Project report

P102351

Refurbishment of hot dip galvanized products – environmental impacts in a life cycle perspective

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Preface

This report contains a life cycle assessment of hot dip galvanized steel. The study was carried out within the framework of an assignment performed for RISE KIMAB by Mats Zackrisson at RISE IVF, in the project Optimal Maintenance of Hot-Dip Galvanized Steel Structures. The report is financed by Infra Sweden 2030, a joint innovation program by Vinnova, Formas and Energimyndigheten. Steffen Schellenberger at RISE IVF has reviewed the report. Björn Tidbeck at RISE KIMAB and Björn Stam at ST Control have with the aid of paint manufacturers, painting contractors, equipment manufacturers and painting inspectors contributed with data and knowledge to the study. The report and conclusions in their current form are not intended for comparisons with competing products, but to form a basis for developing optimal maintenance routines for hot-dip galvanized infrastructure objects in the long term.

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Summary

This report contains a life cycle assessment of hot dip galvanized steel and refurbishment methods for hot dip galvanized steel. The purpose of the report is to investigate the environmental impact of different refurbishment methods and to compare the environmental impact of replacing hot-dip galvanized steel structures with maintenance of the corrosion protection of hot-dip galvanized steel structures. The analysis was carried out within the framework of an assignment performed for RISE KIMAB by Mats Zackrisson at RISE IVF, in the project Optimal maintenance of hot-dip galvanized products. Paint manufacturers, painting contractors, painting inspectors and researchers at RISE KIMAB have all contributed data and knowledge to the study.

The results show that the pre-treatment and the zinc can give significant impacts for the refurbishment options. From a climate perspective, the results indicate that the refurbishment options need only prolong the life with 1-6 years, which, compared to the expected life extension 30 years indicates a large climate impact reduction potential with any of the refurbishment options. From an ozone formation perspective, the results indicate that the refurbishment options need to prolong the life with 3-33 years, which, compared to the expected life extension 30 years indicates that the right choice of refurbishment option is crucial in order to achieve potential ozone impact reductions with refurbishment. The practical corrosion tests carried out in the project will give more definite answers.

The difference in potential impact between the refurbishment options should not be taken as absolute, since the information was mostly gathered from open sources, like safety data sheets and product information sheets. Nevertheless, the low (inherent) ozone formation impacts associated with the waterborne zinc silicate is worth mentioning, as well as Induraguard 9200´s environmentally benign pre-treatment (wire brushing).

The study focuses on 8 mm thick steel structures. The thicker and heavier object, the more is, in general, to gain by refurbishing instead of replacing with new infrastructure object.

Introduction

The project's goal is to compare different methods for refurbishment of hot-dip galvanized products. A life cycle assessment has been performed to study the environmental impact of complete replacement of a hot-dip galvanized steel structure, in comparison to life-extension by refurbishment with different methods. A key parameter being investigated is the service life required of a refurbishment of a hot-dip galvanized steel structure in order for the refurbishment to be more advantageous than replacing the entire steel structure. The study focuses on 8 mm thick steel structures, but can probably also be useful for other steel structures as the functional unit is m^2 surface protection. With knowledge of the product category mass per m^2 that needs to be surface protected, the results can be recalculated to virtually any infrastructure object in steel.

Method

The life cycle assessment, LCA, is performed in accordance with ISO 14044 (ISO 2006) and the ILCD Handbook (Wolf and Pant 2012). Start-up meetings were held on 13th and 15th of June 2018 with representatives from, among others, RISE KIMAB, Swedish Powergrids, Nordic Galvanizers, the Swedish Transport Administration, relevant paint manufacturers and consultants.

Simplified LCA has been used in the sense that data for upstream production of energy, paint ingredients, metals, etc. are generic, i.e. taken from generally available data and generally represent global or European averages, depending on which market the materials were assumed to be sourced from. Product specific data has been obtained from safety data sheets and technical descriptions of the paints and equipment studied, as well as from RISE IVF's own database and the commercial database Ecoinvent. SimaPro[1] 9.1.0.11 was used for the calculations.

Functional unit

Maintenance by refurbishment of galvanized steel with at least 20-30 microns of remaining zinc will be examined. The functional unit is corrosion protection for steel infrastructure per m^2 and year. A number of maintenance cases are compared with the base case, which is to replace the old, galvanized structure with a new galvanized structure. The results are expressed, among other things, as the number of years the maintenance must last to constitute an environmental improvement compared with the base case. If the annual environmental impact of the galvanized structure is to be minimized, the *Environmental Impact of Maintenance* (*EIM*) per year must be less than or equal to the *Environmental Impact* of *New Production* (*EINP*) per year. If *LM* is the extended *Life* thanks to the *Maintenance*, in number of years, and *LNP* is the expected *Life* of the *Newly Produced* structure, then this can be expressed mathematically as:

1. $EIM/LM<EINP/LNP$ or, $LM>LNP*EIM/EINP$

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[1] Internal note: project Rostskyddsmålning.

Equation 1 can also be written as:

$$LM > LNP * \frac{EIM}{EINP}$$

That is, if the service life of the maintained structure (LM) is greater than: the expected life of a new structure (LNP) multiplied by the ratio between the environmental impact of the maintenance (EIM) and the environmental impact of the new production (EINP), it is environmentally beneficial to maintain (compared to new production). The lifespan of new galvanized infrastructure can perhaps be assumed to be 50 years (Erlandsson 2011) or 63 years (EGGA 2016) or 20 years (Miljögiraff 2013). As an example, if the difference in environmental impact between maintenance and new galvanized infrastructure is 1/10, i.e. EIM/EINP=1/10, then, assuming LNP=20 years as Miljögiraff (2013), the maintained galvanized infrastructure must extend its life, LM>20*1/10=2 years, to be environmentally beneficial. Assuming LNP=63 years as EGGA (2016), the maintained galvanized infrastructure must extend its life, LM>63*1/10=6.3 years, to be environmentally beneficial.

Conversion to another type of infrastructure object can be based on that the infrastructure in this study weighs 62.4 kilograms per 2.032 m^2 (i.e. 31 kg/m^2) that needs surface protection, which equals surface protection of both sides of 1 m^2 sheet steel with 8 mm thickness. As a comparison, 20 mm steel thickness weighs 75 kg/m^2 surface. Thus, recalculation to 20 mm steel thickness involves multiplying the environmental impact of new production with the factor 75/31, i.e. the heavier object, the more to gain by maintaining instead of replacing.

Ten different cases have been compared with the base case, see below. The base case is a newly manufactured and hot-dip galvanized steel infrastructure object. The base case will be compared with maintenance of the infrastructure object by:

- Thermally sprayed zinc after wet abrasive blasting, or
- Painting with:
    - Zinc ethyl silicate (after wet abrasive blasting or laser cleaning), or
    - Waterborne zinc silicate (after wet abrasive blasting or laser cleaning), or
    - Zinc epoxy (after wet abrasive blasting or laser cleaning), or
    - Zinga[2] (after wet abrasive blasting or laser cleaning), or
    - Induraguard 9200[3] after pre-treatment with wire brush

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[2] One-component zinc rich coating.

[3] One-component high-build penetrating barrier paint.

Results are presented primarily as the number of years that maintenance must extend the service life in order to be environmentally better than the base case, assuming that the expected Life of the Newly Produced structure, LNP=63 years (EGGA 2016).

System boundary

Principle system boundaries for the study are shown in Figure 1. SS-EN 15804: 2012 + A1: 2013 Sustainability of construction works - Environmental declarations - Product-specific rules have been used as a general guideline for performing the life cycle analysis. The environmental impact of the base case of newly manufactured hot-dip galvanized object (see blue system boundaries in Figure 1) will be compared with the environmental impact of maintaining the object on site (see red system boundaries in Figure 1).

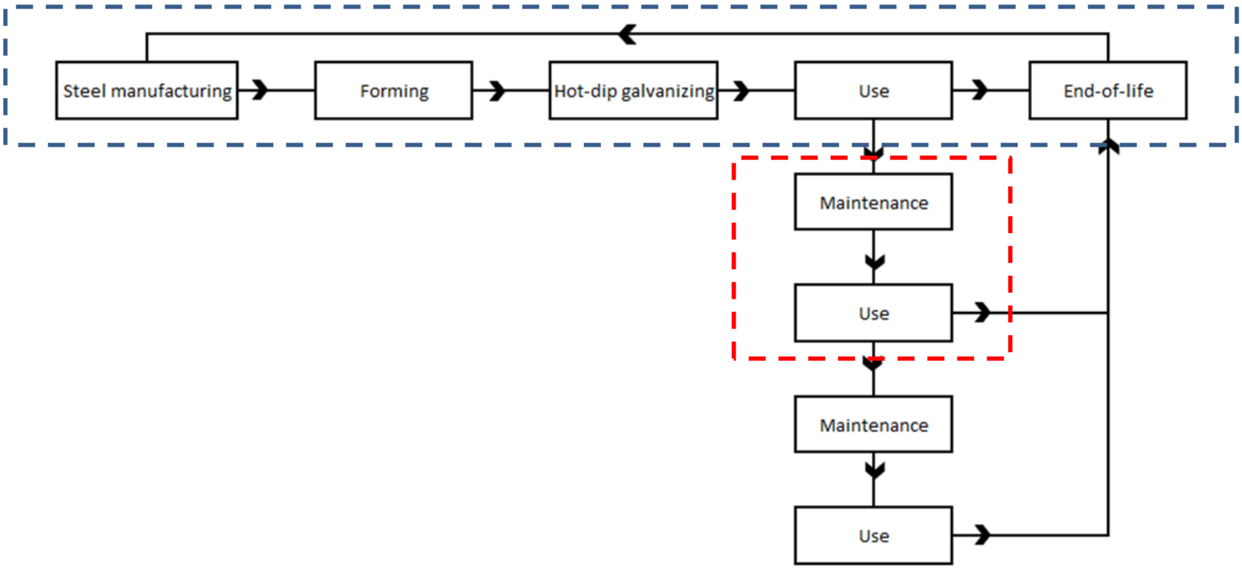

Figure 1 Study system boundaries. Environmental impact of maintenance, (red system limit), compared with environmental impact of new manufacturing (blue system limit)

SS-EN 15804: 2012 + A1: 2013 requires, among other things, that waste processes must be included in each life cycle phase until the waste ceases to be a waste. The principle of delimiting the studied product system where waste ceases to be waste is interpreted as the same as so-called cut-off. Background data with cut-off modeling has therefore been used in general. For the waste of the system studied, the principle of delimiting where waste ceases to be waste means the following:

- Metals, plastics and other materials that will be recycled as raw materials. The transport to the collection center is carried by the studied product.

Subsequent recycling processes are carried by the next product system. An exception is the infrastructure object, the recycling of which is within the system boundaries. Since this steel is expected to be used for new production of similar products, the studied system carries only necessary transports, remelting, re-rolling, and some losses.

