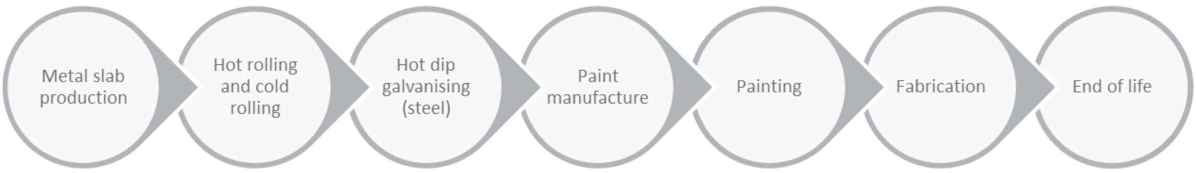
European Coil Coating Association (ECCA)

Comparative life cycle assessment of pre-painted (coil coated) and post-painted sheet steel for domestic appliance manufacture.

Summary Report



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Comparative life cycle assessment of pre-painted (coil coated) and post-painted sheet steel for domestic appliance manufacture.

Executive summary

Background

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 steel 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 steel for use by domestic appliance manufacturers;
- **Product system 2:** Post-painted steel for use by domestic appliance manufacturers;

The system boundary for each product system of this LCA study was '**cradle-to-grave**', from extraction and refining of raw materials to the 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 0.6 mm sheet steel coated both sides with a polyester-based paint for use as a domestic appliance wrapper in Europe with a lifetime of 15 years"

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

Figure 1 provides characterised end-point results per m^2 for paint manufacture and paint application stages of both pre-painted steel and post-painted steel. 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.

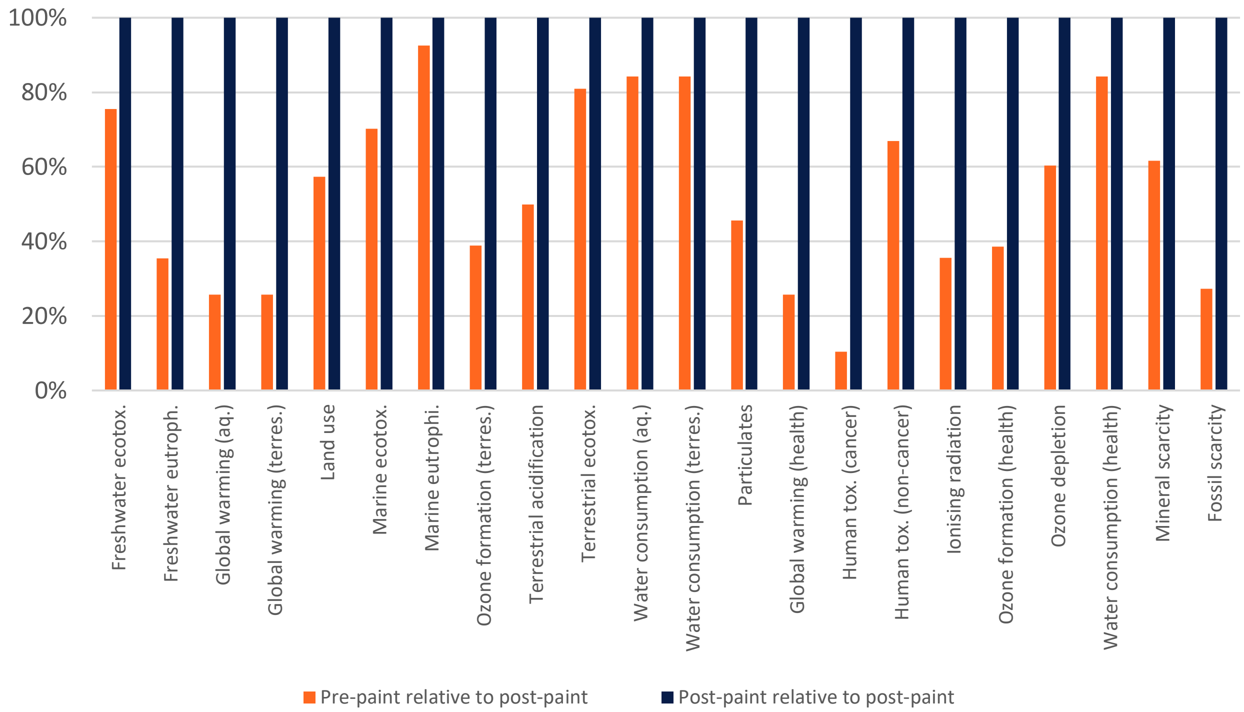


Figure 1 – Characterised end-point results for pre-painted versus post-painted steel (paint manufacture and application only, pre-paint relative to post-paint)

It is evident from Figure 1 that for all impact categories, pre-painted steel has a lower impact than post-painted steel.

The following conclusions can be drawn from this study:

- For all impact categories, pre-painted steel has a lower impact than post-painted steel (10 – 93% of those of post-painted steel, depending on the impact category, for paint production and application stages, or 82 – <100% of those of post-painted steel for full life cycle impacts).
- For ecosystem, human health and resource depletion impact category groups, impacts of pre-painted steel are 25%, 25% and 27% of those of post-painted steel, respectively (for paint production and application stages, or 98%, 97% and 84% of those of post-painted steel 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 steel almost always has the lowest impact when compared with post-painted steel (except in the case of freshwater ecotoxicity, marine eutrophication, terrestrial ecotoxicity and water consumption).

Table of contents

1 Goal and scope

1.1 Background

The European Coil Coating Association (ECCA) are interested in better understanding the environmental profile of products manufactured by their member companies. By working with Anthesis, ECCA have compared the environmental impacts associated with coil coated (pre-painted) sheet steel in comparison to post-painted sheet metal for use by domestic appliance manufacturers.

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.

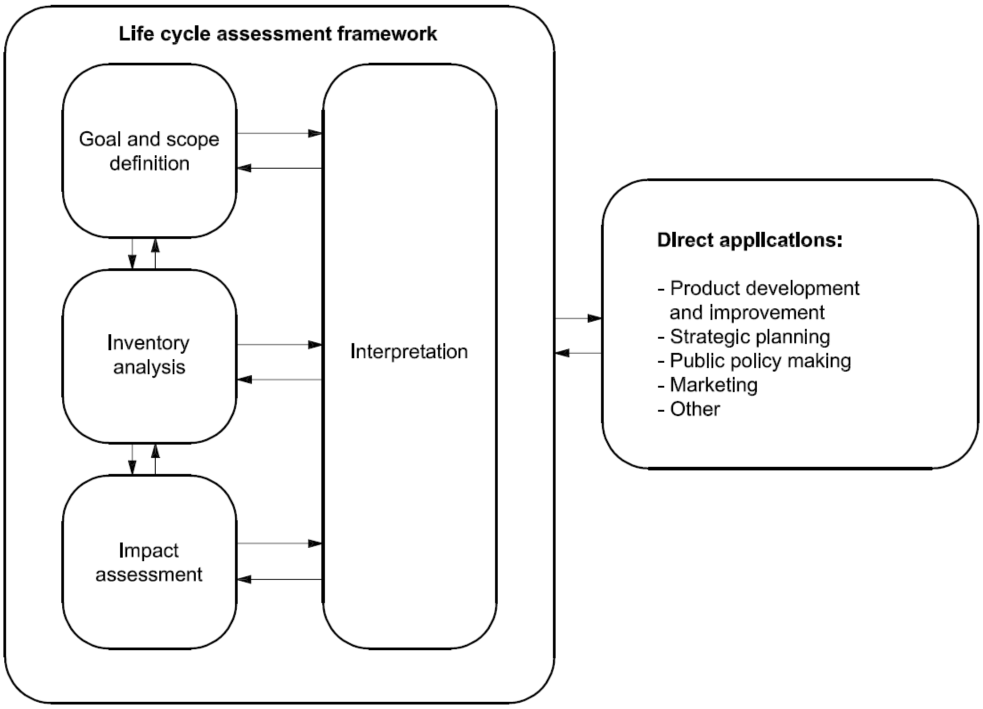


Figure 2 – The four stages of LCA as defined by ISO 14040 (source: ISO).

1.2 Goal of the study

The goal of this study was to generate environmental profiles of pre- and post-painted sheet steel 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 steel for use by domestic appliance manufacturers;
- **Product system 2:** Post-painted steel for use by domestic appliance manufacturers;

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 steel;
- 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 study has undergone a critical review by a panel of experts and the critical review statement is 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 steel sheet (e.g. smelting, refining, rolling), continuous hot dip galvanising (HDG) both sides, coil coating of both sides of steel (or in-house powder coating by appliance manufacturers or 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. It should be noted that in both pre- and post-painted product systems the same specification of steel has been modelled. In addition, whilst aspects of the use phase have been considered, an assessment of the impacts has been excluded from the study because there is no firm evidence that there would be any difference in durability between pre-painted and post-painted metal (see Section 1.4).

