European Coil Coating Association (ECCA)

Comparative life cycle assessment of pre-painted (coil coated) and post-painted sheet aluminium for the construction market

Summary Report

Date: October 2019

Anthesis Consulting Group

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Comparative life cycle assessment of pre-painted (coil coated) and post-painted sheet aluminium for the construction market

Executive summary

Background

The European Coil Coating Association (herein referred to as ECCA) are a trade association for the pre-painted metal industry, including coil coaters and paint/coatings manufacturers. Their mission is to increase the awareness of pre-painted metal through promoting its environmental, cost, quality and design benefits. ECCA are interested in better understanding the environmental profile of products manufactured by their member companies. They would like to compare the environmental impacts associated with coil coated (pre-painted) sheet aluminium in comparison to post-painted sheet aluminium for the construction industry. To this end, life cycle assessment (LCA) can be used to generate quantitative environmental profiles for different product systems across their entire lifecycle, which allows a fair basis for comparison with each other.

Life cycle assessment is a decision support tool that allows quantitative environmental profiles to be generated for different products systems. This report has been written to be consistent with the international standards for LCA: ISO 14040:2006 and ISO 14044:2006 and follows the required four-stage iterative process of: goal and scope, inventory analysis, impact assessment and interpretation.

The goal of this study was to generate environmental profiles of pre- and post-painted sheet aluminium to better understand the associated lifecycle environmental impacts of each in comparison to one another. Results will be disclosed to the public and used to make comparative assertions and as such the study has been critically reviewed by a panel of experts. The following product systems were investigated:

- **Product system 1:** Pre-painted aluminium for use in building panels by the construction industry; and
- **Product system 2:** Post-painted aluminium for use in building panels by the construction industry.

The system boundary for each product system of this LCA study was '**cradle-to-grave**', which comprises: extraction and refining of raw materials, manufacturing of aluminium sheet (e.g. smelting, refining, rolling), coil coating both sides of the aluminium (or powder coating by construction material companies), fabrication into appropriate components (e.g. cutting, bending, shaping), end-of-life, and all transportation and waste stages (except final transportation to customer). This boundary allows for all life cycle impacts to be captured and compared against each other.

The functional unit for this study was defined as:

> *"1 square metre of 0.8 mm sheet aluminium coated both sides with a polyester-based paint for use in a building panel in Europe with a lifetime of 30 years"*

In this LCA the life cycle impact assessment (LCIA) method applied was ReCiPe 2016 v1.1 (Hierarchic).

The ReCiPe end-point environmental impact categories used in this study comprised the following:

- Freshwater ecotoxicity;
- Freshwater eutrophication;
- Global warming (freshwater ecosystems);
- Global warming (terrestrial ecosystems);
- Land use;
- Marine ecotoxicity;
- Marine eutrophication;
- Ozone formation (terrestrial ecosystems);
- Terrestrial acidification;
- Terrestrial ecotoxicity;
- Water consumption (aquatic ecosystems);
- Water consumption (terrestrial ecosystems);
- Fine particulate matter formation;
- Global warming (human health);
- Human carcinogenic toxicity;
- Human non- carcinogenic toxicity;
- Ionising radiation;
- Ozone formation (human health);
- Stratospheric ozone depletion;
- Water consumption (human health);
- Mineral resource scarcity; and
- Fossil resource scarcity.

These ReCiPe impact categories are grouped into either:

- **Damage to ecosystems (species loss)**: this group of indicators assesses the loss of species as a result of the products being produced and used and includes impact categories such as climate change, eutrophication and acidification.
- **Damage to human health (disability adjusted life years, DALY)**: this group of indicators considers damage to human life and includes impact categories climate change, human toxicity, and particulates.
- **Damage to resources (USD)**: this group of indicators considers the indicators fossil resource and mineral resource scarcity.

Characterised end-point results for pre- versus post-painted aluminium

Figure 1 provides characterised end-point results per m^2 for paint manufacture and paint application stages of both pre-painted aluminium and post-painted aluminium. Only paint manufacture and application stages are compared in Figure 1, as all other life cycle stages are identical in impact. Results are presented relative to the highest impact product system for each impact category, which is fixed at 100%. This representation of results allows for easier comparison between product systems.

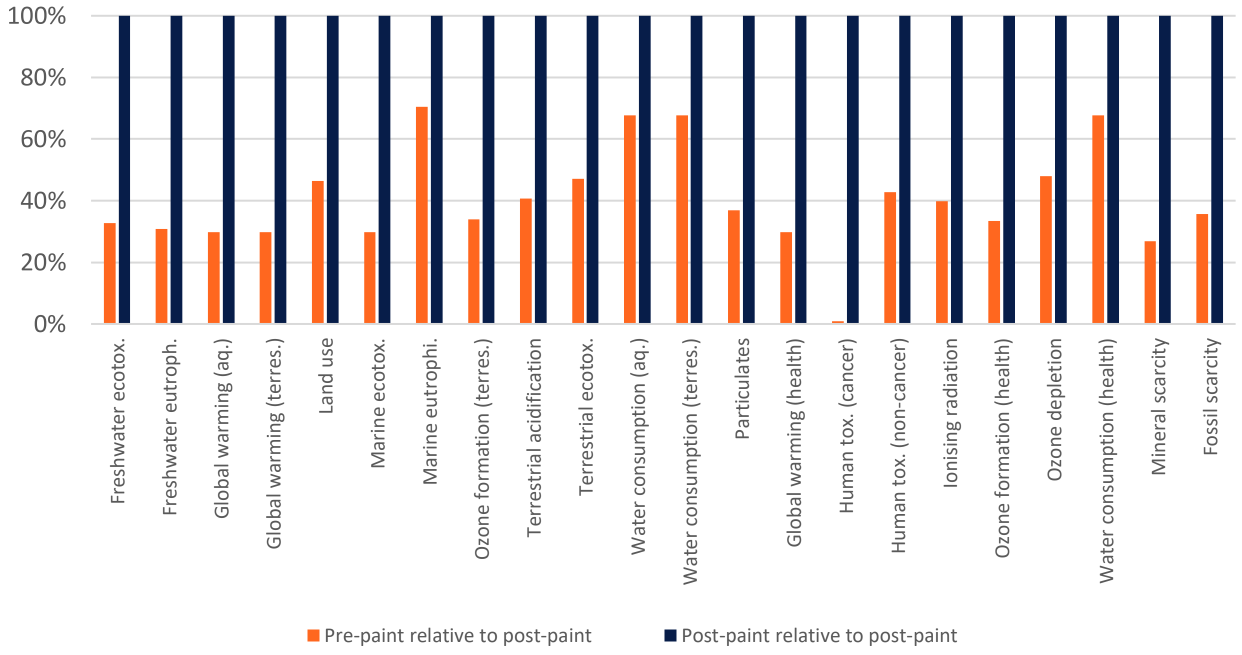

Figure 1 – Characterised end-point results for pre-painted versus post-painted aluminium (paint manufacture and application only, pre-paint relative to post-paint)

The following conclusions can be drawn from this study:

- For all impact categories, pre-painted aluminium has a lower impact than post-painted aluminium (1 – 70% of those of post-painted aluminium, depending on the impact category, for paint production and application stages, or 64 – <100% of those of post-painted aluminium for full life cycle impacts).
- For ecosystem, human health and resource depletion impact category groups, impacts of pre-painted aluminium are 24%, 24% and 36% of those of post-painted aluminium, respectively (for paint production and application stages, or 97%, 94% and <100% of those of post-painted aluminium for full life cycle impacts, respectively).
- The differences in impact are mostly driven by coil coating using less energy during paint application in comparison to powder-coating, less paint being required for coil coating compared to powder-coating, per kg impacts of organic solvent-based paint being less than those of powder-based paint and less intensive pre-treatment being required for coil coating in comparison to powder coating.
- Whilst paint thickness is an important parameter, within the range of paint thicknesses modelled in the sensitivity analysis, pre-painted aluminium always has the lowest impact when compared with post-painted aluminium.

Table of contents

Anthesis Consulting Group....2
Disclaimer....2
Executive summary....3
  Background....3
  Characterised end-point results for pre- versus post-painted aluminium....5
Table of contents....6
1 Goal and scope....7
  1.1 Background....7
  1.2 Goal of the study....8
  1.3 System boundaries....8
  1.4 Functional unit....9
  1.5 Product systems description....9
  1.6 Data collection procedures....15
  1.7 Life Cycle Impact assessment (LCIA) method....15
  1.8 Description of LCA data....17
  1.9 Assumptions....17
  1.10 Exclusions....18
2 Life cycle impact assessment (LCIA)....18
  2.1 Environmental hotspots....18
  2.2 Comparative assessment – characterised end-point results....22
  2.3 Deep dives....25
3. Conclusions....31
4. References....33
Appendix A – critical review statement and report....34

1 Goal and scope

1.1 Background

The European Coil Coating Association (herein referred to as ECCA) are a trade association for the pre-painted metal industry, including coil coaters and paint/coatings manufacturers. Their mission is to increase the awareness of pre-painted metal through promoting its environmental, cost, quality and design benefits.

Life cycle assessment is a decision support tool that allows quantitative environmental profiles to be generated for different products systems. This report has been written to be consistent with the international standards for LCA: ISO 14040:2006 and ISO 14044:2006 and follows the required four-stage iterative process below (and represented in Figure 2). Conformance to other standards, aside from the ISO 14040/44, is not being claimed.

- **Goal and scope**: the first stage of LCA is to define the goal and scope of study to understand the objectives and indented applications, the boundaries of what is being assessed and the performance requirement that the product fulfils.
- **Inventory analysis**: the second stage is inventory analysis, where an inventory of flows to and from nature is created, usually using a combination of primary and secondary data collected for each unit processes of the product system.
- **Impact assessment**: the third stage is impact assessment, which is where inventory data are applied to characterisation factors to generate the main results and determine the environmental impacts.
- **Interpretation**: the final stage is interpretation, which is where conclusions are drawn, sensitivity and uncertainty analyses are performed, and recommendations made.

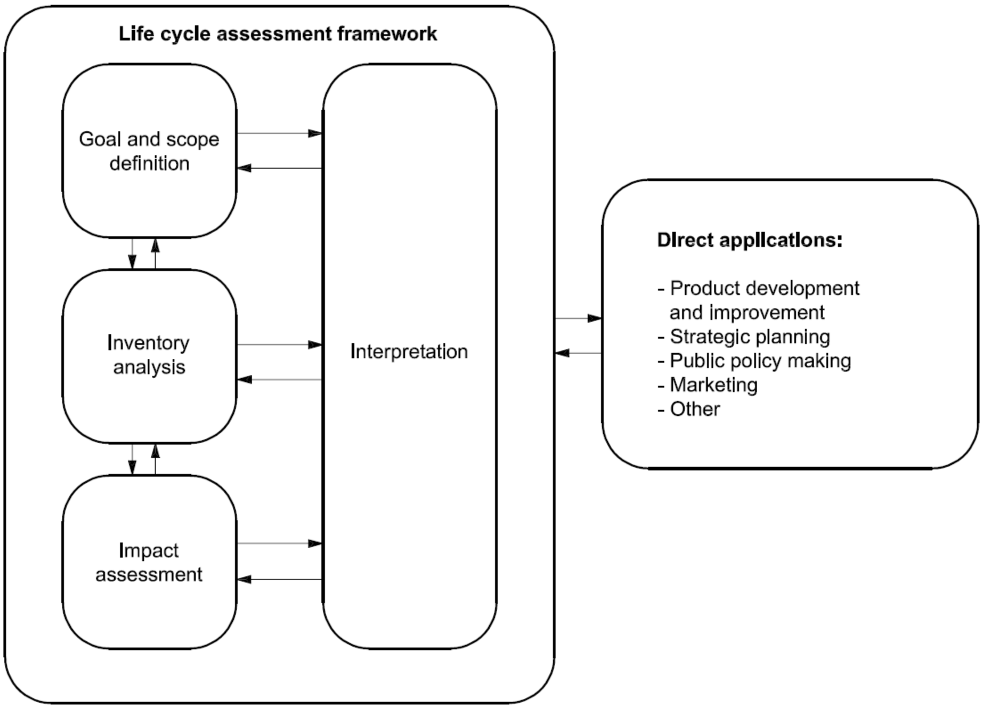

Figure 2 – The four stages of LCA as defined by ISO 14040 (source: ISO).