- Wastes that will be burned for energy recovery. The system studied carries the transport to the incineration plant and the emissions from the incineration of the wastes. The recycled energy is credited to the next product system, which can thus theoretically have almost emission-free energy (since the emissions burden the studied system). This includes, for example, any covering material waste, which can arise during surface preparation in the field.
- Waste that is treated and disposed of. The studied product carries all emissions because there is no other product system involved. This applies as an example for all disposal of hazardous waste, such as blasting waste during surface preparation.

Regarding temporal system boundaries, both historical and current and future emissions are included without temporal limitations in the generic data from the database Ecoinvent 3.6 (Wernet et al 2016) that are normally used. The Ecoinvent database normally also includes emissions and resources for necessary infrastructure, such as production equipment, roads, facilities, etc. Ingredients not found in the Ecoinvent database or in other available databases were modeled (from chemicals contained in the databases) using molar calculations and estimates of energy use but without estimating losses in the modeled synthesis.

Environmental impact assessment

Environmental impacts in the form of the following environmental impact categories are taken into account:

- Greenhouse effect
- Ground-level ozone (smog)

SS-EN 15804 also stipulates eutrophication, resource depletion, ozone depletion and acidification. For other LCAs of painting, among other bridge painting, the choice was also to focus on the greenhouse effect and ground-level ozone (Zackrisson 2018).

For calculations of each environmental impact category, the ReCiPe 2016 Midpoint (H) method was used as it was implemented in SimaPro 9.1.0.11. For ground-level ozone, the environmental impact of ecosystems is calculated. Furthermore, a match is made of the solvent emissions, which reflects that the aromatic solvents have a significantly higher ozone-forming ability than the aliphatic ones. However, the thinners are not matched as the base case is that the paints are not diluted with thinner.

Modelling

The modelling description starts with describing the base case which is to replace the infrastructure object with a new, similar, object, instead of refurbishing it.

Base case

How the life cycle is modelled for the base case is described in the tables below.

Table 1 Base case, steel product

Materials/assemblies	**Value**	**Unit**	**Comment**
Steel, low-alloyed {RER}| steel production, converter, low-alloyed | Cut-off, S	31,2	kg	1m*1m 8 mm steel weighs 62,4 kg according to EGGA (2016) but two sides so 1 m^2 weighs 31,2 kg
Sheet rolling, steel {RER}| processing | Cut-off, S	31,2	kg	8,6% waste included in dataset
Drawing of pipe, steel {RER}| processing | Cut-off, S	31,2	kg	
Transport, freight, lorry 16-32 metric ton, euro6 {RER}| market for transport, freight, lorry 16-32 metric ton, EURO6 | Cut-off, S	62,4*400=2,5E4	kgkm	400 km average transport of steel to infrastructure object factory

Table 2 Base case, Forming

Processes	**Value**	**Unit**	**Comment**
Welding, gas, steel {RER}| processing | Cut-off, S	2	m	2 m welding per 1 m^2 sheet steel approximatively
Cutting steel	31,2	kg	31,2 kg for 1 m^2 8 mm sheet steel
Hot dip galvanizing	1	m^2	
Transport, freight, lorry 16-32 metric ton, euro6 {RER}| market for transport, freight, lorry 16-32 metric ton, EURO6 | Cut-off, S	31,2*300=9,36E3	kgkm	300 km average transport from forming factory to the placement of the infrastructure object

Table 3 Base case, Use

Processes	Value	Unit	Comment
Transport, freight, lorry 3.5-7.5 metric ton, euro6 {RER}| market for transport, freight, lorry 3.5-7.5 metric ton, EURO6 | Cut-off, S	31,2*50=1560	kgkm	50 km average transport according to Miljögiraff (2013)

Table 4 Base case, End-of-life

Materials/assemblies	Value	Unit	Comment
Steel recycling in Sweden	31,2	kg	Zinc recycling from the EAF filter dust is included, but very little impact
Steel, low-alloyed {RER}| steel production, converter, low-alloyed | Cut-off, S	-0,9*31,2= -28,1	kg	90% recycling credits
Transport, freight, lorry 3.5-7.5 metric ton, euro6 {RER}| market for transport, freight, lorry 3.5-7.5 metric ton, EURO6 | Cut-off, S	31,2*(50+200)=7800	kgkm	50 km transport of infrastructure object from placement to local or regional node, plus 200 km to regional recycling node

Refurbishment

The base case will be compared with maintenance/refurbishment of existing objects through:

- Thermally sprayed zinc after wet abrasive blasting, or
- Painting with:
    - Zinc ethyl silicate (after wet abrasive blasting or laser cleaning), or
    - Waterborne zinc silicate (after wet abrasive blasting or laser cleaning), or
    - Zinc epoxy (after wet abrasive blasting or laser cleaning), or
    - Zinga[2] (after wet abrasive blasting or laser cleaning), or
    - Induraguard 9200[3], after brushing with wire brush

Wet abrasive blasting or laser cleaning

For the paints (except Induraguard 9200) pre-treatment is done by either wet abrasive blasting or laser cleaning. Wet abrasive blasting is considered to need ground cover that collects hazardous waste. However, the ground cloth should be reusable and has therefore not been included in the model. The tables below contain data used for wet abrasive blasting and laser cleaning.

Concerning the waste treatment, different scenarios are possible based on discussions with Ragn-Sells's environmental manager Miranda Jensen. Heavy metal-containing waste is received, stored and treated to be finally disposed of in a landfill for non-hazardous waste or hazardous waste. Heavy metal-containing waste includes blasting wastes. The treatment is based on fixing the metals by means of the addition of stabilizers, such as ferrous waste, coal ash, lime or cement. By fixing the metals, the content of heavy metals in leachate from the waste decreases. After treatment, a leachate test is performed, and the result compared with leachate criteria for the various landfills. Based on this information, in the best case, the blasting waste is mixed with some other waste (ferrous waste or coal ash) and then placed in a regular landfill, which in the best case is located where the mixing takes place and in the vicinity of the workplace. In the worst case, the blasting waste must be mixed with quite a lot of cement or lime and driven to a special landfill in another location. Since Ragn-Sells could not quantify these scenarios, the blasting waste was assumed to have the same environmental impact as collection, transport, treatment and deposit of hazardous waste from combustion as described and quantified by Sundqvist and Palm (2010).

Table 5 Wet abrasive blasting, 1 m^2

Materials/assemblies	**Value**	**Unit**	**Comment**
Waste packaging glass, unsorted {GLO}| waste packaging glass, unsorted, Recycled Content cut-off | Cut-off, S	7,5	kg	7,5 kg/m^2 +- 2,5 assumed. Blasting material crushed glass must be sorted, washed, crushed and sieved.
Rock crushing {RER}| processing | Cut-off, S	7,5	kg	Approximation for sorting, crushing and sieving
Transport, freight, lorry 3.5-7.5 metric ton, euro6 {RER}| market for transport, freight, lorry 3.5-7.5 metric ton, EURO6 | Cut-off, S	50*(7,5+4+0,15+8,5)=1010	kgkm	50 km transport of materials from local or regional node to place of refurbishment.
Transport, freight, lorry 3.5-7.5 metric ton, euro6 {RER}| market for transport, freight,	50*(200+400)/70=429	kgkm	50 km daily transport of equipment from local or regional node. Assume blaster plus compressor weighs

Materials/assemblies	Value	Unit	Comment
lorry 3.5-7.5 metric ton, EURO6 | Cut-off, S			200+400 kg. Assume productivity 10 m^2/h incl establishment=70 m^2/day
Tap water in Sweden, at user/RER System	4	kg	1 litre water per minute assumed. 15 m^2/h=0,25 m^2/min gives 4 kg water per m^2, i.e., a bit less than information about same amount of water as crushed glass given on https://www.dustlessblasting.website/lathund
Chemical, organic {GLO}| market for | Cut-off, S	0,8/40*7,5= 0,15	kg	rust inhibitor, se https://www.dustlessblasting.website/lathund
Hazardous waste. eg blasting waste	7,5+1=8,5	kg	Only carbonates and oxides to be blasted away, so mainly crushed glass (7,5 kg) and part of the water (1 kg).
Compressor	17,8/15=1,19	kWh	24 hk or 17,8 kW can blast 15 m^2/h assumed.
Compressor	**1**	**kWh**	
Heavy vehicle, per litre diesel	0,254	l	0,254 litre diesel per kWh electricity according to http://www.metalwork.se/img/Miljo%20och%20energibesparing%201108.pdf
Transport, freight, lorry 3.5-7.5 metric ton, euro6 {RER}| market for transport, freight, lorry 3.5-7.5 metric ton, EURO6 | Cut-off, S	0,254*0,8*50 =10,1	kgkm	50 km trp of diesel to placement

Table 6 Laser cleaning, 1 m^2

Materials/assemblies	Value	Unit	Comment
Electricity generator	0,9	kWh	Laser cleaning of galvanized surface with CL300 at 1 kW plus ventilation 1,3 kW. 6-8 cm^2/second. Data from Agaria AB in Åkersberga

Materials/assemblies	Value	Unit	Comment
Transport, freight, lorry 3.5-7.5 metric ton, euro6 {RER}| market for transport, freight, lorry 3.5-7.5 metric ton, EURO6 | Cut-off, S	(150+220)*50/(2,5*7)=1060	kgkm	Trp to site 50 km of generator and CL300. 2,5 m^2/h*7=17,5 m^2/day
Electricity generator	**1**	**kwh**	
Heavy vehicle, per litre diesel	0,19	L	0,19 litre diesel per kWh electricity according to Energimyndighetens test
Transport, freight, lorry 3.5-7.5 metric ton, euro6 {RER}| market for transport, freight, lorry 3.5-7.5 metric ton, EURO6 | Cut-off, S	0,19*0,8*50=7,6	kgkm	50 km trp of diesel to placement

Note that wet abrasive blasting is assumed to be much more productive, 70 m^2/day, compared to the laser cleaning, 17.5 m^2/day; calculated with 7 hours pre-treatment per working day.

Thermally sprayed zinc after pre-treatment

How the thermally sprayed zinc is modelled is shown in the table below.

Table 7 Thermally sprayed zinc per m^2

Materials/assemblies	Value	Unit	Comment
Zinc {GLO}| market for | Cut-off, S	0,7	kg	100 my layer = 10E-4 m3; zinc weighs 7133 kg/m3 so 10E-4 m3 weighs 0,713 kg
Wire drawing, steel {GLO}| market for | Cut-off, S	0,7	kg	Proxy for wire drawing of zinc
Compressor	0,161	kWh	P=U*I=350*22=7700 W; 33,5 kg zinc/h gives 7700/33,5=230 Wh/kg zinc; 230 Wh/kg*0,7 kg/m^2= 161 Wh/m^2; 33,5/0,7=48 m^2/h. (Melting zinc requires 0,39*400=156 kJ/kg=0,156 MJ/3,6=43 Wh/kg) Diesel to Compressor according to Table 5.