The system boundary includes cutting, bending, shaping and powder coating painting of HDG sheet steel that may occur at the domestic appliance manufacturer so that the equivalent processes used in the pre-painted steel option are also modelled in the post-painted option (i.e. processes required to achieve a painted sheet steel component, e.g. a ‘painted wrapper’). However, for both pre- and post-painted steel, the boundary excludes all other processes involved in the manufacture of products that the painted steel is used for (e.g. manufacture of the motor, drum, pump etc. of a washing machine and final assembly of appliance), as there are unlikely to be substantial differences in impact that are a direct result of the two steel options in this lifecycle stage.

1.4 Functional unit

The function of the sheet steel product systems is, in each case, to provide protection from the outer environment to items contained within the sheet metal “wrapper”, provide structural support, and to enhance aesthetics (e.g. surface finish). The painted sheet steel is used to enclose the washing machine, the main function of the product system is to create a barrier between the inner components (e.g. motor, drum, pump etc.) and the outer environment to protect both the user and washing machine components against damage.

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

"1 square metre of 0.6 mm sheet steel coated both sides with a polyester-based paint for use as a domestic appliance wrapper in Europe with a lifetime of 15 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) has been excluded. For most appliances, the expected lifetime of the steel wrapper is longer than the reference service lifetime of the domestic appliance as other components are more likely to fail (e.g. the motor) many years before the wrapper. Therefore, any difference in lifetime between pre- and post-painted steel is irrelevant if the product is no longer in use.

1.5 Product systems description

The following product systems were investigated:

- **Product system 1**: pre-painted steel for use by domestic appliance manufacturers;
- **Product system 2**: post-painted steel for use by domestic appliance manufacturers;

Process flow diagrams for these product systems are provided in Figure 4 and Figure 5, which are broken down into the unit processes described below. 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).

1.5.1 Product system 1: Pre-painted steel for use by domestic appliance manufacturers

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:

Unit process 1 – Steel slab production

Unit process 2 – Hot rolling and cold rolling

Unit process 3 – Continuous hot dip galvanising

Unit process 4 – 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 5 – Coil coating (see Figure 3):

- De-coiling and splicing: coils of sheet steel 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 steel is cleaning/degreased using inputs of quicklime, organic solvents and titanium (excluded) and brushed. Electricity is required and some hazardous waste for treatment is created.
- Drying oven: heat is required to dry the line of sheet steel. 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 steel 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.
- Laminating/embossing: polymer films are added to the line of coated sheet steel using heat and electricity. Excluded (as not relevant for polyester-based paint).
- Coiling and packaging: the line of coated sheet steel is re-coiled (an accumulator stack allows the line to be slowed down so that allows 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. It is assumed that coil coating lines are located on different sites from galvanising lines.

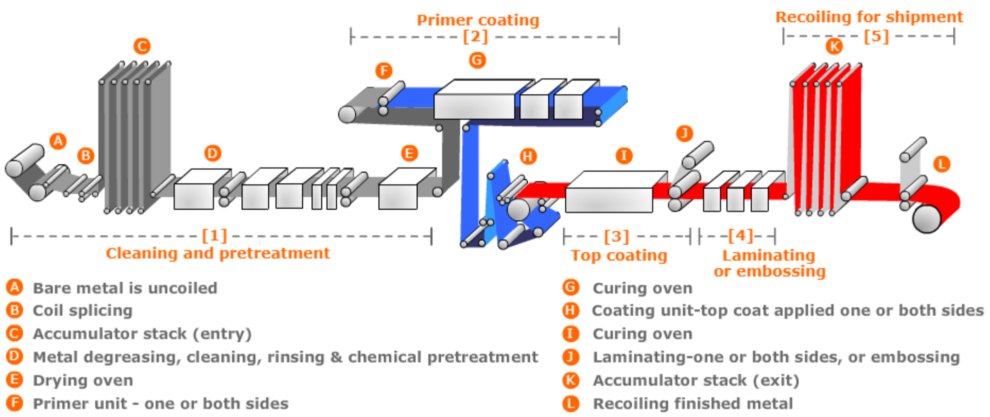


Figure 3 – Coil coating process (source: ECCA). Note - process J is optional.

Unit process 6 – Coated sheet metal fabrication and appliance manufacture:

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

Unit process 7 – Use:

- Replacement of appliance: excluded.
- Maintenance and use of appliance: excluded.
- Transportation of finished product to customer: excluded.

Unit process 8 – End-of-life:

- Recycling: inputs comprise the scrap steel recovered from appliances, which is then sorted and treated by a recycling facility. The process requires heat and electricity. The output is scrap steel to be used in another product system.
- Landfill: inputs comprise the scrap steel which is not recovered from appliances or otherwise ends up in landfill. Emissions to water and soil from landfill leachate include metals.
- End-of-life of appliance: excluded.
- Transportation of waste for treatment.

1.5.2 Product system 2: Post-painted steel for use by domestic appliance manufacturers

A PFD for this product system is provided in Figure 5. Unit process 1 – 3, 6 and 7 are identical processes as described in product system 1, all other unit processes are described here:

Unit process 4 – 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 appliance manufacture:

- Cutting, pressing, bending etc.: the appliance 'wrapper' is formed by cutting, pressing, bending, forming and shaping sheet steel. This may occur at the same site as the appliance manufacturer or at a steel fabricator's site – for this model we have assumed fabrication occurs at a different site to appliance manufacture. Electricity is required.
- Cleaning, degreasing, brushing, other pre-treatment: the sheet steel wrapper components are cleaning/degreased and pre-treated using inputs of sodium hydroxide, iron sulphate, trisodium phosphate, surfactants, deionised water and titanium (excluded) and brushed. Electricity is required.
- Drying oven: the sheet steel wrapper components may be dried in ambient temperature or in an oven. Heat and electricity are required.
- Powder coating: sheet steel components 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: painted sheet steel components are cured in a curing oven. Heat and electricity are required. Packaging is excluded.
- Manufacture of all other components of the domestic appliance: 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 steel for use by domestic appliance manufacturers (hashed boxes indicated that the process is excluded)

