Life Cycle Assessment of Aluminium Beverage Cans in Europe

Methodological report

Metal Packaging Europe

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Glossary

Allocation[1]	Partitioning the input or output flows of a process (e.g. recycling) or a product system between the product system under study and one or more other product systems. Particular case: proportion of material in the input to the production that has been recycled from a previous system
Characterization factor[1]	Factor derived from a characterization model which is applied to convert an assigned life cycle inventory analysis result to the common unit of the category indicator
Critical review[1]	Process intended to ensure consistency between a life cycle assessment and the principles and requirements of the International Standards on life cycle assessment
Cut-off criteria[1]	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
Elementary flow[1]	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
Energy flow[1]	Input to or output from a unit process or product system, quantified in energy units
Functional unit[1]	Quantified performance of a product system for use as a reference unit
Impact category[1]	Class representing environmental issues of concern to which life cycle inventory analysis results may be assigned
Life Cycle Assessment (LCA) [1]	Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle
Primary data[2]	Directly measured or collected data from one or multiple facilities (site-specific data) that are representative for the activities of the company. It is synonymous to "company-specific data".
Process[1]	Set of interrelated or interacting activities that transforms inputs into outputs

[1] Source: Iso 14044

Recycled content (R_1)[2]	Proportion of material in the input to the production that has been recycled from a previous system
Recycling rate (R_2)[2]	Proportion of the material in the product that will be recycled (or reused) in a subsequent system
Reference flow[1]	Measure of the outputs from processes in a given product system required to fulfil the function expressed by the functional unit
Sensitivity analysis[1]	Systematic procedures for estimating the effects of the choices made regarding methods and data on the outcome of a study
System boundaries[1]	Set of criteria specifying which unit processes are part of a product system

[2] Source: PEFCR guidance V6.3

I. Introduction

Metal Packaging Europe (MPE) is the European federation of metal packaging makers. MPE brings together more than 300 manufacturers, suppliers and their national associations, to promote the benefits of rigid metal packaging. MPE supports more than 60,000 employees in 23 European countries. Each year, they use 5 million tonnes of steel and aluminium to produce more than 85 billion units, which reach consumers every day.

MPE has been created by the merger of Beverage Can Makers Europe (BCME) and European Metal Packaging (Empac).

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

Consequently, MPE 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, MPE 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 MPE 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 credits (i.e. avoided impact) along the life cycle of the aluminium beverage cans produced in Europe. This will be done by generating an LCA of 3 volumes of aluminium beverage cans (25, 33 and 50cl) produced in Europe according to the following system boundaries (see Figure 1):
  - Cradle-to-gate + transport to filling site + End-of-Life.
  - Gate-to-gate
- To generate Life Cycle Inventories (LCIs) of the production phases and some selected further life cycle phases of three volumes (25, 33 and 50cl) of aluminium beverage cans produced in Europe according to the following system boundaries (see Figure 1):
  - Cradle-to-gate + transport to filling site + End-of-Life.

The study has been performed according to ISO 14040/44 and provides LCIs and LCA report of the aluminium beverage cans 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 credits connected with the life cycle of the average aluminium beverage cans produced in Europe;
  - To provide to Metal Packaging Europe members with objective and reliable information about the performance of the average aluminium beverage cans production in Europe in 2016 compared to 2009.
- Externally to Metal Packaging Europe:
  - To communicate to external stakeholders the environmental impacts and credits connected with the life cycle of the average aluminium beverage cans 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 shall be under the responsibility of the future LCA practitioner. This responsibility includes the check of 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.

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 phase of the metal packaging.

Two scopes are highlighted on this figure:

- Gate-to-gate scope (orange box): the manufacture of the product at the MPE plants.
- Cradle-to-gate + transport to filling site + End-of-Life (blue box excluding the white box): the production of raw and secondary (recycled) materials, the manufacture of metal packaging, the transport to filling site and the End-of-Life scenarios. The filling and processing phases (including the manutention of the bodies/ends and cans inside the filling plant, the seaming of the end to the body and the final inspection of the cans) and the use phase are excluded from this study as they are not under the direct control of MPE members.

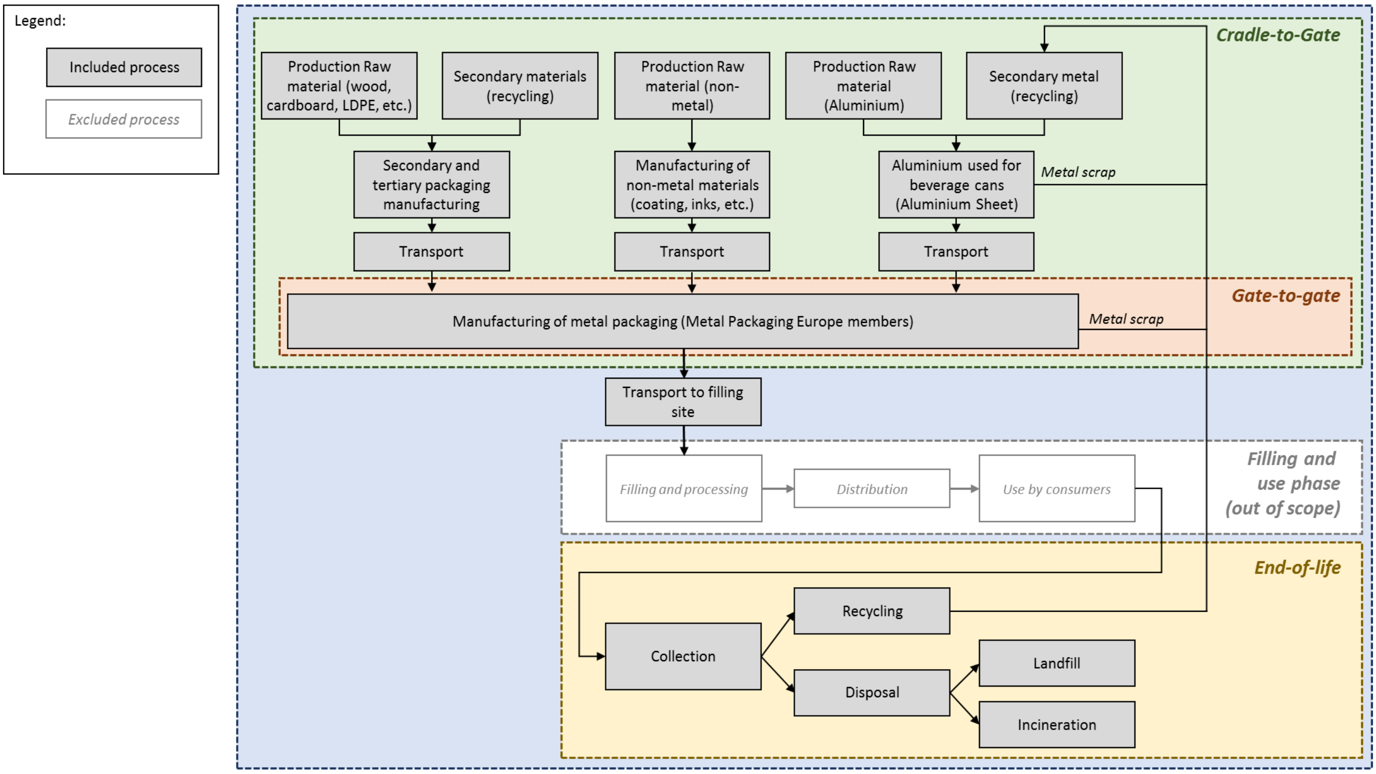

Figure 1: Life cycle flow diagram for the system analysed

The white area indicates processes excluded from the product system analysed in the study: these processes are related to the specific applications of the aluminium beverage cans, which would include, among others, the filling and processing of the cans, its distribution to the market and the use of the cans.

These processes and applications are excluded from the study in accordance with its goal (i.e. generating LCIs of product phases and some further selected life cycle phases) as well as they are not under the direct control of MPE members.

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

II.2.2. Representative products

The weight of the beverage cans selected for this study is defined for 3 standard units existing on the packaging market which volumes are: 25, 33 and 50cl. These standard units are the most sold on the beverage market. The weight includes the body, bottom and the top end (i.e. the lid) of the can. For simplicity, in the report the body and the bottom end are referred to the "body" whereas the top end is referred to the "end".

Despite it was originally intended to include the 44cl can in this study, it has not been possible to gather data from enough plants producing the 44cl can and therefore, due to confidentiality reasons, it has been decided to exclude the 44cl can from this study.

II.2.3. Functional unit

The functional unit of an LCA study represents the quantified performance of a product system for use as a reference unit.

In this study, the provided function of the aluminium beverage cans is defined as: 'to contain, protect and decorate standard volumes of beverages' and is quantified as 1000 units.

Therefore, in accordance with the goals of this study, the functional unit is defined as:

"One thousand (1,000) units of aluminium beverage cans, used to contain, protect and decorate standard volumes of beverage (25, 33 and 50cl)."

II.2.4. System boundaries

The system boundaries define all phases that are included in the selected scope.

As shown on Figure 1, the study includes the following phases (cradle-to-gate + transport to filling site + End-of-Life):

- Upstream processing and production of raw and recycled materials
- Upstream production of secondary and tertiary packaging
- Transport of raw materials, secondary and tertiary packaging to the aluminium beverage cans manufacturers
- Manufacturing of aluminium beverage cans and infrastructure of the plants
- Transport to filling sites
- End-of-Life of used cans: disposal, incineration and recycling

The following phases are not included in the study:

- Filling and grouping
- Packaging of final products
- Transport to warehouse and to final customer
- Use of the product

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 based on mass, energy and environmental significance in order to assess whether 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 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 the can manufacturing equipment (i.e: the equipment used for the manufacture of the body/end in MPE member's plants).

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 can manufacturing 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. As regards the excluded processes, they are not expected to contribute to more than 5% to each impact category assessed in the study.

II.2.6. Data quality requirements

Temporal validity

Primary data (i.e: data from MPE plants, representative of their activities – see also Glossary) were collected on aluminium beverage cans manufacturing for the year 2016. The year 2016 is considered a normal year for the operations and production volume of aluminium beverage cans manufacturing.

Electrical data and secondary datasets come from ecoinvent database v3.4.

Considering that there is no major technological evolution underway for the can manufacturing, the time validity of this study is 3 – 5 years.

Representativeness of the study

There is no official data detailing the European market for aluminium beverage cans, therefore an estimation of the representativeness of this study is provided based on the available information. This estimation provides a higher and lower limit of the representativeness of the study as described below.

<u>Higher limit:</u>

The higher limit is based on information from the three Beverage Can manufacturers, who are members of MPE, and from estimates from GlobalData. Based on a third-party report[3] covering the production volumes of beverage cans in 2016 (which is the activity year considered in this study), the estimates from GlobalData provide that the market coverage of the three can manufacturers is approximately 87% of cans manufactured in Europe. Therefore, the higher limit of the representativeness of the study is 87%.

[3] Analyst report: Jefferies Franchise note, December 2016. Chart 9

Lower limit:

European Aluminium was consulted to estimate the total production of aluminium beverage cans in Europe (EU28 and Turkey) for the year 2017.

European Aluminium is the European association that represents the whole value chain of the aluminium industry in Europe. They bring together more than 80 members including primary aluminium producers; downstream manufacturers of extruded, rolled and cast aluminium; producers of recycled aluminium and national aluminium associations, representing more than 600 plants in 30 European countries.

In 2017, based on data from European Aluminium, the European production of aluminium sheets for rigid packaging applications (i.e. without foil stock) is estimated at 1040 kt. In total, these shipments of rigid packaging represent about 20% of the total European production of aluminium sheets. In addition, Europe imported about 520 kt of aluminium sheet, which represents about 10% of the European market. Unfortunately, it's not possible from the official trade data to indicate in which market the imported sheets are going to. On the other side, Europe exported about 480 kt of aluminium sheets.

Within the 1040kt of aluminium sheets for rigid packaging application delivered by European producers, about 90% of the volume (936 kt) are related to can stock (i.e. sheets for producing mainly beverage cans but also food cans). Assuming that the average pre-consumer scrap generated at the can manufacturing in Europe is equivalent to the average of the three can manufacturers analysed in this study, which is about 18% of the incoming aluminium sheets, the aluminium cans produced in Europe are about 768 kt. Hence, based on these data, the coverage of this study corresponds to 55% and is calculated as the ratio between the production of aluminium beverage cans communicated by MPE members via the questionnaire (422 kt) and the estimation of the total production of aluminium cans in Europe (768 kt) derived from European Aluminium data.

Based on the above information, the representativeness of this study is comprised between 55% and 87%, however it must be noted that the European Aluminium data include beverage cans and food cans, therefore the lower limit of 55% is not accurate.

Considering that the previous LCA study on aluminium beverage cans[4] assessed a market coverage of 80% in 2009, it is more likely that the representativeness of this study is closer to the higher limit of 87%.

Technology coverage

In the study, site-specific data are representative of current technology used in Europe for aluminium beverage cans manufacturing for the reference year 2016.

[4] BCME, EAA, APEAL, PE International, Life Cycle Inventory and impact Analysis for Beverage Cans, 2009

Data collection involved up to 26 manufacturing plants, distributed among 15 countries, and approximately 422 kt of produced aluminium beverage cans.

It is assumed that the technology used for aluminium beverage cans production is the two-piece drawing.

The two-piece can is a can manufactured from two pieces:

- the body which is shaped from one sheet of metal by deep drawing
- and the end

After the filling operation, the body and the end are seamed together to form the can.

To model the aluminium production and the aluminium recycling at the End-of-Life, the datasets provided by European Aluminium in 2017 were used in the study. These datasets are based on primary data from 2015 and are the most up-to-date datasets regarding the produced aluminium in Europe.

Geographical coverage

The geographical coverage is aluminium beverage cans produced in the EU28+Serbia+Turkey.

Table 1 shows the country share based on the produced tonnages (for which RDC collected data). It also gives the number of responding plants in each country.

Table 1: Geographical coverage: representativeness by country

Country	#plants	Repres. of sold tons
AT - Austria	2	5-10%
DK - Denmark	1	<5%
FI - Finland	1	<5%
FR - France	2	5-10%
DE - Germany	4	15-20%
EL - Greece	2	<5%
IT - Italy	1	<5%
IRL - Ireland	1	<5%
NL - Netherlands	1	<5%
PL - Poland	1	<5%
SK - Slovakia	1	<5%
SRB - Serbia	1	<5%
ES - Spain	2	5-10%
UK - United Kingdom	4	20-30%
TR - Turkey	2	<5%
TOTAL	**26**	**100%**

Precision

As regards the data collected at the aluminium beverage cans plants, the precision of these data is considered very good for bill of materials, energy and water consumption. This is due to the fact this information is under control of the metal packaging manufacturers.

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 plants answered to the questionnaires (it is assumed that the margin of error is under 30%).

As regards ecoinvent v3.4 database, the precision of the database is considered as fair to good, depending on the specific dataset. For further details, see v3.4 documentation.

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 v3.4 databases, the completeness of the database is considered as good to very good, depending on the datasets. For further details, see ecoinvent v3.4 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 v3.4 – "Allocation, cut-off by classification") and few processes come from other datasets suppliers (e.g. European Aluminium). Some methodological differences between datasets belonging to different databases are possible. Based on expert judgement, the consequences of these methodological discrepancies have no significant consequences on the results.
- 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, a precision assessment was carried out while collecting data from the plants. Uncertainty is very low for the bill of material composition, energy and water consumptions. Uncertainty is medium to high regarding emissions (such as carbon dioxide, nitrogen oxide, sulphur oxide, VOC and dust).

- 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.

II.2.7. Allocations

II.2.7.1. Recycling allocation and End-of-Life modelling

The End-of-Life modelling was calculated according to the following formula. This formula is compliant with the ISO standard for open-loop and closed-loop formula[5].

$$E = E_V + A \times R_1 \times (E_r - E_D - E_V) + E_D + (1 - A) \times R_2 \times (E_r - E_D - E_V)$$

Equation 1: End-of-Life formula

With this formula, the allocation of environmental credits due to the recycling is shared between the supplier of the recyclable material and the incorporator of the recycled material (into the next life cycle). The parameters of the formula are explained as follows:

A: allocation factor of burdens and credits between supplier and user of recycled materials.

R_1: proportion of material, that has been recycled from a previous system, incorporated as input to the production of the new product.

R_2: proportion of the material in the product that will be recycled (or reused) in a subsequent system. R_2 shall therefore take into account the inefficiencies in the collection and recycling (or reuse) processes. R_2 shall be measured at the output of the recycling plant.

E_V: specific emissions and resources consumed (per functional unit) arising from the acquisition and pre-processing of virgin material.

E_R: specific emissions and resources consumed (per functional unit) arising from the recycling process of the recycled (reused) material, including collection, sorting and transportation process.

E_D: specific emissions and resources consumed (per functional unit) arising from disposal (i.e. landfill and incineration) of waste material at the End-of-Life.

Values for allocation factors and proportion of materials for each destination (R_1 and R_2) for secondary and tertiary packaging materials were taken from the Annex C of the PEF methodology[6].

[5] *Application of the ILCD handbook: "International Reference Life Cycle Data System – General guide for Life Cycle Assessment – Detailed guidance. 2010. Recycling in consequential modelling."*

[6] *http://ec.europa.eu/environment/eussd/smgp/PEFCR_OEFSR_en.htm*

II.2.7.2. Recycling allocations and End-of-Life modelling of the post-consumer aluminium beverage cans

1. Base case: closed-loop scenario

As base case, the End-of-Life of post-consumer aluminium beverage cans is modelled considering a closed-loop system, which means that aluminium is recycled in the same production system as its previous use without any changes to its inherent properties (i.e. aluminium sheet for beverage application). Recycled aluminium displaces virgin material, hence there is no need to define the allocation.

According to the closed-loop formula, the value for R_1 and R_2 are equal and there is no need to define the allocation factor A. The Equation 1 becomes (with $R_1 = R_2 = R$):

$$E = (1 - R) \times E_V + R \times E_R + (1 - R) \times E_D$$

Equation 2: closed-loop formula

In the base case, R is equal to 72.9% according to the latest recycling rate published by European Aluminium in 2014. This recycling rate was the most up to date value for aluminium beverage can recycling in Europe at the time the study was started.

Sensitivity analysis is performed with different recycling rate (from 40% to 95%). The parameters for the base case and the sensitivity analysis are indicated in Table 2.

For this study, the dataset used for primary aluminium production is the 'Aluminium primary ingot used in Europe' provided by European Aluminium (used both for the base case and sensitivity analysis).

The "used in Europe" primary LCI dataset (E_V) corresponds to the production of 1 tonne of ingot from primary aluminium, i.e. from bauxite mining up to the sawn aluminium ingot ready for delivery. This dataset includes all the environmental aspects of the various process steps and raw materials used to deliver 1 tonne of sawn primary ingot. It includes the aluminium which is produced by the European smelters and the aluminium which is imported into Europe and which represent 49% of the primary aluminium used in Europe in 2015.

For this study, the dataset used for recycled aluminium production is the 'Aluminium remelting' (E_R) provided by European Aluminium (used both for the base case and sensitivity analysis) which is described in the next paragraph.

2. Sensitivity analysis: open-loop scenario

In some countries and for some markets, used aluminium beverage cans are recycled into other aluminium applications, such as aluminium sheet for non-beverage application. Therefore it is modelled, in this sensitivity analysis, that used aluminium beverage cans are recycled in the same production system but with changes to its inherent properties (condition for open-loop allocation according to the ISO standard 14040/44). For this study, the European Aluminium recycling dataset for "remelting" aluminium has been used[7] for E_R.

According to European Aluminium[8]: *"the 'remelting' process LCI dataset correspond to the transformation of the aluminium (pre or post-consumer) scrap into a wrought alloy ingot (i.e. aluminium alloys used for e.g. sheet or extrusion where the final product shape is generated by mechanically forming the solid metal) ready for delivery to the user. It also includes the recycling of dross and skimmings. This dataset should be used for the recycling of process scrap as well as for the recycling of some specific end-of-life products using well controlled collection schemes like big aluminium pieces in building or aluminium beverage cans collected through specific collection networks. The 'remelting' data are based on the year 2015"*.

As sensitivity analysis, the End-of-Life of post-consumer aluminium beverage cans is modelled considering an open-loop system. For this system, the Equation 1 is used.

$$E = E_V + A \times R_1 \times (E_r - E_D - E_V) + E_D + (1 - A) \times R_2 \times (E_r - E_D - E_V)$$

Equation 3: Open loop formula

Two types of sensitivity analyses are performed:

- A sensitivity analysis with different allocation factors (A varying from 0 to 100%; R_2 = 72,9% and R_1 = 40%). According to European Aluminium, this value of R_1 corresponds to the average recycled content for aluminium products and is not specific to packaging.
- A sensitivity analysis with different recycling rates (A varying from 0 to 100%; R_2 = 72,9% and R_1 = 40%, 60% and 80%)

3. *Summary of parameters for the post-consumer aluminium beverage cans*

The parameters for these sensitivity analyses are indicated in Table 2.

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[7] *Another scenario of open-loop occurs when aluminium is recycled in a different production system compared to its previous use and with changes to its inherent properties (e.g. aluminium casting); in this case, the European Aluminium recycling dataset for "refining" aluminium should be used, however this scenario has been excluded from the current report for simplicity and could be covered in the next update of the study.*

According to European Aluminium: "The 'refining' process LCI dataset correspond to the transformation of the aluminium (pre or post-consumer) scrap into a casting alloy ingot (i.e. aluminium alloys used for the production of castings where the final product shape is generated by pouring molten metal into a mould) ready for delivery to the user. This dataset includes the melting, purifying and casting operations. It also includes the salt slag processing. The refining data related to the year 2015 are still under preparation, the previous one refers to year 2010".

[8] *European Aluminium, Environmental Profile Report: Life-cycle inventory data for aluminium production and transformation processes in Europe, 2017*

Post-consumer aluminium beverage cans			
Scenarios	**R_1**	**R_2**	**A**
Base case: closed-loop	*Equal to R_2*	*72.9%*	-
Sensitivity analysis 1: closed-loop	*Equal to R_2*	*40-95%*	-
Sensitivity analysis 2: open-loop - Variation of A	*40%*	*72.9%*	*0-100%*
Sensitivity analysis 3: open-loop - Variation of R_1	*40%, 60%, 80%*	*72.9%*	*0-100%*

Table 2: End-of-Life parameters for post-consumer aluminium beverage cans

As explained above, the European Aluminium recycling dataset for "remelting" aluminium has been used for the closed-loop scenario as well as for the open-loop scenario.

The reader should understand that the above described open-loop and closed-loop scenarios of aluminium recycling and production follow the ISO methodology for LCA modelisation; despite these open-loop and closed-loop scenarios may represent specific real cases, a mix of the two scenarios is what occurs usually in reality. As no statistics are available to model a realistic share of the two scenarios, the sensitivity analysis described at paragraph V.3.3 enables the reader to derive the environmental performance of the aluminium beverage cans based on a chosen mix of the two scenarios.