Materials/assemblies	Value	Unit	Comment
Transport, freight, lorry 3.5-7.5 metric ton, euro6 {RER}| market for transport, freight, lorry 3.5-7.5 metric ton, EURO6 | Cut-off, S	200*50/70=143	kgkm	Local transport 50 km of equipment 200 kg distributed on 1 days production (48 m^2/h*7h=336 m^2/day; but wet abrasive blasting is slower and therefore decides pace, i.e. 70 m^2/day). Since thermally sprayed zinc happens after wetblasting, a compressor is already at site.

Painting

Paint consumption is calculated in kilograms of paint per square meter. In cases where normal coverage does not provide sufficient layer thickness, new coverage is calculated with the formula:

Coverage = Volume dry content / Layer thickness, see example in Table 8 below.

Painting one or more coats with a brush to achieve the required rust protection with each paint. Since all paints are painted with a brush, no addition of thinner is assumed. For equivalent rust protection, it is assumed that the following layer thicknesses are needed:

- Solventborne zinc ethyl silicate, 2*37 = 75 µm
- Waterborne zinc silicate, 2*37 = 75 µm
- Zinc epoxy, 2*60 = 120 µm
- Zinga[2], 2*60 = 120 µm
- Induraguard 9200[3], 250 my

Solventborne zinc ethyl silicate

Table 8 Tikkurila's Temasil 90, two-component zinc-rich ethyl silicate paint

Paint	Producer	Density (kg/l)	Coverage (m^2/l)	Thinning (per litre paint)	Reference
Temasil 90, two component zinc rich ethyl silicate paint	Tikkurila	2.0 g/cm^2 use mixture 1 volume part Temasil 90, 1 volume part hardener 008 7380 470 g VOC/l use mixture. 2000-470 = 1530 g/l dry coat	6,9 m^2/l at 160 µm wet or 80 µm dry Volume dry content 55%	0-5%, thinner 1029 with density 0,81 kg/l	Temasil 90 Product data sheet 17.05.2021

Paint	**Producer**	**Density (kg/l)**	**Coverage (m^2/l)**	**Thinning (per litre paint)**	**Reference**
Layer thickness = Volume dry content/Coverage. The volume dry content is dimensionless, but coverage must be recalculated to m^2/m^3, i.e., multiplication with 1000. Example for Temasil 90: Layer thickness = 0.55/(6.9E3) = 80 µm.					

Table 9 Contents of Tikkurila's Temasil 90 two-component zinc-rich ethyl silicate paint according to safety data sheet

Base/Hardener/ Thinner	**Ingredient**	**% in SDS**	**Weight-% model**	**Process in SimaPro**	**Hydrocarbon emissions**
Base	Zinc powder, zinc dust (stabilised)	50-75%	74,8	Zinc powder, or Zinc powder from waste.	
Base	Mix of: m-xylene, o-xylene, p-xylene and ethylbenzene	<6,1%	6,1	Xylen och etylbensen, 1 kg	m-Xylene 3,12E-1 kg NO_x/kg
Base	Zinc oxide	≤ 5%	5	Zinc oxide {GLO}| market for | Cut-off, S	
Base	1-metoxi-2-propanol	≤ 10%	10	Dipropylene glycol monomethyl ether {GLO}| market for | Alloc Rec, S	2-propanol 1,05E-1 kg NO_x/kg
Base	Isopropanol	3,8	3,8	Isopropanol {RER}| market for isopropanol | Cut-off, S	2-propanol 1,05E-1 kg NO_x/kg
Base	Zinc chloride	0,3	0,3	Approximated to zinc powder	
Total		*75,2-100,2*	*100*		
Hardener	Ethanol	≥50 - ≤75	70	Ethanol, without water, in 99.7% solution state, from ethylene {RER}| market for ethanol, without water, in 99.7% solution state, from ethylene | Cut-off, S	Ethanol 1,99E-1 NO_x/kg
Hardener	Isopropanol	≥10 - ≤25	20	Isopropanol {RER}| market for isopropanol | Cut-off, S	2-propanol 1,05E-1 kg NO_x/kg
Hardener	Tetraethyl silicate	≤10	10	Tetraethyl orthosilicate {GLO}| market for | Cut-off, S	
Total		*70-110*	*100*		
Thinner 006 1029	Ethanol	≥75 - ≤90	90,2	Ethanol, without water, in 99.7% solution state, from ethylene {RER}| market for ethanol, without water, in	

Base/Hardener/ Thinner	Ingredient	% in SDS	Weight-% model	Process in SimaPro	Hydrocarbon emissions
				99.7% solution state, from ethylene | Cut-off, S	
Thinner 006 1029	Acetone	≤4,9	4,9	Acetone, liquid {RER}| market for acetone, liquid | Cut-off, S	
Thinner 006 1029	Ethyl methyl ketone	≤2,5	2,5	Approximated with Acetone, liquid {RER}| market for acetone, liquid | Cut-off, S	
	Isopropanol	≤2,4	2,4	Isopropanol {RER}| market for isopropanol | Cut-off, S	
Total		*84,8-99,8*	*100*		

Waterborne zinc silcate

Table 10 Waterborne zinc silicate paint

Paint	Producer	Density (kg/l)	Coverage (m^2/l)	Thinning (per litre paint)	Reference
Fontezinc HR	Tikkurila	Use mixture 3,00 g/l	9,5, use mixture	Not applicable	Safety Data Sheet and Product data Sheet from manufacturer

Table 11 Content in use mixture of waterborne zinc silicate Fontezinc

Ingredient	% in SDS	Weight-% model	Process in SimaPro	Hydrocarbon emissions
Zinc powder, zinc dust (stabilised)	>90% in powder	79	Zinc powder, or Zinc powder from waste.	NA
potassium silicate / water glass / silica gel		6,7	Activated silica {GLO}| market for | Cut-off, S.	NA
Water		*14*	Tap water in Sweden, at user/RER System	NA
Alcohol		*0,2*	Isopropanol {RER}| market for isopropanol | Cut-off, S	2-propanol 1,05E-1 kg NO_x/kg
	Total	*100*		

Zinc epoxy

Table 12 Temazink 99 solventborne two-component epoxy paint

Paint	**Producer**	**Density (kg/l)**	**Coverage (m^2/l)**	**Thinning (per litre paint)**	**Reference**
Temazinc 99 solventborne two-component polyamide zinc rich epoxy paint	Tikkurila	2,6 g/cm^3 use mixture 3 volume parts of paint and 1 volume part of hardener 008 7440 430 g VOC/l use mixture. 2600-430=2170 g/l dry coat	120 µm dry coat equals 4,6 m^2/l.	0% thinner 1031 with density 0,86 kg/l	https://www.tikkurila.se/industrifarger/metallytor/metallytor/metallprodukter/traditionella_produkter/temazinc_99.2647.shtml
One coat gives 40 µm, two 80 µm or three 120 µm. Density/coverage*number of coats = kg/m^2: 2,6/13,7*3=0,57 kg/m^2 for 120 my					

Table 13 Content in Temazinc 99 solventborne two-component epoxy according to SDS

Base/Hardener/ Thinner	**Ingredient**	**% in SDS**	**Weight-% model**	**Process in SimaPro**	**Hydrocarbon emissions**
Base	Zinc powder, zinc dust (stabilised)	75-90%	80	Zinc powder, or Zinc powder from waste.	
Base	Mix of: m-xylene, o-xylene, p-xylene and ethyl benzene	<10%	7,5	Xylen och etylbensen, 1 kg	m-Xylene 3,12E-1 kg NO_x/kg
Base	Epoxy resin (mv 700-1100)	≤ 10%	7,5	Epoxy resin SVEFF	
Base	1-metoxi-2-propanol	≤ 5%	5	Dipropylene glycol monomethyl ether {GLO}| market for | Alloc Rec, S	2-propanol 1,05E-1 kg NO_x/kg
Total		*105-120*	*100*		
Hardener	Mix of: m-xylene, o-xylene, p-xylene and ethyl benzene	≥50 - ≤75	60	Xylen och etylbensen, 1 kg	m-Xylene 3,12E-1 kg NO_x/kg
Hardener	Polyaminoamide	≥25 - ≤50	30	Polyaminoamid, 1 kg	
Hardener	1-metoxi-2-propanol	≤10	8	Dipropylene glycol monomethyl ether {GLO}| market for | Alloc Rec, S	2-propanol 1,05E-1 kg NO_x/kg
Hardener	Diethylenetriamine	≤1,4	1	Dietylentriamin, 1 kg	
Hardener	Polyethylene polyamine	≤1,4	1	Polyaminoamid, 1 kg	
Total		*88-138*	*100*		
Thinner 006 1031	Mix of: m-xylene, o-xylene, p-xylene and ethyl benzene	≥50 - ≤75	70	Xylen och etylbensen, 1 kg	m-Xylene 3,12E-1 kg

Base/Hardener/ Thinner	Ingredient	% in SDS	Weight-% model	Process in SimaPro	Hydrocarbon emissions
					NO_x/kg[4].
Thinner 006 1031	n-butanol	≥10 - ≤25	15	n-butanol, 1 kg	2-Butanol 1,45E-1 kg NO_x/kg[4].
Thinner 006 1031	1-metoxi-2-propanol	≥10 - ≤25	15	Dipropylene glycol monomethyl ether {GLO}| market for | Alloc Rec, S	2-propanol 1,05E-1 kg NO_x/kg[4]
Total		*70-125*	*100*		

Zinga

Table 14 Zinga, one-component zinc rich coating

Paint	Producer	Density (kg/l)	Coverage (m^2/l)	Thinning (per litre paint)	Reference
Zinga	Zinga Sweden AB	2,67 g/cm^3 474 g VOC/l. Thinner Zingasolv	4,83 m^2/l gives 120 µm dry. 474 g VOC/l	10-20%, zingasolv with density 0,876 kg/l, C9-C10 aromatic hydrocarbon solvent. Assume 876 g VOC/l	https://www.zinga.eu/download/tds-zingasolv/

Table 15 Content in Zinga according to SDS

Base/Thinner	Ingredient	% in SDS	Weight-% model	Process in SimaPro	Hydrocarbon emissions
Base	Zinc powder, zinc dust (stabilised). 80% dry content. Parts of this should be binder, but no data on binder.	68,25-78%	80	Zinc powder, or Zinc powder from waste.	
Base	Solvent nafta (petroleum), aromatic	20-30	20	Nafta SVEFF	Hydrocarbons, aromatic 1,63E-1 kg NO_x/kg
Total		*88,25-108*	*100*		
Thinner, Zingasolv	Mesithylene	10	70	Approximated to Nafta SVEFF	Hydrocarbons, aromatic 1,63E-1 kg NO_x/kg