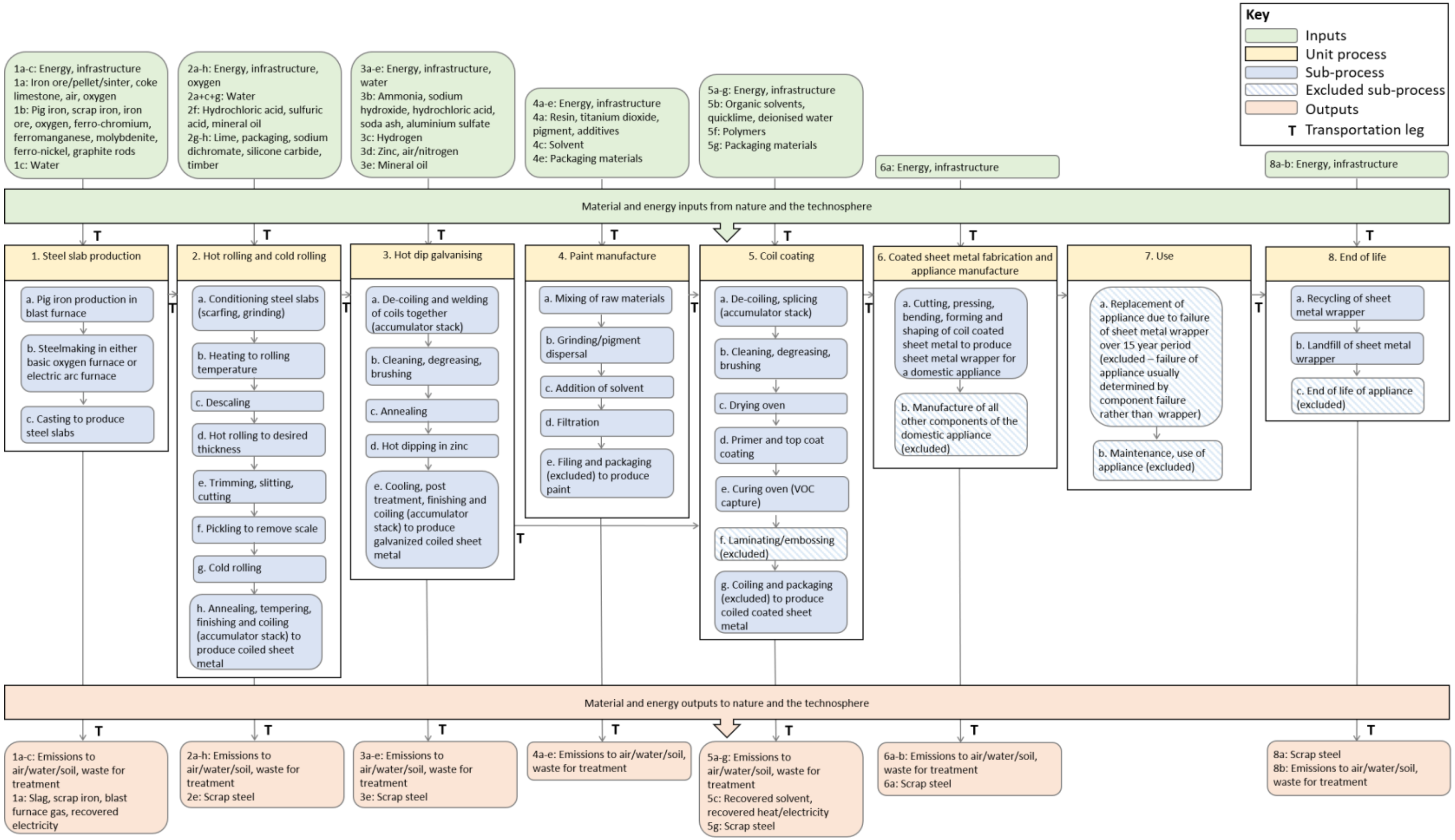
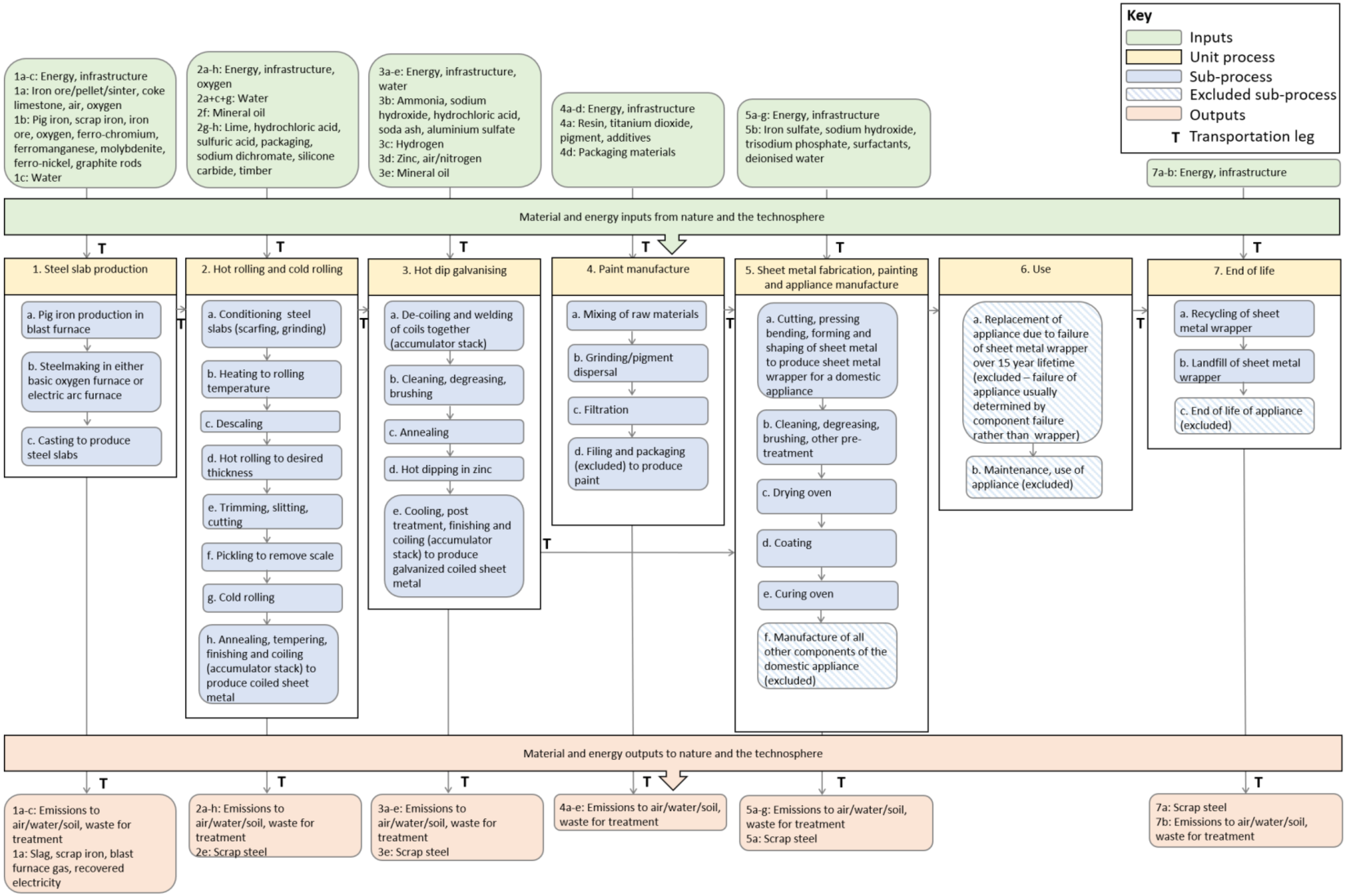


Figure 5 – Process flow diagram for product system 2: post-painted steel for use by domestic appliance manufacturers (hashed boxes indicated that the process is excluded)



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 number of 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:

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

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

The 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 steel (product system 1). Secondary data was used for all other lifecycle stages for pre-painted steel and for the entire lifecycle of post-painted steel (product system 2).

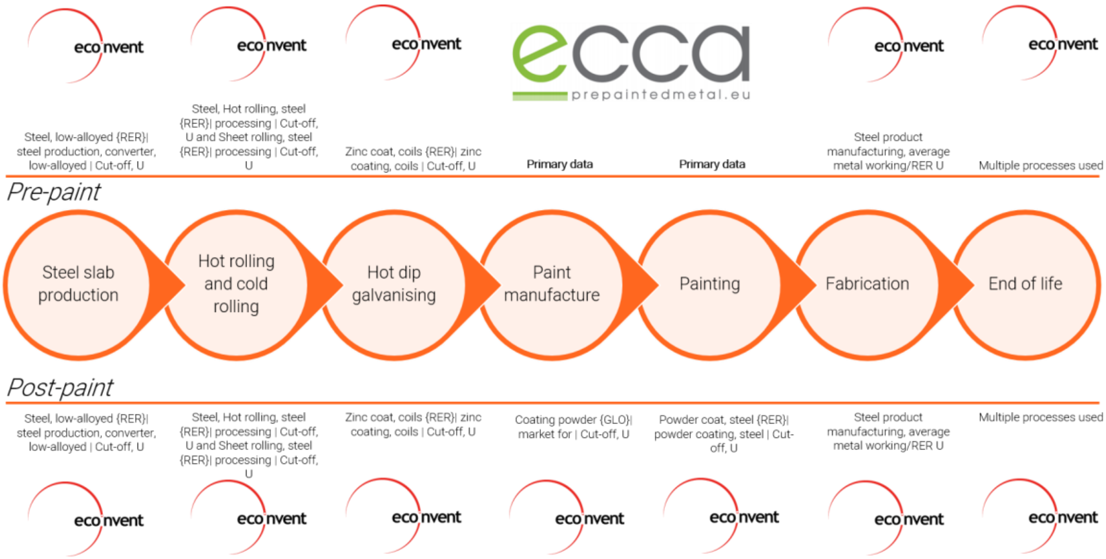


Figure 6 – summary of inventory data used for pre- and post-painted steel

1.9 Assumptions

During this LCA a number of assumptions were made, the most important of these assumptions are described below for transparency.

- All sheet steel was assumed to be both hot rolled and then cold rolled.
- 100% of scrap steel generated during manufacturing stages was assumed to be sent for recycling.
- It was assumed that fabrication of metal takes place at a different site to the domestic appliance or 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.

1.10 Exclusions

In addition to those general exclusions described in Section **Error! Reference source not found.**, a number of specific exclusions to the product systems were made. The most important of these exclusions are described below for transparency, with justification in parenthesis.

- Use of titanium in pre-treatment of steel for both pre- and post-painted (same for pre-and post-paint);
- Packaging of paint for all product systems (likely the same for pre-and post-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 domestic appliance for all product systems (out of scope).

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 steel for use by domestic appliance manufacturers;
- **Product system 2**: post-painted steel for use by domestic appliance manufacturers;

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. Sensitivity analyses are presented in Section **Error! Reference source not found.**. 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 units, which are defined as “1 square metre of 0.6 mm sheet steel coated both sides with a polyester-based paint for use as a domestic appliance wrapper in Europe with a lifetime of 15 years” for steel. The only exception is in the “deep dive” of paint manufacture where results are presented per kg of output.

2.1 Environmental hotspots

2.1.1 Product system 1: pre-painted steel 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 steel, 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 below shows the breakdown of each environmental impact category for paint manufacture and paint application stages of pre-painted steel only.