1.2 Goal of the study

The goal of this study was to generate environmental profiles of pre- and post-painted sheet metal to better understand the associated lifecycle environmental impacts of each in comparison to one another. The following product systems were investigated:

- **Product system 1:** Pre-painted aluminium for use in building panels by the construction industry; and
- **Product system 2:** Post-painted aluminium for use in building panels by the construction industry.

The above product systems are described in more detail in Section 1.5 and with data and assumptions given in Section 1.9.

The main objectives of the study were to:

- Compare the environmental profiles of pre-painted and post-painted sheet aluminium;
- Identify significant contributions to the environmental impacts (“hotspots”) across the product lifecycle; and
- Identify possible improvement areas of the studied systems that would be of interest for further analyses.

The intended applications are to:

- Understand the opportunities and risks of pre-painted sheet metal manufacture;
- Help inform opportunities for environmental impact reduction; and
- Inform ECCA’s environmental policy.

The intended audiences are a wide range of internal stakeholders in the first instance, including process engineers, research and development scientists and marketing teams.

The study has undergone a critical review by a panel of experts and the critical review report and review statement are provided in Appendix A.

1.3 System boundaries

The system boundary for each product system of this LCA study was ‘**cradle-to-grave**’, which comprises: extraction and refining of raw materials, manufacturing of aluminium sheet, coil coating of both sides of aluminium (or in-house powder coating by construction material companies), fabrication into appropriate components (e.g. cutting, bending, shaping), end-of-life, and all transportation and waste stages (except final transportation to customer). This boundary allows for all life cycle impacts to be captured and compared against each other. Whilst aspects of the use phase have been considered, an assessment of the impacts has been excluded from the study because differences in durability between pre-painted and post-painted aluminium were not considered in the study (see Section 1.4). The boundary also excludes any further processes involved in the manufacture of building panels that the painted aluminium is used for (e.g. insulation).

Arguably, upstream impacts associated with pre- or post-painted aluminium could also have been excluded on this basis, but Anthesis believe it is worthwhile to include these to better understand the hotspots of pre- and post-painted aluminium coating in the context of the entire lifecycle. Similarly, downstream impacts from the point of painted sheet aluminium component manufacture (e.g. end-of-life) could be said to be identical for the two metal options and excluded, but it is useful to include these for the same reason.

1.4 Functional unit

The function of sheet aluminium product systems is, in each case, to provide protection to a building from the outer environment and to enhance aesthetics (e.g. surface finish).

The functional unit describes the function provided by the product system and serves as a basis of comparison between systems. The functional unit for this study was defined as:

"1 square metre of 0.8 mm sheet aluminium coated both sides with a polyester-based paint for use in a building panel in Europe with a lifetime of 30 years[1]"

Whilst a reference service lifetime has been added to the functional unit definition, the use phase (and therefore durability and replacements during use) have been excluded. This is because in the case of the building panel, there are numerous variables affecting the service lifetime including paint thickness, product application, manufacturer and geographic location of the use phase, which are difficult to constrain. Without strong supporting evidence for differences in lifetime solely attributed to the paint application method (i.e. pre- vs post-painting) it was thought prudent to exclude this aspect from base-case results. We have, however, considered the impact of durability over the 30-year reference service lifetime in a sensitivity analysis using assumptions on the lifetime of pre- and post-painted aluminium building panels by ECCA.

1.5 Product systems description

The following product systems were investigated:

- **Product system 1**: pre-painted aluminium for use in building panels by the construction industry; and
- **Product system 2**: post-painted aluminium for use in building panels by the construction industry.

Process flow diagrams for these product systems are shown in Figures 4 and 5. Quantitative and qualitative primary and secondary data were collected for each flow, for all unit processes within the system boundary of these product systems and these data were used to compile the life cycle inventory (LCI).

Product system 1: Pre-painted aluminium for use in building panels by the construction industry

A PFD for this product system is provided in Figure 4 and is broken down into the following unit processes (the smallest element in the product system for which LCI data are collected) and sub-processes:

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[1] Assumed upper range of typical lifetime of pre- and post-painted aluminum building panels based on estimate by ECCA.

Unit process 1 – Aluminium slab production:

Unit process 2 – Hot rolling and cold rolling:

Unit process 3 – Paint manufacture:

- Mixing: inputs of polyester resin, titanium dioxide, other pigments and additives are mixed together. Electricity is required and some hazardous waste for treatment is created.
- Pigment dispersal: the paint mix is agitated to homogenously disperse the pigment through the mix. Electricity may be required (if filtration not gravity fed) and some hazardous waste for treatment is created.
- Addition of solvent: an organic solvent is added, and paint is mixed further. Electricity is required and some hazardous waste for treatment is created.
- Filtration: Impurities are removed via filtration. Electricity is required and some hazardous waste for treatment is created.
- Filing and packaging: the finished paint is packaged in drums. Packaging is excluded.
- Transportation of all raw materials to site and waste for treatment offsite are considered.

Unit process 4 – Coil coating (see Figure 3):

- De-coiling and splicing: coils of sheet aluminium are de-coiled and each coil is stitched together. Electricity is required for this process. An accumulator stack allows the line to be slowed down so that coils can be stitched together without interrupting the continuous coil coating line. Coil coating line productivity is typically around 7,000 m^2 of sheet metal per hour.
- Cleaning, degreasing, brushing: the line of sheet aluminium is cleaning/degreased using inputs of sodium hydroxide, trisodium phosphate, surfactants, deionised water and brushed. Electricity is required and some hazardous waste for treatment is created.
- Drying oven: heat is required to dry the line of sheet aluminium. Electricity is also required.
- Primer and topcoat coating: the line of sheet metal is continuously coated (both sides) with inputs of paint. Electricity is required and some hazardous waste for treatment is created.
- Curing oven: the line of coated sheet aluminium is heated in an enclosed curing oven to cure the paint. Evaporated solvent is captured and either condensed and reused or incinerated for energy recovery. Electricity and natural gas are required.
- Coiling and packaging: the line of coated sheet aluminium is re-coiled (an accumulator stack allows the line to be slowed down so that coils can be re-coiled without interrupting the continuous coil coating line). Electricity is required. Packaging is excluded.
- Transportation of all raw materials to site and waste for treatment offsite are considered.

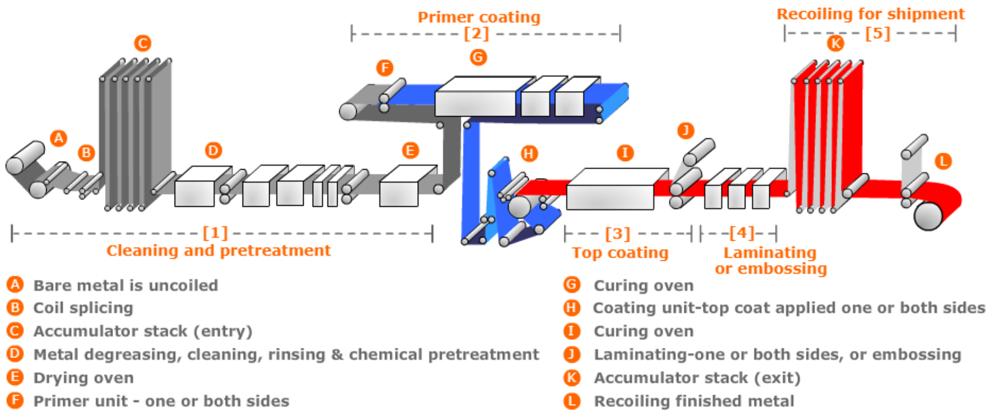


Figure 3 – Coil coating process (source: ECCA). Note - process J is optional.

Unit process 5 – Coated sheet metal fabrication and building panel manufacture:

- Cutting, pressing, bending etc.: the building panel is formed by cutting, pressing, bending, forming and shaping coil coated aluminium. This may occur at the same site as the building panel manufacturer or at an aluminium fabricator's site – for this model we have assumed fabrication occurs at a different site to building panel manufacture. Electricity is required.
- Manufacture of all other components of the building panel: excluded.
- Transportation of all raw materials to site and waste for treatment offsite are considered.

Unit process 6 – Use:

- Replacement of panel: excluded.
- Maintenance of panel etc: excluded.
- Transportation of finished product to customer: excluded.

Unit process 7 – End-of-life:

- Recycling: inputs comprise the scrap aluminium recovered from building panels, which is then sorted and treated by a recycling facility. The process requires heat and electricity. The output is scrap aluminium to be used in another product system (avoided product "Aluminium, primary, ingot {GLO}| market for | Cut-off, U").
- Landfill: inputs comprise the scrap aluminium which is not recovered from building panels or otherwise ends up in landfill. Emissions to water and soil from landfill leachate include metals.
- Transportation of waste for treatment.

Product system 2: Post-painted aluminium for use in building panels by the construction industry

A PFD for this product system is provided in Figure 5. Unit processes 1 – 2, 4, 6 and 7 are identical processes as described in product system 1, all other unit processes are described here:

Unit process 3 – Paint manufacture: similar process to that described in product system 1, however, powder-based paint rather than solvent-based paint is used.

- Mixing: inputs of polyester resin, titanium dioxide, other pigments and additives are mixed together. Electricity is required and some hazardous waste for treatment is created.
- Pigment dispersal: the paint mix is agitated to homogenously disperse the pigment through the mix. Electricity is required and some hazardous waste for treatment is created.
- Filtration: Impurities are removed via filtration. Electricity may be required (if filtration not gravity fed) and some hazardous waste for treatment is created.
- Filing and packaging: the finished paint is packaged in drums. Packaging is excluded.
- Transportation of all raw materials to site and waste for treatment offsite are considered.

Unit process 5 – Sheet metal fabrication, painting and building panel manufacture:

- Cutting, pressing, bending etc.: the building panel is formed by cutting, pressing, bending, forming and sheet aluminium. This may occur at the same site as the building panel manufacturer or at an aluminium fabricator’s site – for this model we have assumed fabrication occurs at a different site to building panel manufacture. Electricity is required.
- Cleaning, degreasing, brushing, other pre-treatment: the building panels are cleaning/degreased and pre-treated using inputs of sodium hydroxide, trisodium phosphate, surfactants, chromium (III) flakes, sulfuric acid, hydrofluoric acid, phosphoric acid, lime, deionised water and brushed. Electricity is required.
- Curing oven: the building panels are cured in an oven. Heat and electricity are required.
- Powder coating: building panels are coated with inputs of powder-based paint (both sides). Some hazardous waste for treatment is created (transfer efficiency is less efficient than coil coating). Powder coating line productivity is typically around 375 m^2 of sheet metal per hour (or up to 900 m^2 / h if optimised).
- Curing oven: building panels may be cured in ambient temperature or in a curing oven. Heat and electricity are required. Packaging is excluded.
- Manufacture of all other components of the building panel: excluded.
- Transportation of all raw materials to site and waste for treatment offsite are considered.