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[4] but not modelled

Base/Thinner	Ingredient	% in SDS	Weight-% model	Process in SimaPro	Hydrocarbon emissions
Thinner, Zingasolv	1,2,4-Trimethylbenzene	35	15	Approximated to Nafta SVEFF	Hydrocarbons, aromatic 1,63E-1 kg NO_x/kg
Thinner, Zingasolv	Propylben	4	15	Approximated to Nafta SVEFF	Hydrocarbons, aromatic 1,63E-1 kg NO_x/kg
Total		*70-125*	*100*		

Induraguard 9200

Table 16 Induraguard 9200 one-component high-build penetrating barrier paint

Paint	Producer	Density (kg/l)	Coverage (m^2/l)	Thinning (per litre paint)	Reference
Induraguard 9200	Induron	1,8 kg/l 70 g VOC/l.	3,68 m2/l gives 250 my dry coat. Density/Coverage =1,8/3,68=0,5 kg/m^2	No thinning when when using brush, paint-mitt or roller.	Technical data Induraguard 9200

Table 17 Content in Induraguard 9200 according to SDS

Ingredient	% in SDS	Weight-% model	Process in SimaPro	Hydrocarbon emissions
Zinc powder, zinc dust (stabilised)	10-20%	20	Zinc powder, or Zinc powder from waste.	
Ethyl benzene	<1%	1	Xylen och etylbensen, 1 kg	m-Xylene 3,12E-1 kg NO_x/kg
Xylene	<1%	1		
Solvent Total 8% solvents assumed	?	6	Nafta SVEFF.	Hydrocarbons, aromatic 1,63E-1 kg NO_x/kg
Ethyl methyl ketoxime	<1%	1	Methyl ethyl ketone {RER}| market for methyl ethyl ketone | Cut-off, S.	
Linseed oil. Rest is assumed linseed oil	?	51	Linseed oil SVEFF..	
Mio-pigment 10% assumed	?	10	Iron oxide, yellow. Approx för mio.	
Ceramic pigments 10% assumed	?	10	Ceramic pigment from waste	
		100		

More about solvent emissions

As previously mentioned, a matching of the solvent emissions is made which reflects that the aromatic solvents have a significantly higher ozone-forming ability than the aliphatic ones. The matching is shown in Table 9 – Table 17, the Hydrocarbon Emissions column. In this study the thinners are not matched as the base case is that the paints are not diluted with thinner. The matching enables accurate comparison of ground-level ozone forming of different paint systems with the model. The ozone-forming ability is calculated using the ReCiPe 2016 Midpoint (H) method for the environmental impact of ecosystems, as implemented in SimaPro 9.1.0.11.

It should be mentioned that, in all cases in the model, more solvent is produced than what is emitted during painting. It reflects that the figures are calculated from different sources[5], but also that there are solvent losses in the production, formulation and transportation, in addition to the inevitable solvent emissions during painting.

Paint formulation

In previous paint-related projects, paint formulation in Europe has been inventoried with results according to the Table below. The mean is used in the baseline case of this study. The data for International Paint applies to their factory in Angered 2017 in which they manufacture paint for fire and corrosion protection.

Table 18 Data for paint formulation

Resources/emissions	Study 1	Study 2	Average	International Paint 2017
Electricity kWh/kg paint	0.25	0.325	0.287	0.185
Oil litre l/kg paint	0.027	0.029	0.028	0.0002
VOC g/kg paint	1.1	1.382	1.241	0.27
Hazardous waste kg/kg paint	0.0647	0.035	0.050	0.011
COD g/kg paint	-	0.042	0.042	0

Paint ingredients

For some of the paint ingredients, it was not possible to find an exact match in the database. These are explained in more detail below.

Zinc powder

Zinc powder can be manufactured from virgin sources or from recycled sources, e.g. from electric arc furnace (EAF) dust or zinc wastes from the galvanizing industry. In the model, it is possible to use either of these sources for all paints. Zinc powder from wastes give much less climate impact than zinc powder from virgin sources.

Zinc powder from virgin sources starts with the Ecoinvent process *Zinc {GLO}| market for | Cut-off, S.* Powder production is assumed to take place by

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[5] Production figures are calculated from the weight-% given in Table 9 – Table 17, whereas emission figures are calculated from VOC content per litre declared by the manufacturers.

atomization, a process that for steel requires approximately 12 MJ of electricity per kg of powder and has a yield of around 50%. Since the melting point of zinc is about one third of steel, it is assumed that 4 MJ of electricity per kg of zinc powder is needed for the atomization. The same 50% yield as for steel is assumed. The atomization is assumed to take place in Sandefjord, Norway, so Norwegian electricity mix is used.

Zinc powder from wastes assumes sourcing zinc waste from hard dross waste from the Nordic galvanizing industry. Together with some (4%) virgin zinc, Everzinc Norway AS produces zinc gas which condensates to zinc powder using 7,2 MJ electricity/kg, thus Norwegian electricity mix is used. An average transport distance of 1120 km is assumed.

Transports

Refurbishment or replacement of infrastructure object is expected to be coordinated locally or regionally. It then requires first a longer transport of raw materials from the place of production to such a local or regional node, and then a shorter transport from the node to the respective cluster of infrastructure objects. Conversely, in the case of recycling or waste treatment, a shorter local transport is required, followed by a longer transport to, for example, steel recycling, or treatment of hazardous waste. The following transport distances have been used:

- 400 km transport of steel to infrastructure object factory
- 300 km transport from infrastructure object factory to local or regional node
- 300 km transport from manufacturers of paint, blasting material, etc. to local or regional node. The transports of the paint raw materials to the paint manufacturers are embedded in the "market data sets" used
- 50 km transport of infrastructure object from local or regional node to the place where it is to be mounted. The same distance for local collection of infrastructure object when replacing.
- 200 km further transport of scrapped objects to regional recycling node. The transport from there to the steelworks is included in the dataset Steel recycling in Sweden.
- 50 km transport of paint, blasting agents and equipment from the local or regional node to the place where the object is to be refurbished. Here, however, assumptions are made that equipment for a number of infrastructure objects can share the same daily transport.

Transport of personnel is only included to the extent that they travel with the material.

Electricity

The report uses a number of different electricity mixes. How they are used and the climate impact from each mix are described in the Table below.

Table 19 Electricity

Name of data set	Climate impact (gram CO_2-eq/kWh)	Use in model
Electricity, medium voltage {SE}| market for | Cut-off, S	40	Refurbishing in Sweden. Paint formulation.
Electricity, medium voltage {NO}| market for | Cut-off, S	29	Manufacturing of zinc powder.
Electricity, medium voltage {ENTSO-E}| market group for | Cut-off, S	440	Manufacturing of ceramic pigments in Induraguard 9200.

Compressed air and electricity generation in the field

Diesel consumption, 0.25 l/kWh, for compressed air generation in the field was obtained from Metal Work Sverige AB[6]. Associated emissions were modeled with data from IVL[7].

Electricity generation in the field was modeled with data from tests of power plants made by the Swedish Energy Agency in 2015[8]. The two diesel-powered 3-phase generators that were tested both required 0.19 liters of diesel/kWh of electricity.

Results

The figure below shows the climate impact for the base case compared with refurbishment by thermally sprayed zinc.

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[6] http://www.metalwork.se/img/Miljo%20och%20energibesparing%201108.pdf

[7] IVL Miljöfaktabok för bränslen 2001

[8] See http://www.energimyndigheten.se/tester/tester-a-o/reservelverk-2015/?showTable=1&productTypeVersionId=1767

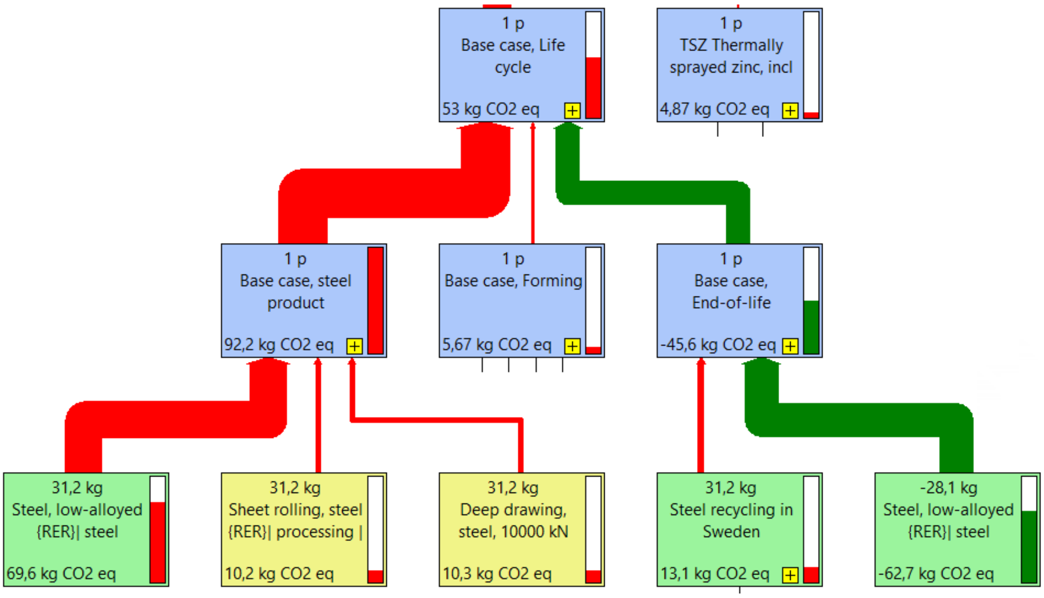

Figure 2 Climate impact of the base case, replacement of infrastructure object, compared with refurbishment by thermally sprayed zinc, cut-off 5%

The amount is at the top of each box (p means piece and is understood together with the name of the box, for example: 1 p TSZ Thermally sprayed zinc incl means 1 m^2 thermally sprayed zinc including pre-treatment). The environmental impact is in the lower left corner of the box, i.e. here 4.87 kg CO_2-eq per m^2 thermally sprayed zinc. If we assume the same life span as EGGA (2016), 63 years for a newly galvanized object, then the refurbishment should last more than 63 * 4.87 / 53 = 5.8 years to be better from a climate perspective than replacing the object, because, as explained in page 4, if the service life of the maintained structure is greater than the service life of a new structure (assumed to 63 years) multiplied by the ratio between the environmental impact of the maintenance (4.87 kg CO_2) and the environmental impact of the new production (53 kg CO_2), it is environmentally beneficial to refurbish (compared to new production).

With cut-off 5%, means that no processes contributing to the total[9] with less than 5% are shown, but they are included in the total. Green colour means negative impacts. It is assumed that (90% of) the infrastructure object can be recycled to produce new similar structures. Thus, 90% of the climate impact of steel-making is credited to the studied system. The climate impact of 1 m^2 replacement infrastructure sums up to 53 kg CO_2 with significant impacts from steel production (net 7 kg), rolling (10 kg), drawing (10 kg), forming including hot dip galvanizing (6 kg) and recycling (13 kg), see figure above.

