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LCA of zinc phosphating and thin film pre-treatment

Deliverable D 4.5 in ImpThin project

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This report has been reviewed and approved in accordance with IVL's audited and approved management system.

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1 Introduction

1.1 Background

IVL Swedish Environmental Research Institute has been part of the Vinnova-funded research project ImpThin (Implementation study of thin film pre-preatments). In the project, Task 4.3 entailed conducting a life cycle assessment (LCA) comparing zinc phosphating and thin film pre-treatment processes. This report documents the LCA and covers methodological choices, what data has been used and how the LCA has been modelled, as well as results and final conclusions.

This document corresponds to deliverable D 4.5 in the project and represents a revised rendition of a prior report produced for project internal purposes.

1.2 About LCA

Life cycle assessment investigates the environmental impacts related to a product or a process during its whole life cycle. This includes evaluating energy and resource consumption as well as emissions, from all life cycle stages including material production, manufacturing, use and maintenance, and end-of-life (Figure 1).

LCA is a widely used and accepted method for studies of environmental performance of various products and processes. The LCA in this report is performed in accordance with ISO 14040:2006 (International Organization for Standardization, 2006a) and ISO 14044:2006 (International Organization for Standardization, 2006b) standards.

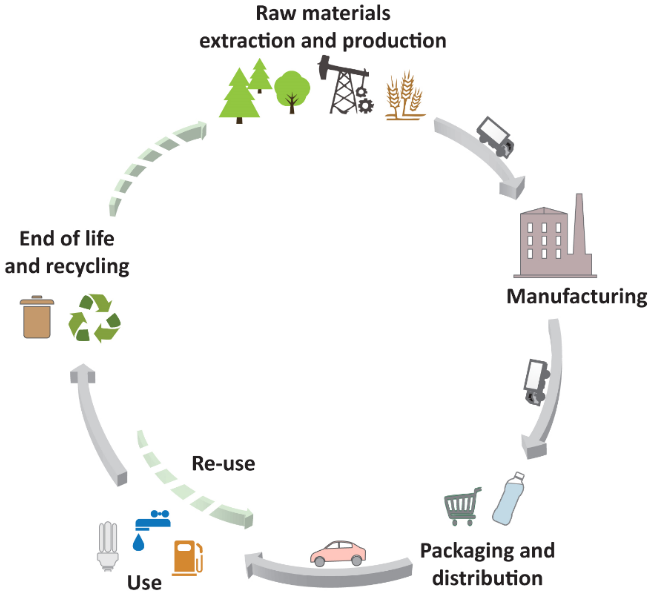


Figure 1: Illustration of an LCA-system.

2 Goal and Scope

2.1 Goal

The primary goal of this LCA study is to compare two pre-treatment processes, zinc phosphating and thin film pre-treatment, in terms of environmental performance.

The findings obtained from the study will be disseminated both internally within the ImpThin project and publicly to a wider audience. The results can inform actors in the field of pre-treatment technology, such as OEMs and subcontractors, and help identify opportunities to reduce environmental impact.

2.2 Scope

2.2.1 Studied process and functional unit

The scope of this study is pre-treatment processes, zinc phosphating and thin film pre-treatment, used in the automotive industry. Vehicle components, such as car-body parts, are pre-treated to ensure corrosion protection, adhesion to the subsequent coatings, electrical insulation and to minimize surface friction and abrasion.

The two processes consist of several steps where the component is treated a certain time by immersion in bath or by spraying. A generic overview of the processes is depicted in Figure 2.