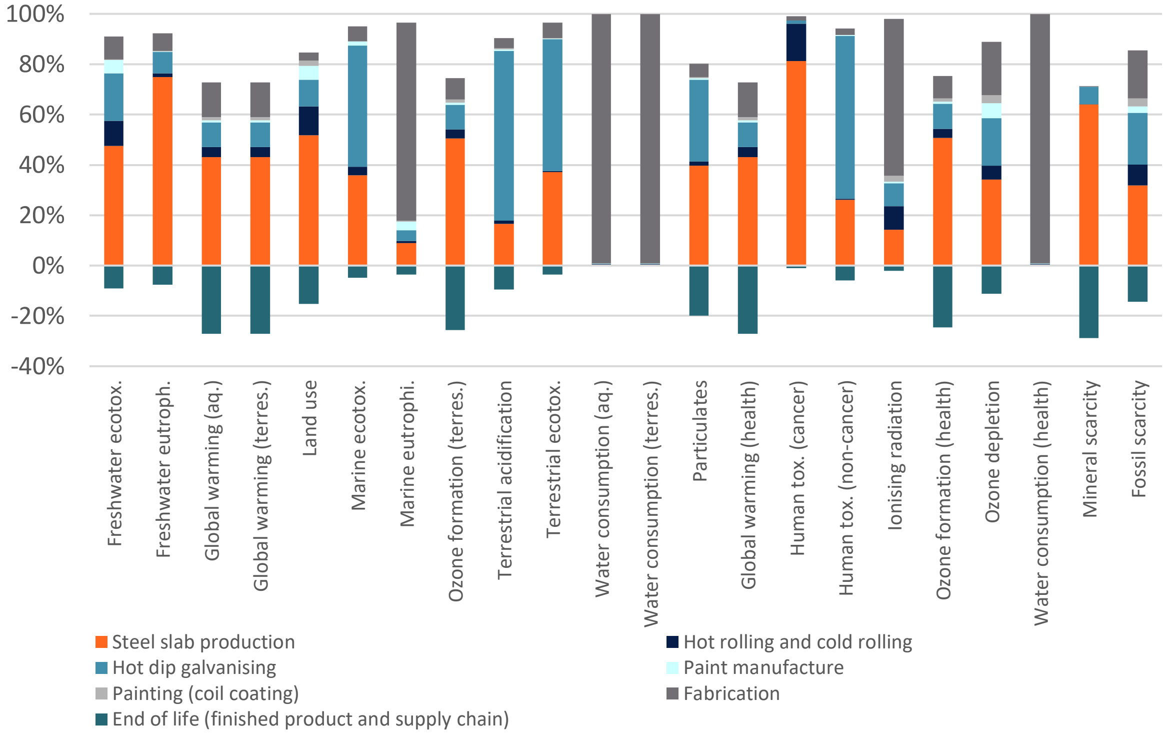


Figure 7 – Environmental hotspots for pre-painted steel (cradle-to-grave)

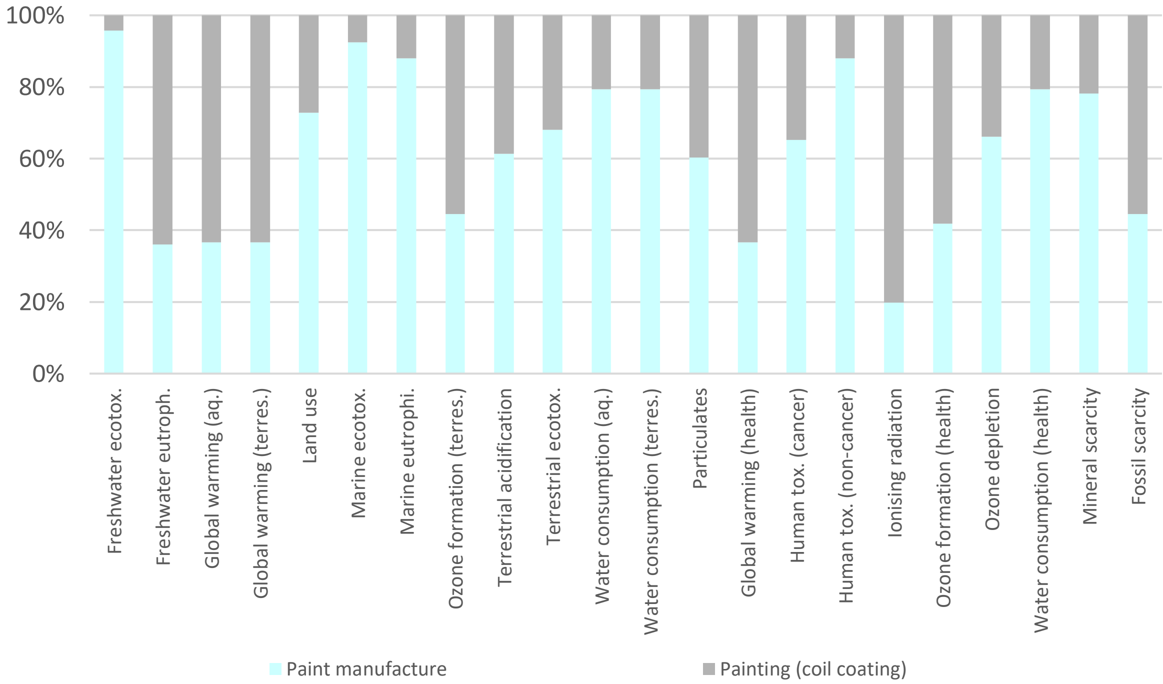


Figure 8 – Environmental hotspots for pre-painted steel (paint manufacture and application)

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

- Steel slab production and continuous hot dip galvanising dominate total cradle-to-grave impacts for most impact categories;
- Metal fabrication dominates some impact categories (e.g. water consumption, marine eutrophication and ionising radiation) and contributes substantially to most other impact categories;
- Digging deeper into hotspots for steel slab production, the production of pig iron dominates most impact categories, except in the cases of freshwater eutrophication (where production of molybdenite is most important), water use (where cooling water during casting is most important) and toxicity/eco-toxicity impact categories (where production of ferronickel, production of ferromanganese and production of ferrochromium are more important);
- In the case of continuous hot dip galvanising hotspots, the production of zinc dominates most impact categories, with natural gas use during galvanising also being important for global warming and fossil resource scarcity impact categories;
- The key hotspot for metal fabrication is electricity use, which 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 manufacture and application represents a small proportion of total cradle-to-grave impacts for most categories (0 – 7%), except for ozone depletion and land use where it is notable (~11%) mainly due to adipic acid used in polyester resin (discussed in Section 2.3); and
- When paint manufacture and application are compared in isolation (Figure 8), paint manufacture dominates for around half the impact categories, whereas paint application (coil coating) only dominates for ionising radiation, with impacts for the remaining impact categories being fairly evenly split between paint manufacture and application.

2.1.2 Product system 2: post-painted steel 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 steel, 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 steel only.

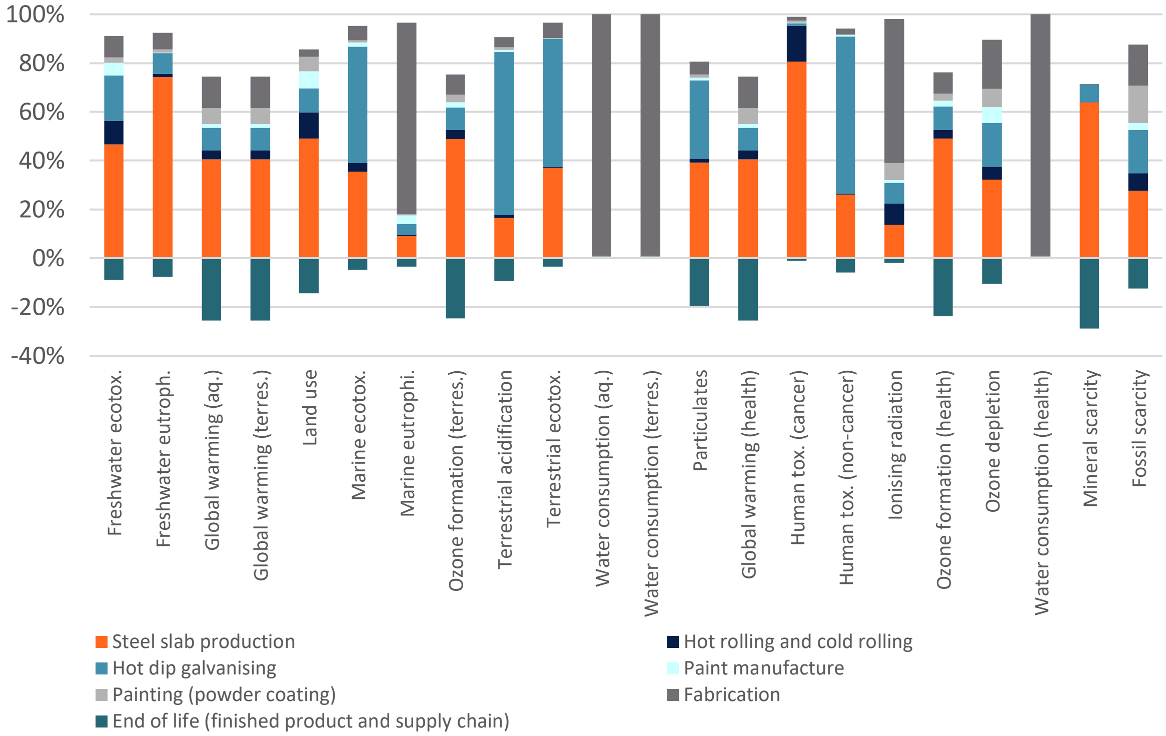


Figure 9 – Environmental hotspots for post-painted steel (cradle-to-grave)