In the figure below, the climate impact of thermally sprayed zinc is shown. The virgin zinc and the wet abrasive blasting give major impacts. Zinc and the wet abrasive blasting is similarly dominating ozone formation impacts. Concerning

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[9] Which in this case is the sum of the climate impact per m^2 of the base case and all the refurbishment cases, in this case 77 kg CO_2eq

wet abrasive blasting, it is primarily the compressor's diesel consumption, transports of blasting agents and the disposal of the blasting waste, that make a significant contribution to the climate impact. For ozone formation, the compressor is even more dominant (not shown).

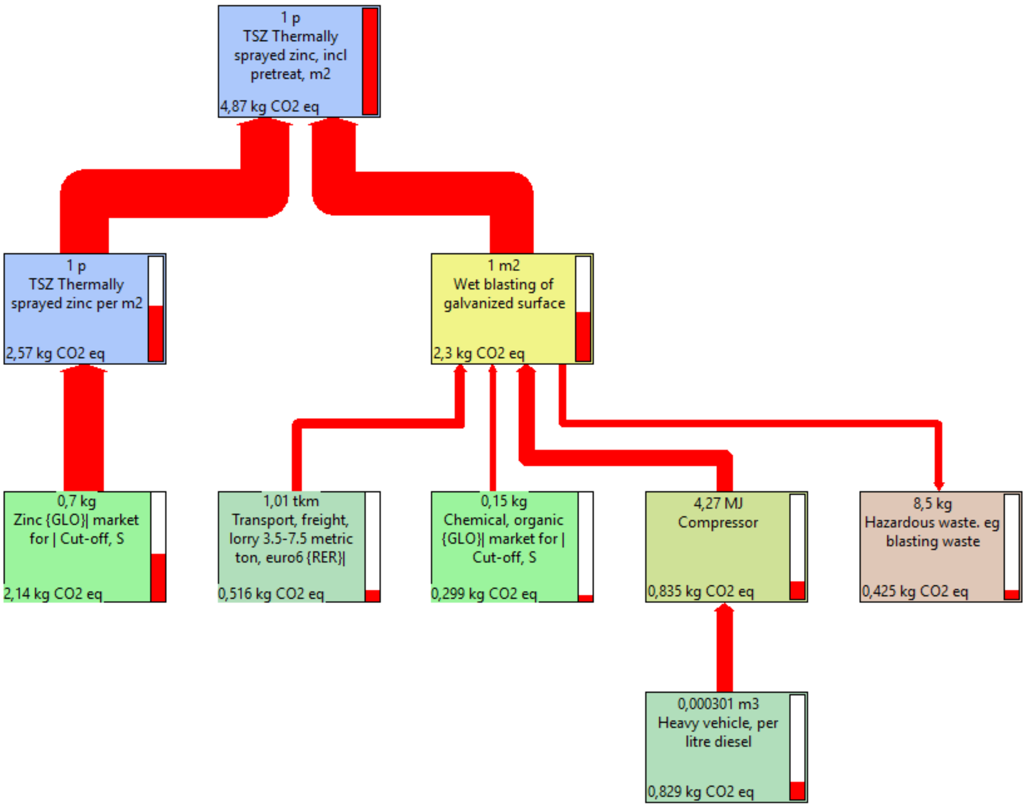

Figure 3 Climate impact of thermally sprayed zinc, cut-off 5%

Due to the significance of the zinc source and the pre-treatment, all paint refurbishments options were calculated with laser treatment as an alternative to wet abrasive blasting and with zinc from either virgin or secondary source. As shown in the diagrams below, virgin zinc and wet abrasive blasting creates the largest impacts, both climate and ozone formation, and recycled zinc and laser cleaning creates the lowest impacts. Table 20 lists the refurbishment option with the lowest and highest impact for calculations with virgin zinc and wet abrasive blasting, and calculations with recycled zinc and laser cleaning. Sankey diagrams for these cases and refurbishment options are found in the Appendix with the exception of the diagram for thermally sprayed zinc which is shown above. They represent the lowest and the highest values obtained in the study and could thus be considered as framing it, i.e., under real life conditions, impacts would most likely be inside this frame.

Table 20 Refurbishment options with the lowest and highest impact for the cases with lowest and highest impact

Case	Impact	Lowest	Highest
virgin zinc&wetblast	Climate	Induraguard	Solventborne epoxy
	Ozon	Induraguard	Solventborne epoxy
rec zinc&laser	Climate	Induraguard	(Thermally sprayed zinc, shown above) Solventborne epoxy
	Ozon	Zinc silicate waterborne	Solventborne epoxy

The two diagrams below show the total climate impact and the ozone formation impact for all cases to be compared with all the possible alternatives regarding zinc source, and laser or wet abrasive blasting as pre-treatment.

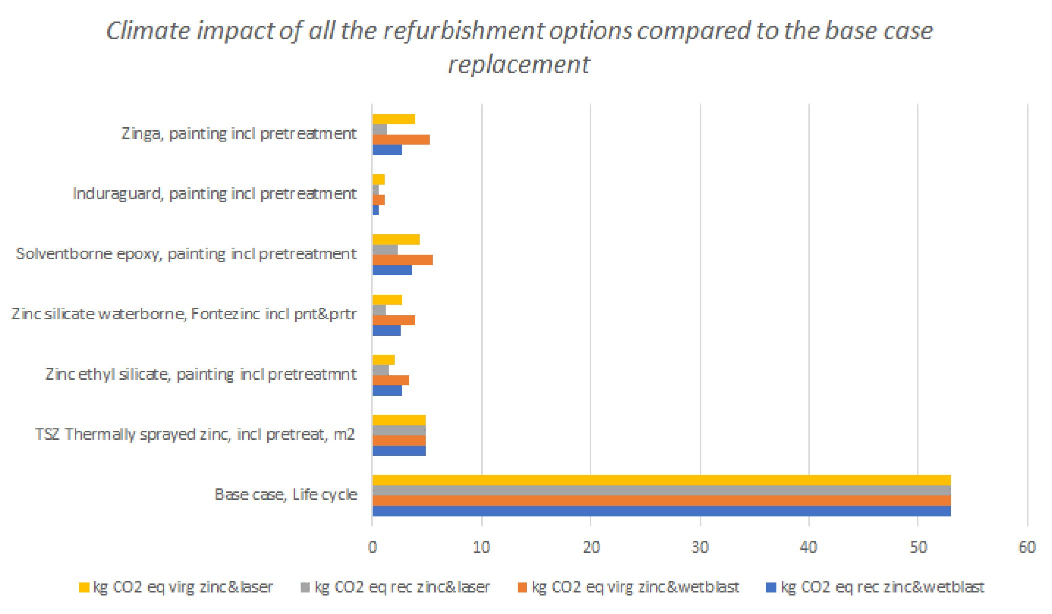

Figure 4 Climate impact of all the cases calculated with wet abrasive blasting or laser cleaning and zinc powder from virgin or recycled sources[10]

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[10] *Note that Induraguard is only calculated with steel brushing as pre-treatment and TSZ is only calculated with wet abrasive blasting as pre-treatment and zinc source according to EGGA (2016)*

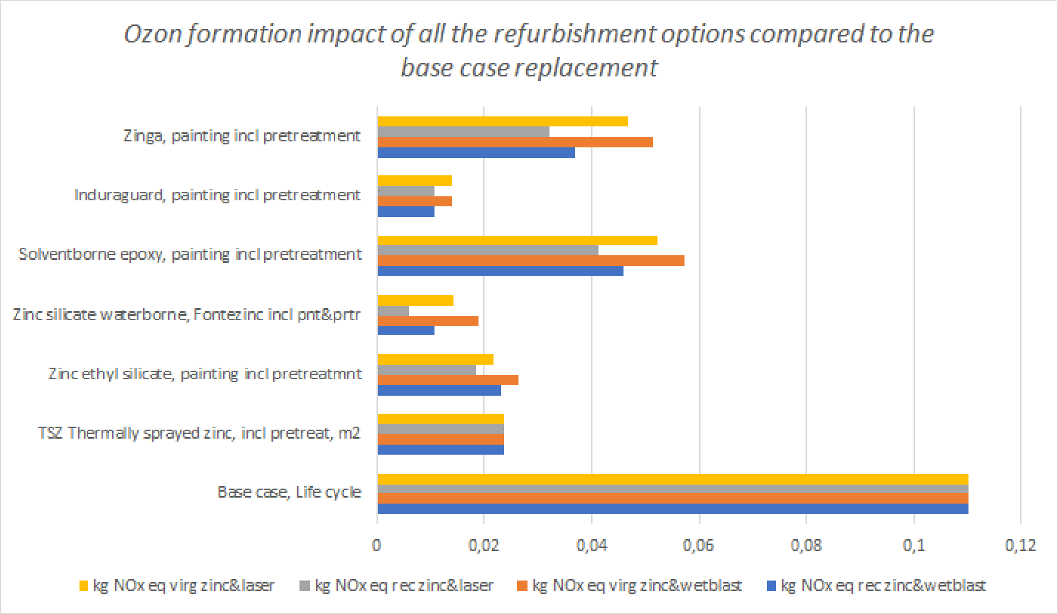

Figure 5 Ozone formation impact of all the cases calculated with wet abrasive blasting or laser cleaning and zinc powder from virgin or recycled sources[10]

As shown in the diagrams above, virgin zinc and wet abrasive blasting creates the largest impacts, both climate and ozone formation, while recycled zinc and laser cleaning creates the lowest impacts. Therefore, only these two extremes are shown in the diagrams below, that give the number of years the maintenance must last to constitute an environmental improvement compared with the base case. As explained earlier, if the service life of the maintained structure is greater than the service life of a new structure multiplied by the ratio between the environmental impact of the maintenance and the environmental impact of the new production, it is environmentally beneficial to refurbish (compared to new production). Note that Induraguard 9200 has only wire brushing as pre-treatment. Thermally sprayed zinc is only pre-treated with wet abrasive blasting and assumed to always use virgin zinc.