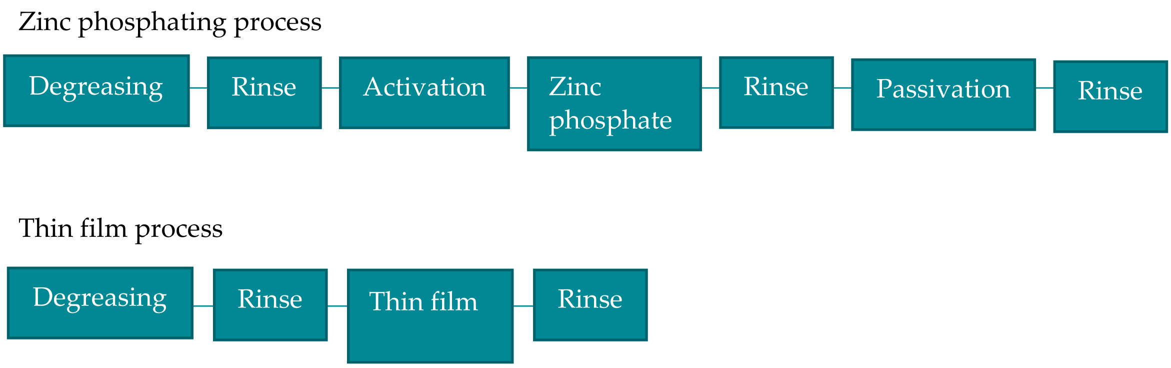


Figure 2 Generic overview of the two studied processes based on process descriptions from project partners. Degreasing and rinsing is typically applied using several consecutive baths or spray chambers.

The functional unit of the LCA is defined as 1 m^2 pre-treated area.

2.2.2 System boundaries

This study is covering the pre-treatment processes only, subsequent processes such as e-coating and powder coating are not included. Those processes are usually not affected by type of pre-treatment process (Risberg, 2021). As the study assess a process rather than a product (e.g. a panel which is pre-treated), product end-of-life activities, i.e. what happens with the pre-treatment coating layer when the coated component is scrapped, are excluded.

The following activities are also excluded in the study:

- Production and maintenance of capital goods and infrastructure (buildings, machines, vehicles etc.) used within the different activities in the life cycle
- Personnel-related environmental impact (travel to work, business travels, food etc.)
- Production, use and end-of-life of packaging materials
- Exchange of parts and consumables (e.g. gaskets and filters). Other maintenance, such as cleaning, is included.

The included activities are summarized in a flowchart in Figure 3 below.

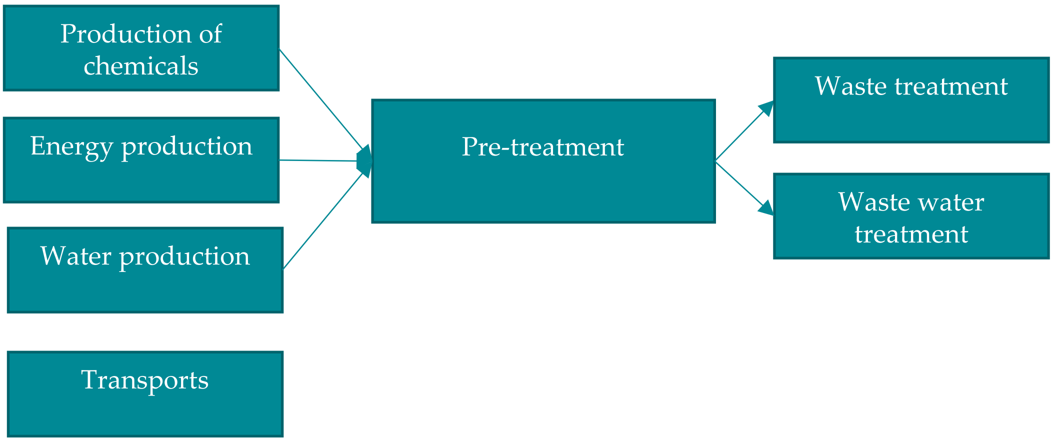


Figure 3: Activities included in the LCA study.

The boundary between nature and the included activities is crossed when materials, such as crude oil and iron ore, are extracted from the ground or when emissions occur to soil, air or water.