II.2.7.3. Recycling allocations and End-of-Life modelling of the pre-consumer aluminium scrap

The End-of-Life of pre-consumer aluminium scrap is modelled considering a closed-loop system. This is valid for every scenario.

The totality of the pre-consumer aluminium scrap is recycled (hence, R=100%).

With this value of R, the Equation 2 for the pre-consumer aluminium, can be written as:

$$\boldsymbol{E} = \boldsymbol{E_R}$$

Equation 4: closed-loop formula with R = 100%

For the closed-loop scenario, the European Aluminium recycling dataset for "remelting" aluminium has been used.

<u>Warning:</u> the future users of the results of the study must be aware that the recycling credits are already included in the LCI, hence they should *not* be accounted additionally.

Background dataset

Most of the background datasets used in the study come from the database ecoinvent v3.4 – "Allocation, cut-off by classification". No change was made to the allocation rules used by ecoinvent.

II.2.8. Selection of life cycle impact assessment methods

The choice of the life cycle impact assessment (LCIA) methods aims at giving an overall view of environmental impacts of metal packaging production in Europe.

Total results are presented for 14 impact categories:

- Most of these impact categories come from the category set referred as 'ILCD 2011', recommended by the EF (Environmental Footprint methodology by the European Commission) in 2011[9].
- For some impact categories, recent method developments were taken into account and the more recent methods, recommended by the PEF (Product Environmenal Footprint) project of the European Commission in 2017 have been used. These methods are updates from similar methods that were included in the ILCD set and refer to the same environmental problematics.
  This is the case for:
  - Climate change was assessed using IPCC 2013 characterization factors (ILCD 2017), while ILCD handbook refers to IPCC 2007 (ILCD 2011). 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.
  - Resource depletion – water scarcity was assessed using AWARE method (ILCD 2017), while ILCD 2011 handbook refers to the 'Swiss Ecoscarcity Model'. This former method was elected as it is in line with the water flows used in the European Aluminium LCIs as no characterization factors exist in the ILCD 2011 method for those flows.

The list of the impact categories is indicated in Table 3.

Table 3: LCIA methods applied in the study

Impact categories	Units	Impact assessment model	Author	Recommended in
Climate change	*kg CO2 eq.*	Bern model – Global Warming Potential over a 100-year horizon	Intergovernmental Panel on Climate Change, 2013	PEF 2017
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	ILCD 2011
Human toxicity – cancer effects	*CTUh*	USEtox 2.0	USEtox 2.0	PEF 2017
Ecotoxicity for aquatic freshwater	*PAF*m³*day*	USEtox 2.0	USEtox 2.0	PEF 2017

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

Impact categories	Units	Impact assessment model	Author	Recommended in
Particulate matter/ respiratory inorganics	*kg PM2.5 eq*	RiskPoll model	Humbert, 2009	ILCD 2011
Ionizing radiations	*kBq U235 eq*	Human Health effect model	Dreicer et al., 1995	ILCD 2011
Photochemical ozone formation	*kg NMVOC eq*	LOTOS-EUROS model	Van Zelm et al., 2008 as	ILCD 2011
Acidification	*mol H+ eq.*	Accumulated Exceedance model	Seppälä et al., 2006;	ILCD 2011
Terrestrial eutrophication	*mol N eq.*	Accumulated Exceedance model	Posch et al., 2008	ILCD 2011
Freshwater eutrophication	*kg P eq.*	EUTREND model	Seppälä et al., 2006;	ILCD 2011
Marine eutrophication	*kg N eq.*	EUTREND model	Posch et al., 2008	ILCD 2011
Land use	*kg C deficit*	Soil Organic matter (SOM) model	Struijs et al., 2008	ILCD 2011
Water use	*m^3 of water-eq deprived*	Available WAter REmaining (AWARE)	Boulay et al., 2016	PEF 2017
Resource depletion-mineral, fossil	*kg Sb eq.*	CML 2002 model	Milà I Canals et al.,	ILCD 2011

Warning: the future user of the LCI must be aware of the use of ILCD2011 and PEF methods in this report.

The detailed results per life cycle phases and the sensitivity analyses are only presented in this study for the following impact categories, which were selected by MPE as the main environmental areas to focus on:

- Climate change (PEF 2017)
- Resource depletion-mineral, fossil (ILCD 2011)
- Water use (PEF 2017)

These categories (or their methods used before being updated) were selected because are the most relevant for MPE members and because were used (among other methods) for the latest LCA studies on steel packaging and, only partly, on aluminium beverage cans commission by the metal packaging industry (see

Table 4). Selecting these categories is therefore the continuation with the previous LCA studies.

Table 4: Methods used in previous studies

Commissioner of the LCA study	EMPAC	BCME/EAA/Apeal
Year of publication	2016	2009
Analysed product	Steel Packaging	Aluminium Beverage cans
Climate change	**X (IPCC 2013)**	**X (CML 2001)**
Resource depletion-mineral, fossil	**X (CML 2002)**	
Resource depletion – water	**X (Swiss Ecoscarcity model 2008)**	

II.2.9. 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: Delphine Bauchot from the company 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 conclusions of the critical review are listed hereunder:

Conclusions of the review:

The CR first set of 53 comments covered the following points:

- *Deviation (11 comments),*
- *Recommendation (31 comments),*
- *Editorial comments and other miscellaneous comments (11 comments).*

Out of these comments, 6 covered methodological issues, 25 about Data and technical issues, 9 about Analysis and Interpretation.

An exhaustive work has been done by RDC Environment and Romeo Pavanello from Metal Packaging Europe 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.

The critical review report is available in Annex VII.1.3 as for further detailed references of the peer reviewer.

III. Limitations of the study

III.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 phases of development.

Uncertainty about the toxicity impact method: the level of uncertainty of the toxicity indicators are very high, especially for metals, due to the elementary flows (inventory) and the characterisation factors (USEtox methodology). Toxicity indicators should be use with caution. See paragraph II.2.6 and Table 6 for more details.

III.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 potential methodological inconsistencies between background databases: most of the background datasets used in the study come from ecoinvent v3.4 – "Allocation, cut-off by classification". The use of different background databases can lead to inconsistencies due to different methodological rules applied in the databases.
As a rough estimation, the influence of this limitation on the results is assumed, based on expert judgement, 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 (see 0) 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 26 plants have to be modelled separately. Hence, this approach was not used for this study.

  In both cases, the weighting applied is the sum of aluminium beverage cans produced by each responding plant.

  It is assumed, based on expert judgement, that the influence of this limitation on the results has an order of magnitude of one percent (1%).

- **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, based on expert judgement, that the influence of this limitation on the results has an order of magnitude of one percent (1%).

- **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. The composition of these raw materials is derived from a previous study carried out by RDC Environment and does not represent the average composition used by MPE members. This proxy is used as these raw materials are not available in the used background database.

  It is assumed, based on expert judgement, that the influence of this limitation on the results has an order of magnitude of one percent (1%).

- **Limitations due to the use of average recycling rate:** The recycling rate for aluminum beverage cans was provided by European Aluminium (for year 2014)[10] and corresponds to the European average post-consumption recycling rate for aluminium beverage cans. It does not stand for any of the specific packaging volumes modelled in this study.
  It is assumed, based on expert judgement, that the influence of this limitation on the results has an order of magnitude of one percent (1%).

- **Limitations due to the geographical scope:** the study refers to the average European production, including Serbia and Turkey. However, differences between countries exist regarding recycling rates, emissions norms (emission norms for truck, for electricity production, for can production), electricity mix and 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 aluminium beverage cans 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, an estimation of the aluminium beverage cans recycled content (as provided by European Aluminium) is used as European average. The specific recycled content was not asked in the questionnaire sent to the members participating to the study.

- **Limitations due to non-regionalized water consumption:** except for the aluminium LCI, the other water flows used in the LCA model of this study are not regionalized.

[10] https://www.european-aluminium.eu/media/1988/european-aluminium-press-release-2014-can-recycling-result-7nov2017_final.pdf

IV. Inventory analysis

IV.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 (aluminium beverage cans manufacturing and printing) and the upstream transport.

IV.1.1. Data sources

Data were collected for aluminium beverage cans manufacturing with:

- 26 responding plants
- 422 thousand tonnes of aluminium beverage cans

The following measures have been taken to ensure confidentiality of collected data: RDC signed a non-disclosure agreement with the Metal Packaging Europe members involved in the study. Individual company data, collected by RDC on a strict bilateral basis, is accessible only to the team of RDC in charge of the project. In addition, RDC has taken the necessary steps to ensure that the information made available in the study is sufficiently aggregated and does not allow the identification of individual confidential company data.

In addition to the 26 responding plants mentioned previously, 2 plants answered the questionnaire but were excluded from the analysis as their production corresponds to steel packaging. The total number of responding plants was thus 28 before the exclusions and 26 after the exclusions.

IV.1.2. Questionnaires

A questionnaire was sent to the 3 members participating to the study. It was developed based on a discussion with Metal Packaging Europe. RDC Environment experience was also used as basis for the questionnaire.

The questionnaire concerns the data related to the manufacturing plant. Three volumes of packaging were clearly identified: 25cl, 33cl and 50cl. Another volume called "other volume" was also included. Three kinds of plants were identified:

- Body manufacturing plants, where only can bodies are manufactured.
- End manufacturing plants, where only can ends are manufactured.
- Body and ends manufacturing plants, where can bodies and can ends are manufactured.

IV.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 25 correction responses from members helped to ensure that data collection was of high quality.

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 (for the 26 members of MPE) 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 with other plants from the same company (i.e: the same MPE member) or with plants from other companies (i.e: from the other MPE member)?
- Are water consumption values (in & out) in the ranges observed with other plants from the same company (i.e: the same MPE member) or with plants from other companies (i.e: from the other MPE member)?
- Are emissions in natural environment acceptable regarding European directive?

IV.1.4. Data averaging

A horizontal averaging approach was performed to average data across the manufacturing plants. The horizontal averaging approach consists in weighting each collected primary data (e.g., amount of aluminium, 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 modelling every plant separately and then average them on the basis on their sales volume (see also section 0).

IV.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".

When empty cells were found in the filled questionnaires, they were assumed to be a "no data entry" and the average value was calculated excluding the empty cells.

This approach mainly concerned:

- Secondary and tertiary packaging for which, at a first time, no data was filled by any plant. Average values of these data were, in a later stage, sent by MPE members (not plant-specific);
- The emissions to the natural environment (air, water).

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 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.

IV.1.6. Foreground data quality assessment

Activities at MPE plants

The following Table 5 shows a qualitative description of the activities occurring at MPE plants which are responsible for the consumption of energy, heat, water and for the VOC emissions.

Note: regarding the office activity at MPE plants, no information was received from the members whether the electricity, water and heat consumptions from offices are included or excluded in the collected data. It is possible that it has been included for some plants whereas excluded for other plants. However, based on our experience, these consumptions are negligible compared to the total consumptions of an industrial plant.

Table 5: List of activities

Process	Electricity	Heat	Water	VOC emissions to air
Coil handling	x			
Can forming	x		x	
End forming	x			
Can coating/printing	x	x		x
Can washing/drying	x	x	x	
End sealing	x	x		x*
End printing/decoration	x	x		x
Transport / Palettizing	x			
Testing	x			
Auxiliaries (HVAC, compressor etc.)	x	x	x	
Offices	x	x	x	
Warehousing	x	x		
*** End sealing usually is a VOC emission free process, however some plants may still use solvent based tab lubes**				

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. No data qualities were filled by any plant, therefore primary data quality is only estimated, for each data, as the percentage of plants encoding the data.

Based on the point mentioned above, the main inputs and outputs of the manufacturing plants can be classified as follows:

- Data with high coverage:
  - Raw material to produce the aluminium beverage cans were answered by every plant, hence has a very good coverage (100%)
  - Electricity consumption has a very good coverage (100%)
  - Heat and water consumptions have a very good coverage (96%)
  - Heat mix consumption has a very good coverage (100%)
  - Atmospheric emissions of CO_2 have a medium coverage (38%)
  - Atmospheric emissions of NO_x, SO_x, dust (unspecified) and VOC have a good coverage (46%)
  - Truck transport of aluminium has a good coverage (61%)

    - Truck transport of raw materials other than aluminium has a medium coverage (38%)
    - Secondary and tertiary packaging: These data were answered by some of MPE members following a 'data validation question' procedure (see 0) (66%).
- Data with low coverage:
    - Water emissions have a very low coverage (under 25%)
    - No data were filled in the questionnaire for atmospheric emissions of ammonium and dust (PM 2,5 and PM 10) (0%)
    - No data were filled for ship and train transport of aluminium and other raw materials

IV.1.7. Background data quality assessment

Background datasets used in the study mostly come from ecoinvent v3.4 – "Allocation, cut-off by classification" and RDC models based on COPERT 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

Table 6: data quality assessment

Data	Influence on results	Data quality	Comments
Energy carrier			
Natural gas supply	++	++	Datasets from ecoinvent v3.4 – "Allocation, cut-off by classification". with a good geographical and technological representativeness but low time representativeness
Light fuel supply	+	++	
Electricity	+++	++	
Raw materials production			
Aluminium	+++	++	Dataset from European Aluminium 2017 with a good time, geographical and technological representativeness.
Lacquers, coatings, varnishes	+	++	Datasets from ecoinvent v3.4 – "Allocation, cut-off by classification". with a good geographical. Technological representativeness and Time representativeness are lower.
Printing inks	+	++	
Sealing compounds	+	++	
Transports			
Truck emissions	+	++	Datasets produced by RDC according to Copert IV methodology, considering truck classes, pollution norm, real payload, etc. Emission from Diesel production are already considered in ecoinvent v3.4 – "Allocation, cut-off by classification".
Infrastructure			
Metal working factory (used as infrastructure for metal packaging plants)	+++	+	Datasets from ecoinvent v3.4 – "Allocation, cut-off by classification". 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 v3.4 – "Allocation, cut-off by classification".

IV.2. Life cycle model description

IV.2.1. Categories

Three volumes of cans are used to present the data. These volumes result of the combination of one body and one end, as described below:

- 25cl can: consisting of one 25cl body and one 25cl end
- 33cl can: consisting of one 33cl body and one "33-50cl" end
- 50cl can: consisting of one 50cl body and one "33-50cl" end

Note: the same end may be used for 33cl cans or for 50cl cans. Therefore, these ends are named in this report as "33-50cl" ends.

Note 2: other can volumes exist but are not part of the scope of this study.

IV.2.2. Raw materials for beverage cans (body and end)

Data collected

The weight of the average final products (body and end) has been calculated from member's data.

Table 7: Weight of final products - Source: member data (2016)

Weight of products (g)	Can 25 cl	Can 33 cl	Can 50 cl
Body	7.9	9.8	12.8
End	2.5	2.4	2.4
Can (body + end)	**10.4**	**12.2**	**15.1**

The efficiency of the cans manufacturing process is 82% based on collected data, meaning that 18% of 1 kg of aluminium sheet becomes scrap (i.e. pre-consumer scrap, also known as skeleton of aluminium sheet).

Assumption on coatings

According to MPE members, coating is rather complex subject as it depends on different aspects; for instance, the amount and chemical composition of the coating depend on:

- The application of the cans, for instance more coating is needed respectively for ciders, soft drinks, beers.
- The internal or external surfaces of the cans; the top can end is coated externally by the aluminium producer whereas the internal surface and the external wall of the cans are coated by the packaging manufacturer. Also, coating on the external wall of the can depends on the customer specifications.

Coating materials used today by the metal packaging industry are almost all water based; this means that the composition is more than 50% water with the remaining constituents being solids and solvents; this applies, in particular, to internal coating which is in contact with the beverage. The composition of the coatings used in this study is derived from a previous study carried out by RDC Environment and does not represent the average composition used by MPE members. This proxy is used as these raw materials are not available in the used background database.

IV.2.3. Secondary and tertiary packaging

Data collected

Consumption of secondary and tertiary packaging was calculated for bodies and ends. It is assumed that secondary and tertiary packaging are similar no matter the volume of cans. Four materials were included in the questionnaire to encode the data, see table below.

Table 8: Secondary and tertiary data – Source: member data (2016)

Consumption of secondary and tertiary packaging (g/1,000 units)	Body 25cl	Body 33cl	Body 50cl	Ends
Wood pallet (reused 15 times on average)	*152.56*	*197.99*	*284.61*	*5.58*
Polypropylene pallet (reused 60 times on average)	*38.14*	*49.50*	*71.15*	*1.40*
Corrugated board	*162.18*	*200.28*	*165.08*	*45.67*
Polypropylene film and straps	48.17	56.19	41.68	1.84
TOTAL	**401.05**	**503.95**	**562.52**	**54.48**

The data encoded for the pallet was split between wooden pallet (20%) and polypropylene pallet (80%). It is considered that the polypropylene pallets are reused 60 times before disposal whereas the wooden pallets are reused 15 times. This was validated by MPE members.

IV.2.4. Energy data

Consumption data were calculated from members' data for both consumption of electricity and heat. It was assumed that heat and electricity consumptions are proportional to the weight of the cans, therefore heat and electricity consumptions were allocated based on the mass of the cans. This approach is aligned with the previous LCA study on metal packaging (i.e. food and non-food applications, excluding beverage) commissioned by MPE.

Electrical mixes

The electricity consumption needed to produce the raw materials is already accounted and included in the datasets used to model the production of those materials (i.e. for aluminium the European Aluminium datasets, for other raw materials the ecoinvent datasets). See section *IV.2.2 Raw materials for* and *IV.2.3 Secondary and tertiary packaging* for more details.

For the manufacturing of bodies and ends, participating members encoded the total consumption of electricity consumed during a full year of production (2016). The average electrical mix was calculated per energy source from the countries of all participating members (weighted by the country production). The next two figures give the final electrical mixes calculated for the body production (Figure 2) and for the end production (Figure 3), decomposed by energy source. More information on the modelling of the electrical mix is available in annex *VII.1.1*.

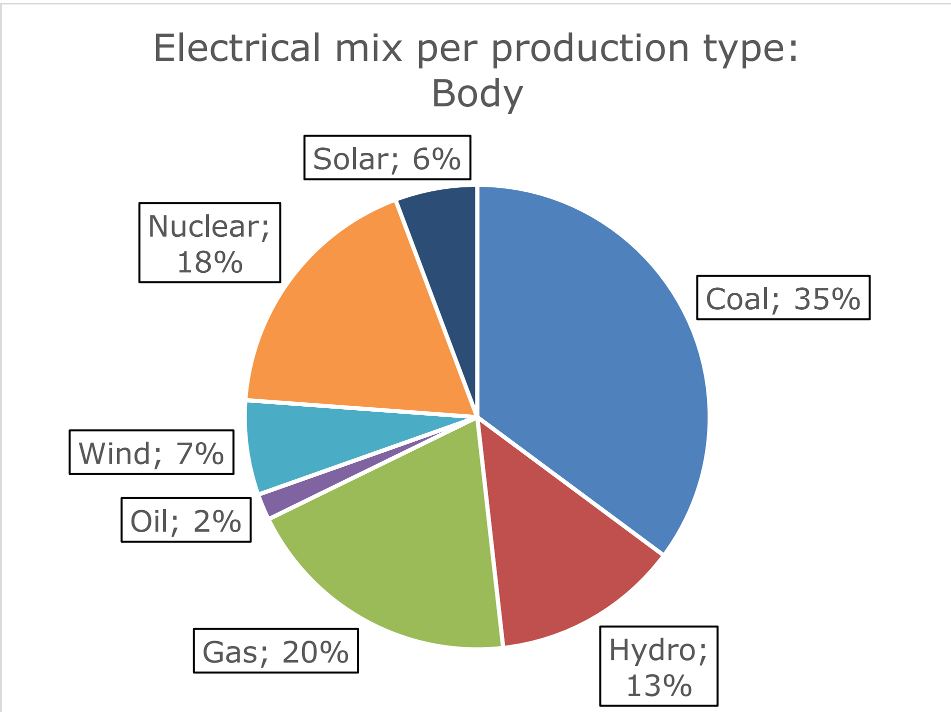

Figure 2: Electrical mix per energy source to produce the body

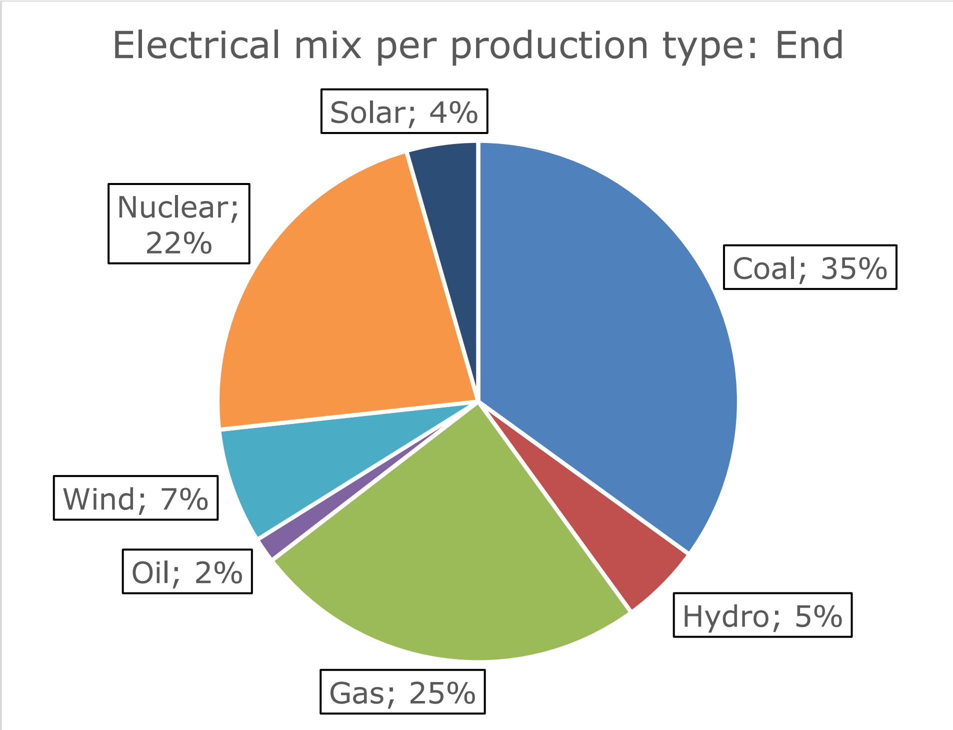

Figure 3: Electrical mix per energy source to produce the ends of the cans

IV.2.5. Transport

The main transports occur in the following three phases of the life cycle:

- Transport of raw materials to the manufacturing plant
- Transport of produced cans from manufacturing plant to the filler
- Transport to collect the used beverage cans and to deliver to the recycler at End-of-Life phase

Distances

Distances are calculated from members data (as regards the raw materials and the transport to filler) or estimated based on literature. The

Table 9 gives the repartition of transport for raw materials.

According to member's data, all transport is done by truck. No transport is done by boat nor train.