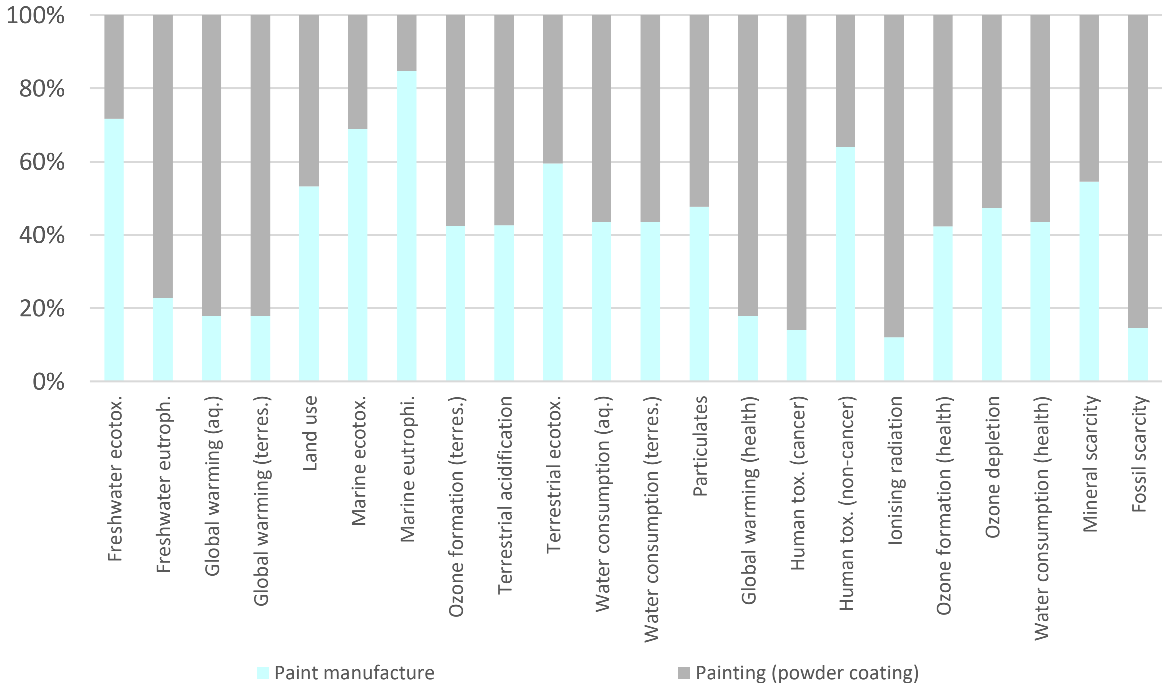


Figure 10 – Environmental hotspots for post-painted steel (paint manufacture and application)

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

- The absolute values for steel slab production, hot and cold rolling, continuous hot dip galvanising and metal fabrication are identical to those of product system 1:

pre-painted steel; only their relative contributions change due to the contribution of paint manufacture and application stages;

- Therefore, the above points noted for product system 1 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 steel, but it is still small for most impact categories (0 – 15%);
- The contribution of paint production and application is notable for fossil scarcity (~21%, due to energy use during application), land use (~18%, due to soy used in polyester resin) and ozone depletion (~17%, due to adipic acid used in polyester resin) (discussed in Section 2.3); and
- When paint manufacture and application are compared in isolation (Figure 10), there is a fairly even split of impacts for most impact categories, except in the case of freshwater eutrophication, global warming, carcinogenic human toxicity, ionising radiation and fossil scarcity, where paint application (powder coating) dominates.

2.2 Pre-painted versus post-painted: characterised end-point results

In this comparison between product system 1: pre-painted steel and product system 2: post-painted steel, 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 steel and post-painted steel 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 122) or resources (USD, in Figure 13). **Error! Reference source not found.** provides all characterised end-point results per m^2 f or paint manufacture and paint application stages.

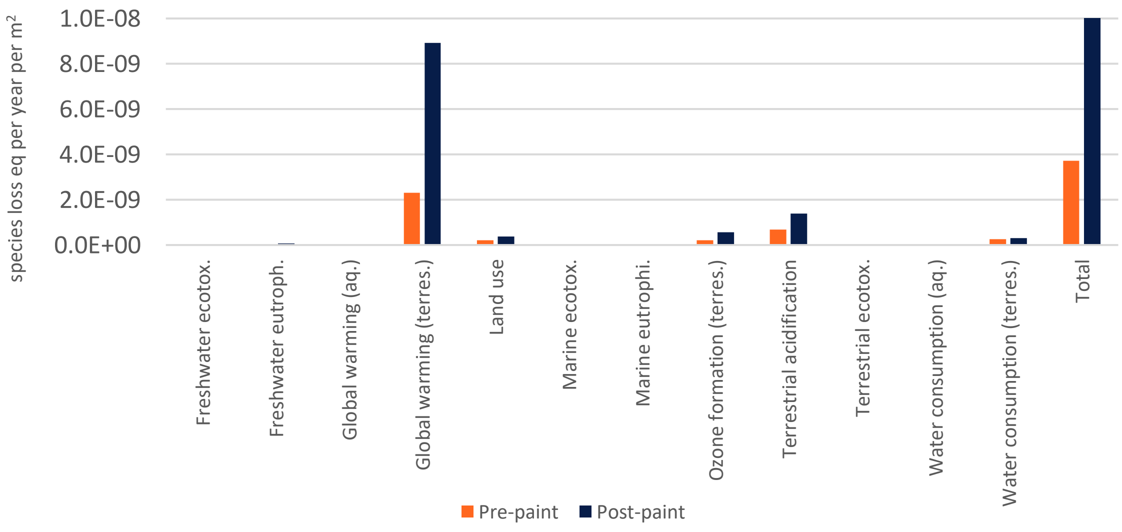


Figure 11 – Characterised end-point results for pre-painted versus post-painted steel (ecosystem impact categories, paint manufacture and application only)

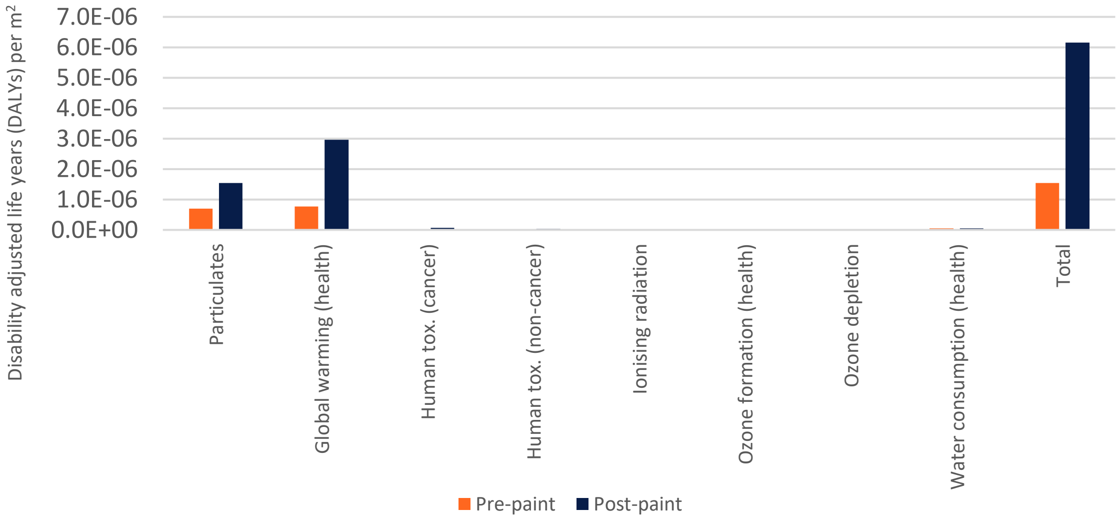


Figure 12 – Characterised end-point results for pre-painted versus post-painted steel (human health impact categories, paint manufacture and application only)