2.2.3 Impact categories

The impact categories selected for analysis in this study are described in Table 1.

Impact category	Indicator	Unit	Method
Climate change	Radiative forcing as Global Warming Potential (GWP100)	kg CO_2 eq	Baseline model of 100 years of the IPCC (based on IPCC 2013)
Ozone depletion	Ozone Depletion Potential (ODP)	kg CFC-11 eq	Steady-state ODPs as in (WMO 1999)
Particulate matter	Impact on human health	disease incidence	PM method recommended by UNEP (UNEP 2016)
Photochemical ozone formation, human health	Tropospheric ozone concentration increase	g NMVOC eq	LOTOS-EUROS model (Van Zelm et al, 2008) as implemented in ReCiPe 2008
Acidification	Accumulated Exceedance (AE)	mol H^+ eq	Accumulated Exceedance (Seppälä et al. 2006, Posch et al, 2008)
Eutrophication, terrestrial	Accumulated Exceedance (AE)	mol N eq	Accumulated Exceedance (Seppälä et al. 2006, Posch et al, 2008)
Eutrophication, freshwater	Fraction of nutrients reaching freshwater end compartment (P)	kg P eq	EUTREND model (Struijs et al, 2009) as implemented in ReCiPe
Eutrophication, marine	Fraction of nutrients reaching marine end compartment (N)	kg N eq	EUTREND model (Struijs et al, 2009) as implemented in ReCiPe

Table 1: Selected impact categories.

The selected categories are the ones considered most robust according to the Product Environmental Footprint Category Rules Guidance (European Commission, December 2017), with *Ionising radiation, human health* excluded.

Methods for toxicity and resource depletion are available and of interest in this kind of study. However, there is lack of experience in applying these methods to LCA databases. The current assessment methods should be used with caution since they are not sufficiently robust for decision making. Regarding toxicity, no characterization factors are available for many specific chemicals and must be calculated separately.

These facts, in combination with limited access to relevant process data, makes it hard to provide sufficient results for toxicity and resource depletion. Therefore, results for these categories are not calculated from the LCA models but instead qualitatively discussed and evaluated in the results section.

2.2.4 Assessed cases and sources of data

Five existing zinc phosphating process lines are assessed based on data measured by the project partners. To assess thin film pre-treatment, estimations on how these five lines would change if converted to thin film technology have been used. The estimations have been provided by the project partners.

	ZnPh case (measured data)	Thin film case (estimated data)		
		Consumption of process chemicals	*Energy consumption*	*Other data*
Process line 1	Project partner 1	Project partner 5	IVL	Diff. based on evaluation by project partners 2 and 5
Process line 2	Project partner 2	″	Diff. based on evaluation by project partners 2 and 5	″
Process line 3	″	″	″	″
Process line 4	Project partner 3	″	Project partner 3	″
Process line 5	Project partner 4	No data obtained		

Table 2: List of assessed cases and sources of data (grey cells)

One project partner is capable of thin film pre-treatment as of today, the others are not. However, this thin film treatment is only used in low volumes, operative a few days per year, which makes it hard to obtain accurate and comparable measurements on e.g. chemicals and energy consumption.

2.2.5 Main limitations and assumptions

- Ideally the results for thin film pre-treatment should be based on measured data, instead of estimations. This was not possible here as no project partners could provide this and efforts to obtain data from other companies were unsuccessful. The results representing thin film pre-treatment could therefore be viewed as less accurate.

- In some cases it has been hard to isolate the pre-treatment processes from subsequent coating processes, e.g. when it comes to energy consumption data which is often measured for the pre-treatment/coating process combined. In these cases allocations has been made which might increase uncertainty of the results.

- For waste treatment a limited number of generic database data were available. This might lead to uncertainties as the waste reported has large differences (e.g. waste source, wet content) meaning the actual treatment might differ from what is modelled.