Figure 4 – Process flow diagram for product system 1: pre-painted aluminium for use in building panels by the construction industry (hashed boxes indicated that the process is excluded)

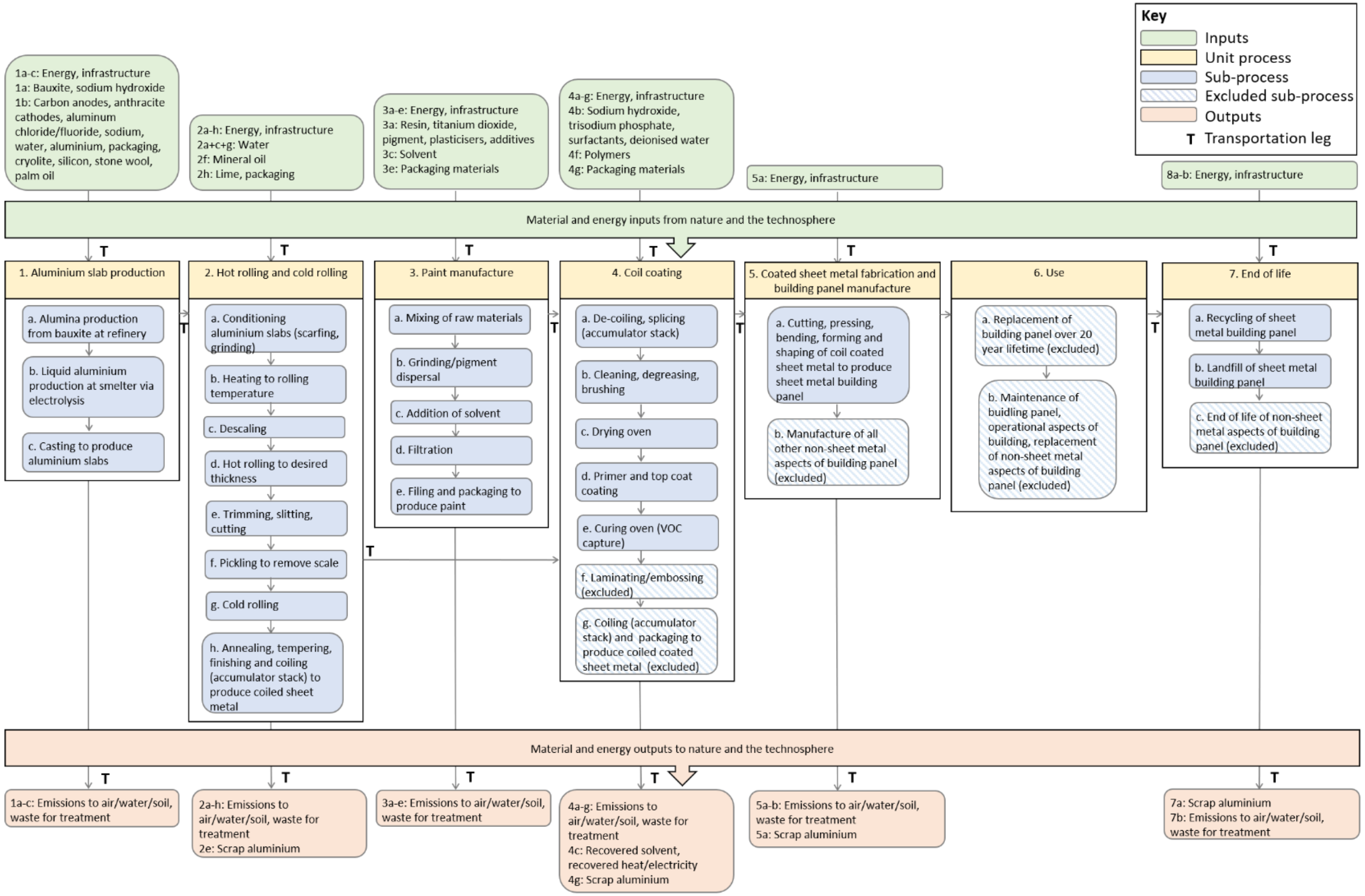
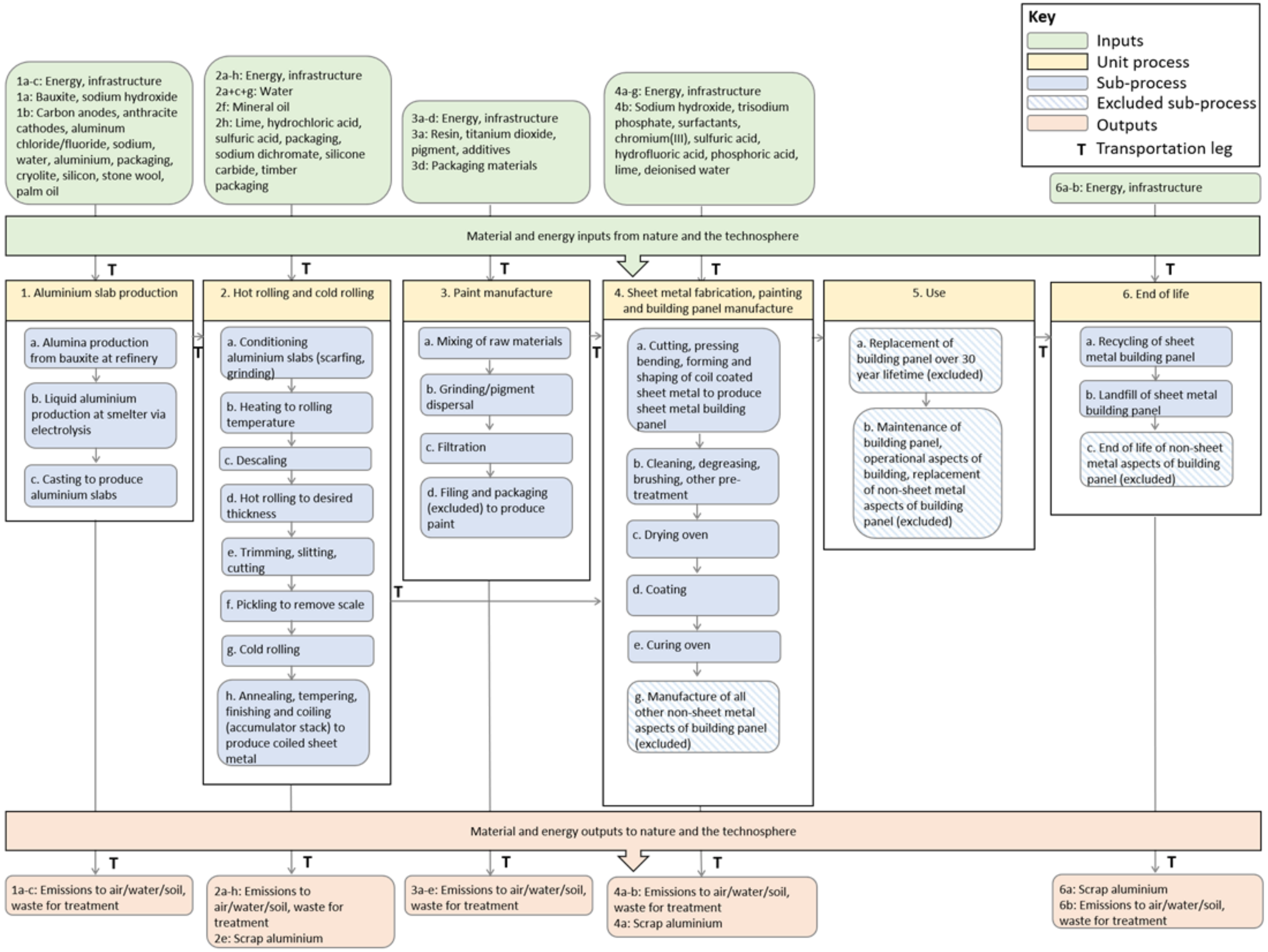


Figure 5 – Process flow diagram for product system 2: post-painted aluminium for use in building panels by the construction industry (hashed boxes indicated that the process is excluded)



1.6 Data collection procedures

Quantitative and qualitative primary and secondary data were collected for all processes within the system boundary and these data were used to compile the LCI. Primary data were collected for ECCA members covering a period of 01/01/17 until 31/12/17 i.e. the calendar year of 2017

In this study, primary data were collected for all process likely to be under the operational control of representative ECCA members (e.g. coil coating and paint manufacture) and all other processes were modelled using secondary data, including all stages of comparison product systems. Primary data were collected from representative ECCA members using data collection sheets via an iterative process.

Secondary data were collected from a range of LCI databases (e.g. ecoinvent v3.4, Worldsteel Association LCI, IEA, Defra/DECC) and literature sources.

1.7 Life Cycle Impact assessment (LCIA) method

For this study, the LCIA method ReCiPe (acronym from initials of main collaborators in its design) 2016 v1.1 (Hierarchic) (Geodkoop et. al, 2016) was used, which was developed by PRé Consultants, the University of Leiden (CML), Radboud University Nijmegen (RUN) and the National Institute for Public Health and the Environment in the Netherlands (RIVM). It was derived from predecessor methods CML 2 baseline 2000 and eco-indicator 99 and is considered as the “go to” European and international LCIA method, which is why it was selected for this project.

The ReCiPe impact assessment method transformed data gathered in the inventory phase to a few indicator scores for various impact categories, giving a broad range coverage of environmental issues. These indicator scores express the relative severity on an environmental impact category and can either be represented at the ‘mid-point’ or ‘end-point’ stage. At the ‘mid-point’ stage, individual impact categories are shown, whereby a score is given for each in the appropriate reference unit, whereas at the end-point stage, the potential damage to ecosystems, human health and resources is shown.

To provide an example of the difference, at the mid-point level the contribution to climate change is measured in kg CO_2e, which tells us the amount of greenhouse gas equivalents that are released into the environment. In order to estimate the potential environmental damage caused by an amount of CO_2e released into the environment, end-point characterisation factors can be applied, and results expressed in terms of damage to ecosystems (species loss), human health (disability adjusted life years, DALY) or resources (USD). In this study, characterised results are represented at the end-point stage.

For comparison between impact categories a process known as normalisation was applied to characterised end-point results. This process is necessary as different environmental impact categories and impact category groups of ReCiPe have different units at the characterised mid-point level (kg CO_2e, kg N eq etc) and end-point level (species loss, disability adjusted life years (DALY), USD), which makes it challenging to compare each impact category against each other. With different units there is no sense of scale of importance to determine the key environmental impact categories. Therefore, characterised results were normalised by converting to a unit known as people emission equivalents, so that they are all in the same units. A people emission equivalent in a European context may be defined with the equation below:

$$1\ people\ emission\ equivalent = \frac{Impact\ in\ EU\ in\ 1\ year}{Population\ in\ EU}$$

Using normalised results allows all environmental indicators to be reported to the same unit: people emission equivalents. It therefore allows direct comparisons of each environmental indicator that cannot be done if each indicator has a different unit. However, it should be noted that it does not actually tell us which environmental issue is more important in terms of its sustainability. Instead, it reveals which environmental issues are high compared with the average impact *per capita* in modern society, i.e. in Europe.

The ReCiPe end-point environmental impact categories used in this study comprised the following):

- Freshwater ecotoxicity;
- Freshwater eutrophication;
- Global warming (freshwater ecosystems);
- Global warming (terrestrial ecosystems);
- Land use;
- Marine ecotoxicity;
- Marine eutrophication;
- Ozone formation (terrestrial ecosystems);
- Terrestrial acidification;
- Terrestrial ecotoxicity;
- Water consumption (aquatic ecosystems);
- Water consumption (terrestrial ecosystems);
- Fine particulate matter formation;
- Global warming (human health);
- Human carcinogenic toxicity;
- Human non- carcinogenic toxicity;
- Ionising radiation;
- Ozone formation (human health);
- Stratospheric ozone depletion;
- Water consumption (human health);
- Mineral resource scarcity; and
- Fossil resource scarcity.

