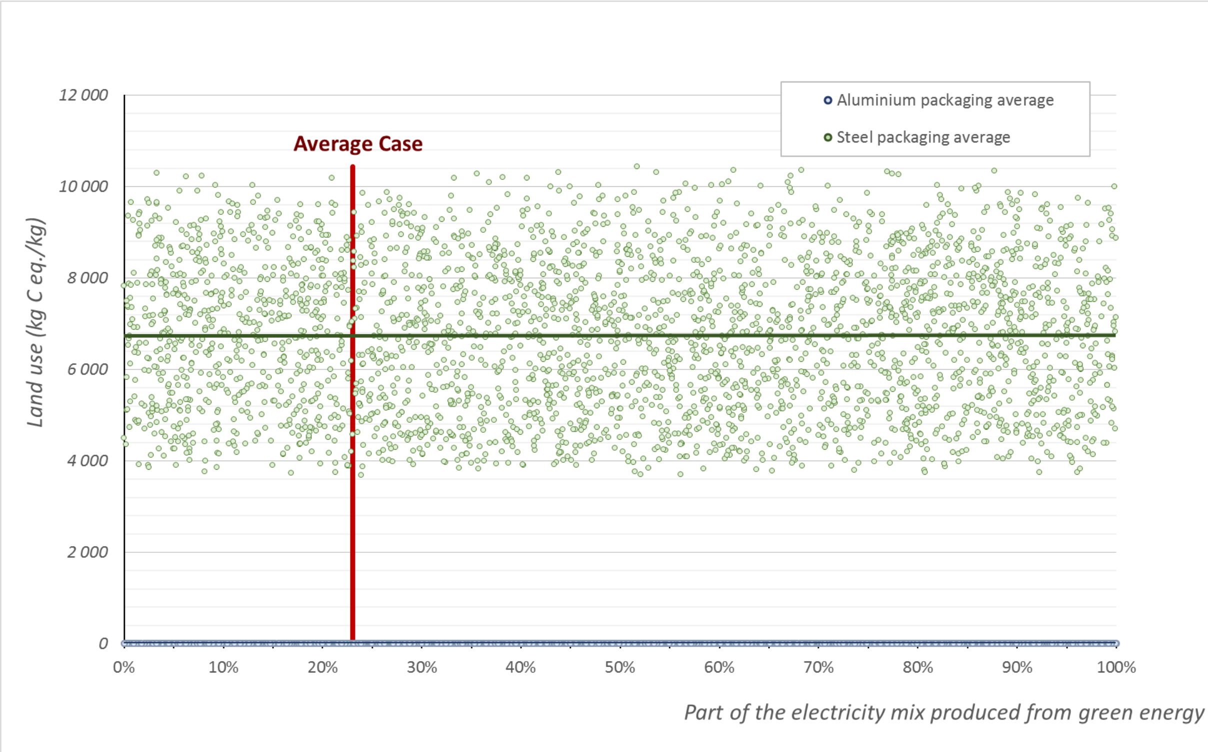

Average Case
Aluminium packaging average
Steel packaging average
Marine eutrophication (kg N eq./kg)
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0.000
-2%
0%
2%
4%
6%
8%
10%
Additional percentage of recycling rate


Average Case
Aluminium packaging average
Steel packaging average
Marine eutrophication (kg N eq./kg)
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0.000
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Part of the electricity mix produced from green energy