3 Life cycle inventory analysis

3.1 Data collection and modelling procedure

Data collection was performed during 2021 by IVL in cooperation with the project partners. A template for data collection was prepared and distributed to the partners, see Appendix A. The data provided was representing one year’s production. The total pre-treated area for one year was also reported to be able to obtain data per functional unit (1 m2).

Modelling of the activities based on the collected data was made in the LCA software GaBi. In the model, generic data from different databases (e.g. data representing production of 1 kg NaOH) was used together with specific data from project partners (e.g. data representing production of 1 kg thin film pre-treatment chemical). For a list of the generic data used in the models, see Appendix B.

Data collection and modelling for each activity are briefly described in sub-sections 3.2 - 3.6.

3.2 Production of chemicals

Data collection for chemicals are important in both pre-treatment processes since they differ in type and content. The amounts of chemicals used in the processes are provided by production sites involved in the study. As far as possible, LCA results for specific chemicals received from the supplier has been used in the LCA. However, results for all chemicals could not be provided. In these cases, assumptions based on similarities in chemical content have been used. The assumptions are in some cases assisted by the supplier and otherwise supported by research in chemical documentation such as safety data sheets. Since the full chemical content is mostly often not provided publicly due to corporate secrecy, there is an uncertainty regarding some of these assumptions.

3.3 Energy production

The obvious energy usage for these processes is the energy used to maintain temperature of the process baths that needs to be heated. Energy is also used for e.g. pumps, conveyor system and water treatment system. Typical energy consumers in a pre-treatment process were obtained from discussions with the project partners and are summarized in Table 3, which also then defines the energy consumption included in this study. As energy consumption figures were reported per factory building or factory hall also energy consumption such as heating or lighting were included in the study.

Table 3 Typical energy consumers in a pre-treatment process, and energy consumers related to the facility where the process is located.

Pre-treatment process	Facilities
Heating baths	Heating
Pumps	Lighting
Conveyor system	Ventilation/Dehumidification
Water treatment system	
Deionised water production	
Oil separation	
Cyclone	
Filtration	
Process ventilation	
Control system/electronics	

The energy wares used at project partners 2 and 4 are electricity and district heating. The electricity used are reported to be from renewable resources, for project partner 4 it is specified to be from 100% hydro power. As hydro power is the most common renewable resource used for electricity production in Sweden an electricity mix from 100% hydro power is also assumed for the project partner 2 cases.

The district heating is modelled based on how it is produced according to data reported by Energiföretagen Sverige (Khodayari, 2021). The relative shares of different sources of energy used are presented in Table 4.

Table 4 Energy sources used to produce district heat for the different cases.

	Process line 5	Process line 3	Process line 2
Recovered energy[1]	56,1%	18,5%	91,0%
Renewable energy[2]	39,7%	80,3%	6,4%
Fossil energy	1,0%	0,1%	2,7%
Other[3]	3,3%	1,1%	-

(1) E.g. from flue gas condensation or waste incineration. Not associated with any impact in the study.

(2) E.g. from secondary biofuels or pellets, briquettes and powder

(3) E.g. from peat or electricity from nuclear power

Project partner 1 is using LPG and project partner 3 natural gas for heating of the baths. Both production and combustion of these energy carriers are included. National average mixes were used to represent electricity production as no specific origin of electricity was reported for these two cases.

3.4 Water production and Wastewater treatment

Water is needed in large amounts in the process, but the water used is recycled in a closed loop system in order to minimize wastewater. If the process generates wastewater it is going through an internal wastewater treatment system before it is released to rivers or lakes or municipal sewage. A small share of the used tap water ends up in the waste (sludge or other waste concentrate) and the remainder is assumed to be released to air as water vapour.

Generic data sets are used to model the production of water and the municipal wastewater treatment.

3.5 Waste treatment

Different types of waste, often classified as hazardous, are generated through the process, e.g. sludge from the zinc phosphating step or the internal wastewater treatment, or oil emulsions from degreasing steps.