These ReCiPe impact categories are grouped into either:

- **Damage to ecosystems (species loss)**: this group of indicators assesses the loss of species as a result of the products being produced and used and includes impact categories such as climate change, eutrophication and acidification.
- **Damage to human health (disability adjusted life years, DALY)**: this group of indicators considers damage to human life and includes impact categories climate change, human toxicity, and particulates.
- **Damage to resources (USD)**: this group of indicators considers the indicators fossil resource and mineral resource scarcity.

1.8 Description of LCA data

LCI data used for each unit process of each product system is summarised here in Figure 6. Primary data covered paint manufacture and application stages for pre-painted aluminium (product system 1). Secondary data was used for all other lifecycle stages for pre-painted aluminium and for the entire lifecycle of post-painted aluminium (product system 2).

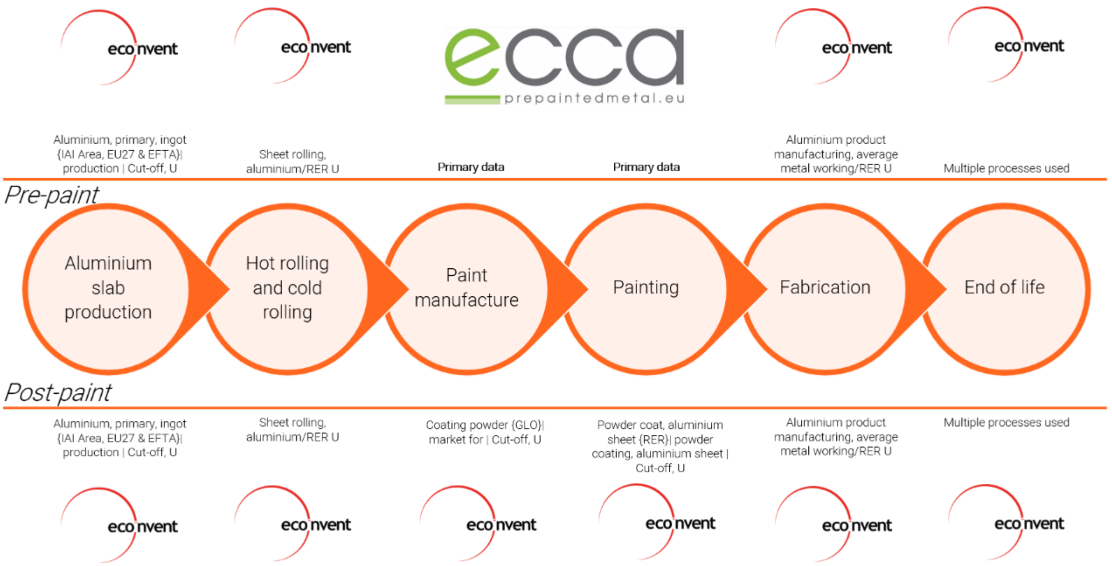


Figure 6 – summary of inventory data used for pre- and post-painted aluminium

1.9 Assumptions

During this LCA a number of assumptions were made, which are documented in Appendix B alongside LCI data. The most important of these assumptions are also described below for transparency.

- 100% of scrap aluminium generated during manufacturing stages was assumed to be sent for recycling.
- Rolling lines are located on same site as the metal producer.
- It was assumed that fabrication of metal takes place at a different site to the building panel manufacturer.
- Selected ECCA coil coating lines and paint manufacturers are representative of coil coating in Europe.
- Coil coating using polyester-based organic solvent paint assumed representative method of pre-painting.
- Powder coating using polyester-based powder paint was assumed representative of post-painting.
- Recycling rate: 90% aluminium from construction in Europe (Aluminium Europe) – sensitivity analyses were performed on different recycling rates. Note that different paint thicknesses may impact the effort required to recycle sheet aluminium, but it is likely to impact post-painted aluminium more (as the coating is thicker than pre-painted aluminium), so not considering it in this study is a conservative approach. It is also not known if this increased effort impacts recycling rates (e.g. due to economic reasons), therefore, the impact of paint thickness on recycling rates has not been considered in this study.

1.10 Exclusions

In addition to those general exclusion, a number of specific exclusions are also described below for transparency, with justification in parenthesis.

- Packaging of paint for all product systems (likely the same for pre-and post-paint);
- Laminating/embossing for all product systems (not relevant for polyester- based paint);
- Product packaging for all product systems (immaterial [calculated to be <<1% of full life cycle of <1% of paint production and application stages only for carbon footprint] and same for pre-and post-paint);
- Manufacture, use (replacement and maintenance) and end-of-life of all other non-sheet metal aspects of building panels for all product systems (out of scope); and
- Transportation of final product (building panel) to customer (difficult to define and identical for each product system and same for pre-and post-paint).

2 Life cycle impact assessment (LCIA)

This section presents all LCIA results from this study for all four product systems:

- **Product system 1**: pre-painted aluminium for use in building panels by the construction industry; and
- **Product system 2**: post-painted aluminium for use in building panels by the construction industry.

Results comprise environmental hotspot analyses where key areas of impact in the lifecycle of each product system are examined; a comparative assessment where the environmental profile of product system 1 is compared with that of product system 2; and a deep dive, where the key drivers of paint manufacture and paint application are identified. Note that due to the uncertainty of using normalisation factors from a different version of ReCiPe to the characterisation factors, normalised results have not been presented in the main body of the report and have not been used to derive conclusions.

All results are presented in terms of the functional unit, which is defined as “1 square metre of 0.8 mm sheet aluminium coated both sides with a polyester-based paint for use in a building panel in Europe with a lifetime of 30 years”. The only exception is in the “deep dive” of paint manufacture where results are presented per kg of output.

2.1 Environmental hotspots

Product system 1: pre-painted aluminium hotspots

Figure 7 shows the breakdown of each environmental impact category, as a percentage in a 100% stacked bar chart, for the lifecycle of pre-painted aluminium, based on characterised end-point results. Environmental hotspot results show which unit processes of the cradle-to-grave boundary contribute most (and least). Figure 8 shows the breakdown of each environmental impact category for paint manufacture and paint application stages of pre-painted aluminium only.

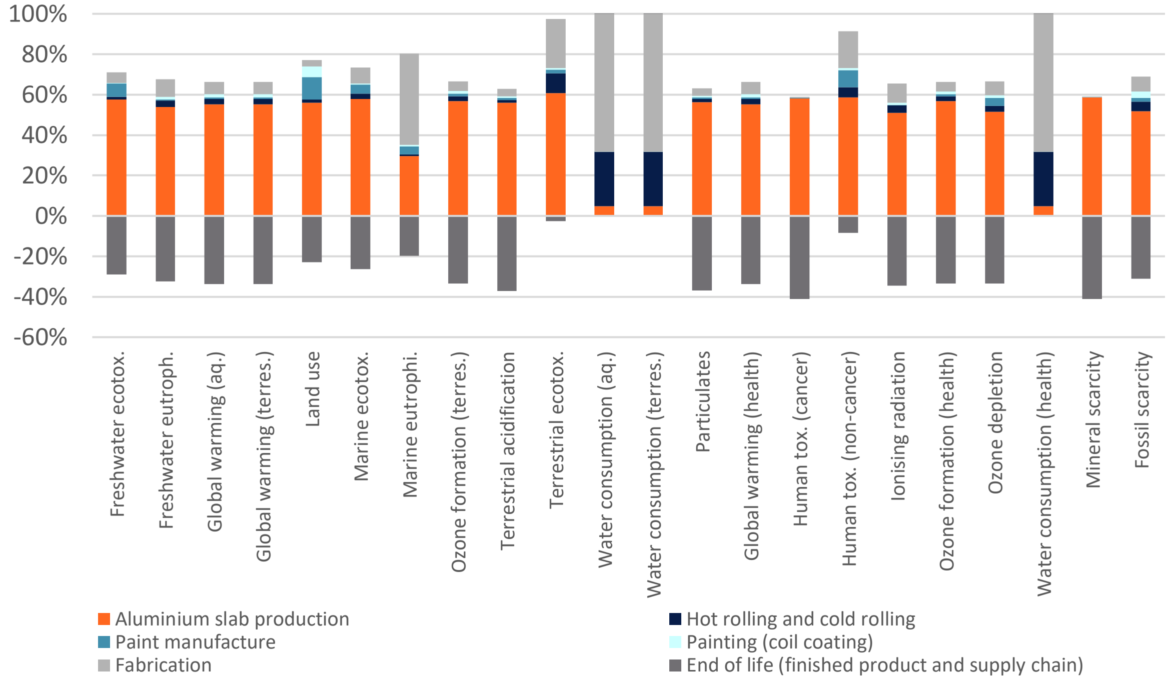


Figure 7 – Environmental hotspots for pre-painted aluminium (cradle-to-grave)

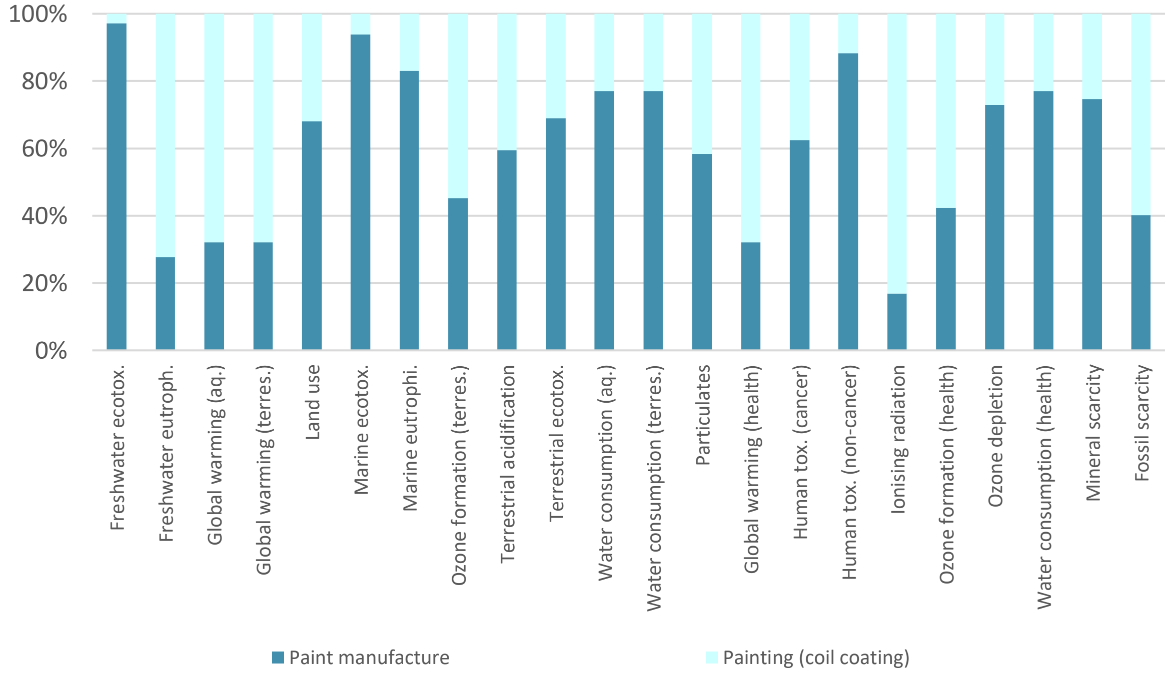


Figure 8 – Environmental hotspots for pre-painted aluminium (paint manufacture and application)

The following points are evident from Figure 7 and Figure 8:

- Aluminium slab production dominates total cradle-to-grave impacts for most impact categories;

- Metal fabrication dominates some impact categories (e.g. water consumption, terrestrial ecotoxicity, marine eutrophication) and contributes substantially to all other impact categories;
- Digging deeper into hotspots of aluminium slab production, production of liquid aluminium dominates all impact categories except marine eutrophication (where dross from electrolysis is equally as important);
- In the case of hotspots of metal fabrication, electricity use contributes substantially to most impact categories, except in the case of ecotoxicity/non-carcinogenic human toxicity impact categories (where light fuel oil burned for heat contributes substantially);
- Paint production and application represents a small proportion of total cradle-to-grave impacts for most categories (0 – 12%), but is notable for ozone depletion (~16%, due to adipic acid used in polyester resin), land use (~30%, due to soy used in polyester resin) and freshwater ecotoxicity (~16%, due to titanium dioxide production used in paint) (discussed in Section 2.3); and
- When paint manufacture and application are compared in isolation (Figure), paint manufacture dominates for around half the impact categories, whereas paint application (coil coating) only dominates for freshwater eutrophication, global warming, ionising radiation and fossil scarcity, with impacts for the remaining impact categories being fairly evenly split between paint manufacture and application.