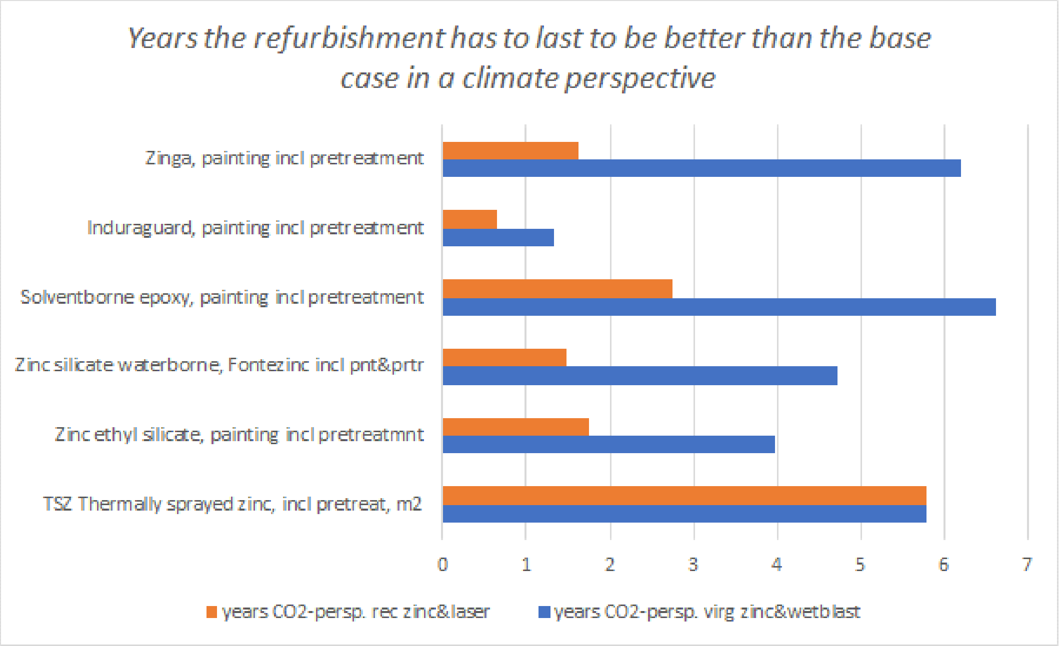

Figure 6 Number of years the refurbishment has to last to be better than the base case in a climate perspective assuming 63 years service life of replacement (base case)

The results indicate that, from a climate perspective, it is preferable to refurbish if the life (of the infrastructure) is prolonged 1-6 years, see above, while from an ozone formation perspective, the equivalent span is between 3-33 years life prolongation, see below. These figures could be compared to the practical corrosion tests carried out in the project, in order to decide whether refurbishment is environmentally better compared to new production.

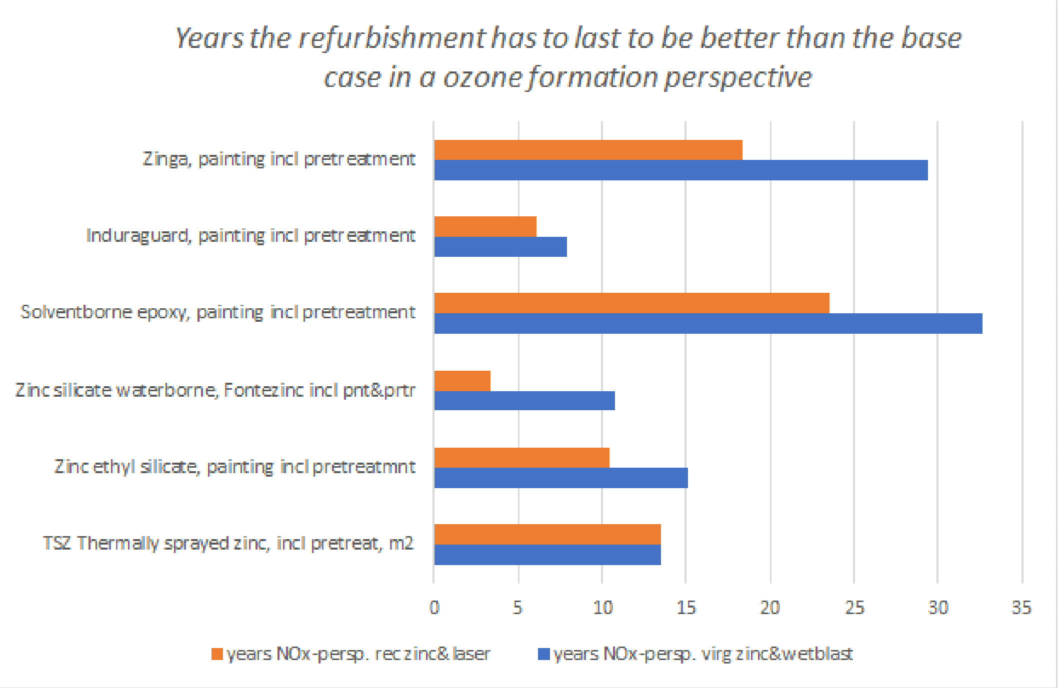

Figure 7 Number of years the refurbishment has to last to be better than the base case in a ozone formation perspective assuming 63 year service life of replacement (base case)

Discussion and conclusions

Comparison of paint systems

The developed LCA model for refurbishment of infrastructure objects can be used to compare different paints with the replacement option, with regard to climate impact and ground-level ozone. In this context, special mention should be made of the matching of solvent emissions that is made and which reflects that the aromatic solvents have a significantly higher ozone-forming ability than the aliphatic ones. However, it may be necessary to evaluate additional environmental aspects, such as toxicity, in order to fully compare the environmental impact of different paint systems. The environmental impact of complete zinc-based painting systems has been investigated in the report Livscykelanalys av rostskydd – broar (Zackrisson 2018).

Working environment

The work environment has not been specifically treated or included in this study. Several of the paint systems examined contain so-called phase-out substances, such as ethyl methyl ketoxime in Induraguard 9200, epoxy in the Temazinc 99 and aromatic solvents which are potential carcinogens. The content of potentially dangerous substances may need to be investigated further.

Climate impact versus ozone formation

The climate impact is in the order of 5 kg CO_2eq/m^2 for the refurbishment options, whereas the ozone formation impacts are in the order of 0.02 kg NO_xeq/m^2. How do these two measures compare? The simple answer is that they do not compare. They give rise to different environmental problems, climate change versus ground-level ozone formation, which cannot be compared in any scientifically correct way. To anyway give an idea, a Golf VII diesel from 2012 emits 0.00023 kg NO_x per km and 0.112 kg CO_2 per km (VW 2012). Thus, refurbishing per m^2 compares to driving per km as 5/0.112=50 in a climate impact sense and in an ozone formation sense as 0.02/0.00023=87, just to give some sort of view point.

Conclusions

The goal of the project was to compare different methods for refurbishment of hot-dip galvanized infrastructure, with replacing the entire steel infrastructure. The results show that the pre-treatment and the zinc can give significant impacts for the refurbishment options. From a climate perspective, the results indicate that the refurbishment options need only prolong the life with 1-6 years, which, compared to the expected life extension 30 years indicates a large climate impact reduction potential with any of the refurbishment options.

From an ozone perspective, the results indicate that the refurbishment options need to prolong the life with 3-33 years, which, compared to the expected life extension 30 years indicates that the right choice of refurbishment option is crucial in order to achieve potential ozone impact reductions with refurbishment. The practical tests carried out in the project will give more definite answers.

The difference in potential impact between the refurbishment options should not be taken as absolute as the information was mostly gathered from open sources, like safety data sheets and product information sheets. Nevertheless, the low (inherent) ozone formation impacts associated with the waterborne zinc silicate is worth mentioning, as well as Induraguard 9200´s environmentally benign pre-treatment (wire brushing).

The study focuses on 8 mm thick steel structures. The thicker and heavier object, the more is, in general, to gain by refurbishing instead of replacing with new object.

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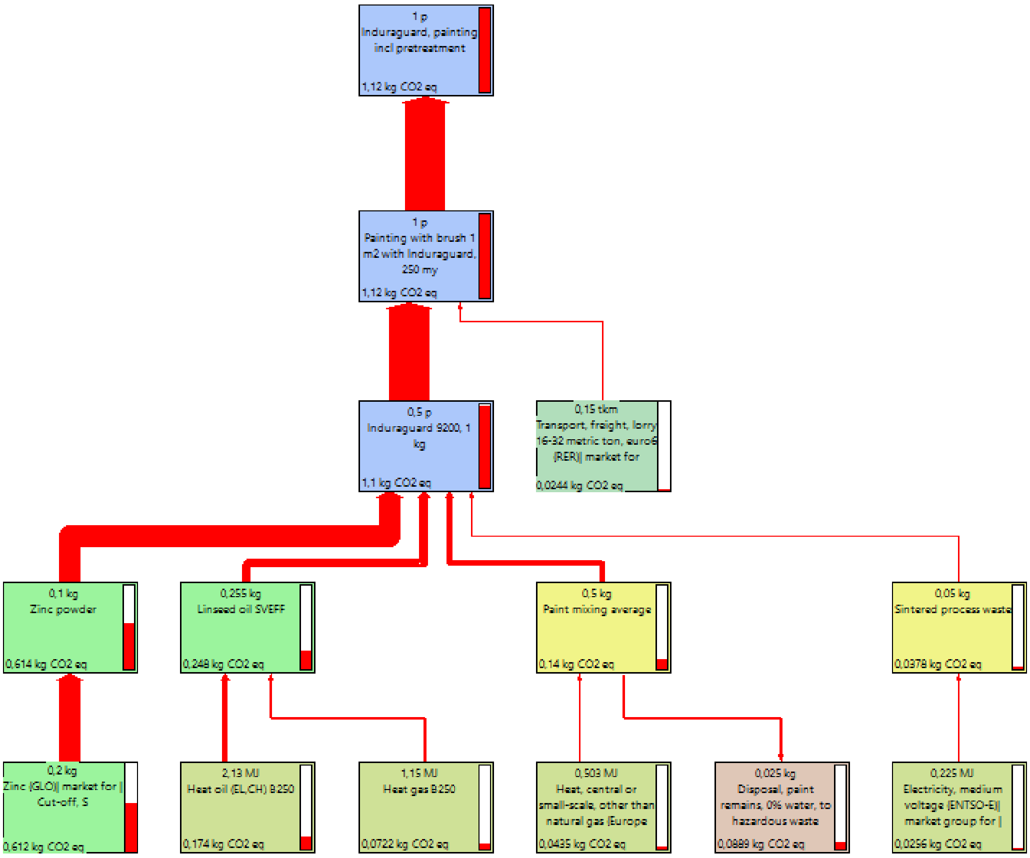
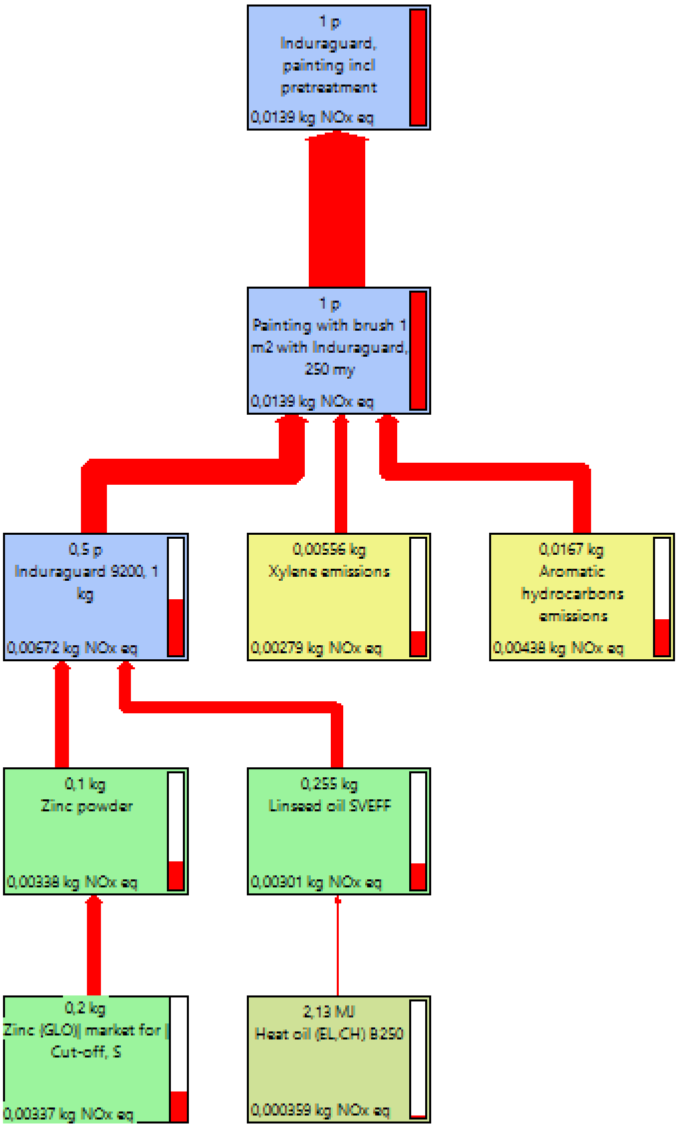
Appendix 1