Table 9: Distances for the main transports

<table>
<tr><th colspan="3">Transport</th><th>Truck</th><th>Train</th><th>Boat</th></tr>
<tr><td rowspan="8">Raw materials transport</td><td rowspan="2">Aluminium</td><td>Distance (km)</td><td>1,220</td><td>-</td><td>-</td></tr>
<tr><td>Part (%)</td><td>100%</td><td>0%</td><td>0%</td></tr>
<tr><td rowspan="2">Lacquers, coatings, varnishes</td><td>Distance (km)</td><td>1,000</td><td>-</td><td>-</td></tr>
<tr><td>Part (%)</td><td>100%</td><td>0%</td><td>0%</td></tr>
<tr><td rowspan="2">Printing inks</td><td>Distance (km)</td><td>1,000</td><td>-</td><td>-</td></tr>
<tr><td>Part (%)</td><td>100%</td><td>0%</td><td>0%</td></tr>
<tr><td rowspan="2">Sealing compounds</td><td>Distance (km)</td><td>1,000</td><td>-</td><td>-</td></tr>
<tr><td>Part (%)</td><td>100%</td><td>0%</td><td>0%</td></tr>
<tr><td>2ary and 3ary packaging</td><td colspan="2">From suppliers to members – distance (km)</td><td>250</td><td colspan="2">Estimation agreed between RDC Environment and MPE</td></tr>
<tr><td>Delivery</td><td colspan="2">From members to fillers – distance (km)</td><td>250</td><td colspan="2">Estimation agreed between RDC Environment and MPE</td></tr>
<tr><td rowspan="3">Transport at the End-of-Life phase</td><td rowspan="2">Waste collection</td><td>Non selective (km)</td><td>12.2</td><td colspan="2" rowspan="2">ADEME 2012[11]</td></tr>
<tr><td>Selective (km)</td><td>86</td></tr>
<tr><td colspan="2">Transport to the recycler (km)</td><td>395</td><td colspan="2">Assumption</td></tr>
</table>

Modes of transportation

Transport by truck

Fuel consumptions and airborne emissions from trucks are obtained from the COPERT 4 methodology (version 5.0).

The trucks considered in this study:

- Have a maximum payload of 24 tons;
- Are "Articulated 34-40 tons" (framework);
- The impact of the truck is modelized as follows:
    - When the truck is fully loaded, its impact (per km) is equal to 100% of its maximal impact.
    - When the truck is travelling empty, its impact (per km) is equal to 70% of its maximal impact. The factor 70% is a coarse average value derived from the Copert 4 methodology by considering a set of trucks of various

[11] Data for 2007, published in 2009. « La collecte des déchets par le service public en France » Ademe.

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).

The repartition in Euro Code is indicated in Figure 4. This comes from MPE members data.

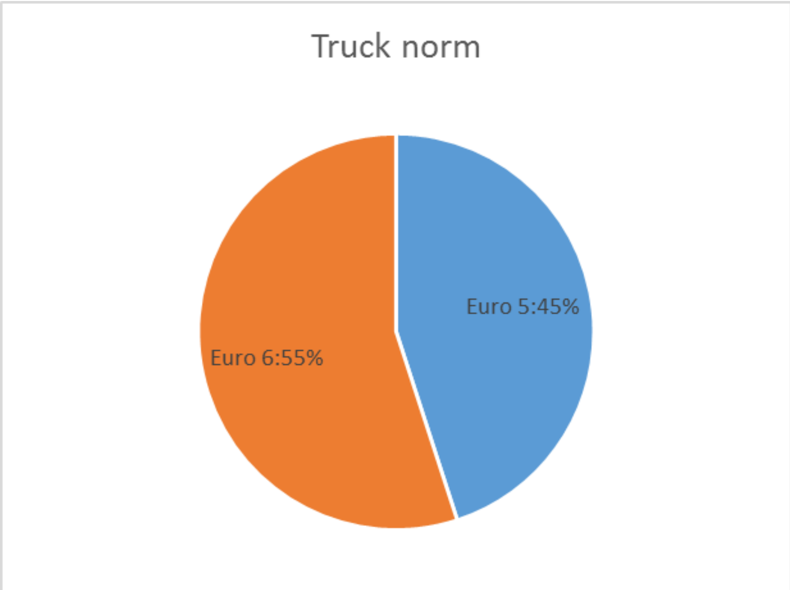

Figure 4: Truck norm according to Euro Code

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

For the transport of bodies and ends from manufacturing site to filling site, the payload is assumed to be under 100% (i.e. lower than the maximum payload). Indeed, the filling of the truck is constraint by the volume of the empty packaging rather than their weight. The total weight of loaded pallets are presented in the section *IV.2.3 Secondary and tertiary packaging*. The next table shows the payload for the 3 types of bodies and ends.

Table 10: Loading rates

	25 cl	33 cl	50 cl	Ends
Number of pallets/truck (data from one member)	20.6	20.2	20.0	26
Number of bodies/ends per truck	225,055	170,044	117,120	7,800,000
Number of bodies/ends per pallet	10,925	8,418	5,856	300,000
Bodies/ends per pallets (kg/pallet)	86.4	82.5	74.8	706
Secondary and tertiary packaging (kg/pallet)	38.5	38.5	38.5	16.3
Weight of one loaded pallet (kg/pallet)	124.9	121.0	113.3	722.8
Load/truck (t)	2,574	2,445	2,265	18,793
Payload for 24t truck (%)	11%	10%	9%	78%

IV.2.6. End-of-Life

End-of-Life of pre-consumer aluminium scrap

The pre-consumer aluminium scrap produced during the cans manufacturing phase is assumed to be 100% recycled (in base case scenario and sensitivity analyses). It is accounted as recycled in closed loop (including, in the open loop sensitivity analysis). The transport distance is assumed to be the same as for post-consumer cans.

End-of-Life of post-consumer aluminium beverage cans

The post-consumer aluminium beverage cans are assumed to be either recycled or sent to elimination (landfill and incineration). Parameters for End-of-Life of post-consumer aluminium beverage cans are indicated in Table 2 for the different scenarios. The transport distance is indicated in

Table 9.

End-of-Life of secondary and tertiary packaging

The secondary and tertiary packaging (e.g. pallet or cardboard) are assumed to be either recycled or sent to elimination (landfill and incineration). Parameters for End-of-Life of secondary and tertiary packaging are indicated in the next table.

End-of-Life parameters for secondary and tertiary packaging (for all End-of-Life scenarios)				Source
	R_1	R_2	A	
Corrugated board	88%	75%	20%	PEF project – Annex C[12]
LDPE	0%	27.5%	50%	
PP	0%	0%	50%	
Wood pallet	0%	30%	80%	

Table 11: End-of-Life parameters for secondary and tertiary packaging

[12] *http://ec.europa.eu/environment/eussd/smgp/PEFCR_OEFSR_en.htm - Annex C*

V. Life Cycle Impact Assessment (LCIA)

V.1. System considered and methodology

Figure 5 shows the system boundaries considered for the study: cradle-to-gate + transport to filling site + End-of-Life.

The environmental results are calculated for the 3 volumes of cans (25cl, 33cl, 50cl) and are presented for the 14 impact categories recommended by the EF methodology. Normalisation and weighting of the results are excluded in accordance to the goal and scope of the study.

Detailed results per life cycle phases are then analysed for three selected categories (climate change, resource fossil depletion, water depletion).

Three types of sensitivity analyses were assessed (see also section II.2.6):

- Closed-loop scenario with different recycling rates
- Open-loop scenario with different allocation factors
- Open-loop scenario with different allocation factors for different recycled contents

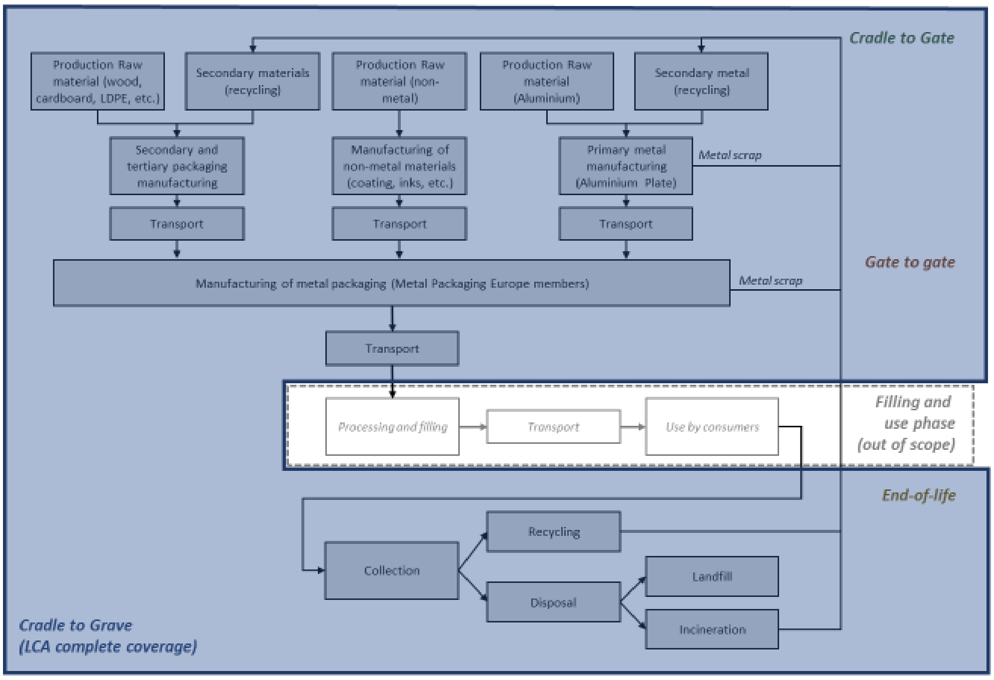

Figure 5: LCA system boundaries

Note:

- the metal production phase indicated in the following tables includes the aluminium production and the transport to MPE members.

- The other raw material production phase in the following tables includes the other raw materials production and transport to MPE members, including the production and end-of-life of secondary and tertiary packaging
- The Body manufacturing/End manufacturing include the manufacturing of Body/End at MPE plants
- The Distribution phase includes the body and end transport to the filling plant
- The EoL – Pre-consumer aluminium scraps includes the End-of-Life of the aluminium scraps
- The EoL – Post-consumer aluminium includes the End-of-Life of the aluminium cans including transport linked to End-of-Life of aluminium cans

V.2. Results – Base case scenario

For the closed-loop scenario, all the collected used beverage cans are recycled to produce new aluminium sheet for beverage use, hence there is no need to define an allocation factor and the recycling rate and the recycled content are equal ($R_1 = R_2$).

The recycled content and the recycling rate of aluminium beverage cans are set to 72,9%.

The formula for the End-of-Life modelling is according to the Equation 2.

V.2.1. Environmental impacts of the closed-loop scenario

Table 12 shows the environmental impacts for each impact category (14) for the 3 packaging volumes. Results are expressed per functional unit, i.e. 1,000 units of packaging.

Table 12: Impact results based on the closed-loop scenario. Results are expressed by 1,000 unit of packaging.

Name	Unit	Can 25 cl	Can 33 cl	Can 50 cl
Climate change	*kg CO_2 eq.*	62.27	77.21	106.09
Abiotic resource depletion	*kg Sb eq.*	2.51E-03	3.01E-03	4.05E-03
Water scarcity	*m3 water eq.*	7.61	10.13	12.43
Acidification	*Moles H+ eq.*	2.61E-01	3.17E-01	4.25E-01
Photochemical ozone formation	*Mass C2H4 eq.*	1.04E-01	1.24E-01	1.66E-01
Eutrophication freshwater;	*kg P eq.*	9.09E-04	1.20E-03	1.51E-03
Respiratory inorganics	*kg PM2.5 eq.*	1.99E-02	2.45E-02	3.38E-02
Stratospheric ozone depletion	*kg CFC11 eq.*	3.09E-06	4.03E-06	5.64E-06
Ionising radiation	*kg U235 eq.*	4.10E-05	4.78E-05	6.12E-05
Eutrophication terrestrial	*Moles N eq.*	5.79E-01	7.15E-01	9.52E-01
Eutrophication marine	*kg N eq.*	3.11E-02	3.62E-02	4.68E-02
Land use	*Mass deficit of Soil Organic Carbon*	80.83	100.47	139.27
Toxicity human	*CTU*	1.19E-06	1.60E-06	2.29E-06
Ecotoxicity freshwater	*CTU*	311.42	461.48	777.08

V.2.2. Climate change

This section presents and analyses results for Climate change. The average climate change impact of 1,000 aluminium beverage cans are:

- **62.27 kg** of CO_2 equivalents for the 25cl volume.
- **77.21 kg** of CO_2 equivalents for the 33cl volume.
- **106.09 kg** of CO_2 equivalents for the 50cl volume

The main environmental impacts come from the aluminium production, mainly from the electrolysis which is an energy-intensive process (it requires 15,460 kWh/ton of produced aluminium[13]), whereas the aluminium recycling at the End-of-Life provides an environmental credit.

[13]*European Aluminium, Environmental Profile Report: Life-cycle inventory data for aluminium production and transformation processes in Europe, 2017*

The body manufacturing is the second highest contribution to the environmental impact, mainly due to:

- The indirect emissions linked to the consumption of electricity
- The direct and indirect emissions linked to respectively the consumption and extraction of natural gas
- The direct emissions of NO_X, SO_X and VOC

Regarding the contribution of the aluminium production, its impact (almost 97%) is mainly due to the electricity used at the smelters (38%), the fuel consumption mostly at the alumina refineries (28%) and the processing i.e. mostly the carbon anode consumption (31%)14. Due to the aggregated European Aluminium datasets, it is not possible to further specify the contribution of the direct and indirect emissions of the electrolysis process.

At the manufacturing phase, almost 70% of the contribution is due to the electricity consumed by the MPE plants whereas 25% is due to the natural gas consumption (mainly used in the drying oven for coating and inks treatments). Finally, almost 5% is due to the infrastructure, which takes into account an average impact for the buildings, roads and parking spaces on the premises as well as other land occupation; it is based on an average standard impact from ecoinvent for a 27-ha metal factory.

Almost all the contribution to the post-consumer can recycling (-108% of the post-consumer can recycling) is linked to the credits of recycling the aluminium.

When summing up the impact of aluminium production and the credit of aluminium recycling, the net impact of aluminium represents about 60%, 55% and 50% of the total footprint respectively for the 25cl, 33cl, 50cl cans, whereas the impact of the can manufacturing is 18% on average.

V.2.3. Resource depletion-mineral, fossil

This section presents and analyses results for Resource depletion-mineral, fossil. The average resource depletion-mineral, fossil impact for 1,000 aluminium beverage cans is:

- **2.51E-3 kg** of Sb equivalents for the 25cl volume.
- **3.01E-3 kg** of Sb equivalents for the 33cl volume.
- **4.05E-3 kg** of Sb equivalents for the 50cl volume.

The main environmental impacts come from the aluminium production, mainly due to the related consumption of fluorspar and bauxite whereas the aluminium recycling provides an environmental credit.

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[14] *European Aluminium, Environmental Profile Report: Life-cycle inventory data for aluminium production and transformation processes in Europe, 2017. Table 4-17.*

The body manufacturing is the second highest contribution to the environmental impact, mainly related to the consumption of indium and cadmium when building the infrastructures of the plant.

Regarding the contribution of the aluminium production, almost 57% of the total impact is due to the use of fluorspar and 38% to the use of bauxite.

At the manufacturing phase, almost 98% of the contribution is due to the infrastructure, for which the main contributions are indium (82%) and cadmium (10%). The contribution of natural gas and fossils in the energy mix is less than 1% of the manufacturing phase.

At the distribution phase, all the contribution is linked to the truck production for which the main contributions come from indium (82%) and cadmium (10%)

All the contribution to the post-consumer can recycling phase (121% of the post-consumer can recycling) is linked to the credits of recycling the aluminium. The transport of aluminium contributes to an impact of 15% to the phase.

When summing up the impact of aluminium production and the credit of aluminium recycling, the net impact of aluminium represents about 33%, 31% and 30% of the total footprint respectively for the 25cl, 33cl, 50cl cans, whereas the impact of the can manufacturing is 45% on average.

V.2.4. Resource depletion – water scarcity

This section presents and analyses results for Resource depletion-water scarcity. The average water scarcity impact for 1,000 aluminium beverage cans is:

- **7.61 m³** of water equivalent for the 25cl volume.
- **10.13 m³** of water equivalents for the 33cl volume.
- **12.43 m³** of water equivalents for the 50cl volume.

The main environmental impacts come from the aluminium production, whereas the aluminium recycling provides an environmental credit. The body manufacturing is the second highest contribution to the environmental impact.

Regarding the contribution of the aluminium production, this is mainly due (almost 94,5%) to water consumed for the aluminium ingot production (including alumina production and electrolysis) whereas the sheet manufacturing stage is responsible for 6,5% of the impact.

At the manufacturing phase, almost 70% of the contribution is due to the water usage to produce the electricity consumed by the MPE plants (i.e. cooling water of power plants and for hydroelectric energy production - see Figure 2 and Figure 3 for more details) whereas 12% of the contribution is due to the water consumption at the factory and only 2% is due to the natural gas consumption (mainly used in the drying oven for coating and inks treatments). Finally, almost 14% is due to the infrastructure, which takes into account an average impact for the buildings, roads and parking spaces on the premises as well as other land occupation; it is based on an average standard impact from ecoinvent for a 27-ha metal factory.

Regarding the post-consumer can recycling, almost all the contribution to the post-consumer can recycling (-105% of the post-consumer can recycling) to the avoided impact is linked to the credits of recycling the aluminium.

When summing up the impact of aluminium production and the credit of aluminium recycling, the net impact of aluminium represents about 65%, 54% and 56% of the total footprint respectively for the 25cl, 33cl, 50cl cans, whereas the impact of the can manufacturing is 23% on average.

V.3. Sensitivity analysis

V.3.1. Sensitivity analysis: variation of the recycling rate

The purpose of the analysis is to evaluate the influence of the recycling rate of used beverage cans on the impact results.

In this scenario, aluminium beverage cans are considered recycled in a closed-loop (as per the base case scenario) and the recycling rate (R_2) varies from 40% to 95% in order to represent the different recycling rates of the main European countries.

As it is a closed-loop scenario, all the collected used beverage cans are recycled to produce new aluminium sheet for beverage use, hence there is no need to define an allocation factor and the recycling rate and the recycled content are equal ($R_1 = R_2$) and varies accordingly.

The formula for the End-of-Life modelling is according to Equation 2. The other parameters are unchanged compared to the base case scenario.

This sensitivity analysis focuses on three main impact categories.

V.3.1.1. Climate change

The influence of the recycling rate is shown in Figure 6, Figure 7 and Figure 8 (for 25, 33 and 50cl respectively), where it can be seen that an increase of the recycling rate allows a decrease of the environmental impact. Inversely, a decrease of the recycling rate is responsible for an increase of the impact.

In the closed-loop scenario, any percentage increase of the recycling rate avoids producing an equivalent amount of virgin aluminium and therefore decreases the total impact.

Compared to the base case scenario (where the recycling rate is set to 72,9%), an increase of the recycling rate by 1% would allow reducing the climate change impact by:

- 1.35% in the case of 25cl cans
- 1.22% in the case of 33cl cans
- 1.11% in the case of 50cl cans

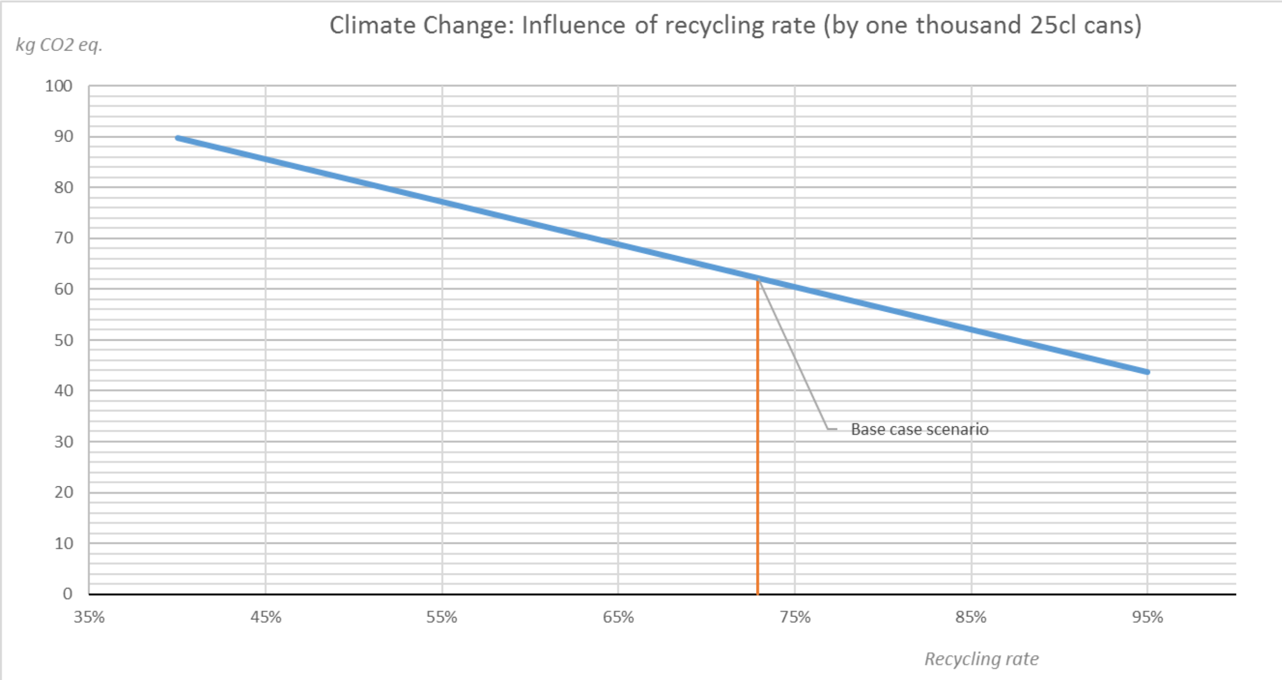

Figure 6: Influence of recycling rate (by one thousand 25cl cans)