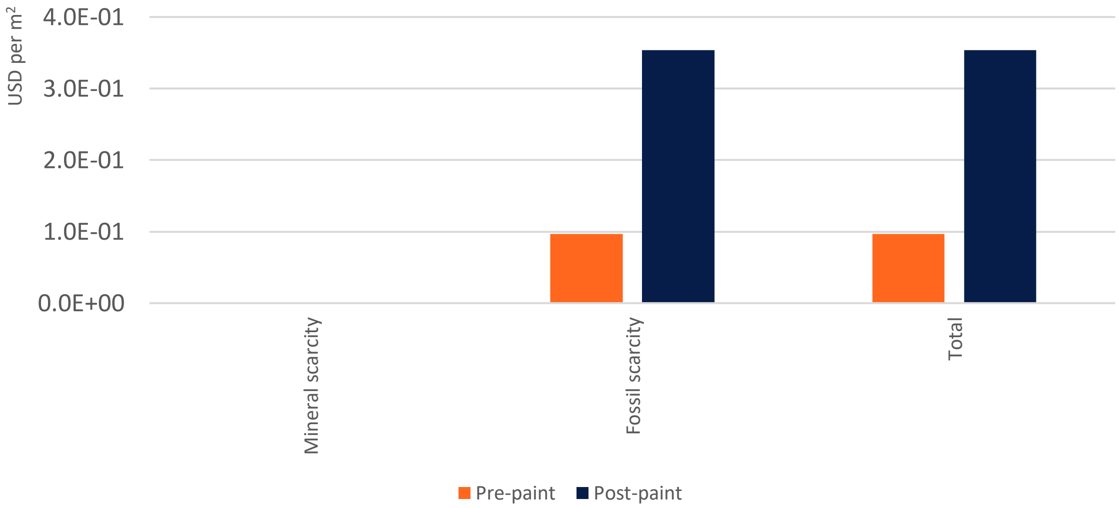


Figure 13 – Characterised end-point results for pre-painted versus post-painted steel (resource depletion impact categories, paint manufacture and application only)

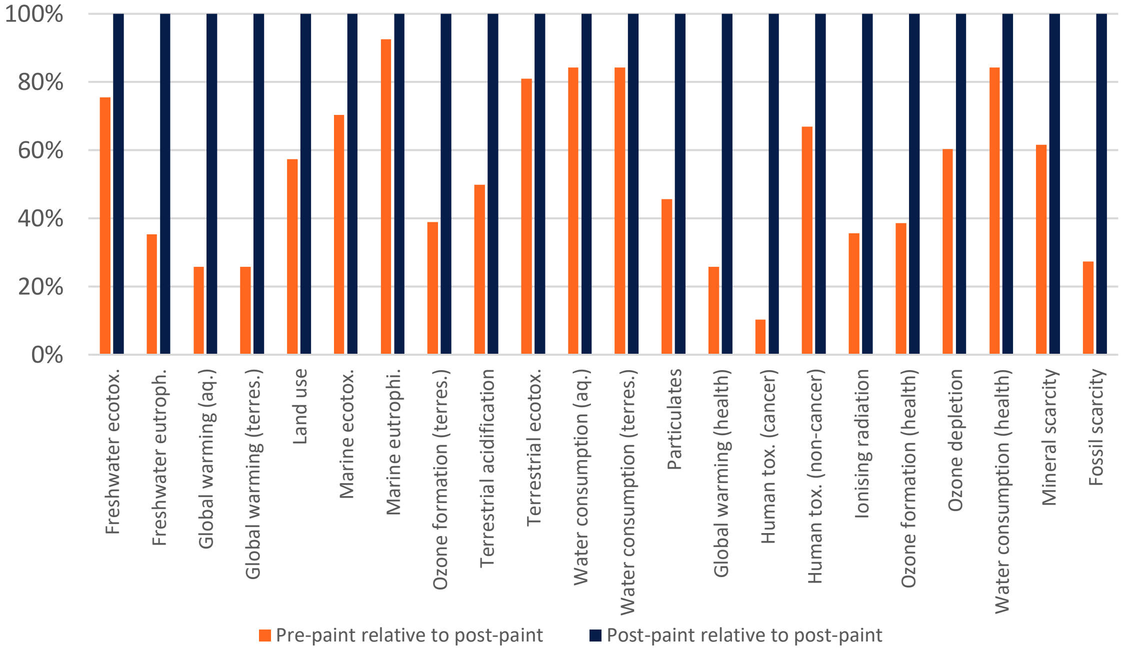


Figure 14 – Characterised end-point results for pre-painted versus post-painted steel (paint manufacture and application only, pre-paint relative to post-paint)

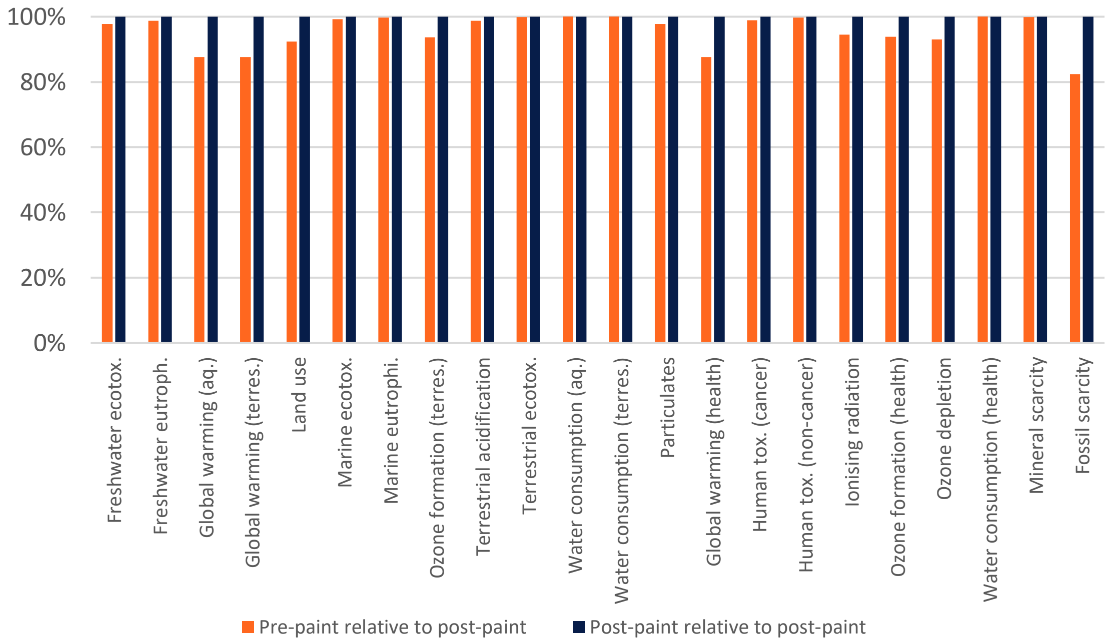


Figure 15 – Characterised end-point results for pre-painted versus post-painted steel (full life cycle)

Figure 14 provides characterised end-point results per m^2 for paint manufacture and paint application stages of both pre-painted steel and post-painted steel, as provided in Figure 11, Figure 122 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 15 shows this comparison over the full life cycle for context.

The following points are evident from Figure 11, Figure 122, Figure 13, Figure 14 and Figure 15:

- For all impact categories, pre-painted steel has a lower impact than post-painted steel;
- For ecosystem, human health and resource depletion impact category groups, impacts of pre-painted steel are 25%, 25% and 27% of those of post-painted steel, respectively (for paint manufacture and application only);
- For ecosystem, human health and resource depletion impact category groups, impacts of pre-painted steel are 98%, 97% and 84% of those of post-painted steel, 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 steel are 10 – 93% of those of post-painted steel (depending on the impact category, or 82 – <100% of those of post-painted steel for full life cycle impacts).

2.3 Deep dives

2.3.1 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 steel, based on characterised end-point results. Deep dive results show which materials and activities contribute most (and least) to this particular process.