Product system 2: post-painted aluminium hotspots

Figure 9 shows the breakdown of each environmental impact category, as a percentage in a 100% stacked bar chart, for the lifecycle of post-painted aluminium, based on characterised end-point results. Environmental hotspot results show which unit processes of the cradle-to-grave boundary contribute most (and least). Figure 10 shows the breakdown of each environmental impact category for paint manufacture and paint application stages of post-painted aluminium only.

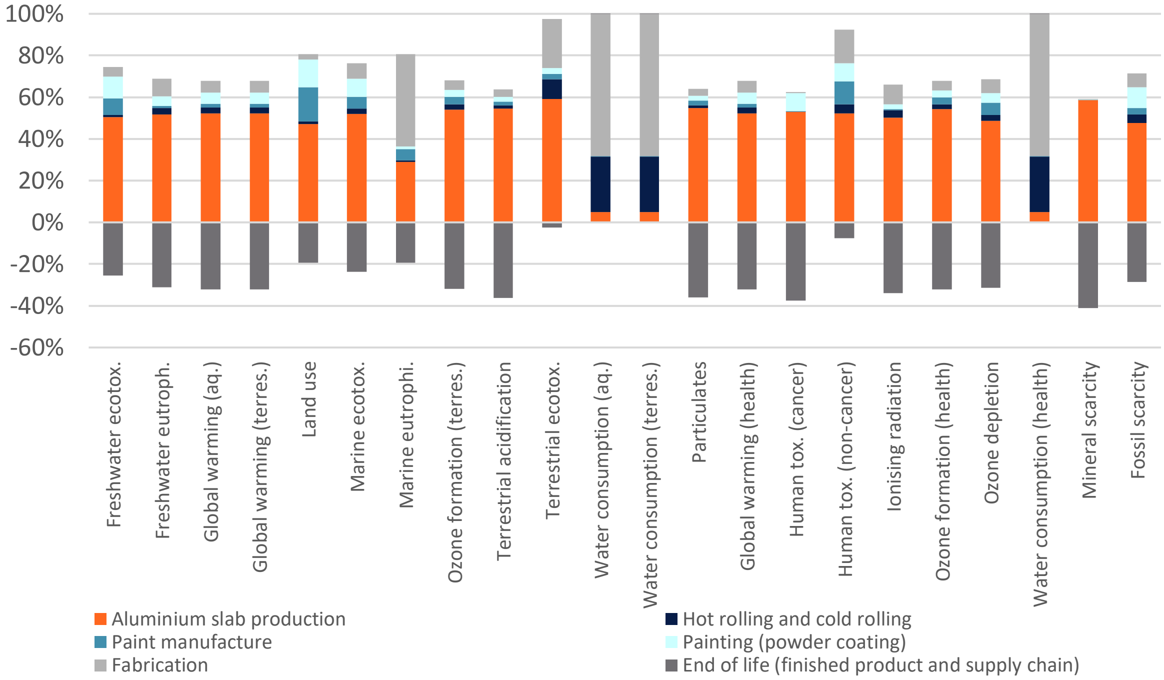


Figure 9 – Environmental hotspots for post-painted aluminium (cradle-to-grave)

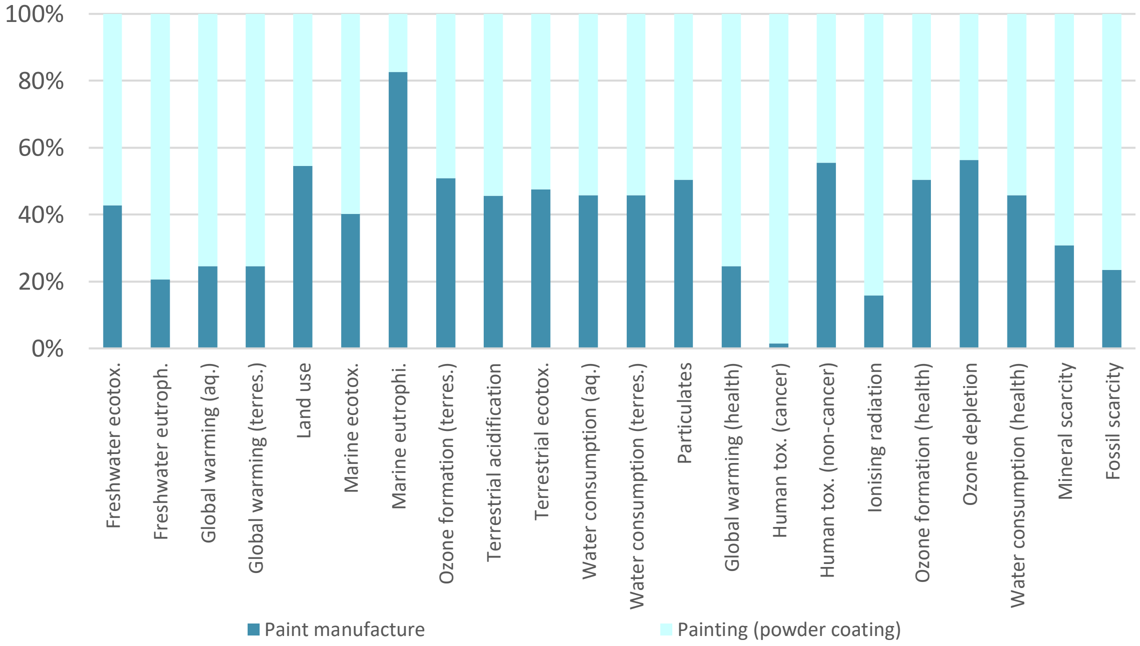


Figure 10 – Environmental hotspots for post-painted aluminium (paint manufacture and application)

The following points are evident from Figure 9 and Figure 10:

- The absolute values for aluminium slab production, hot and cold rolling and metal fabrication are identical to those of product system 3: pre-painted aluminium, only their relative contributions change due to the contribution of paint manufacture and application stages;

- Therefore, the above points noted for product system 3 for these unit processes also apply here;
- The contribution of paint production and application to total cradle-to-grave impacts is greater than in the case of pre-painted aluminium, and is substantial for land use (~48%, due to soy used in polyester resin), freshwater ecotoxicity (~37%, due to due to titanium dioxide production used in paint) and carcinogenic human toxicity (~36%, due to waste processes associated with chromium production used in powder-coating pre-treatment) (discussed in Section 2.3); and
- When paint manufacture and application are compared in isolation (Figure 10), paint application is either equal to or greater than that of paint manufacture for most impact categories, except in the case of marine eutrophication.

2.2 Comparative assessment – characterised end-point results

In this comparison between product system 1: pre-painted aluminium and product system 2: post-painted aluminium, only paint manufacture and application stages are compared, as all other life cycle stages are identical in impact.

Figure 11, Figure 12 and Figure 13 provide characterised end-point results per m^2 for paint manufacture and paint application stages of both pre-painted aluminium and post-painted aluminium in order that they can be compared with each other. Characterised end-point results show the potential damage to the environment that each product system has and are expressed in terms of damage to ecosystems (species loss, in Figure 11), human health (disability adjusted life years, DALY, in Figure 12) or resources (USD, in Figure 13). Figure 14 provides all characterised end-point results per m^2 for paint manufacture and paint application stages.

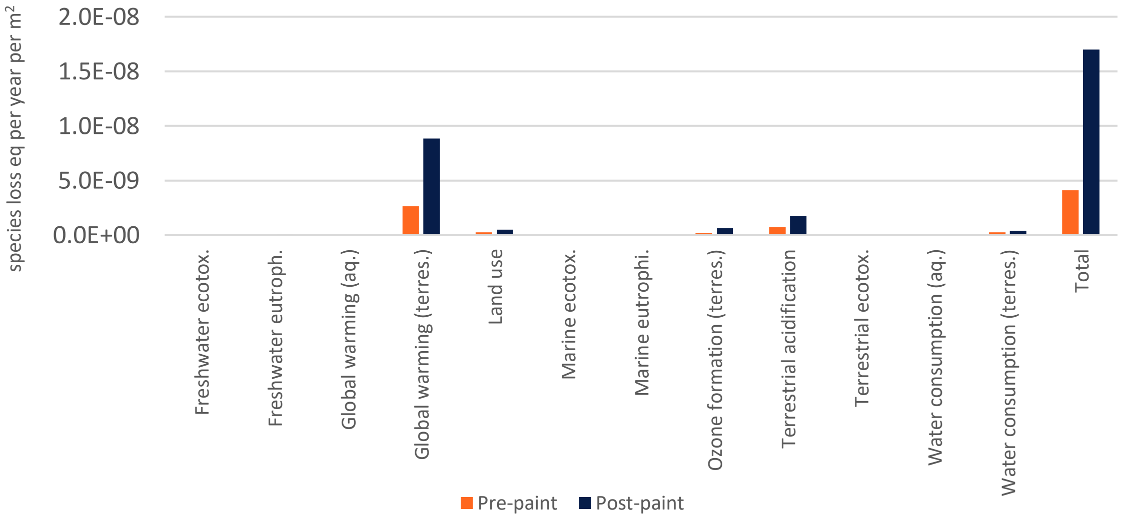


Figure 11 – Characterised end-point results for pre-painted versus post-painted aluminium (ecosystem impact categories, paint manufacture and application only)

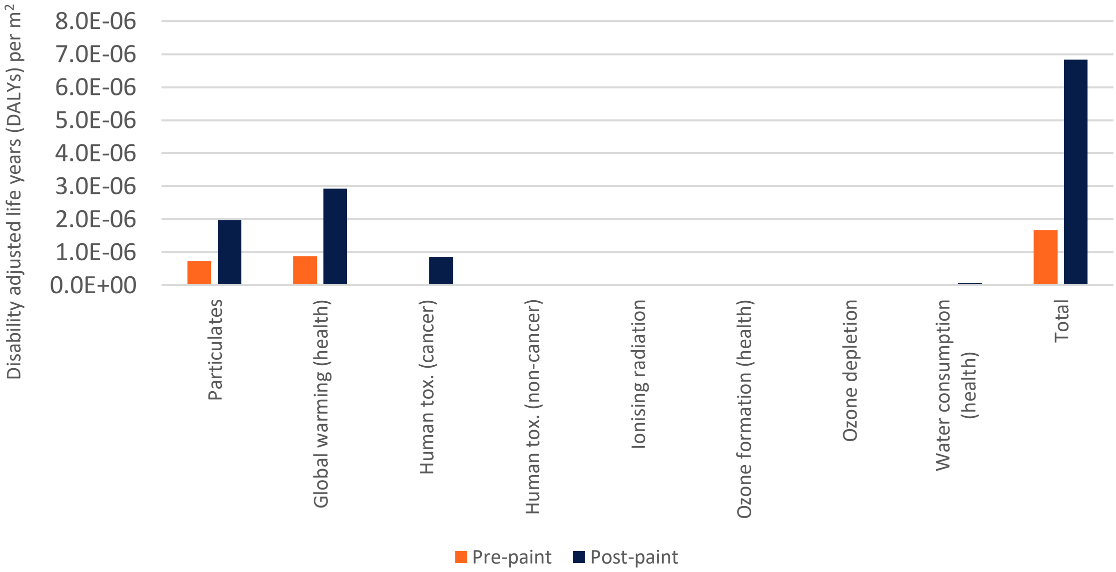


Figure 12 – Characterised end-point results for pre-painted versus post-painted aluminium (human health impact categories, paint manufacture and application only)