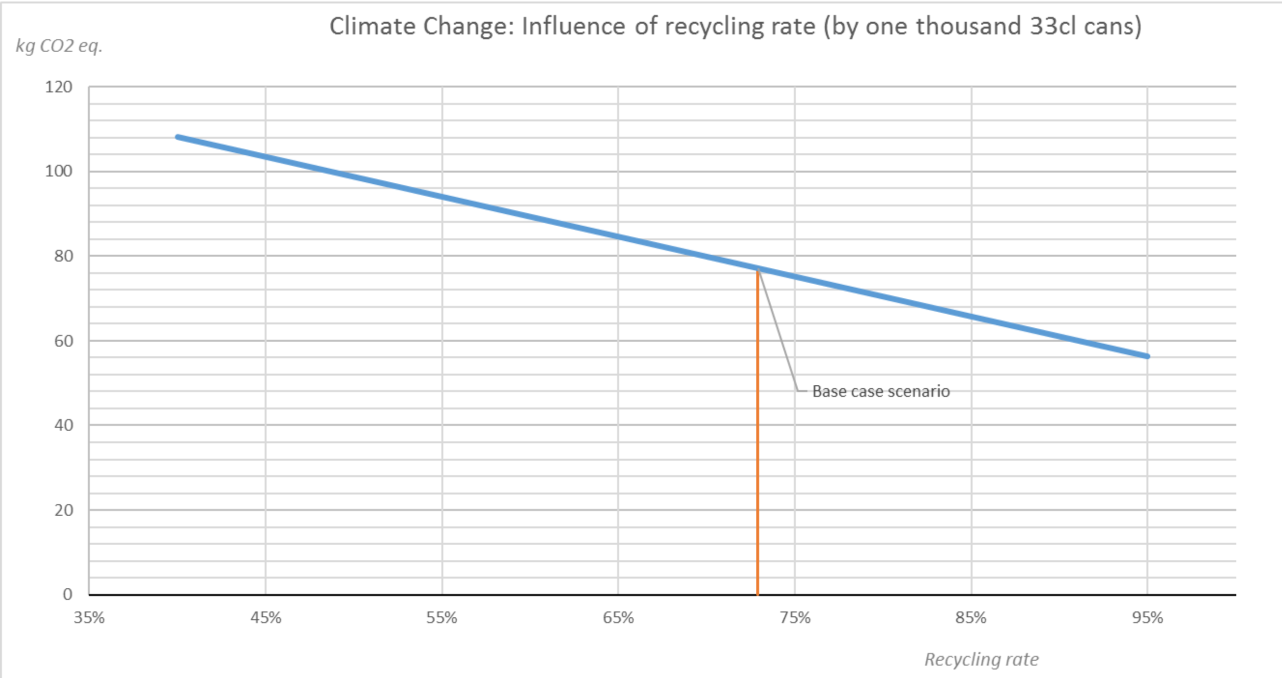

Figure 7: Influence of recycling rate (by one thousand 33cl cans)

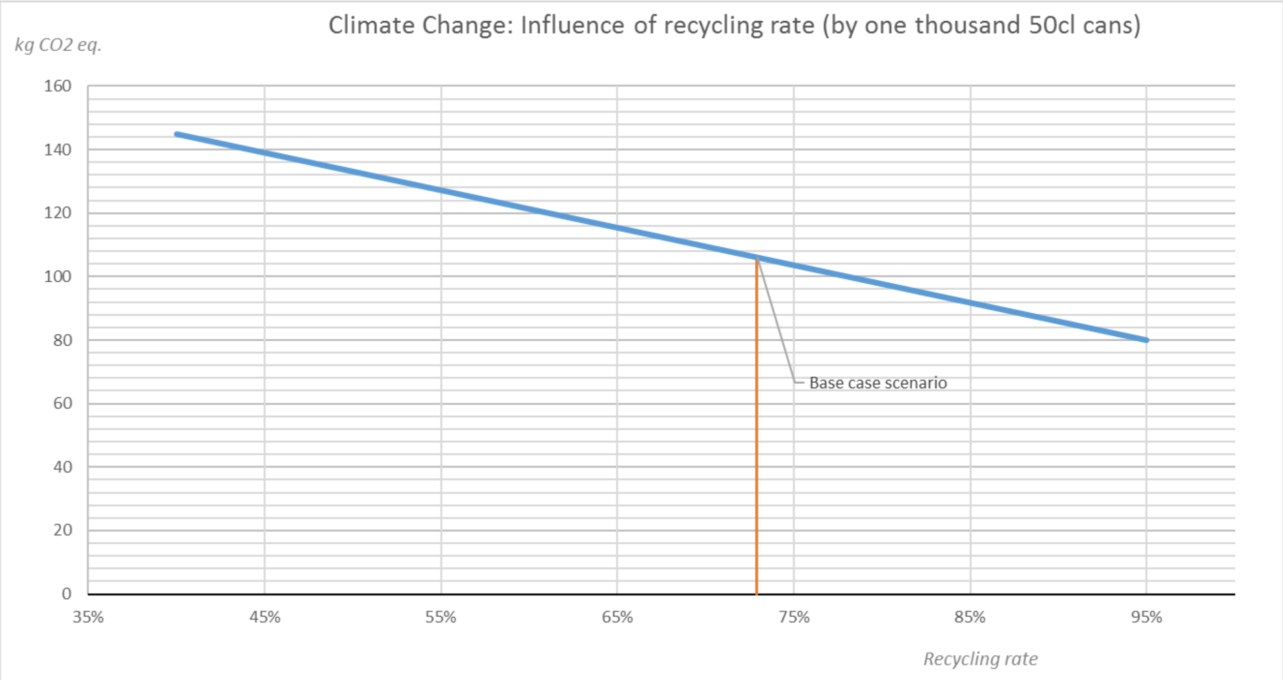

Figure 8: Influence of recycling rate (by one thousand 50cl cans)

V.3.1.2. Resource depletion-mineral, fossil

The influence of the recycling rate is shown in Figure 9, 27 and Figure 11 (for 25, 33 and 50cl respectively), where it can be seen that an increase of the recycling rate allows a decrease of the impact. Inversely, a decrease of the recycling rate is responsible for an increase of the impact.

The reduction of the *Resource depletion-mineral, fossil* impact is not as sharp as for the *climate change* impact. This is because the aluminium production and recycling have a lower contribution to the *Resource depletion-mineral, fossil* than for the *climate change* impact.

Compared to the base case scenario (where the recycling rate is set to 72,9%), an increase of the recycling rate of 1% would allow reducing the Resource depletion-mineral, fossil impact by:

- 0.47% in the case of 25cl cans
- 0.44% in the case of 33cl cans
- 0.41% in the case of 50cl cans

Note: there is not a consistent behaviour of the above percentages compared with the corresponding ones of the climate change impact, as the main contributions are different; the body and end manufacturing contribute more to this impact category than to the climate change category.

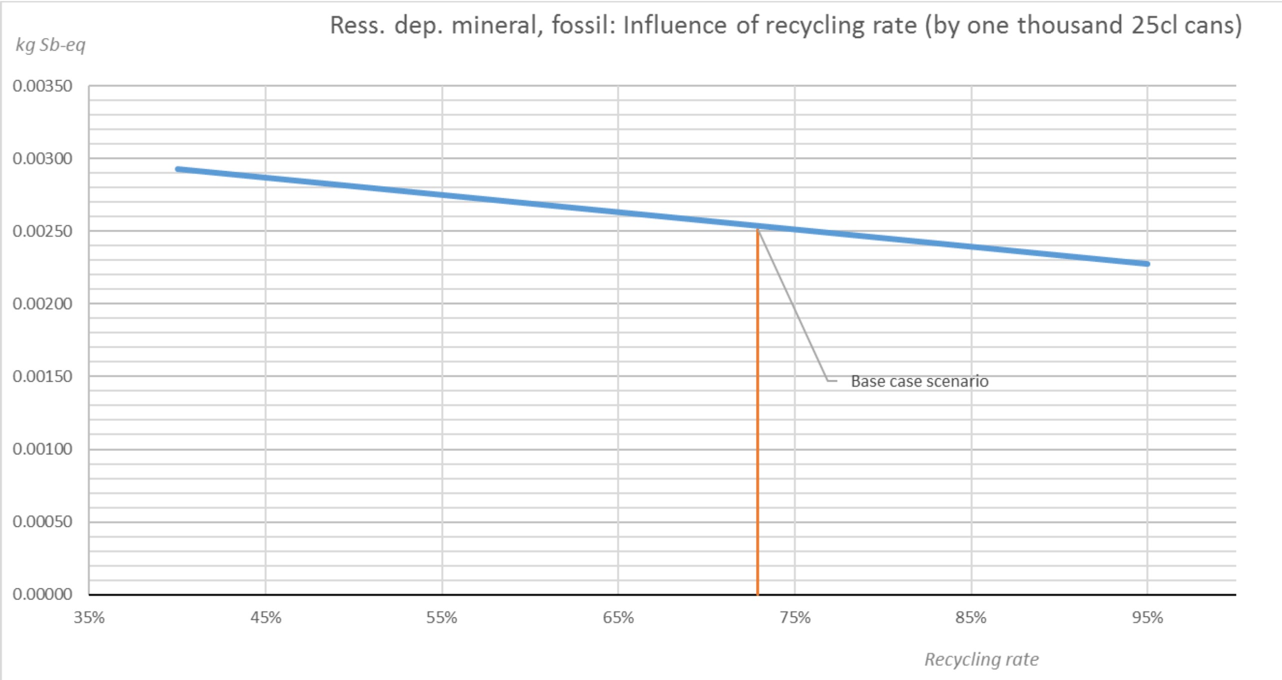

Figure 9: Influence of recycling rate (by one thousand 25cl cans)

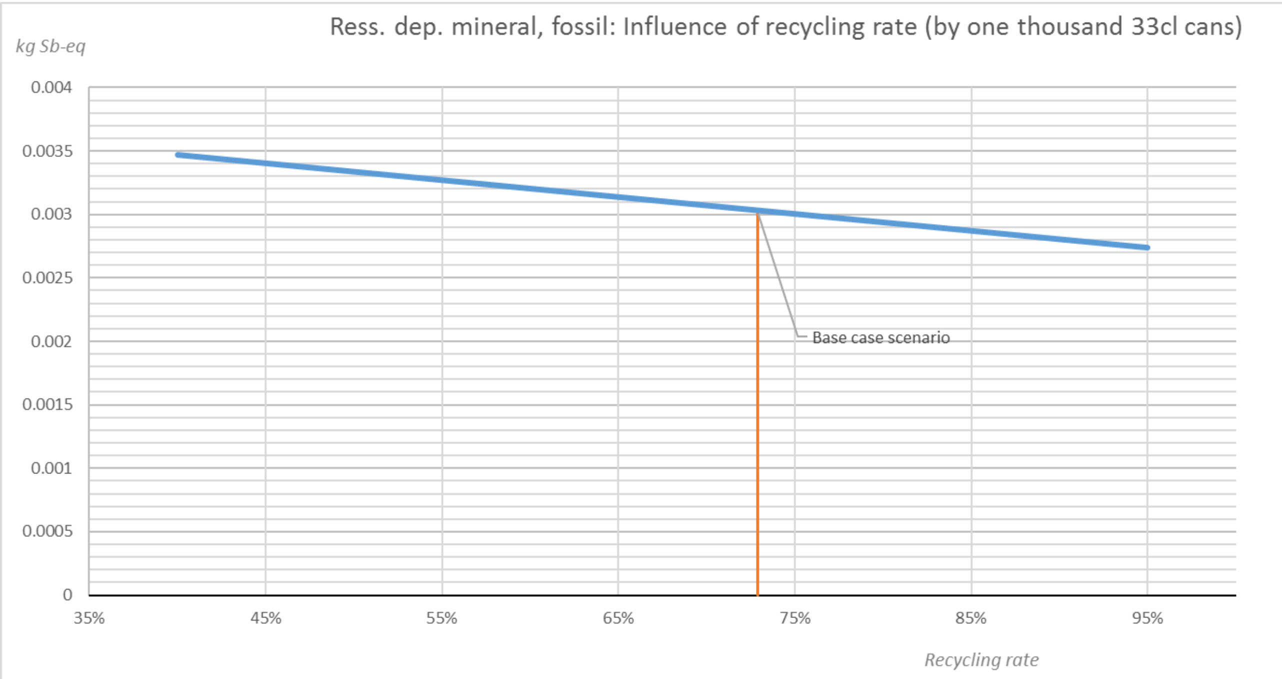

Figure 10: Influence of recycling rate (by one thousand 33cl cans)

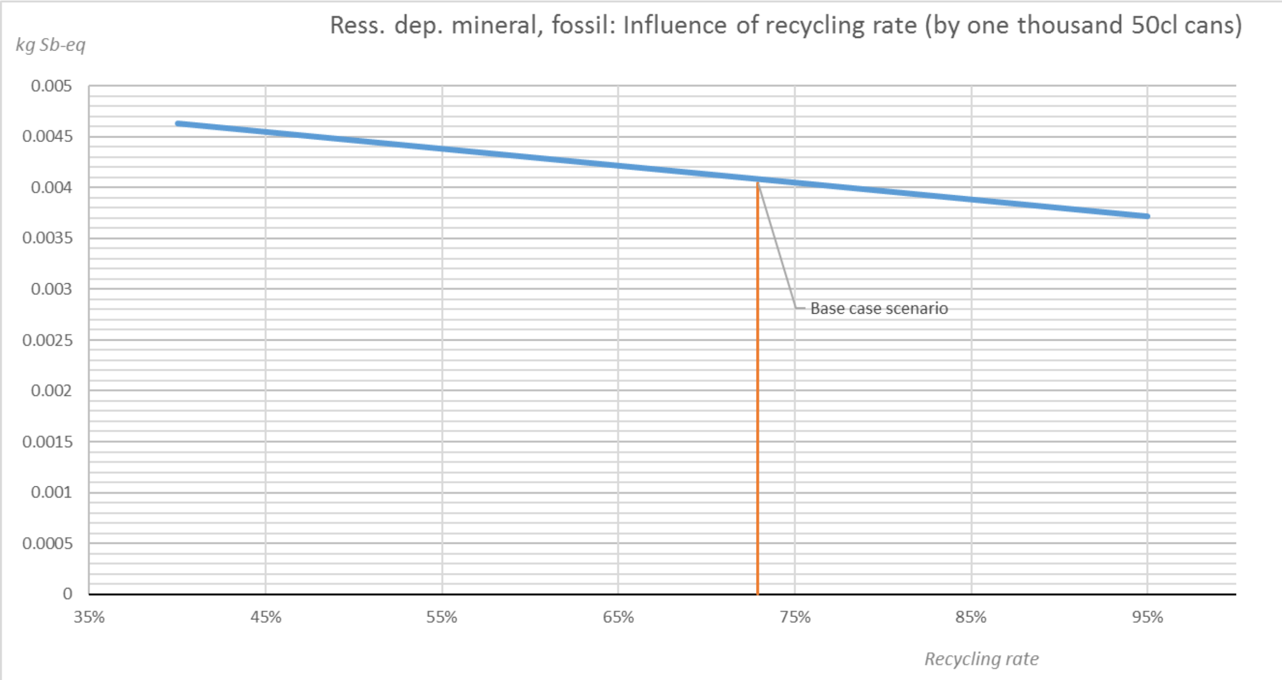

Figure 11: Influence of recycling rate (by one thousand 50cl cans)

V.3.1.3. Resource depletion-water scarcity

The influence of the recycling rate is shown in Figure 12, Figure 13 and Figure 14 (for 25, 33 and 50cl respectively), where it can be seen that an increase of the recycling rate allows a decrease of the environmental impact. Inversely, a decrease of the recycling rate is responsible for an increase of the impact.

In the closed-loop scenario, any percentage increase of the recycling rate avoids producing an equivalent amount of virgin aluminium and therefore decreases the total impact.

Compared to the base case scenario (where the recycling rate is set to 72,9%), an increase of the recycling rate by 1% would allow reducing the water scarcity impact by:

- 1.67% in the case of 25cl cans
- 1.41% in the case of 33cl cans
- 1.44% in the case of 50cl cans

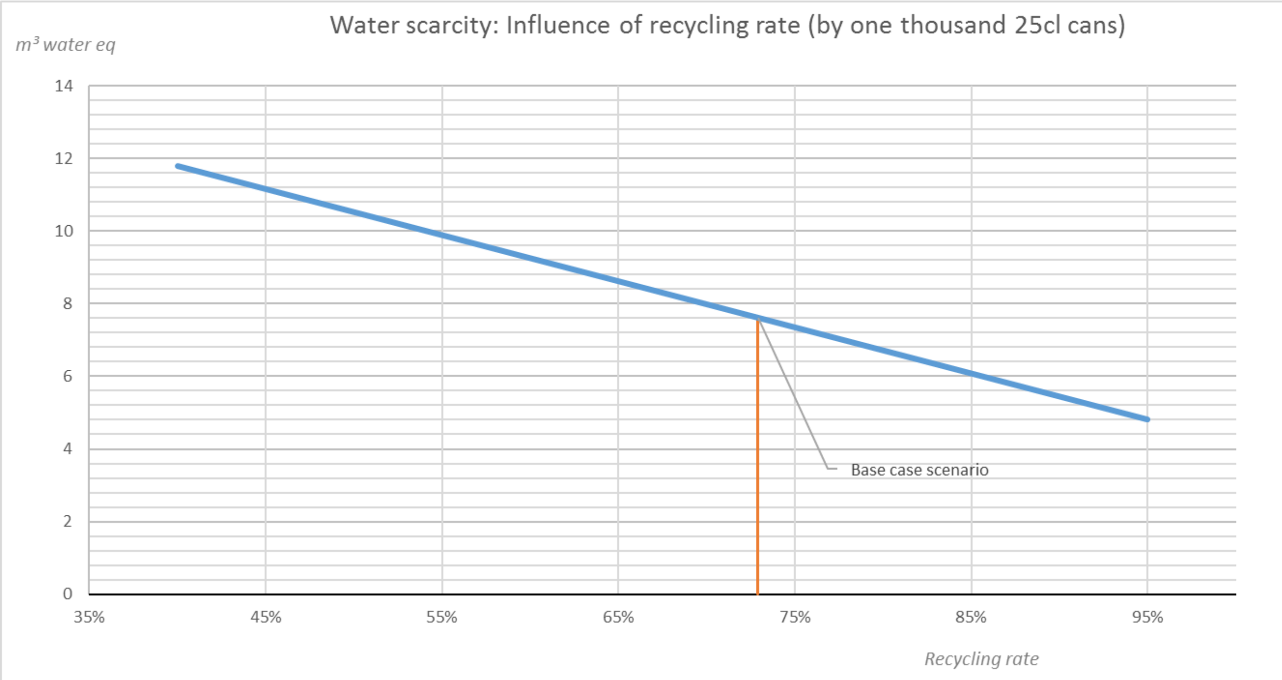

Figure 12:Influence of recycling rate (by one thousand 25cl cans)

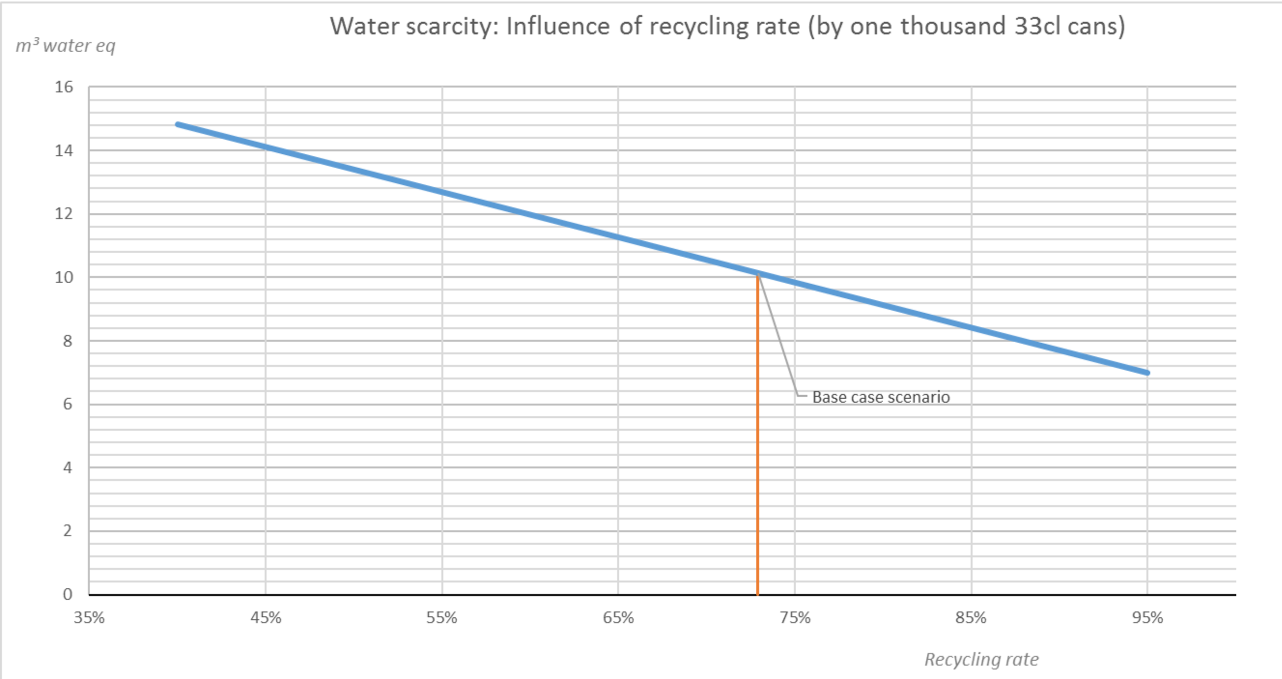

Figure 13: Influence of recycling rate (by one thousand 33cl cans)

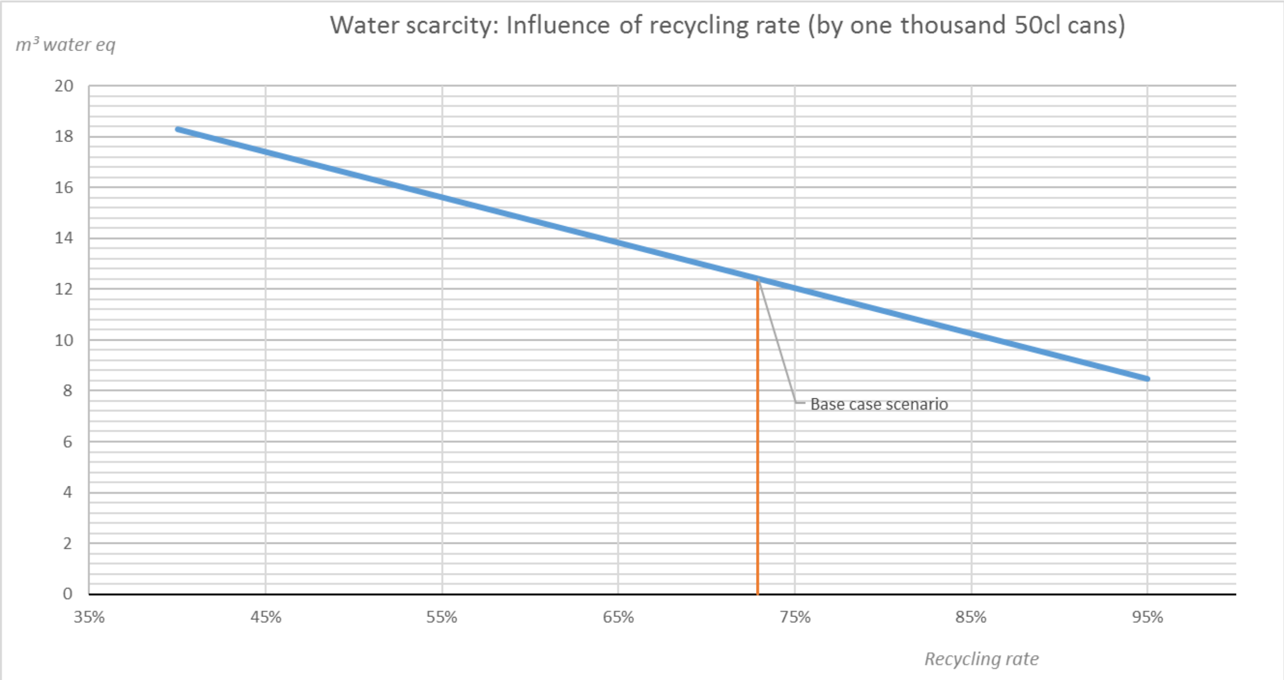

Figure 14: Influence of recycling rate (by one thousand 50cl cans)

V.3.2. Sensitivity analysis: variation of the allocation factor

The purpose of this analysis is to evaluate the influence of the allocation factor on the impact results.