For the different types of sludges generic data has been used to model waste treatment. This data represents drying, neutralization and encapsulation of the waste and final deposition on landfill.

Oil emulsions are assumed to contain 10% oil and the waste treatment is modelled by using generic data representing treatment of used oil.

3.6 Transports

The transports included can be divided into inbound transports of chemicals and outbound transports of waste. For transports of chemicals data on location of production plant and type of transport (truck, ship, train etc.) have been collected by project partners. Transport distances have been calculated by using Google Maps. If the location of the production plant was unknown a default distance of 2500 km has been used as an estimate.

For transports of waste data on location of final waste treatment location and type of transport (truck, ship, train etc.) have been collected by project partners. If the location of final waste treatment was unknown a default distance of 100 km has been used as an estimate.

Generic data sets are then used to model the transport. Both the production of the fuel used, and the combustion is accounted for (“Well-to-Wheel” scope). Default parameters are used regarding utilization factor, share of road categories (urban/rural/motorway), share of Sulphur content in fuel and biogenic carbon content in fuel.

4 LCA Results

Based on the system model developed in the LCA software, results have been calculated. First a contribution analysis is presented based on the measured data representing the zinc phosphating process, focusing on climate impact. Then the comparison between the two technologies is presented.

4.1 Contribution analysis, Zinc phosphating pre-treatment

The contribution to climate change, by emissions of greenhouse gases, of the different activities is shown for process line 1 and process line 4 in Figure 4. The production and combustion of energy is clearly the dominant contributor here.

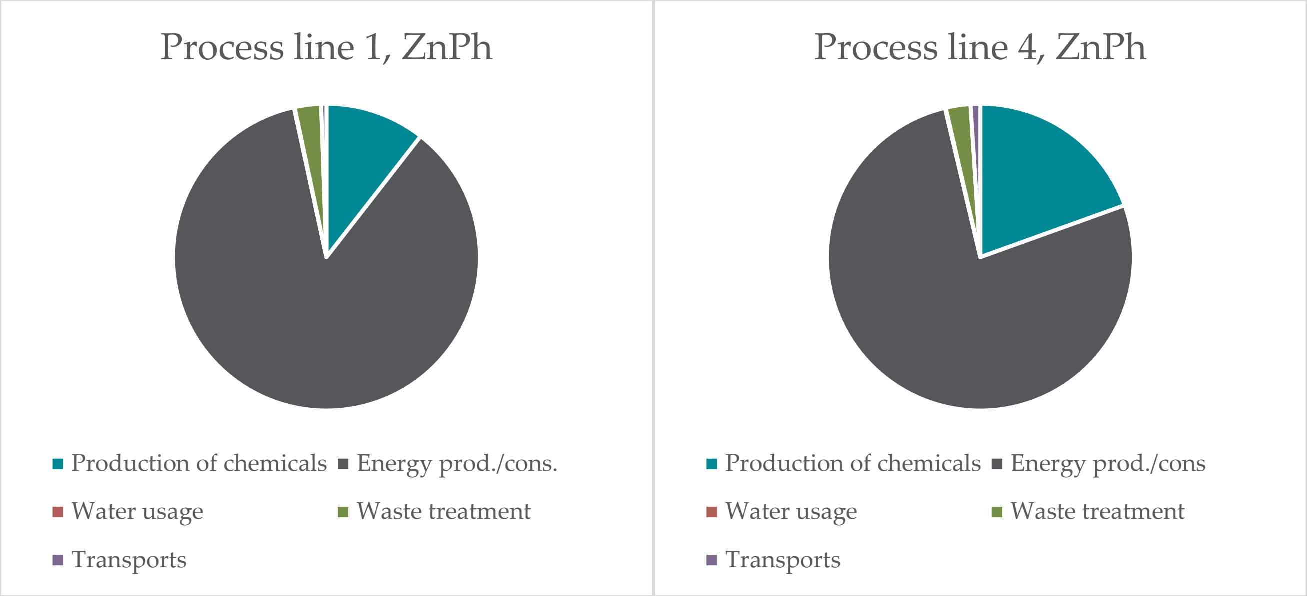


Figure 4: Contribution analysis, climate impact measured in kg CO2 eq. Process line 1 and Process line 4 cases.