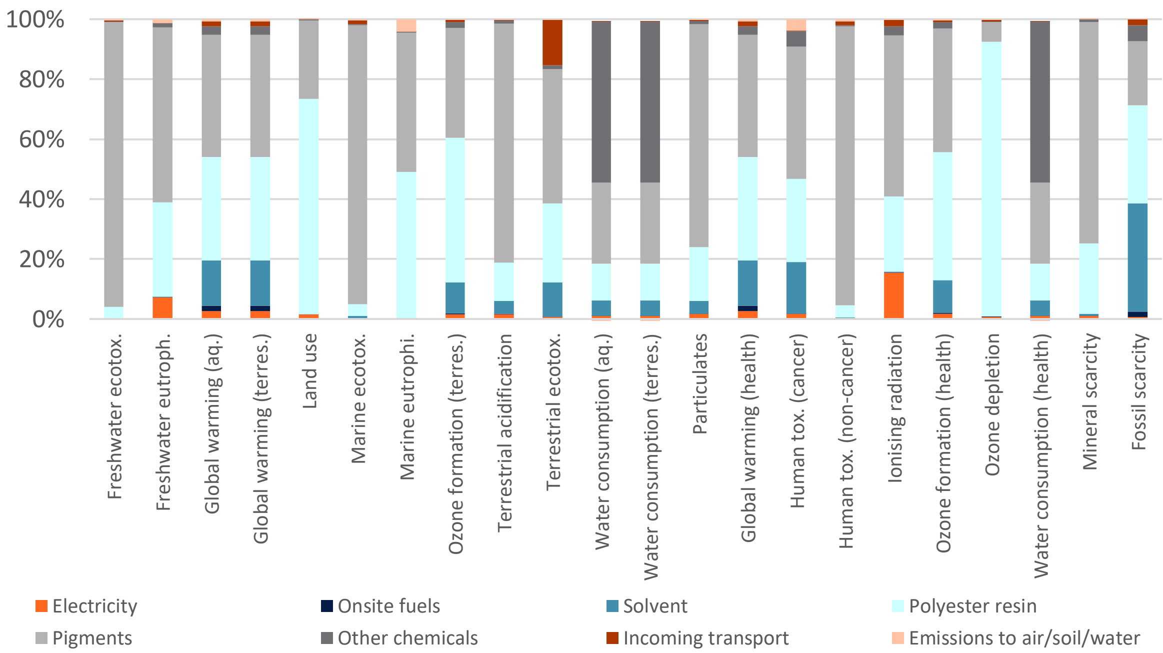


Figure 16 – Deep dive for organic solvent-based paint production (topcoat)

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.

2.3.2 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 steel, based on characterised end-point results. Deep dive results show which materials and activities contribute most (and least) to this particular process.

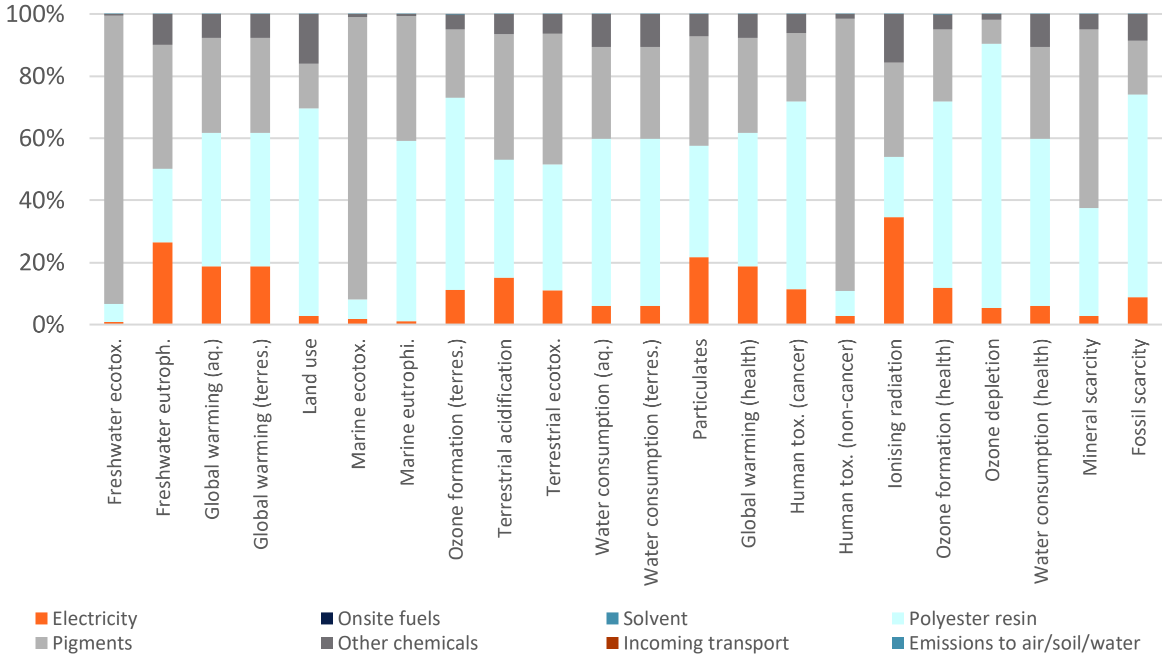


Figure 17 – Deep dive for powder-based paint production

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.

2.3.3 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.

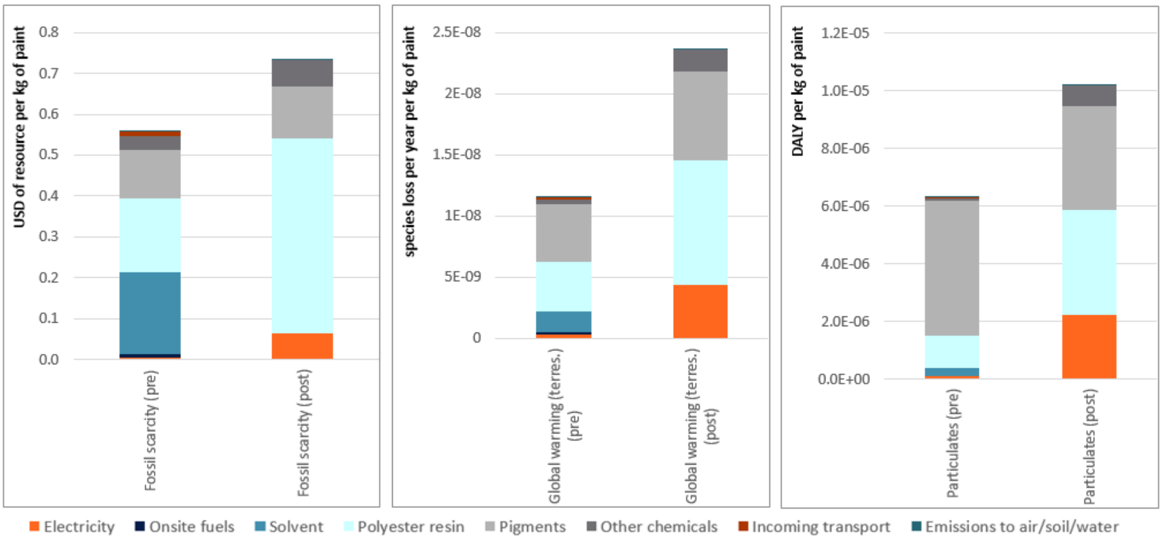


Figure 18 – Deep dive comparison between solvent-based (pre-paint) and powder-based (post-paint) paint for impact category hotspots (for both steel and aluminium product systems).

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).

2.3.4 Steel 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 steel coil coating, based on characterised end-point results. Deep dive results show which materials and activities contribute most (and least) to this particular process.

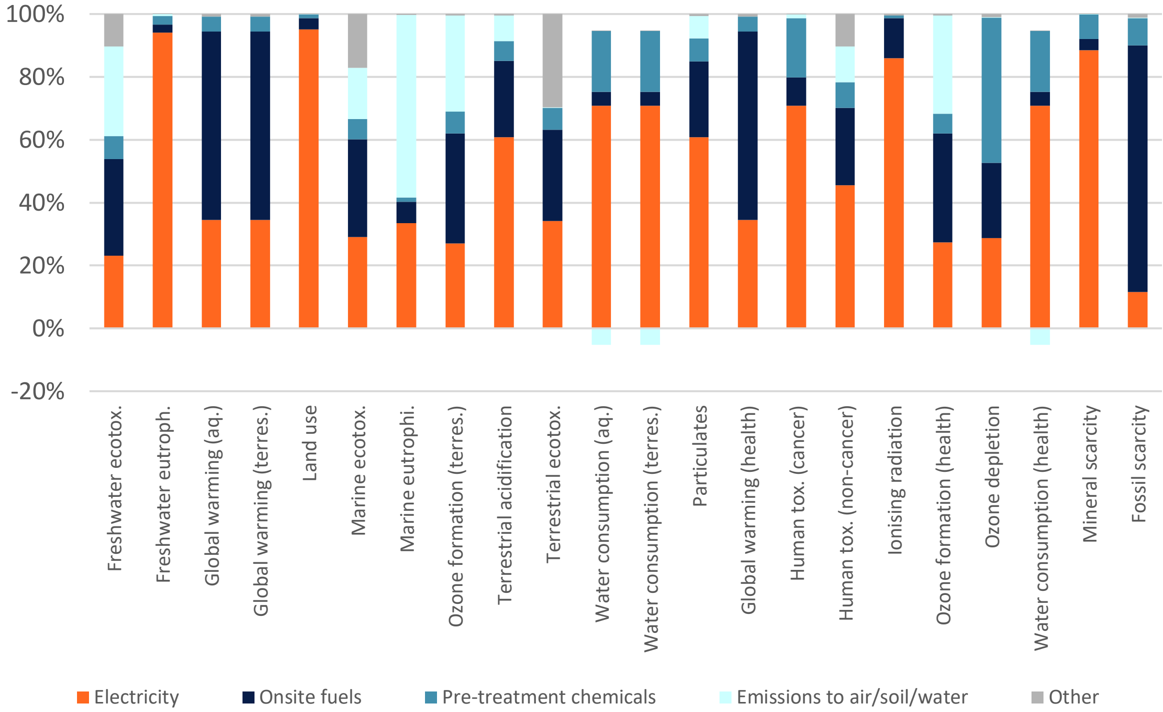


Figure 19 – Deep dive for steel coil coating

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, ozone formation and ozone depletion;
- In the case of freshwater ecotoxicity, marine eutrophication and ozone formation, emissions to air/soil/water contributes most to impacts from paint application (as a result of wastewater and solid waste treatment);
- In the case of terrestrial ecotoxicity, transportation of incoming materials contributes most to impacts from paint application; and
- In the case of ozone formation, pre-treatment chemicals contribute most to impacts from paint application (as a result of production of organic solvents for degreasing).