In order to study the influence of the allocation factor, it is assumed that the aluminium is recycled in an open-loop[15]: this is the case of some countries and some aluminium markets for which it is not always possible (for technical, logistic and economic reasons) to recycle used beverage cans into new aluminium sheet for beverage use, and therefore the aluminium is recycled into aluminium sheet for non-beverage application[16].

The formula for End-of-Life modelling is according to Equation 3 (see section 0), where the recycled content (R_1) is set equal to 40% according to the average recycled content of aluminium (not beverage cans specific) as communicated by European Aluminium, and the recycling rate (R_2) remains equal to 72.9%. The allocation factor (A) varies from 0% to 100%, meaning that:

- A=0% corresponds to the so-called "End-of-Life" or "0:100" allocation approach, which is the allocation supported by metals and MPE. This allocation method accounts for the impact of the recycling process at the End-of-Life (i.e. collection, sorting, remelting) in the first life cycle (i.e. the one providing the recyclable

[15] In the closed-loop scenario, there is no need to define the allocation factor.

[16] Source: Metal Packaging Europe

material, such as the used beverage can) as well as for the credit of avoiding an equivalent virgin material production in the next life cycle (i.e. the one incorporating the recycled material) which are calculated proportionally to the recycling rate[17]. Therefore, in this allocation approach, the recycled content does not affect the results.

- A=20% corresponds the "20:80" allocation approach set by the PEF (Product Environmental Footprint) methodology for metals (and other) materials. It means that 80% of the impact of the recycling process and its credit are allocated to the first life cycle, whereas the 20% are allocated to the next one.
- A=50% corresponds to the allocation approach "50:50" set by some LCA methodologies (as well as previously by the PEF). It means that the impact of the recycling process and its credit are equally split between the first life cycle and the next one.
- A=100% corresponds to the so-called "Recycled content" or "100:0" allocation approach. This allocation method considers the recycling process at the End-of-Life of the first life cycle as belonging entirely to the second life cycle (i.e. the one incorporating the recycled material) and accounts for its impact and credit proportionally to the recycled content of the new product, hence reducing the need of virgin material. Therefore, in this allocation approach, the recycling rate does not affect the results.

This sensitivity analysis focuses on the three main impact categories.

V.3.2.1. Climate change

The influence of the allocation factor is shown in Figure 15, Figure 16 and Figure 17 (for 25, 33 and 50 cl respectively), where it can be seen that an increase of the allocation factor is responsible for an increase of the impact because more weight is given to the recycled content of the product in the next life cycle and less to the recycling rate of the product in the current life cycle: as the recycled content is lower than the recycling rate, it follows that the credit decreases by increasing the allocation factor.

As an example, an increase of the allocation factor from 0% to 10% would increase the Climate change impact by:

- 4.4% in the case of 25cl cans
- 4.0% in the case of 33cl cans
- 3.7% in the case of 50cl cans

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[17] Guidance to the use and interpretation of Life Cycle Assessment (LCA) results through the Instant LCA tool – MPE. Version of 23rd August 2018.

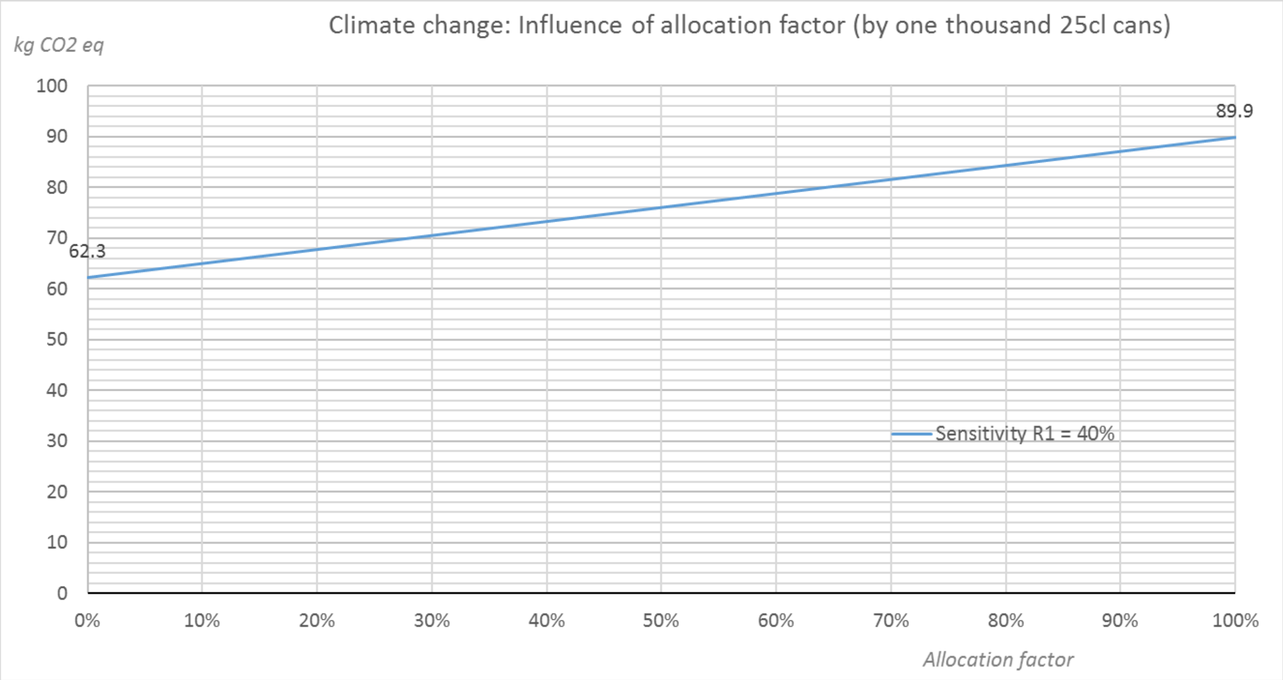

Figure 15: Influence of allocation factor (by one thousand 25cl cans)

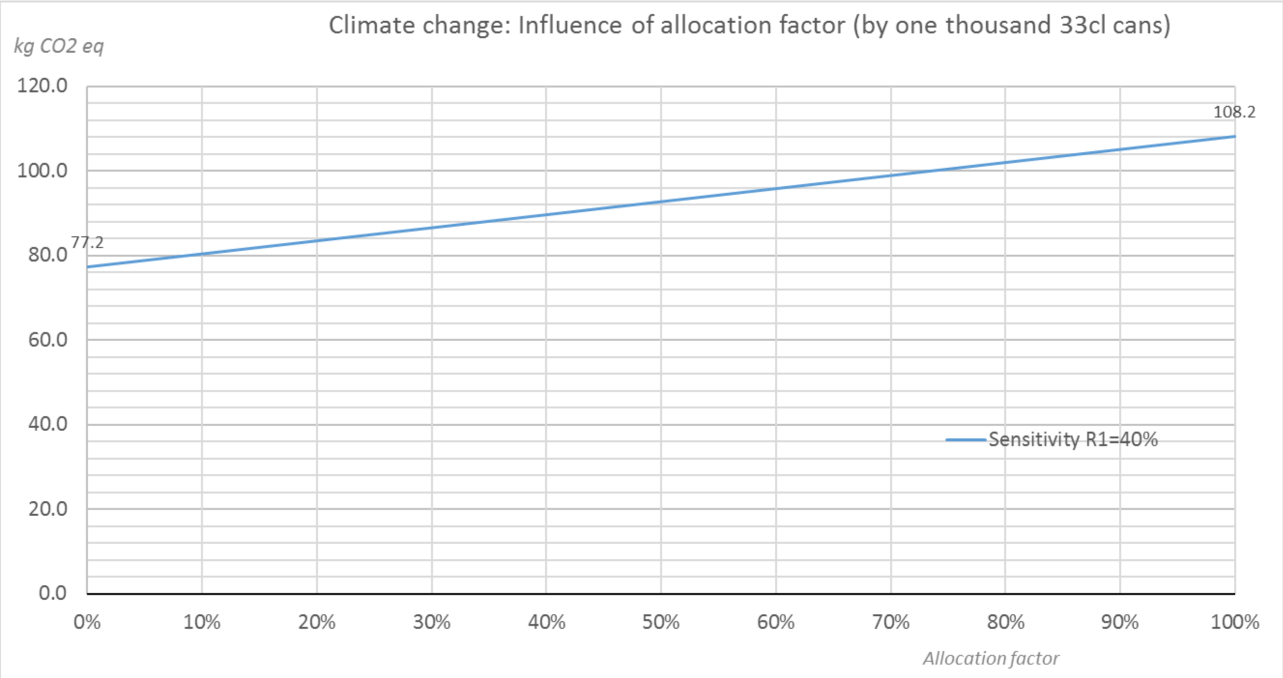

Figure 16:Influence of allocation factor (by one thousand 33cl cans)

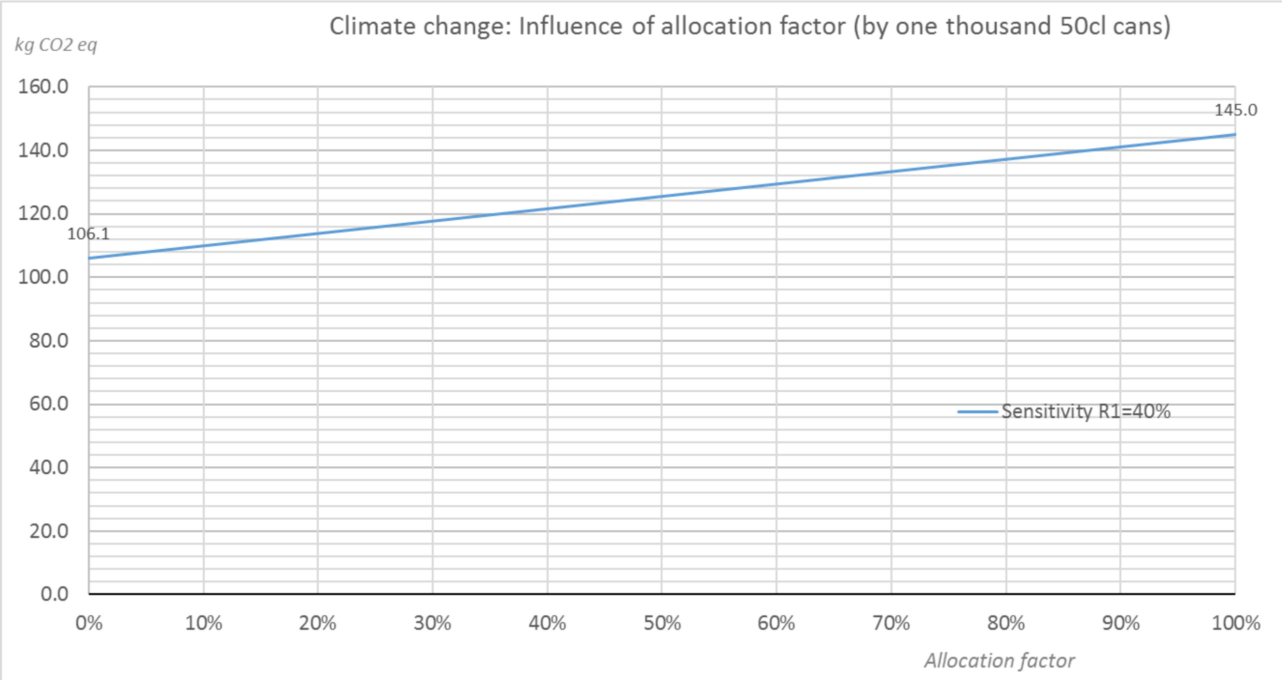

Figure 17: Influence of allocation factor (by one thousand 50cl cans)

V.3.2.2. *Resource depletion-mineral, fossil*

The influence of the allocation factor is shown in Figure 18, Figure 19 and Figure 20 (for 25, 33 and 50 cl respectively), where it can be seen that an increase of the allocation factor is responsible for an increase of the impact as explained in the previous paragraph for Climate change.

As an example, an increase of the allocation factor from 0% to 10% would increase the Resource depletion-mineral, fossil impact by:

- 1.6% in the case of 25cl cans
- 1.5% in the case of 33cl cans
- 1.3% in the case of 50cl cans

As for the previous sensitivity analysis, this increase is not as sharped as the increase for climate change because the aluminium production and recycling have a lower contribution to the Resource depletion-mineral, fossil than to the Climate change impact.

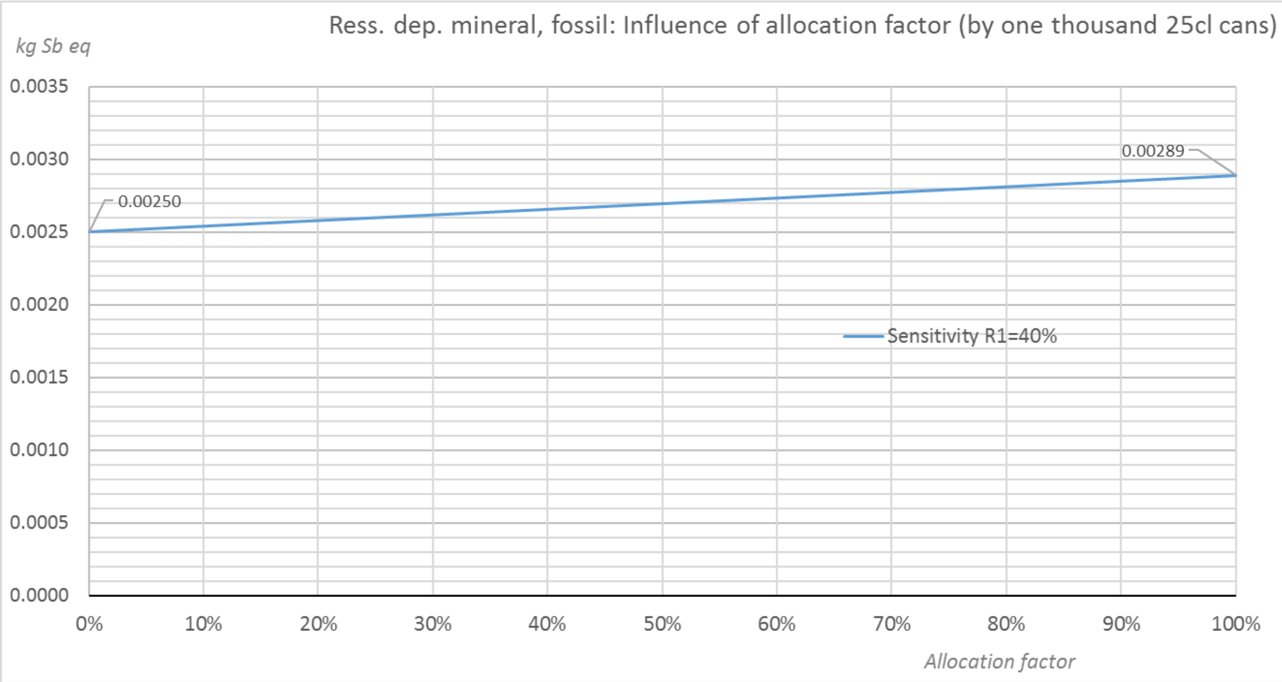

Figure 18: Influence of allocation factor (by one thousand 25cl cans)

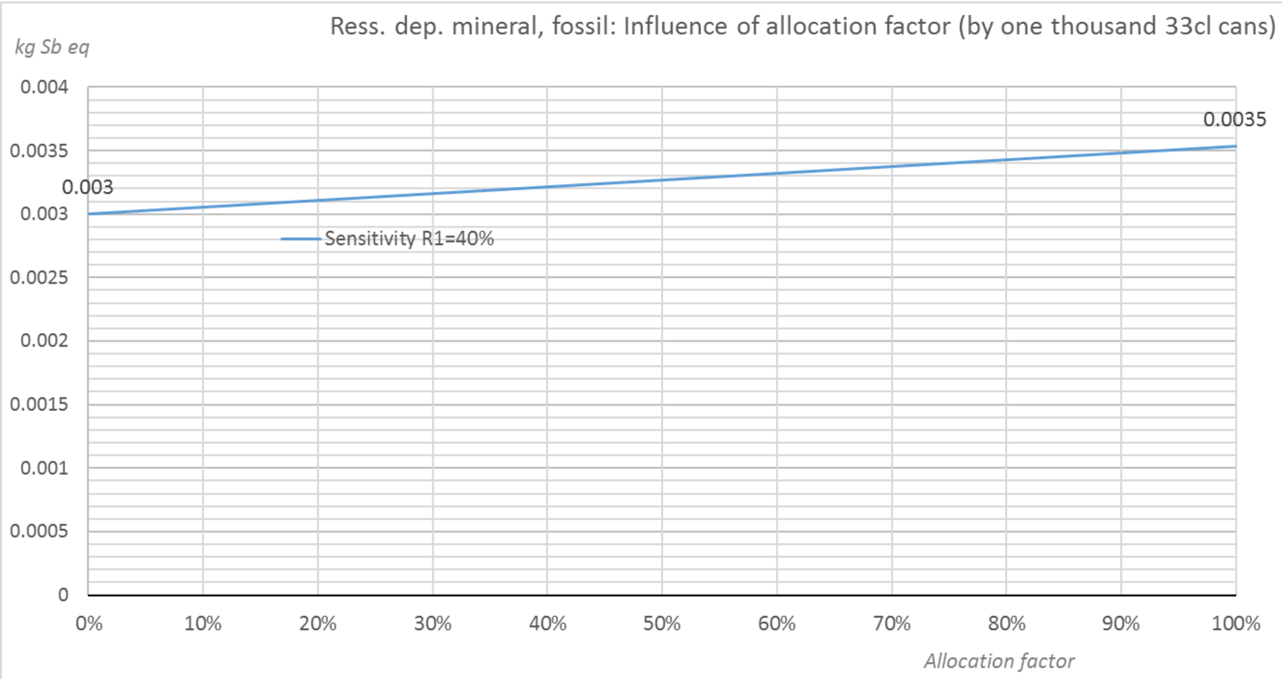

Figure 19: Influence of allocation factor (by one thousand 33cl cans)

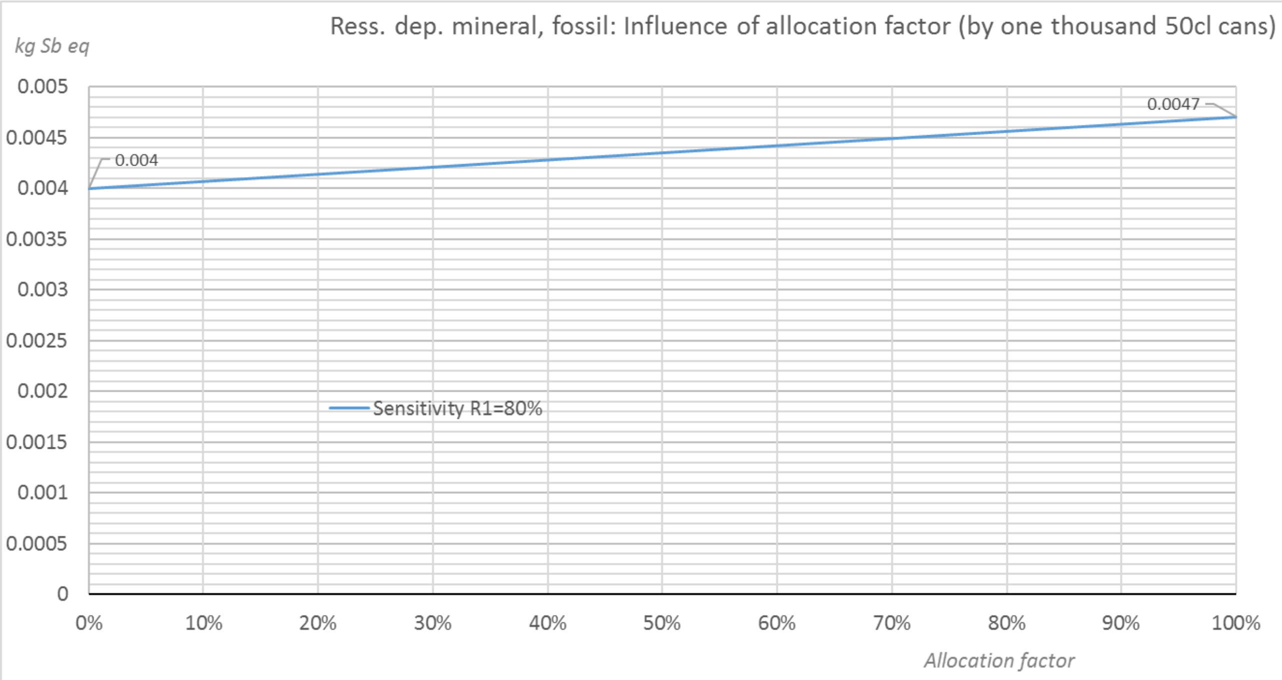

Figure 20: Influence of allocation factor (by one thousand 50cl cans)

V.3.2.3. *Resource depletion – water scarcity*

The influence of the allocation factor is shown in Figure 21, Figure 22 and Figure 23 (for 25, 33 and 50 cl respectively), where it can be seen that an increase of the allocation factor is responsible for an increase of the impact as explained in the previous paragraph for Climate change.