The same results are shown in Figure 5, now for the project partner 2 cases (process line 2 and 3). Here the contribution is more evenly distributed. Energy production stands for less than 50% of the total impact, and for process line 2 it is not even the most impacting activity.

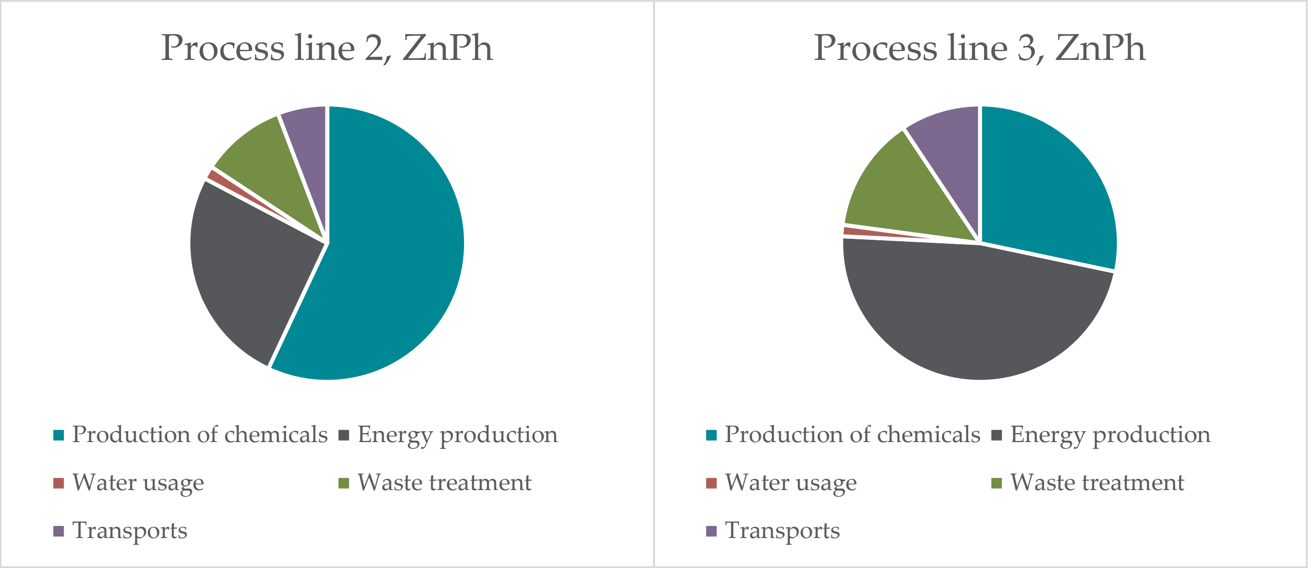


Figure 5: Contribution analysis, climate impact measured in kg CO2 eq. Process line 2 and Process line 3 cases.

Results for the last case, process line 5, is presented in Figure 6. The result shows a similar pattern as the project partner 2 cases, where the impact is more evenly distributed.