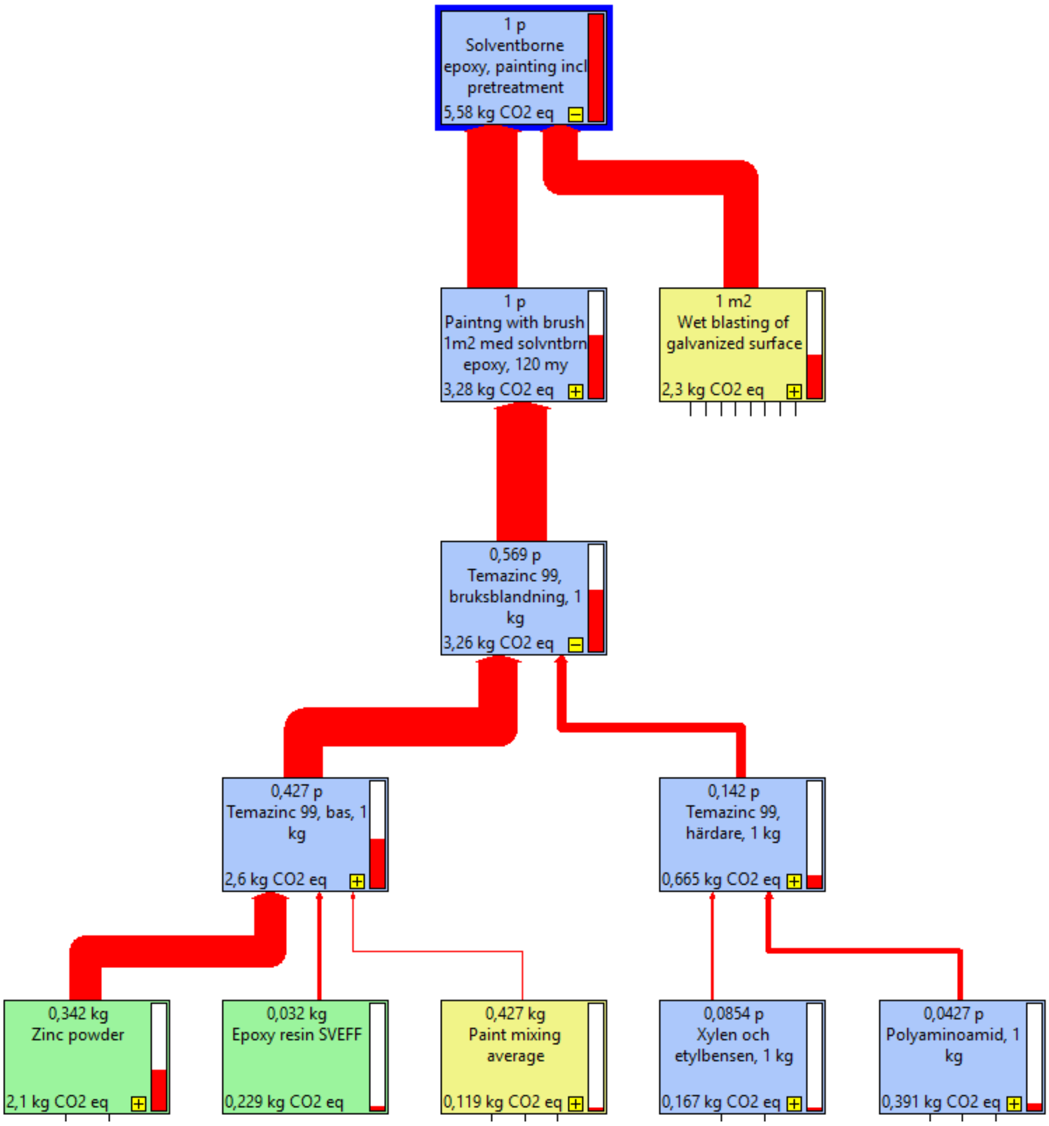
The Swedish terms used in diagrams means:

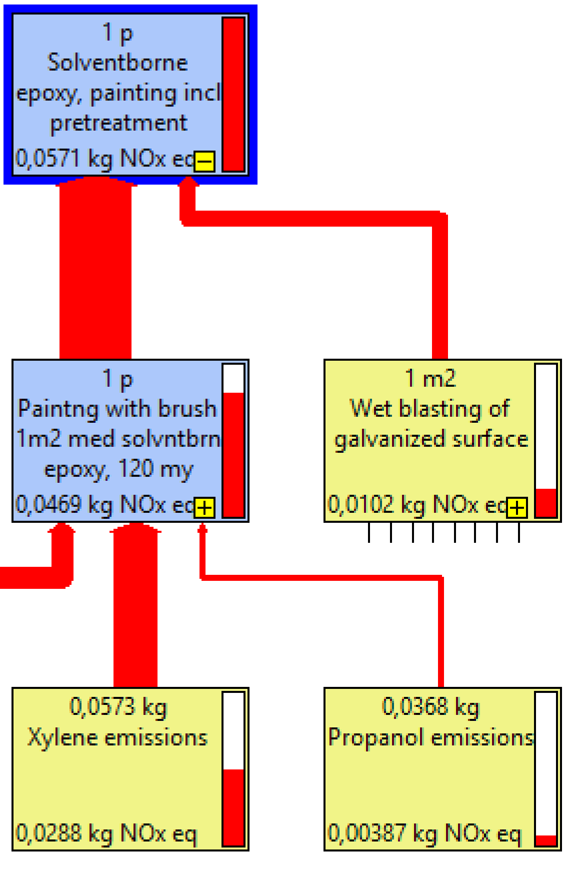
- Bas = Base
- Bruksblandning = Mixed
- Härdare = Hardener

Case: Virgin zinc and wet abrasive blasting. Lowest and highest impacts, cut-off 2%

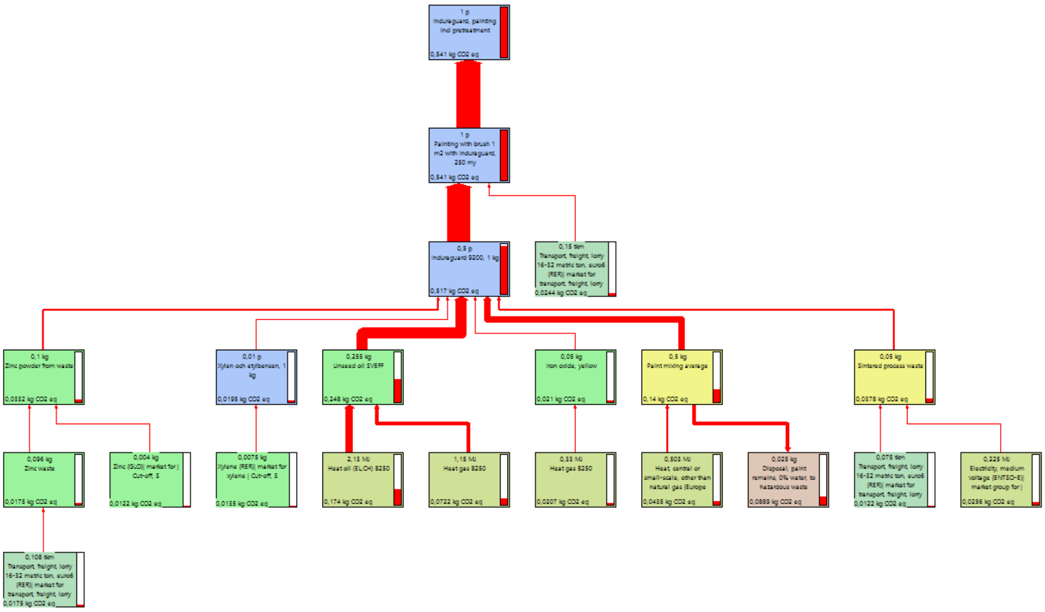


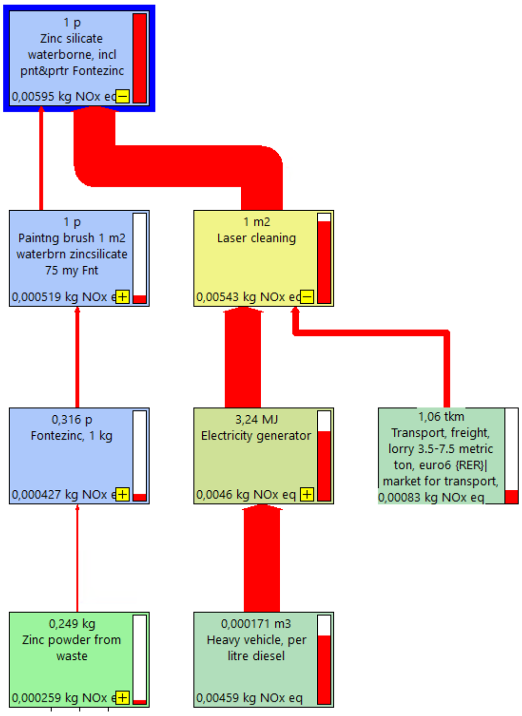

1 p
Induraguard, painting incl pretreatment
0,0139 kg NOx eq
1 p
Painting with brush 1 m2 with Induraguard, 250 my
0,0139 kg NOx eq
0,5 p
Induraguard 9200, 1 kg
0,00672 kg NOx eq
0,00556 kg
Xylene emissions
0,00279 kg NOx eq
0,0167 kg
Aromatic hydrocarbons emissions
0,00438 kg NOx eq
0,1 kg
Zinc powder
0,00338 kg NOx eq
0,255 kg
Linseed oil SVEFF
0,00301 kg NOx eq
0,2 kg
Zinc {GLO}| market for | Cut-off, S
0,00337 kg NOx eq
2,13 MJ
Heat oil (EL,CH) B250
0,000359 kg NOx eq