As an example, an increase of the allocation factor from 0% to 10% would increase the Resource depletion - water impact by:

- 5.5% in the case of 25cl cans
- 4.6% in the case of 33cl cans
- 4.7% in the case of 50cl cans

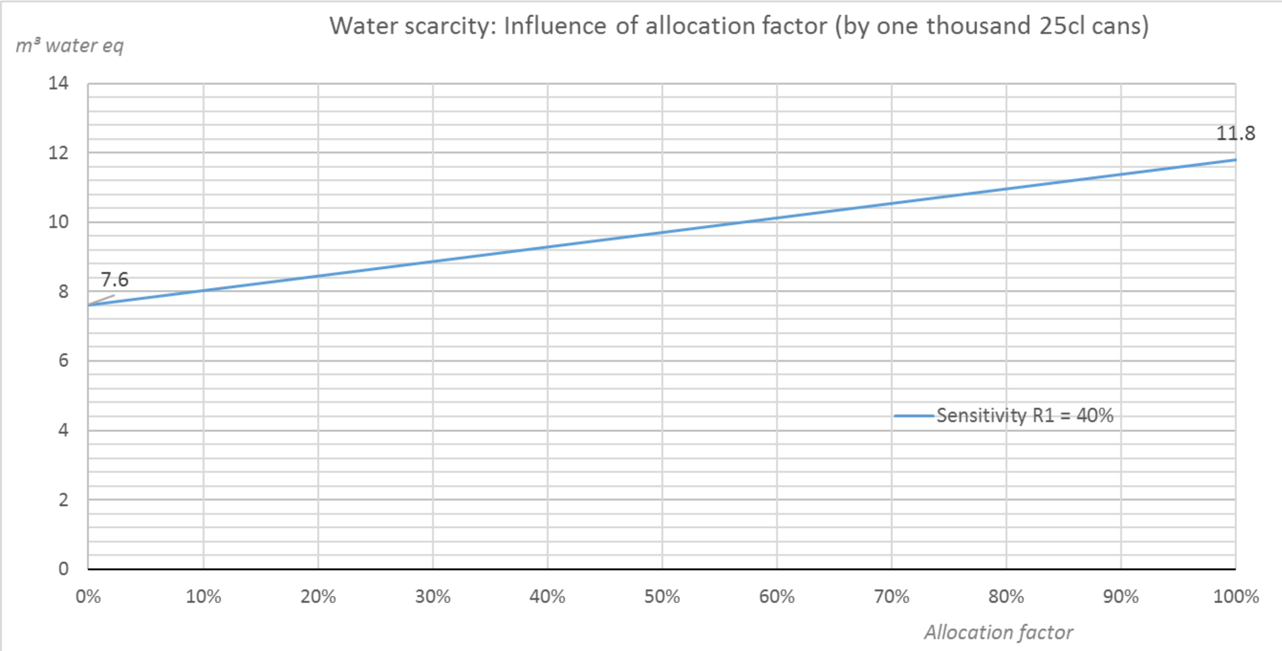

Figure 21: Influence of allocation factor (by one thousand 25cl cans)

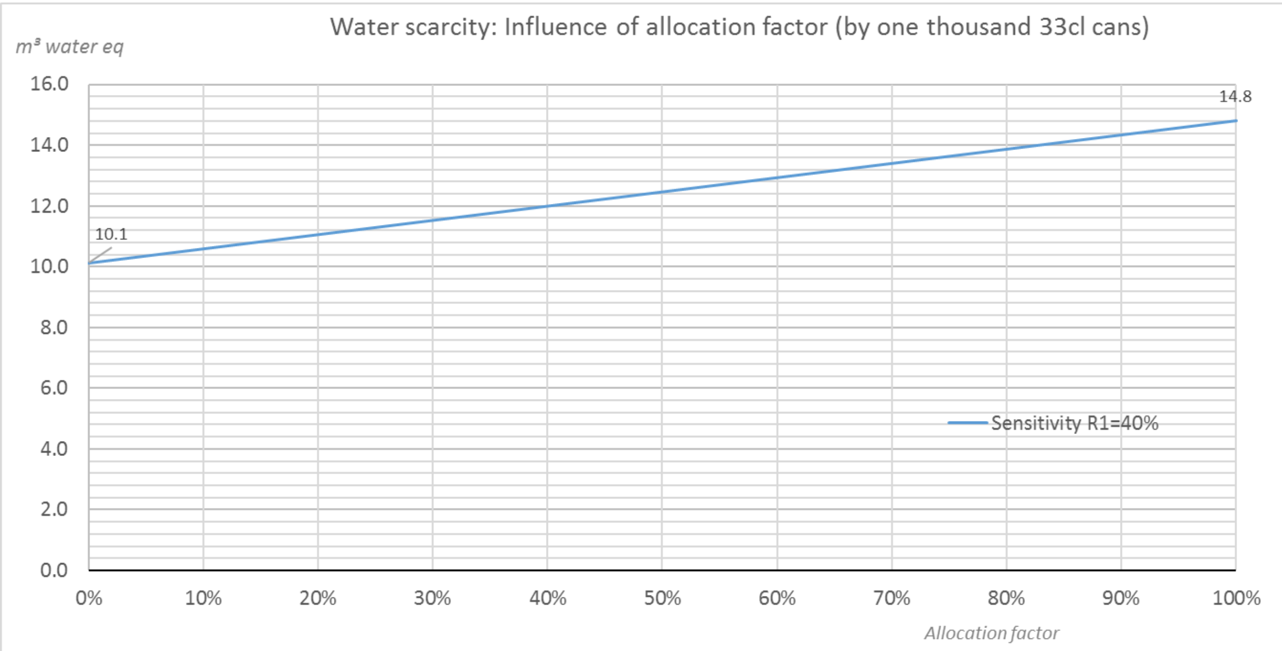

Figure 22: Influence of allocation factor (by one thousand 33cl cans)

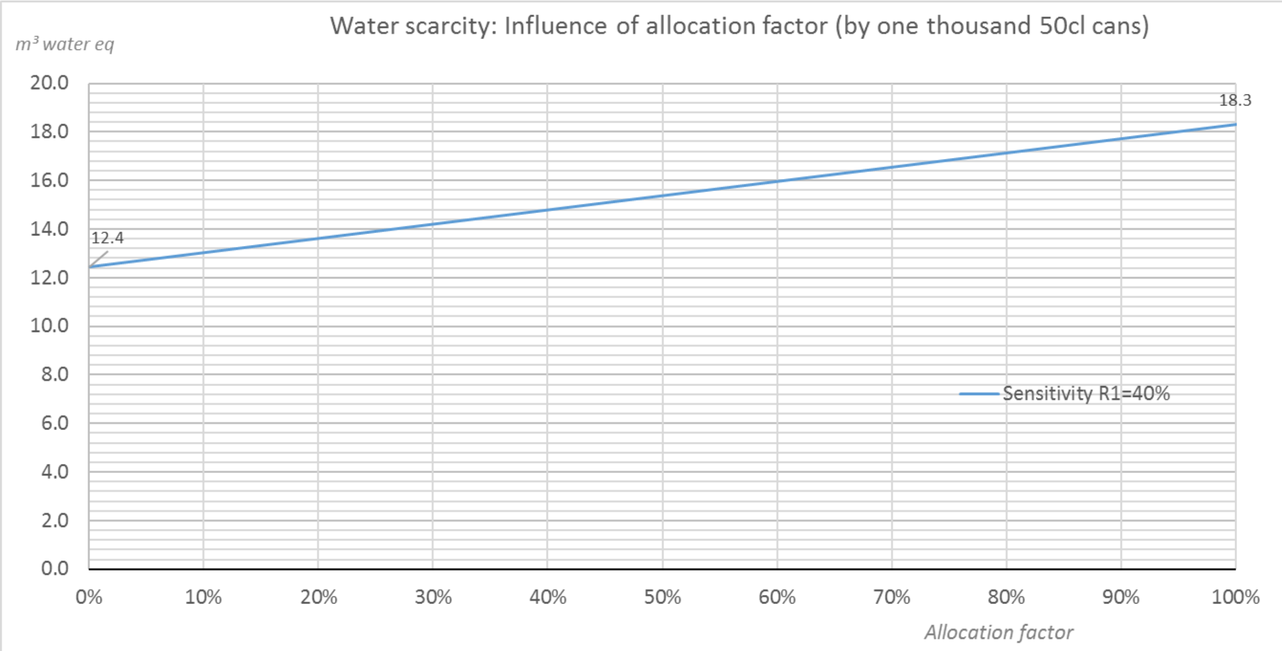

Figure 23: Influence of allocation factor (by one thousand 50cl cans)

V.3.3. Sensitivity analysis: variation of the recycled content

The purpose of the analysis is to evaluate the influence of the recycled content (R_1) of aluminium on the impact results.

As for the previous sensitivity analysis, it is assumed that the aluminium beverage cans are recycled in an open-loop and the recycled content (R_1) varies from 40% to 60% and 80% whereas the allocation factor also varies from 0% to 100%. The recycling rate remains equal to 72.9%.

The formula for End-of-Life modelling is according to Equation 3 (see section 0).

This sensitivity analysis focuses on the three main impact categories.

Regarding the results of this section, it should be noted that:

- The variation of the allocation factor from 0% to 100% corresponds to transfer the recycling credits from the End-of-Life stage of the current life cycle (i.e. the recycler) to the production stage of the next life cycle (i.e. the incorporator).
- The variation of results, observed in the figures hereunder, depends on whether the credits are calculated at the production or at the end-of-life stage because of different recycling rate and recycled content):
  - The recycling credit at the end-of-life depends on the recycling rate (R_2): the higher is the recycling rate, the higher would be the credit.
  - The recycling credit at the production stage depends on the recycled content (R_1): the higher is the recycled content, the higher is the credit.
  - When the recycled content is equal to the recycling rate, according to the equation 1, the allocation factor does not influence the results.

- **When the recycling rate (R_2 = 72.9%) is lower than the recycled content (R_1 = 80%)**, by increasing the allocation factor more credits are transferred to the production stage and consequentially the total impact decreases. The grey line decreases.
- **When the recycling rate (R_2 = 72.9%) is higher than the recycled content (R_1 = 40% and 60%)**, by increasing the allocation factor less credits are transferred to the production stage and consequentially the total impact increases. The blue and the orange lines increase.

V.3.3.1. Climate change

The combined influences of the allocation factor and recycled content is shown in Figure 18, Figure 19 and Figure 20 (for 25, 33 and 50cl respectively). The results vary in conformity with what is explained in section V.3.3.

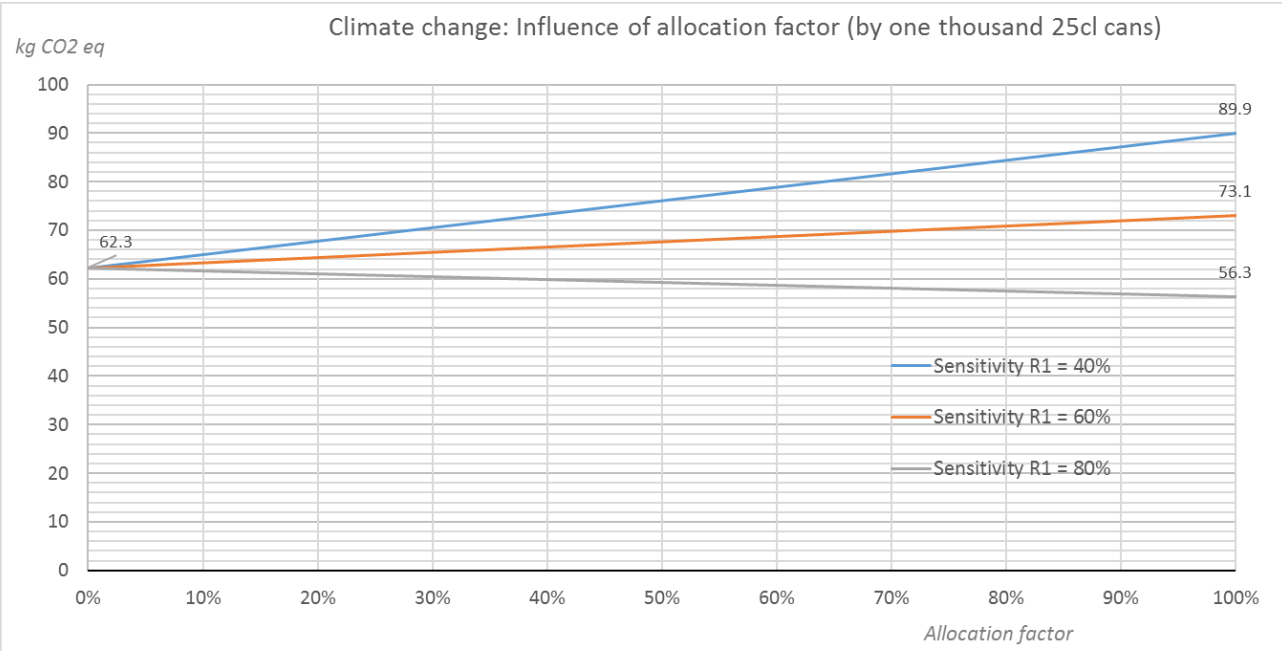

Figure 24: Influence of allocation factor and recycled content (by one thousand 25cl cans)

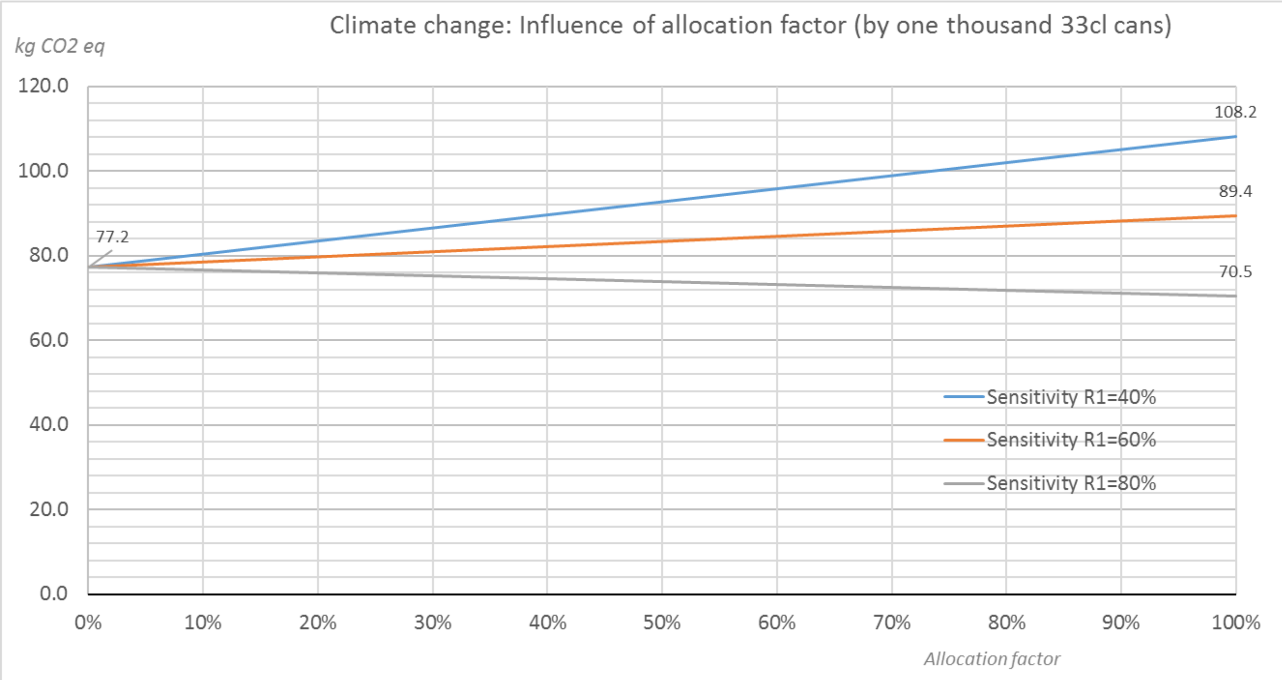

Figure 25: Influence of allocation factor and recycled content (by one thousand 33cl cans)

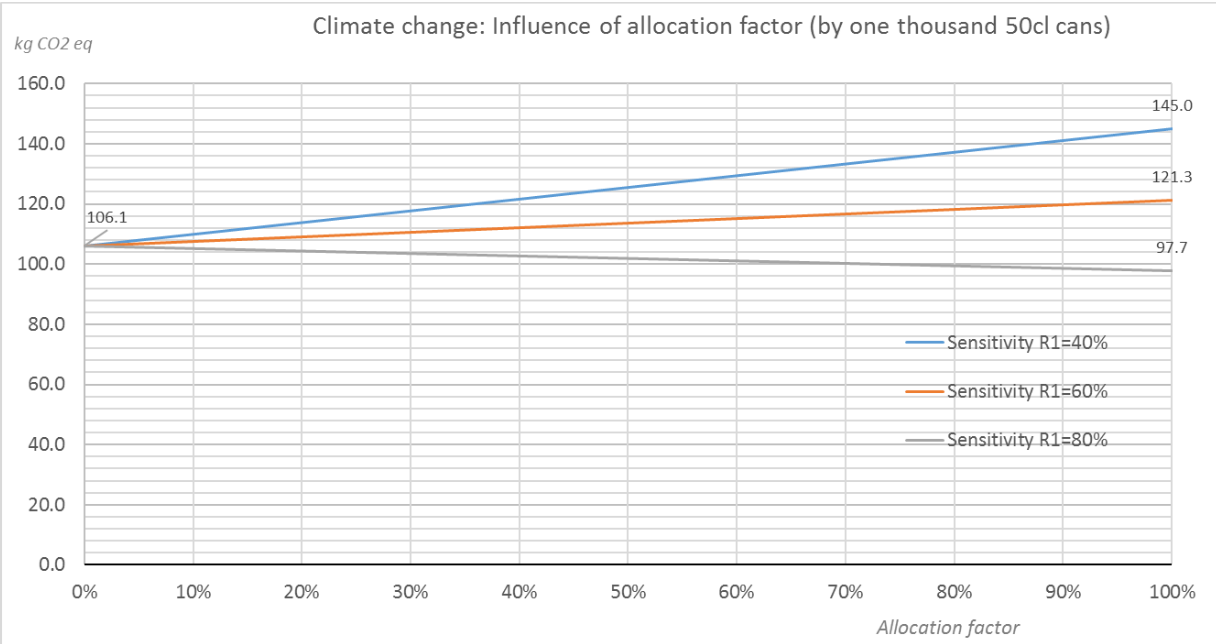

Figure 26: Influence of allocation factor and recycled content (by one thousand 50cl cans)

V.3.3.2. Resource depletion-mineral, fossil

The combined influences of the allocation factor and recycled content is shown in Figure 27, Figure 28, and Figure 29 (for 25, 33 and 50cl respectively). The results vary in conformity with what is explained in section V.3.3.

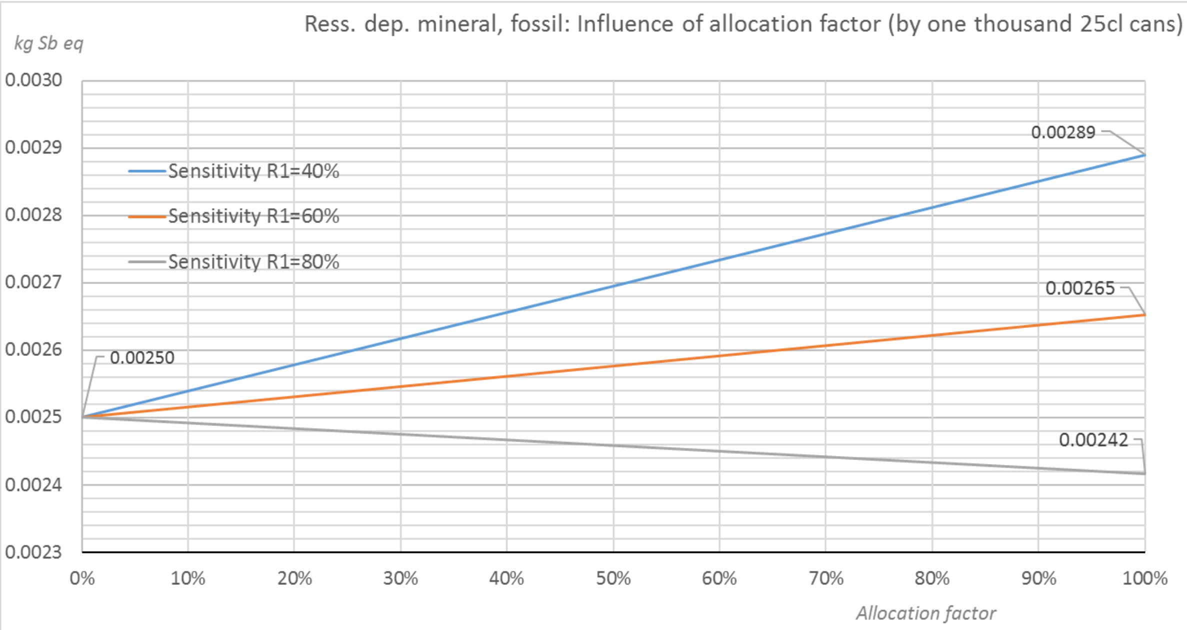

Figure 27: Influence of allocation factor and recycled content (by one thousand 25cl cans)

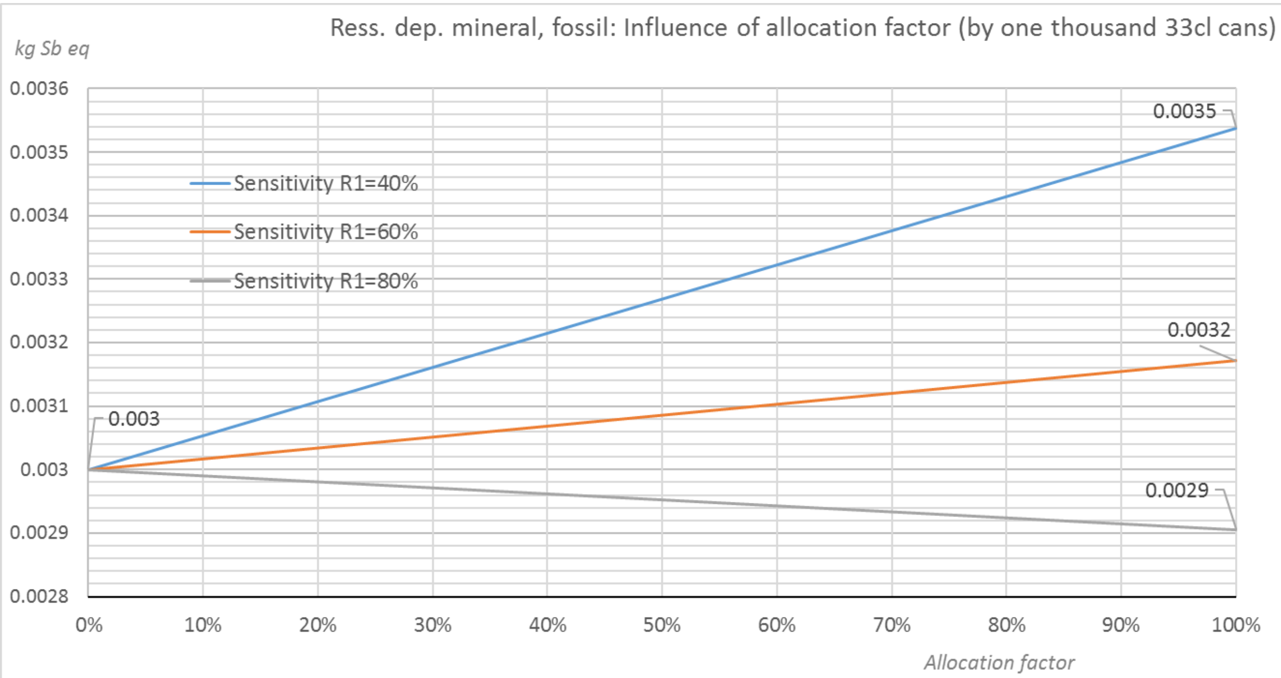

Figure 28: Influence of allocation factor and recycled content (by one thousand 33cl cans)

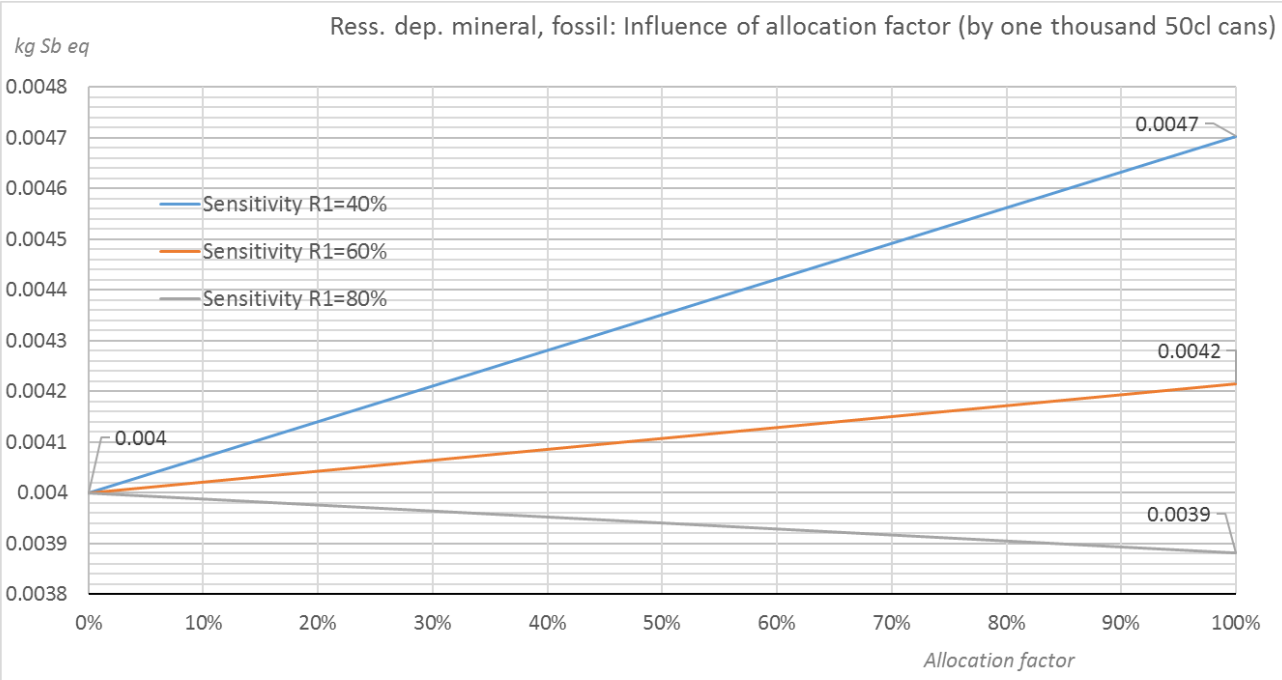

Figure 29: Influence of allocation factor and recycled content (by one thousand 50cl cans)

V.3.3.3. Resource depletion - water

The combined influences of the allocation factor and recycled content is shown in Figure 30, Figure 31 and Figure 32 (for 25, 33 and 50cl respectively). The results vary in conformity with what is explained in section V.3.3.