2.3.5 Steel 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 steel powder-coating, based on characterised end-point results. Deep dive results show which materials and activities contribute most (and least) to this particular process.

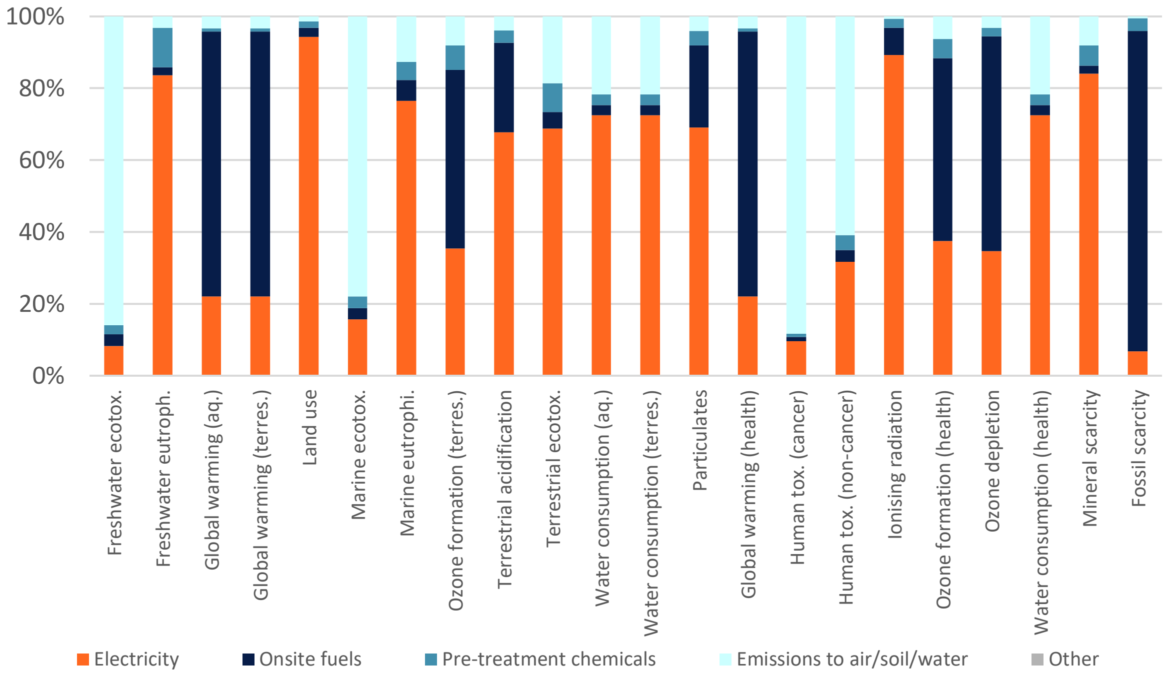


Figure 20 – Deep dive for steel powder coating

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, water consumption and human toxicity; and
- In the case of ecotoxicity impact categories, water consumption and human toxicity, emissions to air/soil/water contributes most to impacts from paint application (as a result of hazardous waste incineration).

2.3.6 Hotspot comparison between steel coil coating and steel powder coating

Figure 2121 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 steel coil coating and steel 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.

The following points are evident from Figure 2121:

- For impact category hotspots, and overall for ecosystems, human health and resources impact category groups (not shown in Figure 2121), application of paint by coil coating used for pre-painted steel has a lower impact than application of paint by powder-coating used for post-painted steel; and
- Larger energy requirements for powder coating relative to coil coating drive these differences except in the case of aquatic ecotoxicity impact categories, marine eutrophication and carcinogenic human toxicity (due to wastewater and solid waste treatment).

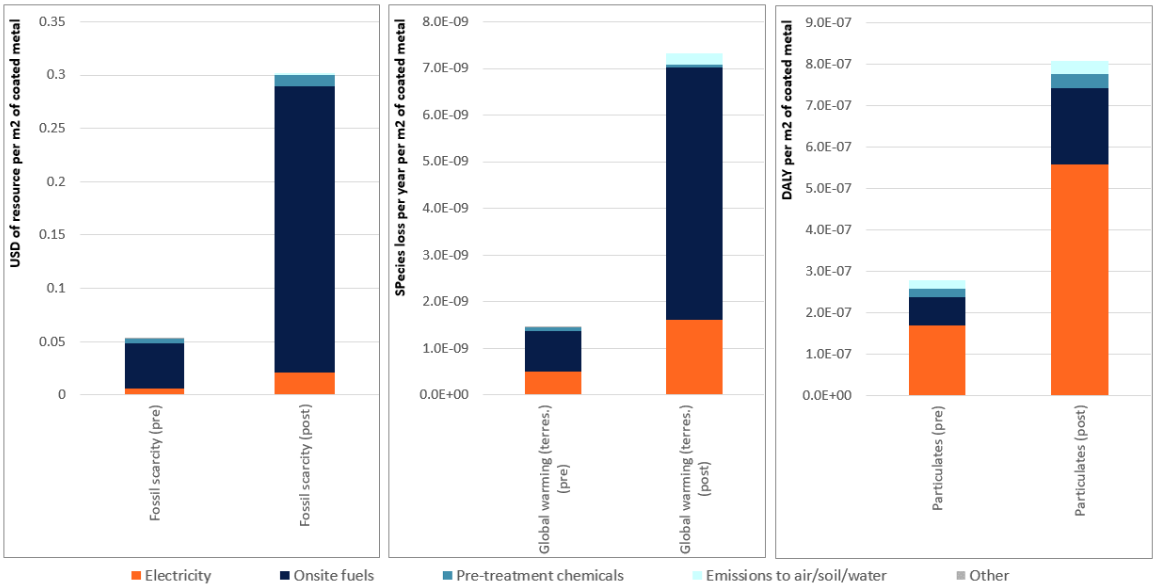


Figure 21 – Deep dive comparison between steel coil coating (pre-paint) and steel powder coating (post-paint) for impact category hotspots

- The above findings do not change the overall conclusion of this study that prepainted steel has a lower environmental impact in comparison to post-painted steel.

3. Conclusions and limitations

The LCA study presented in this report generated environmental profiles of pre- and post-painted steel in order to better understand the associated environmental impacts of both pre- and post-painting of steel in comparison to one another. The functional units for this study were defined as “1 square metre of 0.6 mm sheet steel coated both sides with a polyester-based paint for use as a domestic appliance wrapper in Europe with a lifetime of 15 years” for steel, 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, prepainted steel has a lower impact than post-painted steel (10 – 93% of those of post-painted steel, depending on the impact category, for paint production and application stages, or 82 – <100% of those of post-painted steel for full life cycle impacts).
- For ecosystem, human health and resource depletion impact category groups, impacts of prepainted steel are 25%, 25% and 27% of those of post-painted steel, respectively (for paint production and application stages, or 98%, 97% and 84% of those of post-painted steel 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, 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 steel almost always has the lowest impact when compared with post-painted steel (except in the case of freshwater ecotoxicity, marine eutrophication, terrestrial ecotoxicity and water consumption).
- Sensitivity analyses on the use of Worldsteel Association data for upstream steel production (instead of ecoinvent v3.4 data) and varying end-of-life recycling rates were also performed (not shown) – results of these sensitivity analysis had no impact on conclusions as paint manufacture and application stages remain unchanged in both cases.
- 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 steel were lower for every CML-IA baseline v4.2 / EU25 impact category in comparison to post-painted steel, 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 appliance wrappers specifically;
- The ability of appliance wrappers as products to represent coil coating and powder painting of sheet steel (it is noted, however, that both paint methods are commonly used for these products);
- The secondary data used for product systems 2 and 4;
- The data quality defined within this assessment (see Appendix C);
- 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 steel and post-painted steel.

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 metal

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.

A log of the main review comments may be found attached to this critical review statement. Some of the more minor and editorial comments were removed, in line with the requirements of ISO 14071. 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]