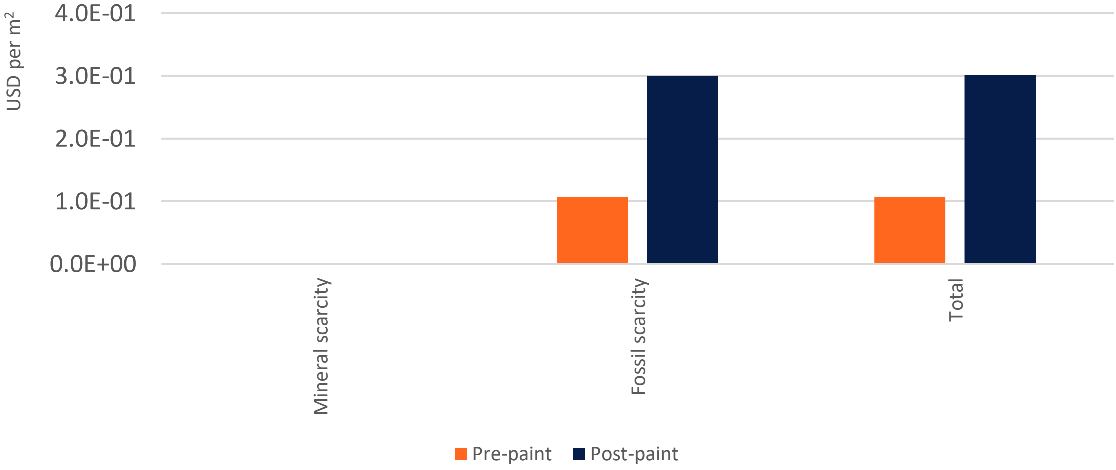


Figure 13 – Characterised end-point results for pre-painted versus post-painted aluminium (resource depletion impact categories, paint manufacture and application only)

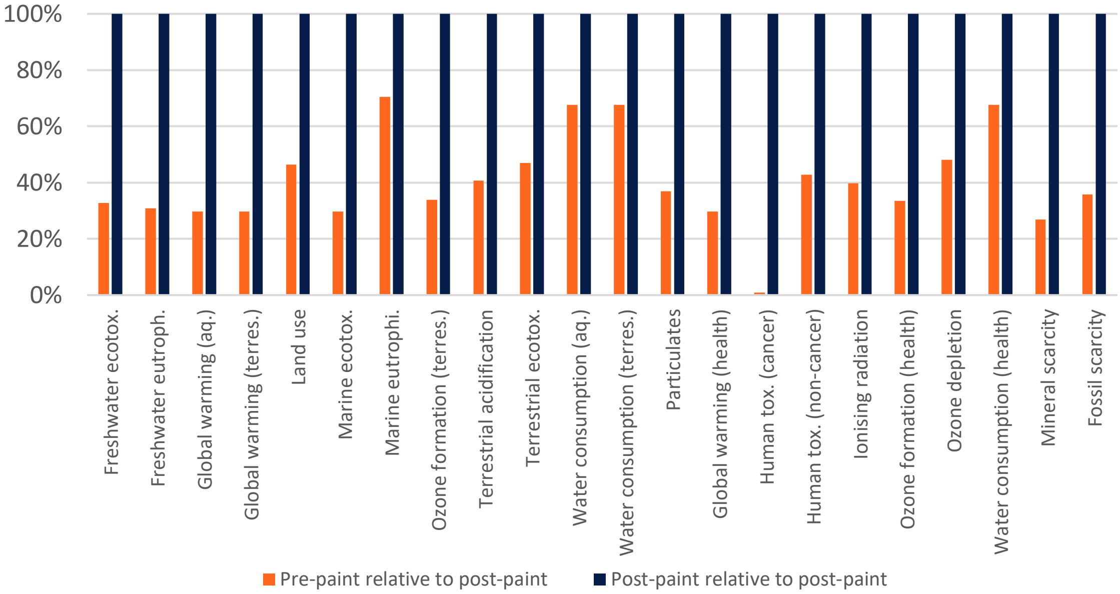


Figure 14 – Characterised end-point results for pre-painted versus post-painted aluminium (paint manufacture and application only, pre-paint relative to post-paint)

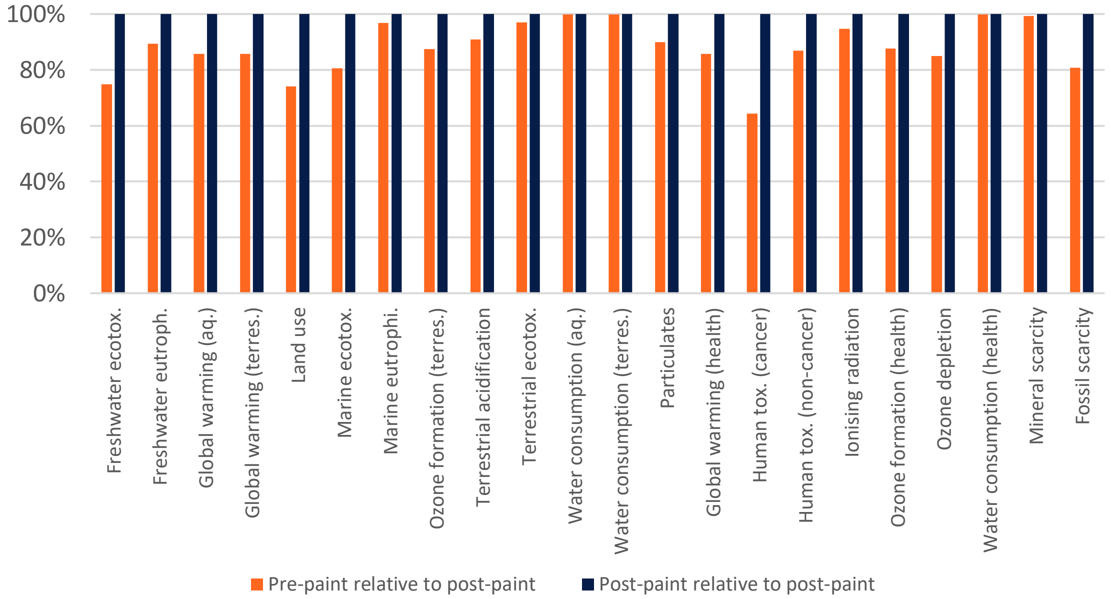


Figure 15 – Characterised end-point results for pre-painted versus post-painted aluminium (full life cycle)

Figure 14 provides characterised end-point results per m^2 for paint manufacture and paint application stages of both pre-painted aluminium and post-painted aluminium, as provided in Figure 11, Figure 12 and Figure 13. However, in this case, results are present relative to the highest impact product system for each impact category, which is fixed at 100%. This representation of results allows for easier comparison between product systems. Figure 1515 shows this comparison over the full life cycle for context.

The following points are evident from Figure 11, Figure 12, Figure 13, Figure 14 and Figure 15:

- For all impact categories, pre-painted aluminium has a lower impact than post-painted aluminium;
- For ecosystem, human health and resource depletion impact category groups, impacts of pre-painted aluminium are 24%, 24% and 36% of those of post-painted aluminium (for paint manufacture and application only), respectively;
- For ecosystem, human health and resource depletion impact category groups, impacts of pre-painted aluminium are 97%, 94% and <100% of those of post-painted aluminium, respectively, over the full life cycle; and
- When results are presented relative to the highest impact product system for each impact category, impacts of pre-painted aluminium are 1 – 70% of those of post-painted aluminium (depending on the impact category, or 64 – <100% of those of post-painted aluminium for full life cycle impacts).

2.3 Deep dives

3.3.1 Solvent-based paint

Figure 16 shows the breakdown of each environmental impact category, as a percentage in a 100% stacked bar chart, for 1 kg organic solvent-based paint used in the coil coating of aluminium, based on characterised end-point results. Deep dive results show which materials and activities contribute most (and least) to this particular process.

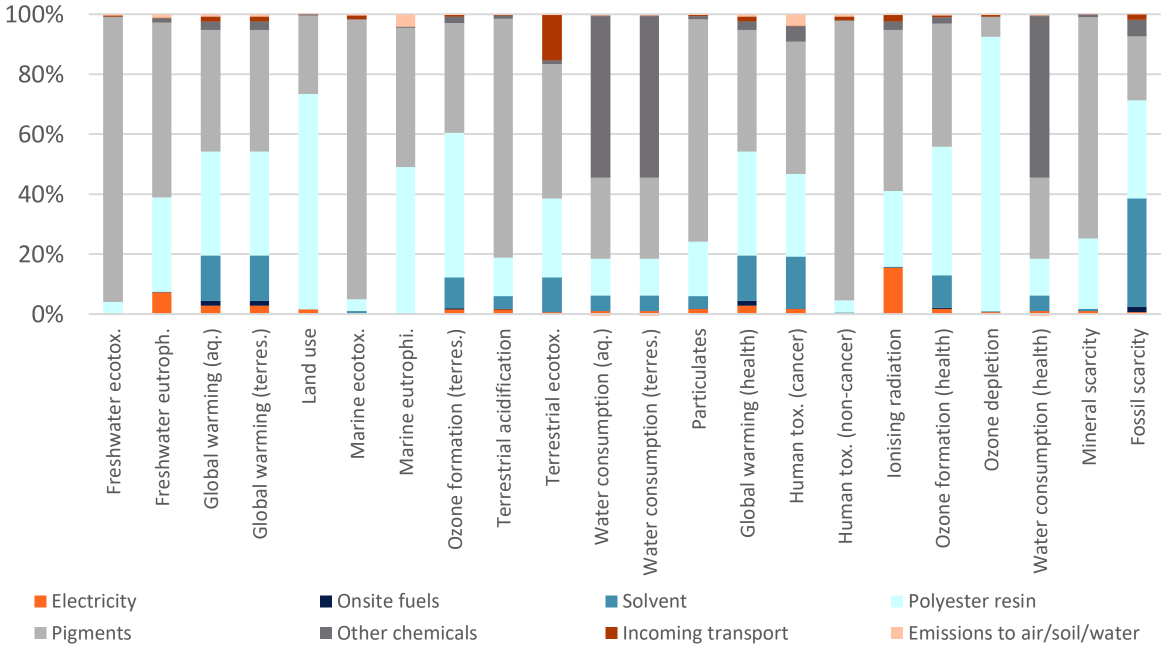


Figure 16 – Deep dive for organic solvent-based paint production (topcoat)

The following points are evident from Figure 16:

- The production of pigments contributes substantially to impacts associated with the production of organic solvent-based paint for most impact categories, with the exception of ozone depletion, global warming, water consumption and fossil scarcity;
- The production of polyester resin contributes notably to impacts associated with the production of organic solvent-based paint, with the exception of ecotoxicity impact categories, carcinogenic human toxicity and mineral scarcity, and it dominates for ozone formation;
- The production of solvent contributes notably to impacts associated with the production of organic solvent-based paint for global warming, ozone formation, terrestrial ecotoxicity, carcinogenic human toxicity and fossil scarcity;
- The impact from onsite fuels, other chemicals and emissions to air/soil/water is immaterial for all impact categories;
- The impact from electricity is immaterial for most impact categories with the exception of ionising radiation (as a result of electricity generation from nuclear fission);
- The impact from incoming transport is immaterial for most impact categories with the exception of terrestrial ecotoxicity (as a result of sulphuric dioxide emissions from vehicle exhaust gases);
- There are no standout hotspots for pigments, but electricity, fuels, production of sulphuric acid and waste gypsum all contribute notably; and
- Digging deeper into the hotspots for polyester resin, production of adipic acid dominates ozone depletion (due to nitrous oxide releases), production of phthalic anhydride dominates marine eutrophication and for other impact categories, production of adipic acid, phthalic anhydride and propylene glycol are all important.