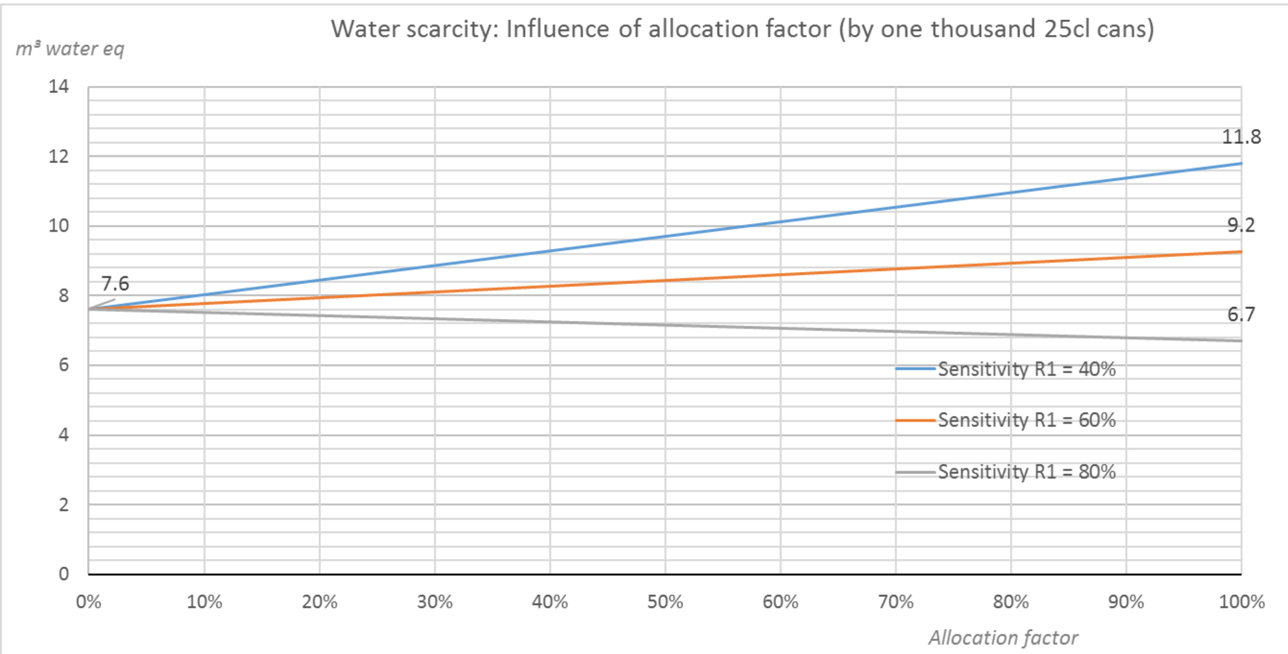

Figure 30: Influence of allocation factor and recycled content (by one thousand 25cl cans)

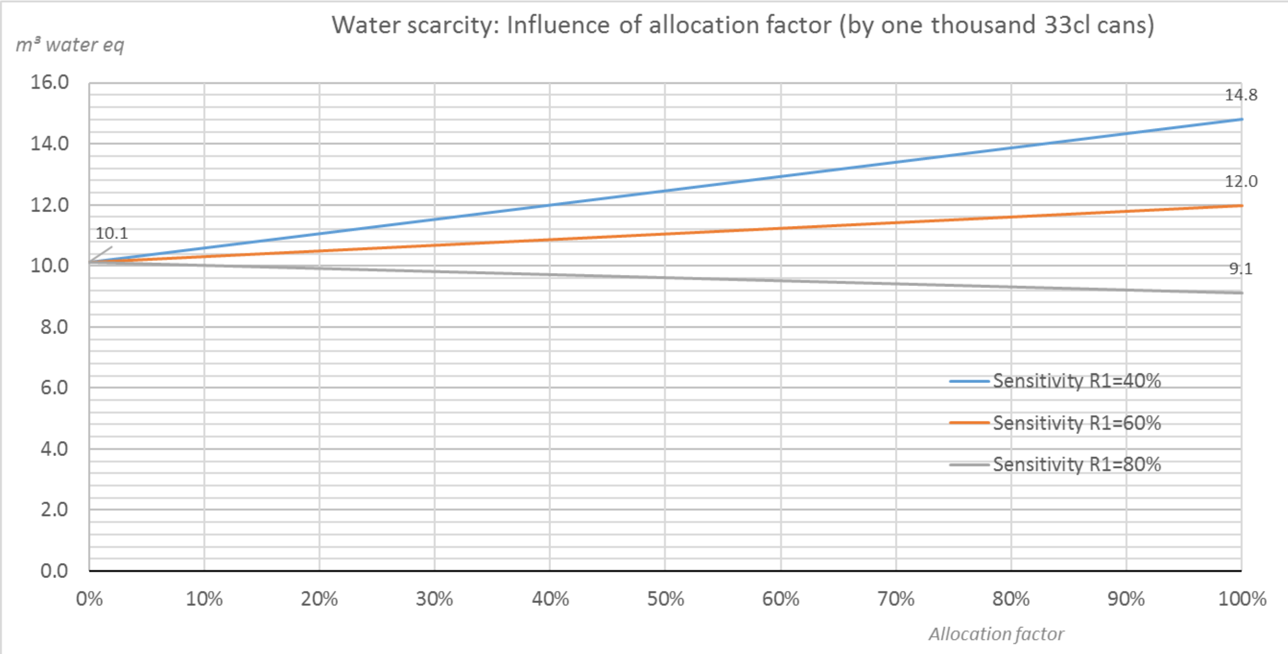

Figure 31: Influence of allocation factor and recycled content (by one thousand 33cl cans)

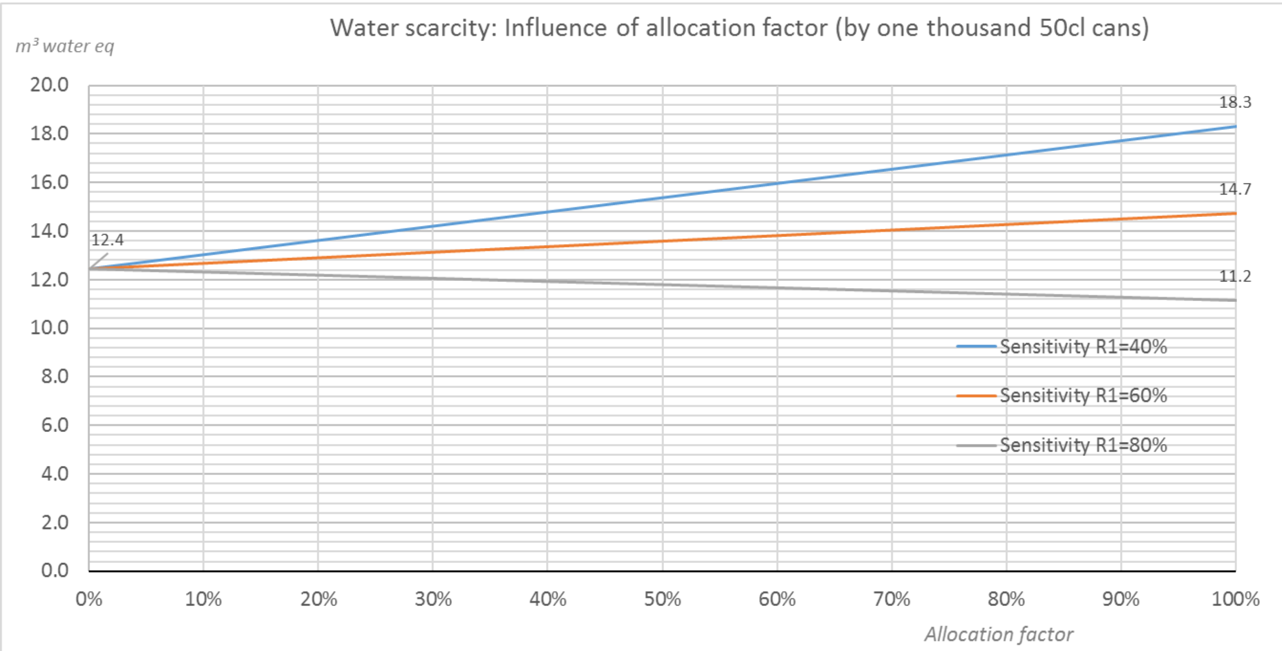

Figure 32: Influence of allocation factor and recycled content (by one thousand 50cl cans)

V.3.4. Sensitivity analysis: yearly improvement

V.3.4.1. Context and limitations

The environmental results of the LCA study on aluminium beverage cans, carried out by Thinkstep (former PE International) in 2009 for BCME/European Aluminium/APEAL[18], cannot be compared with the current one due to methodological differences such as the impact categories and the inclusion of beer in the system boundary of the previous study.

Therefore, the purpose of this sensitivity analysis is to evaluate the environmental effect of the technical improvements made by the metal packaging industry over the last 10 years (referring to the production years 2006 – 2016) from an LCA perspective.

The most relevant improvements of the metal packaging industry focus on the following aspects:

- Weight of the beverage cans (both body and end)
- Weight of other materials (coating, lacquers, inks and sealing)
- Can manufacturing (electricity, thermal and water consumptions, scrap rate)
- Aluminium production
- Used beverage cans recycling rate

The sources of data used for the analysis are listed in the table below.

Table 13 Sources of the most relevant data for 2007 and 2017 scenarios

Parameters	Scenario 1: 2006	Scenario 2: 2016
Weight, composition and manufacturing of the cans	Data collected by PE International and provided by the can makers for 2006[19]	Data collected for the present study
Background dataset for aluminium production	European Aluminium 2005	European Aluminium 2015
Recycling rate	Data published by European Aluminium in 2007	Data published by European Aluminium in 2018
All the other parameters and datasets	Data and datasets taken from the present study	

It must be noted that the companies involved in the data collection for 2006 are not the same ones that participated in the present study: in the previous study, data were provided by Ball Packaging Europe, REXAM and Crown (which at that time represented about 80% of the European market for beverage cans[19]) whereas in the present study data were collected from Ball Packaging Europe, Crown and Ardagh Group.

[18] BCME, EAA, APEAL, PE International, Life Cycle Inventory and impact Analysis for Beverage Cans, 2009

It also must be noted that in order to ensure confidentiality of collected data as described at paragraph IV.1.1, MPE was not involved in any data collection - neither for the previous study nor for the current one - therefore MPE is not aware if any can beverage plant participated in both studies.

V.3.4.2. Data used for 2006 and 2016 scenarios

The raw data for 2006, as provided by Thinkstep to MPE, refer to the same size of the cans of the present study and are expressed per kg as well as per 1000 units.

Data comparison between 2006 and 2016 scenarios: the difference is due to the improvements made by the metal packaging industry, however it cannot be excluded that the different scopes or other factors (e.g. data collection modality, data definition, etc.) of the studies may have an influence. MPE is not able to provide a deeper analysis of the data discrepancy since MPE was not involved in any data collection - neither for the previous study nor for the current one.

V.3.4.3. Environmental results of the life cycle of the cans

The analysis is provided for the base-case scenario of closed-loop (which corresponds to the open-loop scenario with A=0%). The environmental results refer to the life cycle of the cans as described in paragraph II.2.4.

The table below shows that the environmental impacts have been reduced for all indicators and for each size of the cans. This is due to the combined effect of:

- A lower environmental impact of the aluminium production
- A lower weight of the body and the end of the can
- A lower energetic consumption of the can manufacturing
- A higher recycling rate at the end-of-life

Table 14 Environmental impacts between 2006 and 2016 scenarios per size of the cans

Indicators	Unit	25 cl can		33 cl can		50 cl can	
		2006	2016	2006	2016	2006	2016
Climate change	kg CO2 eq.	94.8	62.3	115.4	77.2	145.1	106.1
Eutrophication terrestrial	Moles N eq.	1.17	0.58	1.60	0.72	1.97	0.95
Ecotoxicity freshwater	CTU	422.1	311.4	588.3	461.5	903.1	777.1
Land use	Mass deficit of Soil Organic Carbon	88.8	80.8	113.9	100.5	151.5	139.3
Ionizing radiation	kg U235 eq.	3.3E-04	4.1E-05	4.0E-04	4.8E-05	4.9E-04	6.1E-05
Toxicity human	CTU	2.3E-06	1.2E-06	2.9E-06	1.6E-06	3.6E-06	2.3E-06
Eutrophication freshwater	kg P eq.	2.8E-03	9.1E-04	3.3E-03	1.2E-03	3.8E-03	1.5E-03
Acidification	Moles H+ eq.	0.495	0.261	0.643	0.317	0.800	0.425
Respiratory inorganics	kg PM2.5 eq.	0.028	0.020	0.036	0.024	0.047	0.034
Stratospheric ozone depletion	kg CFC11 eq.	5.6E-06	3.1E-06	6.6E-06	4.0E-06	8.1E-06	5.6E-06
Photochemical ozone formation	Mass C2H4 eq.	0.161	0.104	0.202	0.124	0.257	0.166
Eutrophication marine	kg N eq.	0.051	0.031	0.064	0.036	0.079	0.047
Abiotic resource depletion	kg Sb eq.	3.9E-03	2.5E-03	4.9E-03	3.0E-03	6.3E-03	4.0E-03
Water scarcity	m3 water eq.	10.5	7.6	13.6	10.1	16.5	12.4

The following charts show the percentage of reduction for each format and impact category.

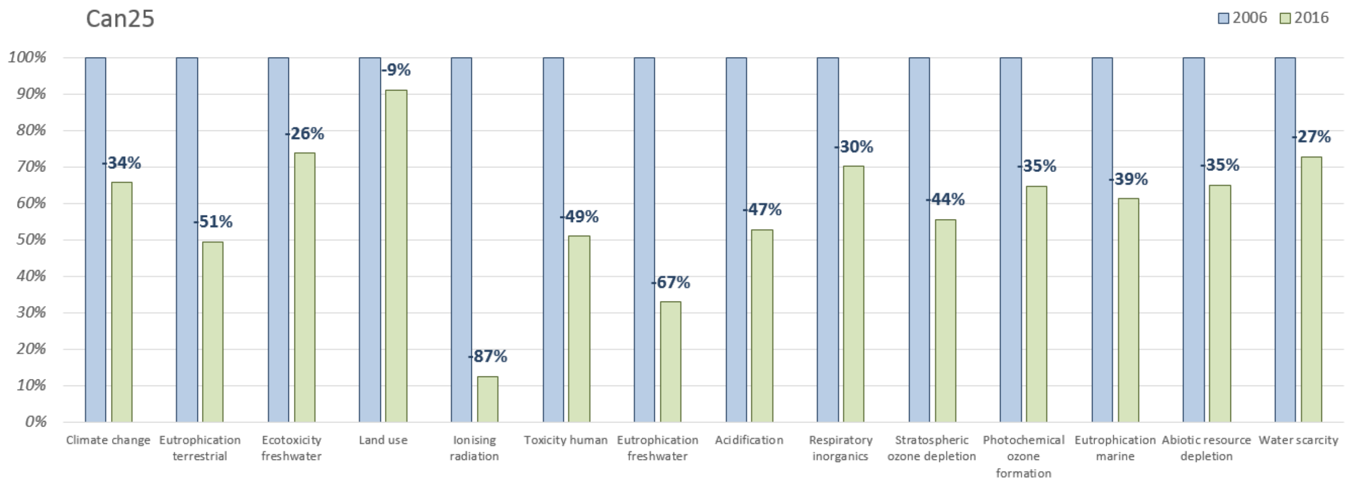

Figure 33 Environmental impacts reduction between 2006 and 2016 scenarios for 25 cl can

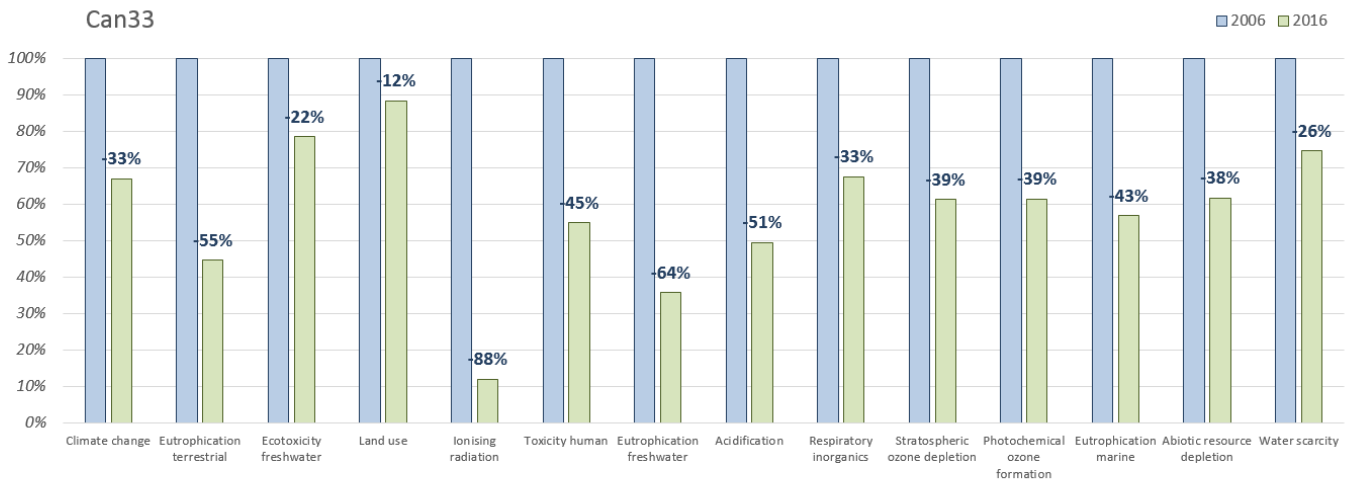

Figure 34 Environmental impacts reduction between 2006 and 2016 scenarios for 33 cl can

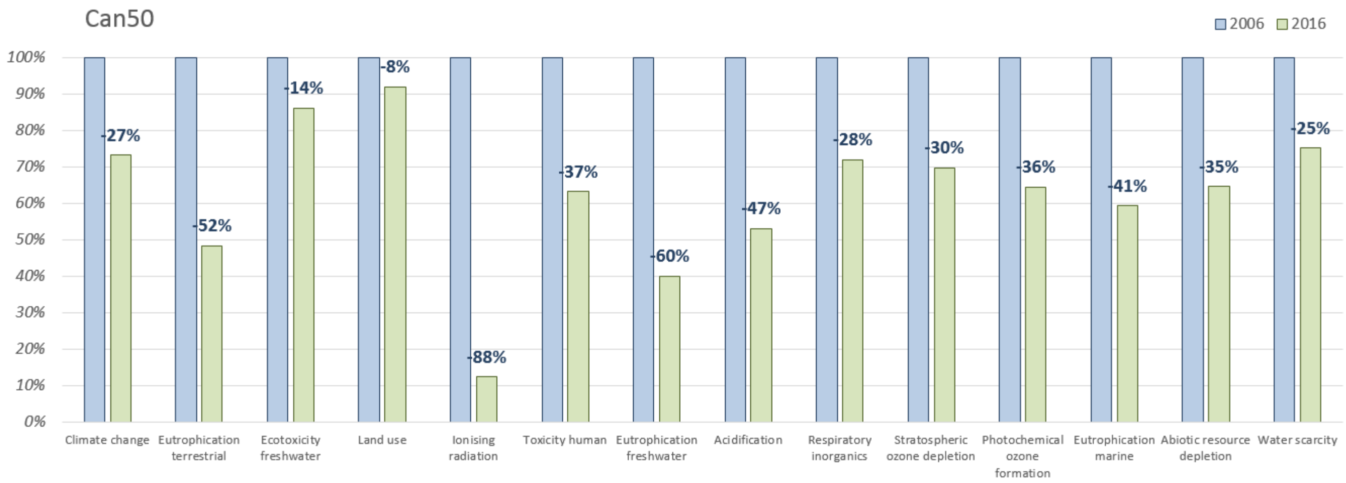

Figure 35 Environmental impacts reduction between 2006 and 2016 scenarios for 50 cl can

V.3.4.4. Detailed analysis for 33 cl can on Climate Change

For the 33 cl can, the improvements made from 2006 to 2016 show a reduction of 33% on the total impact of climate change, as detailed in the table below.