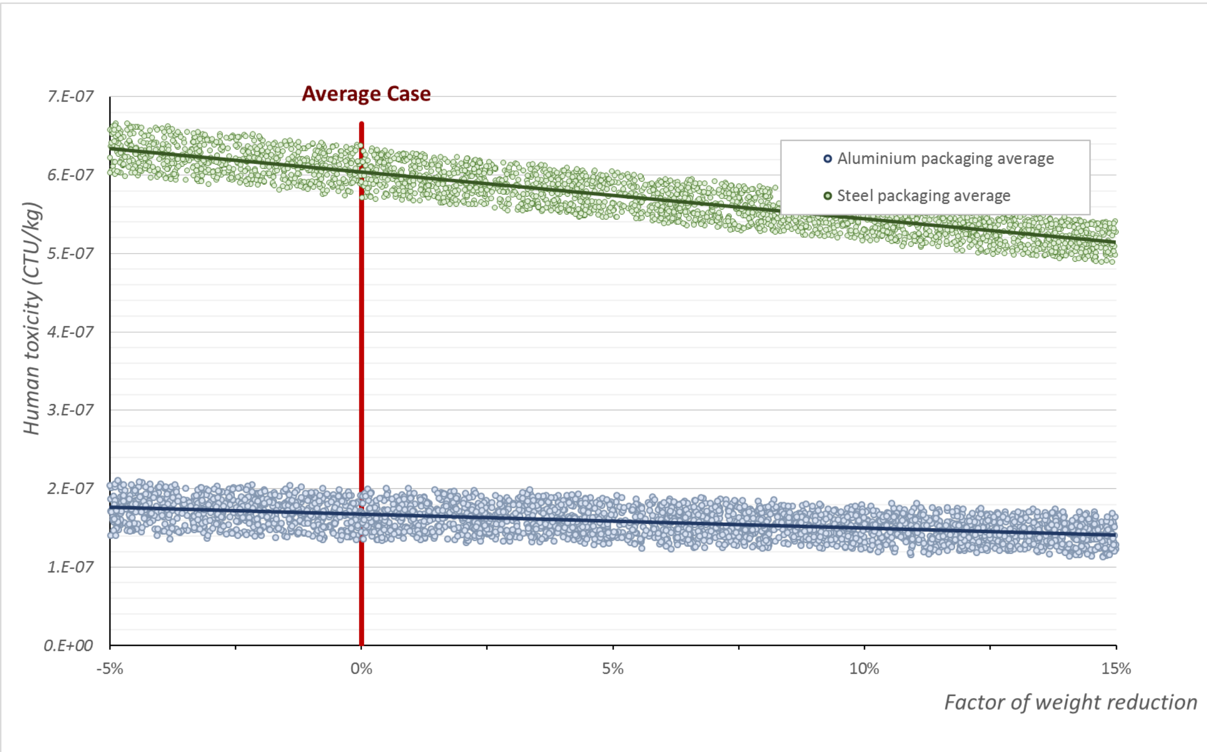
VII.7.12. Land use

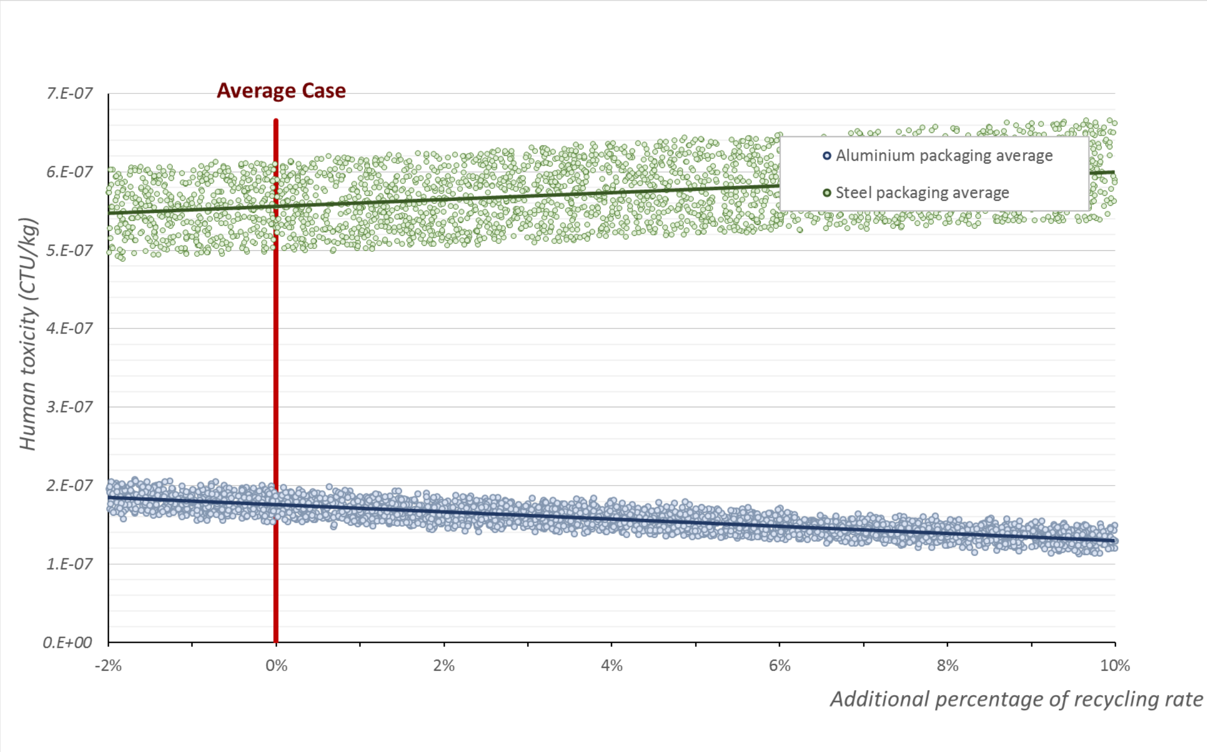


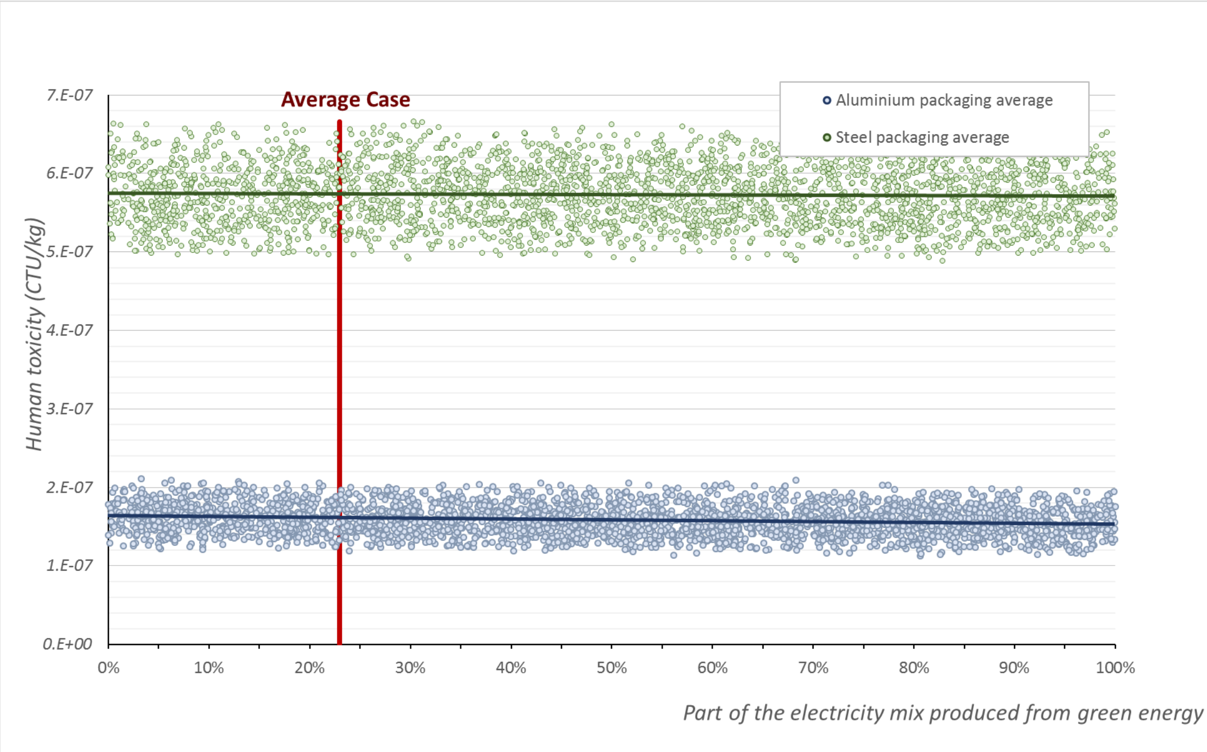




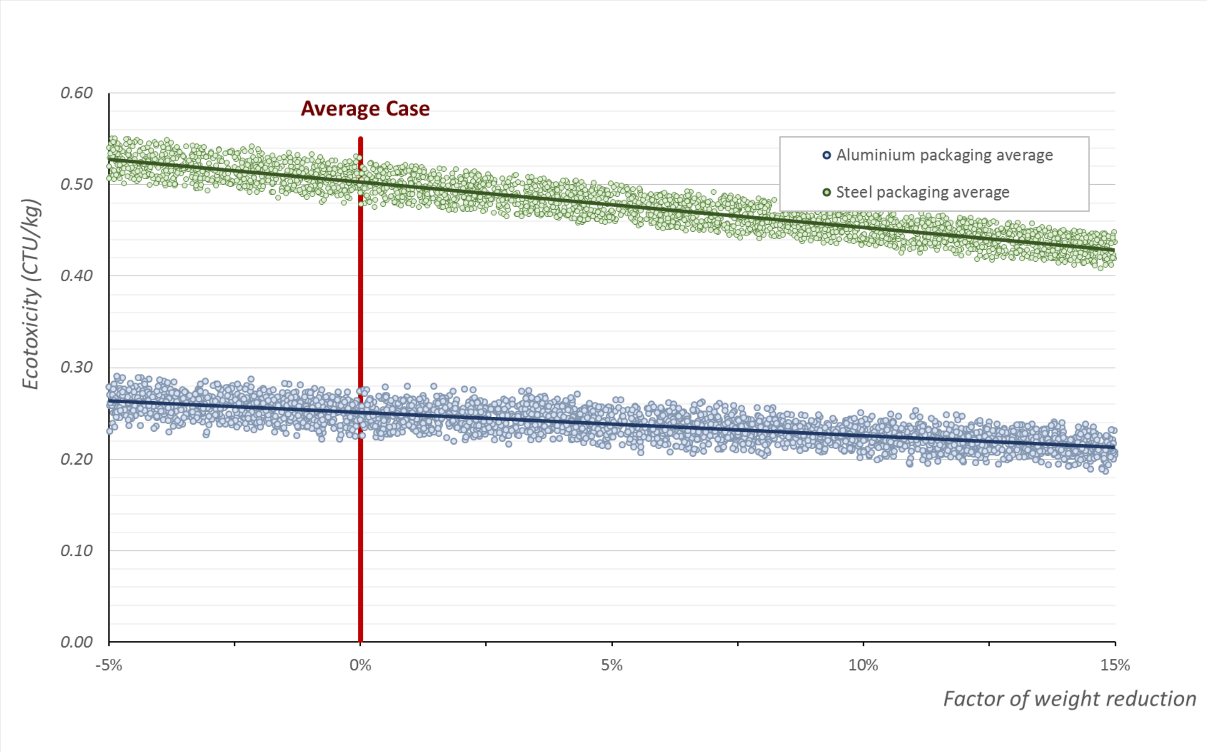
VII.7.13. Human toxicity

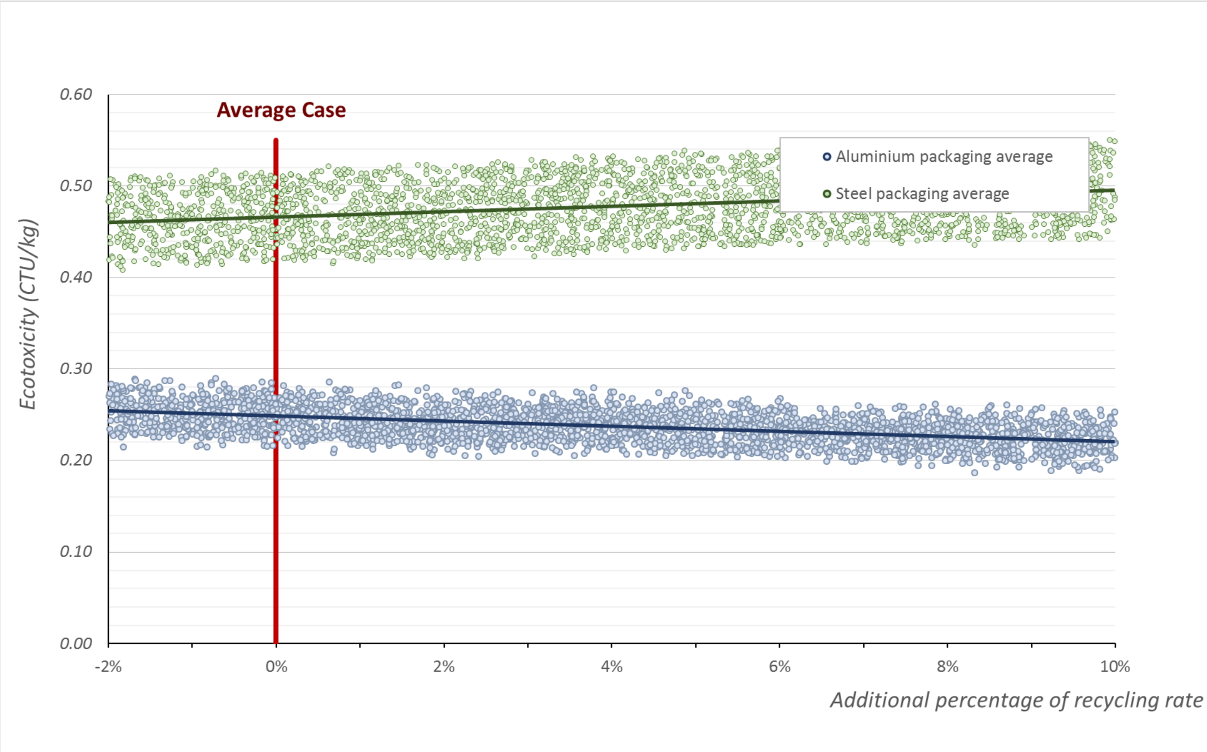