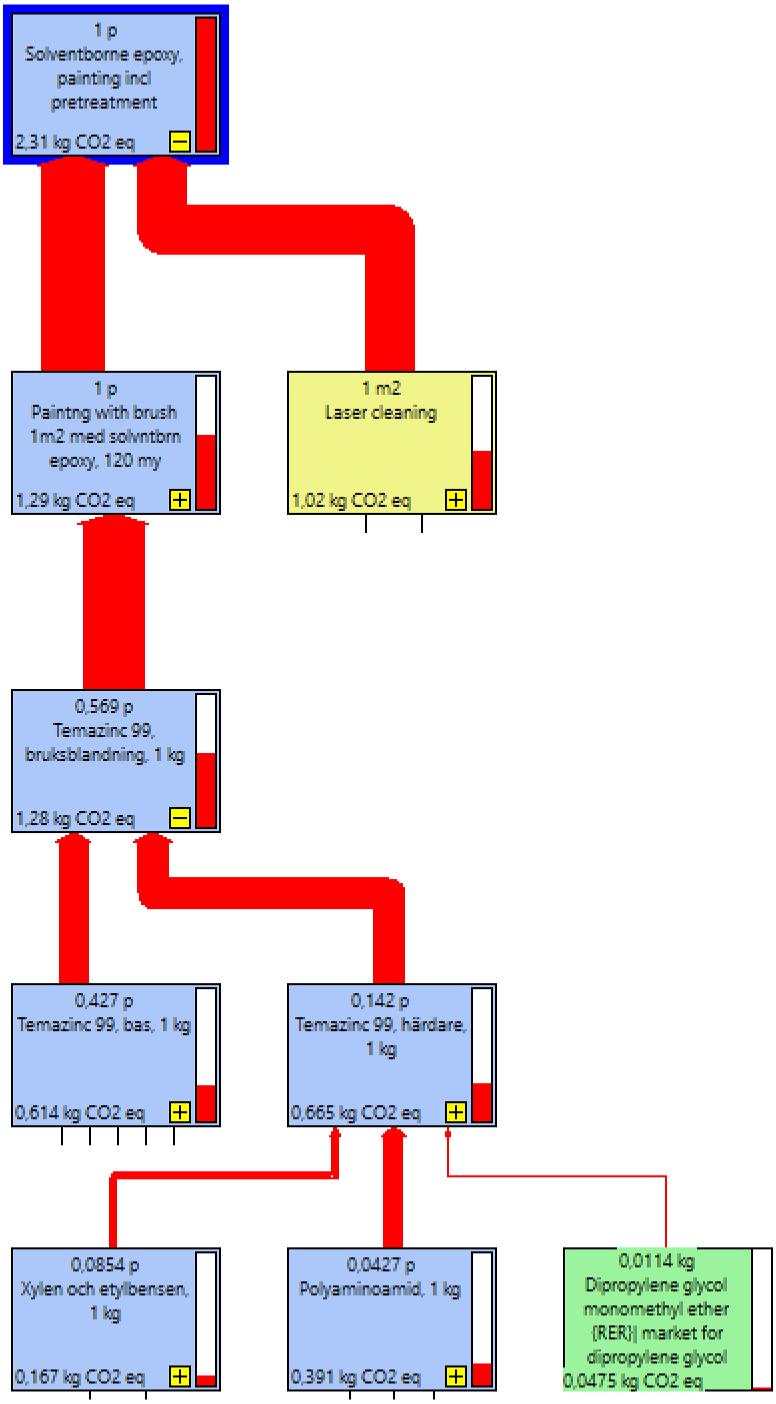

1 p
Solventborne epoxy, painting incl pretreatment
5,58 kg CO2 eq
1 p
Paintng with brush 1m2 med solvntbrn epoxy, 120 my
3,28 kg CO2 eq
1 m2
Wet blasting of galvanized surface
2,3 kg CO2 eq
0,569 p
Temazinc 99, bruksblandning, 1 kg
3,26 kg CO2 eq
0,427 p
Temazinc 99, bas, 1 kg
2,6 kg CO2 eq
0,142 p
Temazinc 99, härdare, 1 kg
0,665 kg CO2 eq
0,342 kg
Zinc powder
2,1 kg CO2 eq
0,032 kg
Epoxy resin SVEFF
0,229 kg CO2 eq
0,427 kg
Paint mixing average
0,119 kg CO2 eq
0,0854 p
Xylen och etylbensen, 1 kg
0,167 kg CO2 eq
0,0427 p
Polyaminoamid, 1 kg
0,391 kg CO2 eq

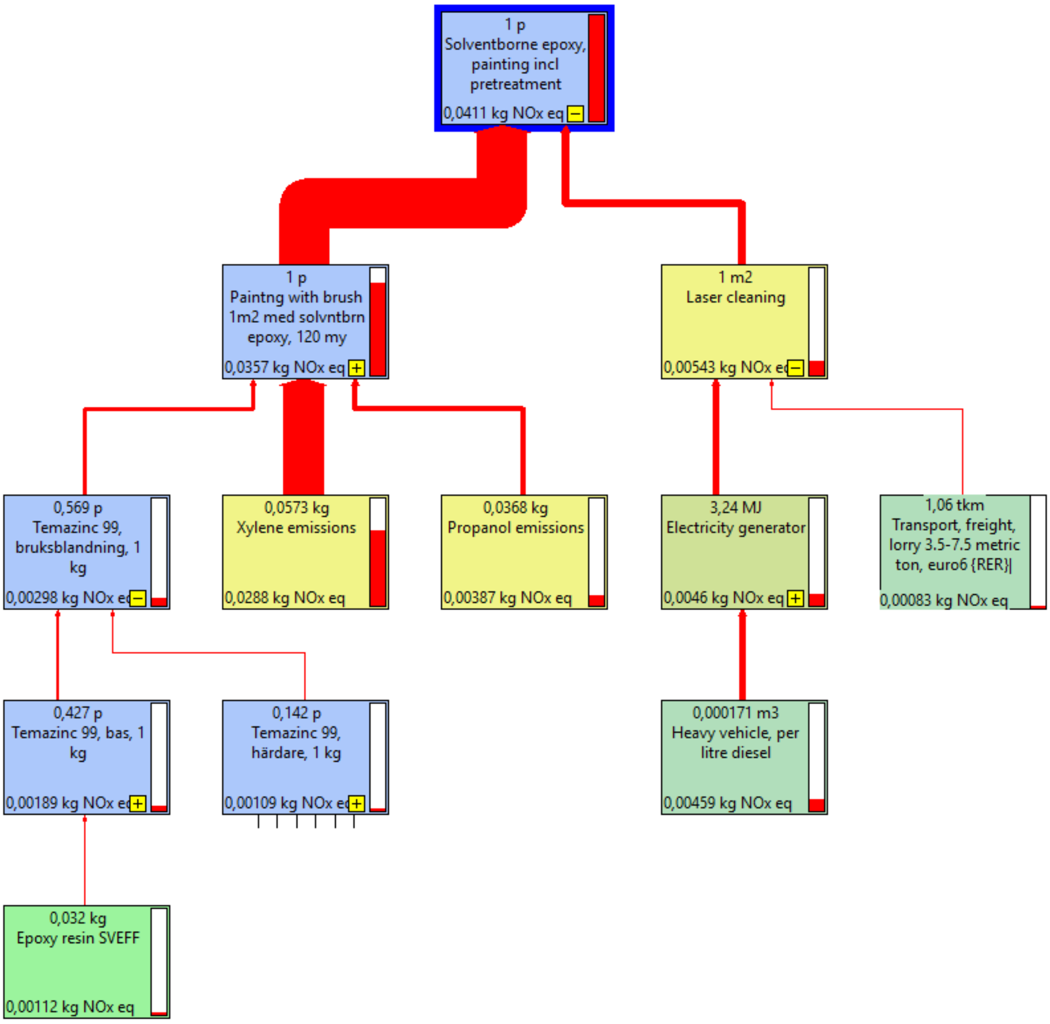

1 p
Solventborne epoxy, painting incl pretreatment
0,0571 kg NOx eq
1 p
Paintng with brush 1m2 med solvntbrn epoxy, 120 my
0,0469 kg NOx eq
1 m2
Wet blasting of galvanized surface
0,0102 kg NOx eq
0,569 p
Temazinc 99, bruksblandning, 1 kg
0,0142 kg NOx eq
0,0573 kg
Xylene emissions
0,0288 kg NOx eq
0,0368 kg
Propanol emissions
0,00387 kg NOx eq
0,427 p
Temazinc 99, bas, 1 kg
0,0131 kg NOx eq
0,342 kg
Zinc powder
0,0115 kg NOx eq

Case: Recycled zinc and laser cleaning, cut-off 2%






1 p
Solventborne epoxy, painting incl pretreatment
2,31 kg CO2 eq
1 p
Paintng with brush 1m2 med solvntbrn epoxy, 120 my
1,29 kg CO2 eq
1 m2
Laser cleaning
1,02 kg CO2 eq
0,569 p
Temazinc 99, bruksblandning, 1 kg
1,28 kg CO2 eq
0,427 p
Temazinc 99, bas, 1 kg
0,614 kg CO2 eq
0,142 p
Temazinc 99, härdare, 1 kg
0,665 kg CO2 eq
0,0854 p
Xylen och etylbensen, 1 kg
0,167 kg CO2 eq
0,0427 p
Polyaminoamid, 1 kg
0,391 kg CO2 eq
0,0114 kg
Dipropylene glycol monomethyl ether {RER}| market for dipropylene glycol
0,0475 kg CO2 eq


1 p
Solventborne epoxy, painting incl pretreatment
0,0411 kg NOx eq
1 p
Paintng with brush 1m2 med solvntbrn epoxy, 120 my
0,0357 kg NOx eq
1 m2
Laser cleaning
0,00543 kg NOx eq
0,569 p
Temazinc 99, bruksblandning, 1 kg
0,00298 kg NOx eq
0,0573 kg
Xylene emissions
0,0288 kg NOx eq
0,0368 kg
Propanol emissions
0,00387 kg NOx eq
3,24 MJ
Electricity generator
0,0046 kg NOx eq
1,06 tkm
Transport, freight, lorry 3.5-7.5 metric ton, euro6 {RER}|
0,00083 kg NOx eq
0,427 p
Temazinc 99, bas, 1 kg
0,00189 kg NOx eq
0,142 p
Temazinc 99, härdare, 1 kg
0,00109 kg NOx eq
0,000171 m3
Heavy vehicle, per litre diesel
0,00459 kg NOx eq
0,032 kg
Epoxy resin SVEFF
0,00112 kg NOx eq