Life Cycle stage	Difference	Contribution to total difference
Aluminium production	-12%	*38.7%*
Other raw materials production	+1%	*0.4%*
Body manufacturing	-35%	*18.5%*
End manufacturing	-2%	*0.1%*
Transport to fillers	-3%	*0.6%*
EoL - Pre-consumer aluminium scrap	-8%	*0.5%*
EoL - Post-consumer aluminium	30%	*41.2%*
Total	**-33%**	*100%*

Table 15 Detailed climate change impact per life cycle stages – 33 cl can

The impact reduction of the **aluminium production** is 12% due to:

- Reduction of the aluminium production (per kg of aluminium): -2.9%
- Reduction of aluminium weight for body production: -3%
- Reduction of aluminium weight for end production: -6.3%

The impact of the **Other raw materials production** raises by 1%. This stage includes the production of secondary packaging, which is identical in both scenarios, and the production of solvent, ink and coating. The small variation comes from the increased consumption in 2016 compared to 2006. It has a very low influence on the results.

The **manufacturing stage** shows the higher reduction of impact with -35%. This is explained by the reduciton of electricity (-30%) and heat (-43%) consumptions.

The **transport to the fillers** shows a slightly lower impact (-3%) due to the mass reduction of the cans.

The **end-of-life** stage shows a greater credit (+30%). Two effects are opposed here: the higher recycling rate (from 50% to 73%) tends to increase the environmental credit, however the lower environmental impact to produce virgin aluminium reduces the avoided impact and overall the credit. The effect of the improved recycling rate is much higher than the effect of the improved aluminium production, which confirms the increase of recycling credit.

V.3.4.5. Contribution to the impact reduction per life cycle stage

On climate change per size of the cans

As seen above for the 33cl can (see column "Contribution to total difference" in Table 15), the life cycle stages have different contribution to the total reduction of impact.

Differences can be observed between the 33cl can and the 25cl format:

- The contribution of the aluminium production is the lowest for the 25cl can. This is explained by the lowest weight reduction (-1.6% for 25cl can versus -3.8% and -3.2% respectively for 33cl and 50cl can).
- This is compensated by the higher contribution of the manufacturing stage mainly due to the highest reduction of thermal energy consumption: -75% for the 25cl cans (versus -40% for 33cl and -14% for 50cl can).
- Those effects compensate each other to provide a total impact reduction (-34%) almost equivalent to the one observed for the 33cl can (-33%).

Differences can be observed between the 50cl can:

- The contribution of the aluminium production is relevant. This is explained by high weight reduction (-3.2%) almost equivalent to the 33cl (-3.8%).
- The contribution of the manufacturing stage is lower than the ones of the two smaller formats. This is explained by the low reduction of electricity and thermal energy consumptions for this format (-6% and -14% respectively).
- The total impact reduction for the 50cl can (-27%) is the lowest observed among the cans.

On different indicators per average size of the cans

Considering an average size of the cans, most of the contribution to the impact reduction is given by the aluminium production, the credits at the end-of-life and the manufacturing stages.

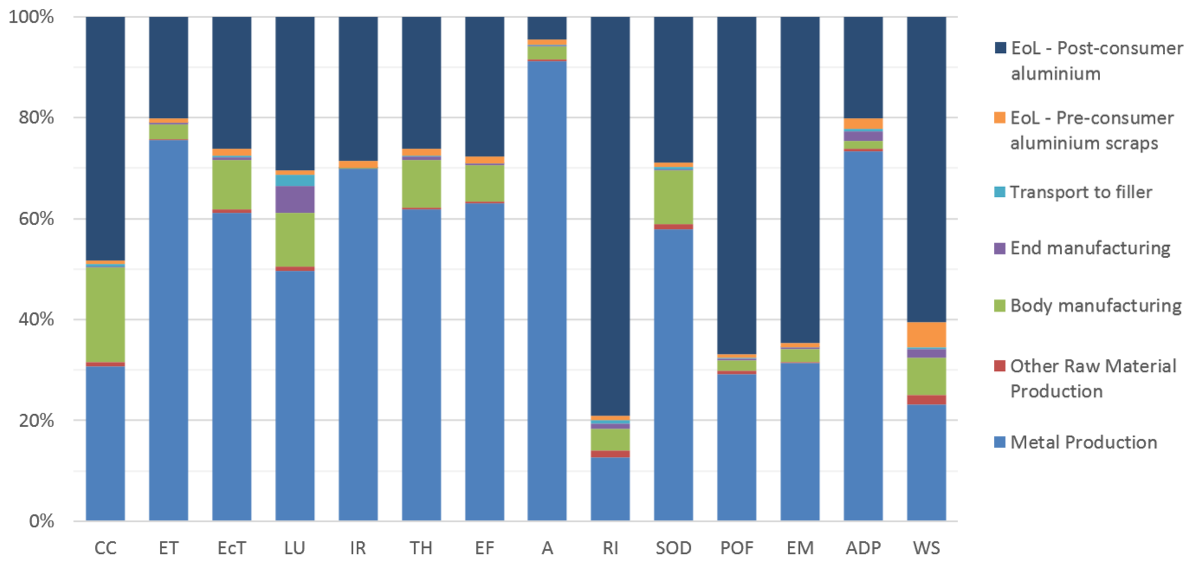

Figure 36. Contribution per life cycle stage to the total reduction of impact – All indicators (percentage gives the total reduction of impact between scenario 2006 and scenario 2016). CC: Climate change - ET: Eutrophication terrestrial - EcT: Ecotoxicity freshwater - LU: Land use - IR: Ionising radiation - TH: Toxicity human - EF: Eutrophication freshwater - A: Acidification - RI: Respiratory inorganics - SOD: Stratospheric ozone depletion - POF: Photochemical ozone formation - EM: Eutrophication marine - ADP: Abiotic resource depletion - WS: Water scarcity

VI. Conclusions

Life Cycle Inventories (LCIs) have been calculated for three different volumes (e.g. 25, 33 and 50 cl) of aluminium beverage cans. Those LCIs must be used for LCA studies analysing the European aluminium beverage cans.

The average results, three sensitivity analyses for different End-of-Life parameters, and an assessment of the improvements made by the metal packaging industry over 10 years have been calculated.

The system boundaries described in this study corresponds to: "cradle-to-gate + transport to filling sites + End-of-Life".

VI.1. Completeness and consistency check

VI.1.1. Completeness

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

- The completeness of process steps as regards primary data provided by the aluminium beverage cans manufacturers
- The energy, input materials as well as emissions from aluminium beverage cans manufacturers. Note that in case where no data were available, average from other plants or data from literature (as for the electrical mix) were used.

For more details, see section IV.

VI.1.2. Consistency

Several checks were made in order to validate the data received from the aluminium beverage cans 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 the section 0.

As regards the results, plausibility of the results and main source of impacts were assessed having a critical view on data quality.

VI.2. Limitations

It is important to remind the future users of the results of the study that the recycling credits are already included in the LCI, hence they should not be accounted additionally.

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 in paragraph III; the main limitations are listed below:

- Limitation due to potential methodological inconsistencies between background databases
- Limitation due to the approach to average the information collected from the different members.
- Limitation due to filling missing data
- Limitation due to simplified modelling for some minor raw materials
- Limitations due to the use of average recycling rate and recycling content
- Limitations due to the geographical scope
- Limitations due to non-regionalized water consumption

VI.3. Identification of significant issues

Depending on the impact category, the environmental impacts of the aluminium beverage cans are mainly shared between the aluminium production and the cans manufacturing.

The key impacts are related to the primary aluminium production, which is an energy-intensive process (about 15 MWh/ton for the electrolysis):

- The indirect GHG emissions and water consumption related to the electricity consumption at smelting process
- The direct GHG emissions and water consumption related to the smelting process and alumina production
- For the resources consumption, the main part of the impact of the aluminium production is related to the consumption of fluorspar and bauxite.

At the cans manufacturing, the key impacts are related to the energy consumption and the infrastructure:

- The indirect emissions linked to the consumption of electricity
- The direct and indirect emissions linked to respectively the consumption and extraction of natural gas
- The direct emissions of NO_X, SO_X and VOC
- For the resources consumption, the main part of the impact of the manufacturing phase is related to the consumption of indium and cadmium when building the infrastructures of the plant. This seems overestimated and may be due to assumptions on the use of rare elements for buildings.

VI.4. Recommendations

This assessment reflects the existing technical situation for the year 2016 representing (as best assumption) 87% of the European production volume of aluminium beverage cans.

The conditions of packaging manufacturing industry will change over time affecting the energy and material inputs and subsequent emissions.

Therefore, it is recommended to perform frequent update of the LCIs (at least every 5 years).

In the next update of the study, it is recommended to collect more specific data of the cans (including data on the surface of the cans) and to use a revised formula to better calculate the contribution of the coatings on the aluminium beverage cans.

VII. Annex

VII.1.1. Electricity mix modelling

For each country, IEA provides data on the quantity of electricity that is produced, exported and imported. Based on these three types of information, it is possible to determine the electricity consumption mix. Electricity consumed is determined based on the following formula:

elec produced + elec imported - elec exported.

The consumption mix is obtained from the combination of two production mixes:

- For the share that is imported (% imports), the mix to be assigned is approximated by the continental production mix, assuming importations from the corresponding continental market, on average.
- For the part of electricity that is consumed locally, i.e. that is not imported (1 - % imports), the mix is taken equal to the production mix of the considered country. The calculation is hence made according to the following formula:

*Consumption mix = % imports * [continental mix] + (1 - % imports) * [country-specific production mix]*

In this study, the attributional approach is used to model the electricity mixes. In this approach, the allocation between the consumers is uniform. In other words, in order to answer the demand of a consumer, all power and heat plants in the country contribute proportionally to their share in the national electricity generation on a yearly basis.

Electricity supply occurs at different voltage levels (110 V, 220 V...). Figures on total losses come from IEA data sources (2009 data) and figures on the electricity losses for each of the voltage levels are based on Ecoinvent modelling (7% of the total losses occur on high voltage, 13% on medium voltage and 80% in low voltage levels).

Parameter	Data	Secondary datasets used in the LCA model
Electricity mix used to model the can body production by MPE members		
Coal	35%	64% electricity production, hard coal, high voltage, DE, EI v3.4 36% electricity production, lignite, high voltage, DE, EI v3.4
Hydro	13%	5% electricity production, hydro, pumped storage high voltage, DE, EI v3.4 43% electricity production, hydro, reservoir, alpine region, high voltage, NO, EI v3.4 8% electricity production, hydro, reservoir, non-alpine region, high voltage, SE, EI v3.4 43% electricity production, hydro, run-of-river, high voltage, PL, EI v3.4
Gaz	20%	44% electricity production, natural gas, combined cycle power plant, high voltage, IT; EI v3.4 36% electricity production, natural gas, conventional power plant, high voltage, IT; EI v3.4 20% heat and power co-generation, biogas, gas engine; high voltage, IT ; EI v3.4
Nuclear	18%	93% electricity production, nuclear, pressure water reactor, high voltage, FR, EI v3.4 7% electricity production, nuclear, boiling water reactor, high voltage, DE, EI v3.4
Oil	2%	electricity production, oil, high voltage, GR, EI v3.4
Wind	13%	26% electricity production, wind, 1-3MW turbine, offshore, high voltage, DK, EI v3.4 74% electricity production, wind, 1-3MW turbine, onshore, high voltage, DK, EI v3.4
Electricity mix used to model the can ends production by MPE members		
Coal	35%	64% electricity production, hard coal, high voltage, DE, EI v3.4 36% electricity production, lignite, high voltage, DE, EI v3.4
Hydro	5%	5% electricity production, hydro, pumped storage high voltage, DE, EI v3.4 43% electricity production, hydro, reservoir, alpine region, high voltage, NO, EI v3.4 8% electricity production, hydro, reservoir, non-alpine region, high voltage, SE, EI v3.4 43% electricity production, hydro, run-of-river, high voltage, PL, EI v3.4
Gaz	25%	44% electricity production, natural gas, combined cycle power plant, high voltage, IT; EI v3.4 36% electricity production, natural gas, conventional power plant, high voltage, IT; EI v3.4 20% heat and power co-generation, biogas, gas engine; high voltage, IT ; EI v3.4
Nuclear	22%	93% electricity production, nuclear, pressure water reactor, high voltage, FR, EI v3.4 7% electricity production, nuclear, boiling water reactor, high voltage, DE, EI v3.4
Oil	2%	electricity production, oil, high voltage, GR, EI v3.4
Wind	11%	26% electricity production, wind, 1-3MW turbine, offshore, high voltage, DK, EI v3.4 74% electricity production, wind, 1-3MW turbine, onshore, high voltage, DK, EI v3.4

VII.1.2. Datasets used

Product/process	Type of activity	Secondary dataset
Aluminium	Aluminium ingot production	EU-27: Aluminium ingot mix EAA update 2015 (consumption mix), EU27, European aluminium
Aluminium	Aluminium sheet production	EU-27: Aluminium sheet [p-agg] EAA update 2015, EU27, European aluminium
Aluminium	Aluminium remelting	Remelting & Casting of rolling scrap [p-agg] EAA update 2015
Aluminium	Aluminium landfill	treatment of waste aluminium, sanitary landfill, CH - Switzerland, EI v3.4
Aluminium	Aluminium incineration	treatment of scrap aluminium, municipal incineration, Europe without Switzerland - Europe without Switzerland, EI v3.4
Heat production	Heat production	heat production, at hard coal industrial furnace 1-10MW, Europe without Switzerland - Europe without Switzerland, EI v3.4
Heat production	Heat production	heat production, natural gas, at industrial furnace low-NOx >100kW, Europe without Switzerland - Europe without Switzerland, EI v3.4
Heat production	Heat production	heat production, light fuel oil, at boiler 100kW, non-modulating, Europe without Switzerland - Europe without Switzerland, EI v3.4
Metal working factory	Machine production	metal working machine production, unspecified, RER - Europe, EI v3.4
Metal working factory	Factory production	metal working factory construction, RER - Europe, EI v3.4
Other raw materials	Inks, lacquers and sealings	hydroformylation of propylene, RER - Europe, EI v3.4
Other raw materials	Inks, lacquers and sealings	ethylene glycol monoethyl ether production, RER - Europe, EI v3.4
Other raw materials	Inks, lacquers and sealings	dimethylamine production, RER - Europe, EI v3.4
Other raw materials	Inks, lacquers and sealings	acetone production, liquid, RER - Europe, EI v3.4
Other raw materials	Inks, lacquers and sealings	solvent production, organic, RER - Europe, EI v3.4
Other raw materials	Inks, lacquers and sealings	epoxy resin production, RER - Europe, EI v3.4
Other raw materials	Inks, lacquers and sealings	acrylic varnish production, product in 87.5% solution state, RER - Europe, EI v3.4
Other raw materials	Inks, lacquers and sealings	polyester resin production, unsaturated, RER - Europe, EI v3.4
Other raw materials	Inks, lacquers and sealings	pigments, paper production, unspecified, at plant, RER [#314], RER - Europe, EI v3.4
Other raw materials	Inks, lacquers and sealings	styrene production, RER - Europe, EI v3.4
Other raw materials	Inks, lacquers and sealings	butadiene production, RER - Europe, EI v3.4

Other raw materials	Inks, lacquers and sealings	paraffin production, RER - Europe, EI v3.4
Other raw materials	Inks, lacquers and sealings	limestone production, crushed, washed, RER - Europe, EI v3.4
Other waste	Non hazardous waste incineration	treatment of municipal solid waste, incineration, CH - Switzerland, EI v3.4
Other waste	Non hazardous waste landfill	treatment of municipal solid waste, sanitary landfill, CH - Switzerland, EI v3.4
Other waste	Hazardous waste incineration	treatment of hazardous waste, hazardous waste incineration, CH - Switzerland, EI v3.4
Secondary and tertiary packaging	Linerboard recycling	treatment of recovered paper to linerboard, testliner, Europe without Switzerland - Europe without Switzerland, EI v3.4
Secondary and tertiary packaging	Linerboard incineration	treatment of waste paperboard, sanitary landfill, Europe without Switzerland - Europe without Switzerland, EI v3.4 (with CO2 correction from RDC)
Secondary and tertiary packaging	Polyethylene landfill	treatment of waste polyethylene, sanitary landfill, Europe without Switzerland - Europe without Switzerland, EI v3.4
Secondary and tertiary packaging	Polypropylene landfill	treatment of waste polypropylene, sanitary landfill, Europe without Switzerland - Europe without Switzerland, EI v3.4
Secondary and tertiary packaging	Polypropylene incineration	treatment of waste polypropylene, municipal incineration, Europe without Switzerland - Europe without Switzerland, EI v3.4
Secondary and tertiary packaging	Wood incineration	treatment of waste wood, untreated, sanitary landfill, Europe without Switzerland - Europe without Switzerland, EI v3.4 (with CO2 correction from RDC)
Secondary and tertiary packaging	Wood incineration	treatment of waste wood, untreated, municipal incineration, Europe without Switzerland - Europe without Switzerland, EI v3.4 (with CO2 correction from RDC)
Secondary and tertiary packaging	Corrugated board production	linerboard production, kraftliner, RER - Europe, EI v3.4
Secondary and tertiary packaging	Corrugated board recycling	treatment of recovered paper to linerboard, testliner, RER - Europe, EI v3.4
Secondary and tertiary packaging	Polyethylene production	polyethylene production, low density, granulate, RER - Europe, EI v3.4
Secondary and tertiary packaging	Polyethylene recycling	polyethylene production, high density, granulate, recycled, RER - Europe, EI v3.4
Secondary and tertiary packaging	Polypropylene production	polypropylene production, granulate, RER - Europe, EI v3.4
Secondary and tertiary packaging	Polypropylene moulding	injection moulding, RER - Europe, EI v3.4
Secondary and tertiary packaging	Wood pallet production	EUR-flat pallet production, RER - Europe, EI v3.4

Secondary and tertiary packaging	Wood pallet recycling	Wood chips, softwood, RER - Europe, EI v3.4
Transport	Transport by truck	transport, freight, lorry 16-32 metric ton, EURO5, RER - Europe, EI v3.4
Transport	Transport by truck	transport, freight, lorry 16-32 metric ton, EURO6, RER - Europe, EI v3.4
Transport	Transport for recycling	municipal waste collection service by 21 metric ton lorry, CH - Switzerland, EI v3.4
Transport	Transport by train	transport, freight train, electricity, Europe without Switzerland - Europe without Switzerland, EI v3.4
Transport	Transport by train	transport, freight train, diesel, Europe without Switzerland - Europe without Switzerland, EI v3.4
Transport	Transport by ship	transport, freight, sea, transoceanic ship, RER - Europe, EI v3.4
Transport	Transport by ship	maintenance, freight ship, transoceanic, RER - Europe, EI v3.4
Transport	Transport by ship	port facilities construction, RER - Europe, EI v3.4

VII.1.3. Critical review report

Critical Review
of
"Life Cycle Assessment of Aluminium
Beverage Cans in Europe
March 2019"

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

SOL 19-015.1
1 April 2019

for

Metal Packaging Europe

1 Introduction

RDC Environment has performed a LCA study for Metal Packaging Europe. The report of this study is entitled "**Life Cycle Assessment of Aluminium Beverage Cans in Europe**" and is dated **March 2019**.

The goals of the study were the following:

- "To determine the environmental impacts and credits (i.e. avoided impacts) along the life cycle of the aluminium beverage cans produced in Europe. This will be done by generating an LCA of 3 volumes of aluminium beverage cans (25,33 and 50 cl) produced in Europe according to the following systems boundaries:
  - Cradle to gate + transport to filling site + end-of-life.
  - Gate to gate."
- "To generate Life Cycle Inventories (LCIs) of the production phase and some selected further life cycle phases of three volumes (25, 33 and 50 cl) of aluminium beverage cans produced in Europe according to the following boundaries: Cradle to gate + transport to filling site + end-of-life."

As a subsidiary goal, the study aims at evaluating the average influence of the technical improvement made by the metal packaging industry between 2009 and 2016 on the studied environmental impacts. This is mainly based on data from a study performed by thinkstep (former PE International) in 2009 for BCME/European Aluminium/APEAL.

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 experts of Solinnen

Dipl. Eng. Delphine Bauchot, Director, Solinnen. Ms. Bauchot has 18 years of experience of the LCA practice, including CR practice. Ms. Bauchot has applied the LCA practice to different packaging systems and metal products systems.

The choice of the expert has been make to make available competencies which cover the studied topics, i.e. sector specific expertise (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 January 2019 and ended up in March 2019. 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 Aluminium Beverage Cans in Europe – March 2019" 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 53 comments covered the following points:

- Deviation (11 comments),
- Recommendation (31 comments),
- Editorial comments and other miscellaneous comments (11 comments).

Out of these comments, 6 covered methodological issues, 25 about Data and technical issues, 9 about Analysis and Interpretation.

An exhaustive work has been done by RDC Environment and Romeo Pavanello from Metal Packaging Europe 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.

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 aluminium production has been done, since these choices have been done by the data providers (European Aluminium) (primary and secondary aluminium production are used as aggregated data in the present study).

During the study itself and then during the critical review, the question of considering some aspects (definition of the functional unit, indicators, circular footprint formula) of the Product Environmental Footprint (PEF) methodology from the European Commission was discussed. At the time of the study, the PEF methodology was still encountering significant changes and is still tested at the time of the critical review (that happens between the pilot phase and the transition phase). As a recommendation, we advise Metal Packaging Europe to consider applying the PEF approach in its next study in order to be prepared to future requests of stakeholders and provide LCA practitioners with representative LCIs of beverage cans that will comply with PEF requirements.

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.

The review of the model highlighted that some data (especially the coating ingredients) came from another study and there was some uncertainty on the level of representativeness of such data for the study. Even if the consequence on the results is very limited, this is a limitation of the study.

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.

One can also regret that there were no statistics about the share of the different end-of-life scenarios (close-loop recycling, open-loop recycling and others) that would allow to give an average European scenario.

Also the evaluation of the improvement of the aluminum packaging sector between 2009 and 2016 should be considered with special care. Indeed, as stated in the study, the scope of those two studies can be different and there was no possibility to explain the discrepancy and confirm the meaning of the data provided within the first study.

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

The conclusions (VI.) are adapted to the goal of the study, taking into account the limitations of the study (chapter III and VI.2) which are adapted and clearly stated: the reader shall take it into account when reading the conclusions.

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.