3.3.2 Powder-based paint

Figure 17 shows the breakdown of each environmental impact category, as a percentage in a 100% stacked bar chart, for 1 kg of powder-based paint used in powder coating of aluminium, based on characterised end-point results. Deep dive results show which materials and activities contribute most (and least) to this particular process.

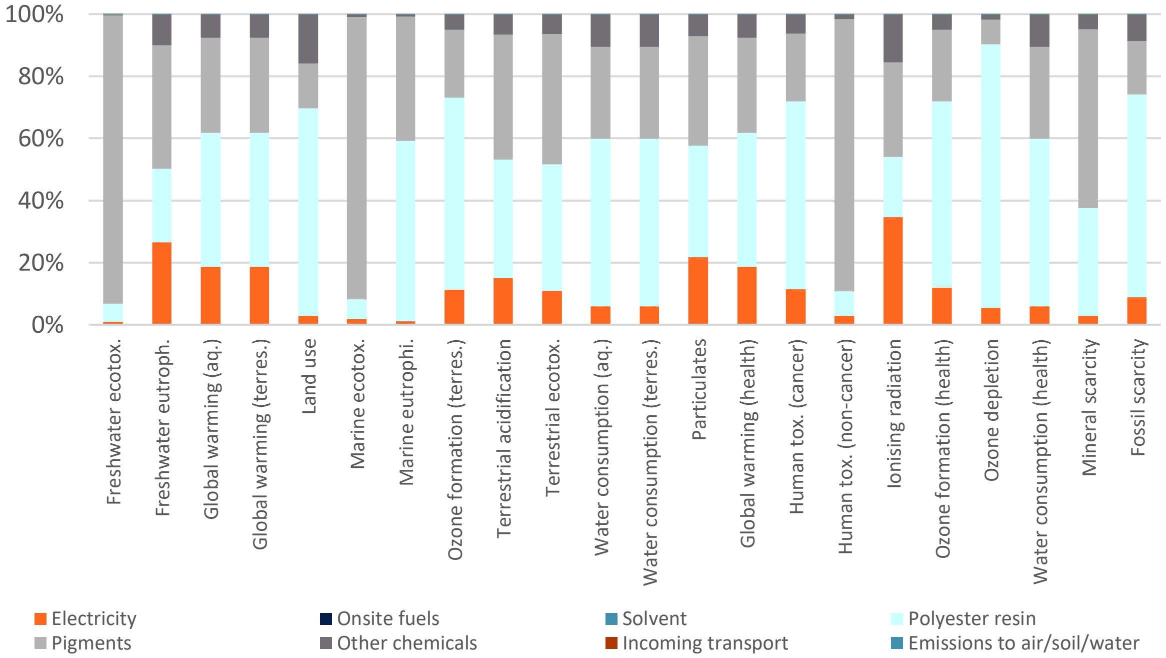


Figure 17 – Deep dive for powder-based paint production

The following points are evident from Figure 17:

- The production of pigments contributes substantially to impacts associated with the production of powder-based paint for most impact categories, with the exception of land use, ozone formation, ozone depletion and fossil scarcity;
- The production of polyester resin contributes substantially to impacts associated with the production of powder-based paint for most impact categories, with the exception of aquatic ecotoxicity impact categories and carcinogenic human toxicity;
- The impacts from electricity and other chemicals is also notable for most impact categories;
- The impact from onsite fuels, incoming transport and emissions to air/soil/water is immaterial for all impact categories;
- No solvents are required for powder paint, therefore the contribution for this material is zero; and
- The hotspots for pigments and polyester resin match those given for organic solvent-based paint.

3.3.3 Hotspot comparison between solvent- and powder-based paint

Figure 18 shows the breakdown of characterised end-point results for hotspot environmental impact categories (fossil scarcity, global warming and particulates), for 1 kg of both solvent- and powder-based paint. This comparison of deep dive results shows which materials and activities contribute most (and least) to these particular processes and how they compare.

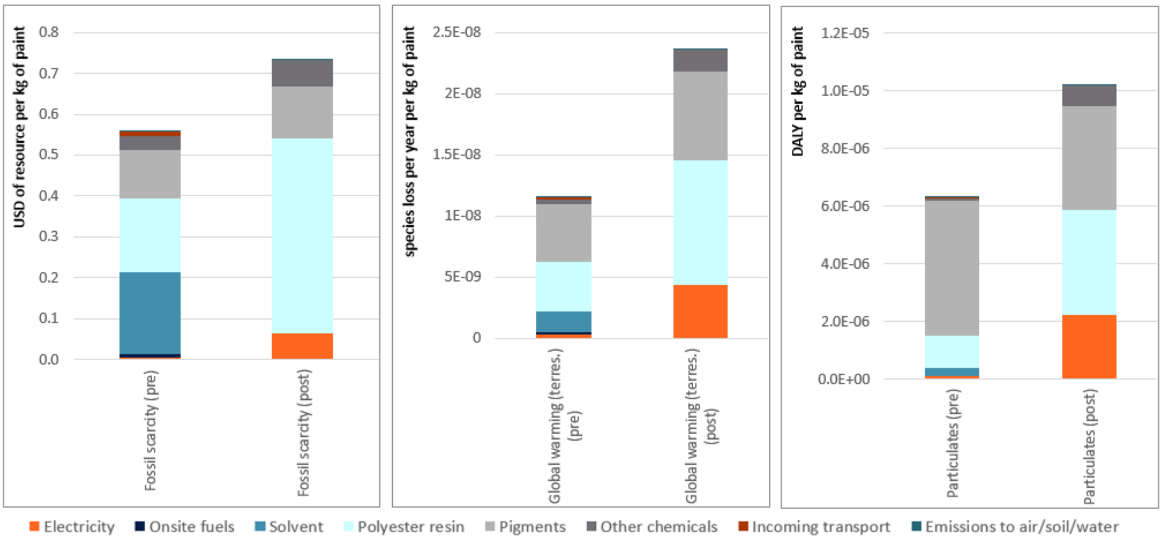


Figure 18 – Deep dive comparison between solvent-based (pre-paint) and powder-based (post-paint) paint for impact category hotspots (for both steel and aluminium product systems).

The following points are evident from Figure 18:

- For impact category hotspots, and all other impact categories (not shown in Figure 18), the impact per kg of solvent-based paint is lower than that of powder-based paint;
- Larger energy requirements for powder-based paint and larger kg of resin per kg of paint relative to those used in solvent-based paint drive these differences;
- Scaling up to the contribution of paint per m^2 of coated steel, the difference in impact is entirely due to differences in the per kg impacts of the paint rather than differences in paint thickness as the mass of paint applied is broadly the same for pre-and post-painted steel (77.9 g / m^2 for pre-paint vs 71.2 g / m^2 for post-paint); and
- Scaling up to the contribution of paint per m^2 of coated aluminium, the difference in impact is partly due to differences in the per kg impacts of the paint and partly due to differences in paint thickness as the mass of paint applied to pre-painted aluminium (77.9 g / m^2) is less than that applied to post-painted aluminium (96.5 g / m^2).

3.3.4 Aluminium coil-coating

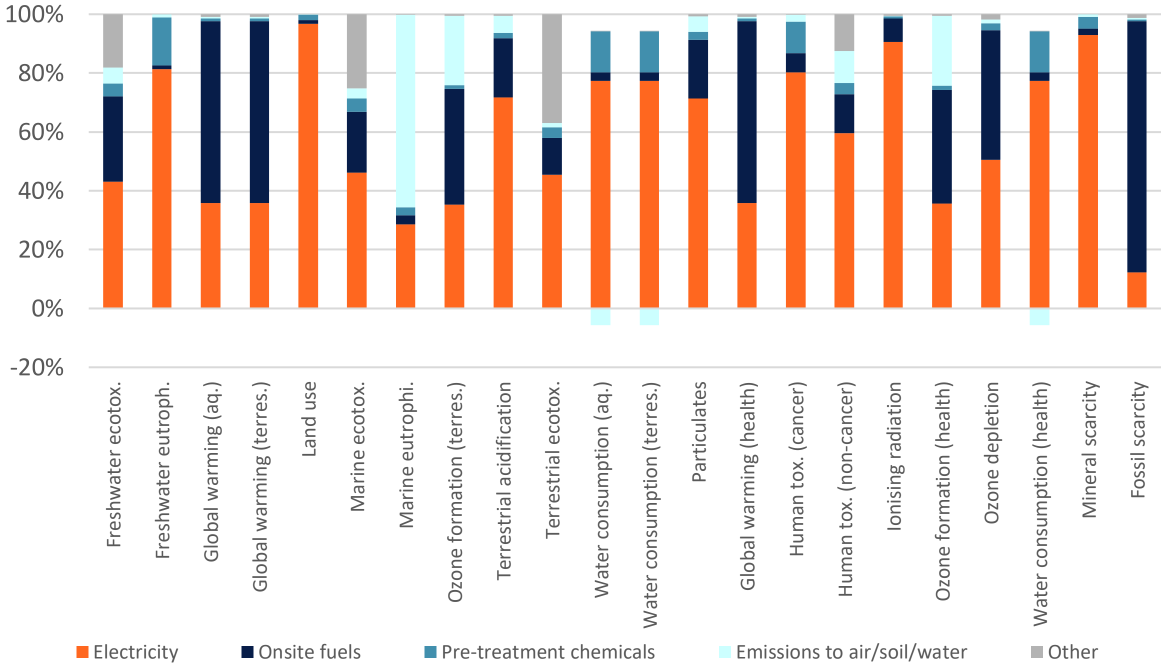


Figure 19 – Deep dive for aluminium coil coating

Figure 19 shows the breakdown of each environmental impact category, as a percentage in a 100% stacked bar chart, for 1 m^2 of aluminium coil coating, based on characterised end-point results. Deep dive results show which materials and activities contribute most (and least) to this particular process.

The following points are evident from Figure 19:

- The contribution of electricity and onsite fuels to impacts from paint application dominates the majority of impact categories, with the exception of ecotoxicity impact categories, marine eutrophication and human toxicity;
- In the case of marine eutrophication and human toxicity, emissions to air/soil/water contributes most to impacts from paint application (as a result of wastewater and solid waste treatment); and
- In the case of ecotoxicity impact categories, transportation of incoming materials contributes most to impacts from paint application.

3.3.5 Aluminium powder-coating

Figure 20 shows the breakdown of each environmental impact category, as a percentage in a 100% stacked bar chart, for 1 m^2 of aluminium powder-coating, based on characterised end-point results. Deep dive results show which materials and activities contribute most (and least) to this particular process.