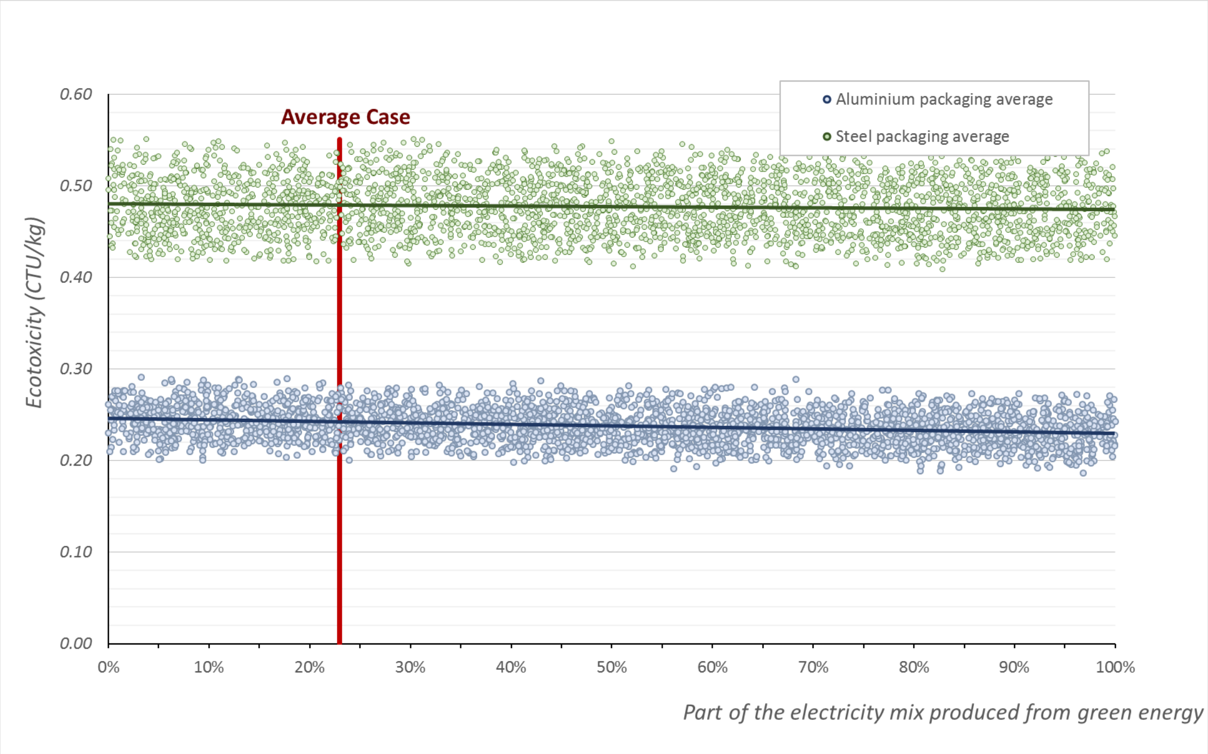

Average Case
Aluminium packaging average
Steel packaging average
Human toxicity (CTU/kg)
7.E-07
6.E-07
5.E-07
4.E-07
3.E-07
2.E-07
1.E-07
0.E+00
-2%
0%
2%
4%
6%
8%
10%
Additional percentage of recycling rate


Average Case
Aluminium packaging average
Steel packaging average
Human toxicity (CTU/kg)
7.E-07
6.E-07
5.E-07
4.E-07
3.E-07
2.E-07
1.E-07
0.E+00
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Part of the electricity mix produced from green energy

VII.7.14. Ecotoxicity







0.60
0.50
0.40
0.30
0.20
0.10
0.00
Ecotoxicity (CTU/kg)
Average Case
Aluminium packaging average
Steel packaging average
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Part of the electricity mix produced from green energy