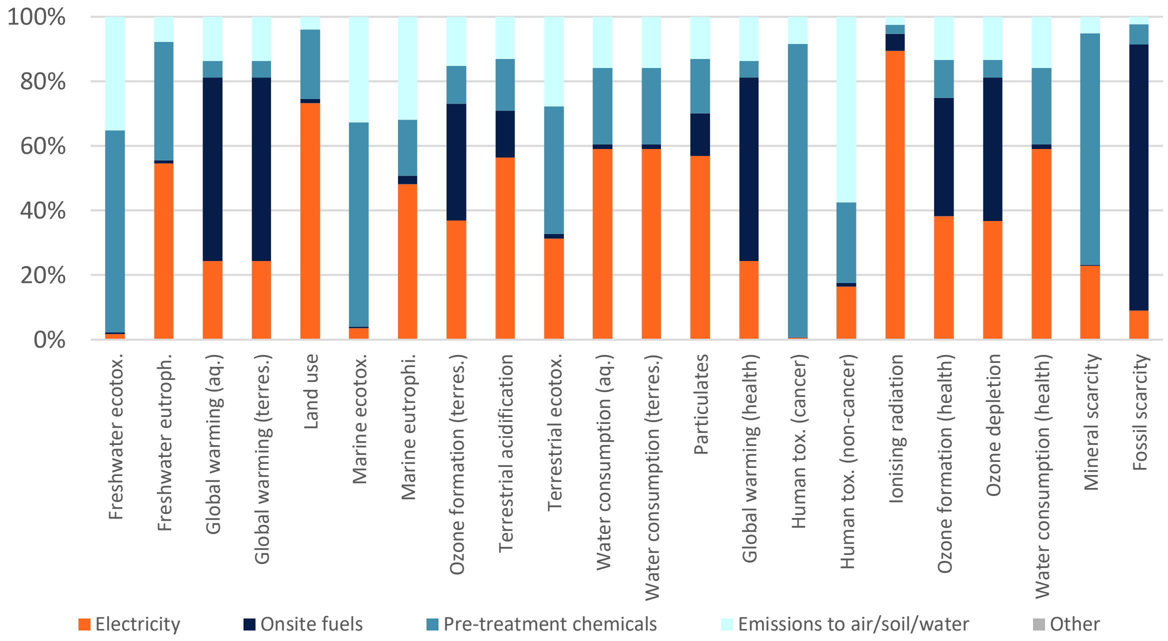


Figure 20 – Deep dive for aluminium powder coating

The following points are evident from Figure 20:

- The contribution of electricity and onsite fuels to impacts from paint application dominates the majority of impact categories, with the exception of ecotoxicity impact categories, eutrophication impact categories, mineral scarcity and human toxicity;
- In the case of eutrophication impact categories (as a result of hazardous waste disposal), ecotoxicity impact categories, mineral scarcity and non-carcinogenic human toxicity (as a result of chromium (III) production), pre-treatment contributes most to impacts from paint application; and
- In the case of carcinogenic human toxicity, emissions to air/soil/water contributes most to impacts from paint application (as a result of hazardous waste disposal).

3.3.6 Hotspot comparison between aluminium coil coating and aluminium powder coating

Figure 21 shows the breakdown of characterised end-point results for hotspot environmental impact categories (fossil scarcity, global warming and particulates), for 1 m^2 of both aluminium coil coating and aluminium powder coating. This comparison of deep dive results shows which materials and activities contribute most (and least) to these particular processes and how they compare.

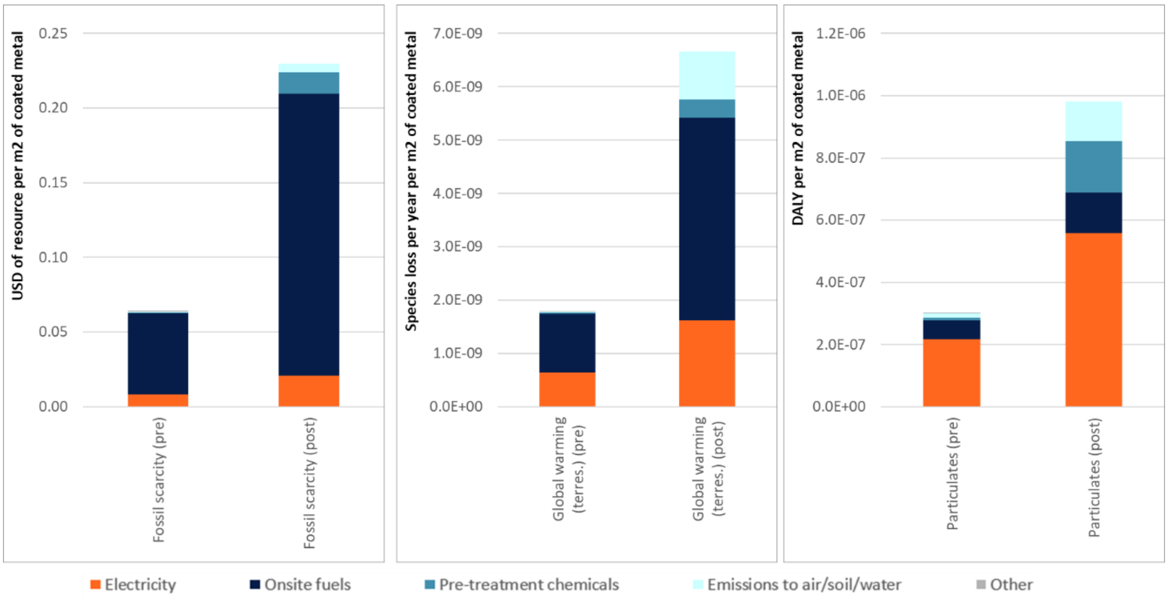


Figure 21 – Deep dive comparison between aluminium coil coating (pre-paint) and aluminium powder coating (post-paint) for impact category hotspots

The following points are evident from Figure 21:

- For impact category hotspots, and overall for ecosystems, human health and resources impact category groups (not shown in Figure 21), application of paint by coil coating used for pre-painted aluminium has a lower impact than application of paint by powder-coating used for post-painted aluminium; and
- Larger energy requirements for powder coating relative to coil coating drive these differences except in the case of aquatic ecotoxicity impact categories (due to chromium (III) production), eutrophication impact categories (due to hazardous waste disposal) and human toxicity (due to chromium (III) production).

3. Conclusions

The LCA study presented in this report generated environmental profiles of pre- and post-painted aluminium in order to better understand the associated environmental impacts of both pre- and post-painting of these metals in comparison to one another. The functional unit for this study was defined as “1 square metre of 0.8 mm sheet aluminium coated both sides with a polyester-based paint for use in a building panel in Europe with a lifetime of 30 years” for aluminium, the system boundary was set at cradle-to-grave (but with a focus on paint manufacture and application stages), the LCIA method used was ReCiPe 2016 v1.1 (Hierarchic) and the LCA model was constructed in SimaPro v8.4.

The following conclusions can be drawn from this study:

- For all impact categories, pre-painted aluminium has a lower impact than post-painted aluminium (1 – 70% of those of post-painted aluminium, depending on the impact category, for paint production and application stages, or 64 – <100% of those of post-painted aluminium for full life cycle impacts).
- For ecosystem, human health and resource depletion impact category groups, impacts of pre-painted aluminium are 24%, 24% and 36% of those of post-painted aluminium, respectively (for paint production and application stages, or 97%, 94%

and <100% of those of post-painted aluminium for full life cycle impacts, respectively).

- The differences in impact are mostly driven by coil coating using less energy during paint application in comparison to powder-coating, less paint being required for coil coating (in the case of aluminium), per kg impacts of organic solvent-based paint being less than those of powder-based paint and less intensive pre-treatment being required for coil coating in comparison to powder coating.
- Whilst paint thickness is an important parameter, within the range of paint thicknesses modelled in the sensitivity analysis, pre-painted aluminium always has the lowest impact when compared with post-painted aluminium.
- For certain impact categories (freshwater ecotoxicity, marine ecotoxicity, carcinogenic human toxicity and mineral scarcity) the removal of chromium from pre-treatment (before post-painting aluminium) results in a reduction of environmental impact. However, the impact is not lower than that of pre-painted aluminium for any impact category.
- An uncertainty analysis was performed using a different life cycle impact assessment method (CML-IA baseline v4.2 / EU25 rather than ReCiPe 2016 v1.1 (Hierarchic) in the base-case). Despite there being a different selection of impact categories in CML-IA baseline v4.2 / EU25 compared with ReCiPe 2016 v1.1 (Hierarchic), impacts for pre-painted aluminium were lower for every CML-IA baseline v4.2 / EU25 impact category in comparison to post-painted aluminium, as was the case in the base-case.

The results within this report are limited by:

- The scope, boundaries and reference period defined within this assessment (e.g. cradle-to-grave system boundary);
- The ability for primary data from ECCA members used in this study to represent coil coating in Europe;
- The ability for primary data from ECCA coil coaters to represent building panels specifically;
- The ability of building panels as products to represent coil coating and powder painting of sheet metal (it is noted, however, that both paint methods are commonly used for these products);
- The secondary data used for product systems 2;
- The assumptions defined within this assessment (see Section 1.9); and
- The exclusions defined within this assessment (see Section 1.10).

Results were validated through a) internal QA/QC procedures at Anthesis, b) presentation of results to ECCA's technical committee, c) distribution of the draft report for comment to ECCA members more widely and d) searching for other studies to compare results against. On this last point, there are no studies to the authors' knowledge that compare pre-painted aluminium with post-painted aluminium.

As with all LCA, this LCA shall not provide the sole basis of comparative assertion.

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Appendix A – critical review statement and report

The below project has been reviewed, against the ISO standard on LCA, ISO 14044. Details of the review are provided in this critical review statement, which has been prepared in accordance with ISO TS 14071.

Title of study: Comparative life cycle assessment of pre-painted (coil coated) and post-painted sheet aluminium for the construction market

Commissioner of the LCA study: European Coil Coating Association (ECCA)

Practitioner of the LCA study: Anthesis Consulting Group

Version of the report which the critical statement belongs: Report dated 29 April 2019

The review was undertaken as a critical review by a panel of interested parties (Section 6.3 of ISO 14044), as required for comparative LCA studies, where the results are intended to be used to support a comparative assertion intended to be disclosed to the public.

The review team was composed of:

Dr Craig Jones (Chair) - PhD in LCA, MEng in Mechanical Engineering, 15 years' experience of LCA.

Jane Anderson - BA MSc DipLCM, 20 years' experience of LCA.

Mauro Chiappini - MSc Applied Mathematics for Decision Making, MSc Applied Mathematics for Systems Control, Certificate from British Columbia University on Climate Change, 14 years' experience of LCA specialist. Part-time lecturer on sustainability.

Dr Nick Coleman - Postgraduate qualification in LCA, PhD and MChem in Chemistry, 16 years' experience of LCA and the steel industry.

Alan Pursglove - MSc, over 30 years' experience in technical roles in paint manufacturing (mainly coil) including R&D, Environment, H&S and Quality.

All reviewers were external and independent of the project.

The critical review process ensured that:

- The methods used to carry out the LCA are consistent with ISO 14040/44;
- 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.

Reviewers were not provided with access to the Life Cycle Inventory (LCI) model. However, they were provided with a detailed LCA report and the project team offered to walk through the model upon request. The review was undertaken at the end of the study. The LCA report identified the individual datasets that were used from the background LCA database, as well as documenting other key data and assumptions. Access was provided to the review team, to primary data that was provided in confidence to the commissioner of the LCA study.

The reviewers used a peer review template to log their comments. These were discussed with the project team and followed up by a written response to each comment. Reviewers proceeded to check that they were satisfied with the responses or requested their final changes.

The separate critical review report provides a log of all review comments.

The review team considered that the LCA was a well-considered study, which has considered a lot of data to produce the LCA results. Sensitivity analysis was used to test the strength of conclusions. The LCA team and the client were also responsive to all requests for further data and in responding to the peer review comments.

In summary, the review team found that the final LCA report was in accordance with ISO 14044.

Yours sincerely,

Dr Craig Jones, Review Team Chair

[Signed on behalf of the full review team]