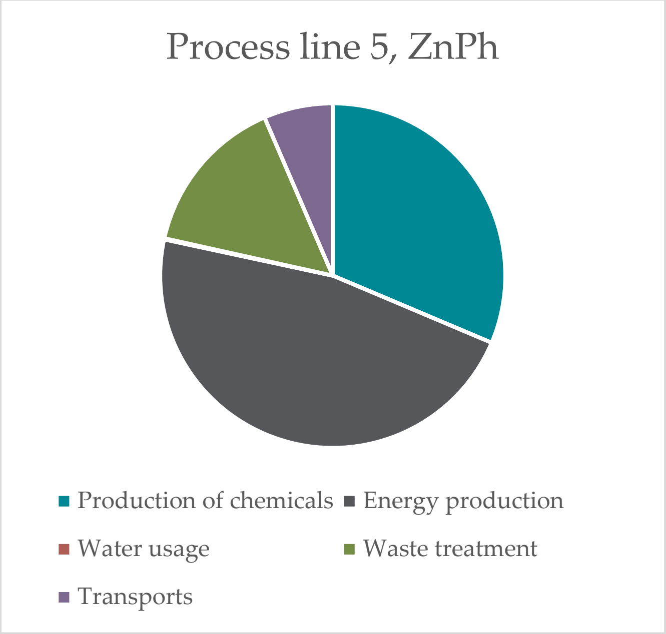


Figure 6 Contribution analysis, climate impact measured in kg CO2 eq. Process line 5 case.

4.2 Results, Zinc phosphating vs. thin film pre-treatment

A comparison between zinc phosphating and thin film pre-treatment with regards to climate impact, is presented in Figure 7 for process line 1 and in Figure 8 for process line 4. The impact from energy production and consumption is decreased due to less required energy for heating the thin film process step. In both cases impacts from production of chemicals is significantly decreased. In total a reduction of around 20% is achieved.

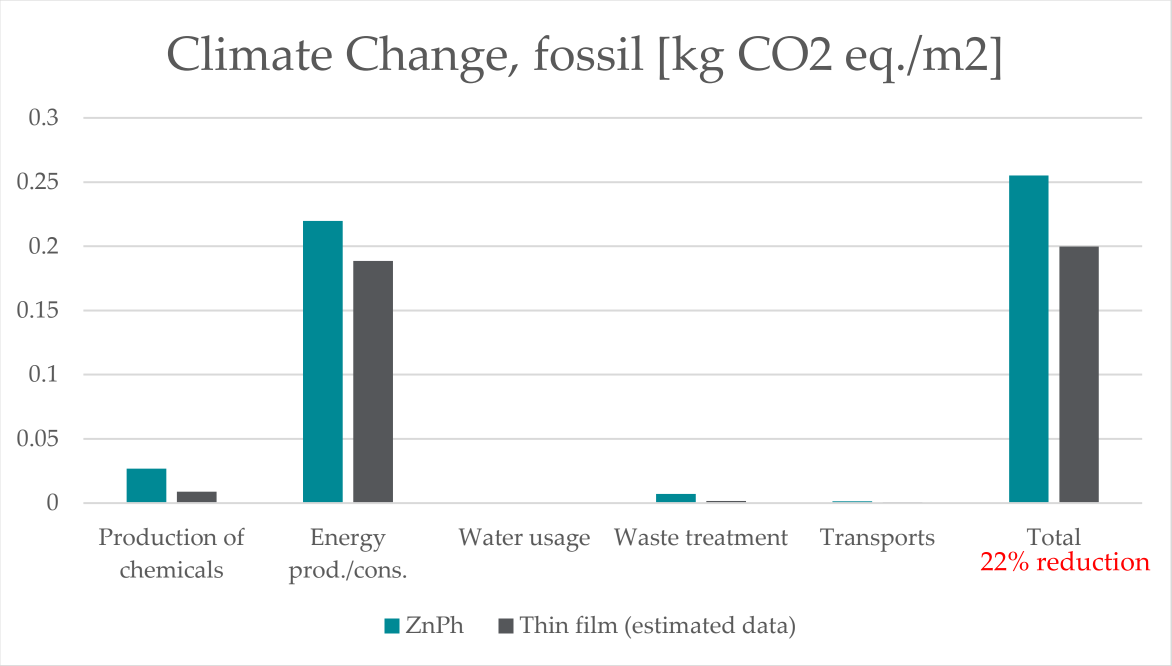


Figure 7: Climate impact, ZnPh vs. thin film, Process line 1 case.

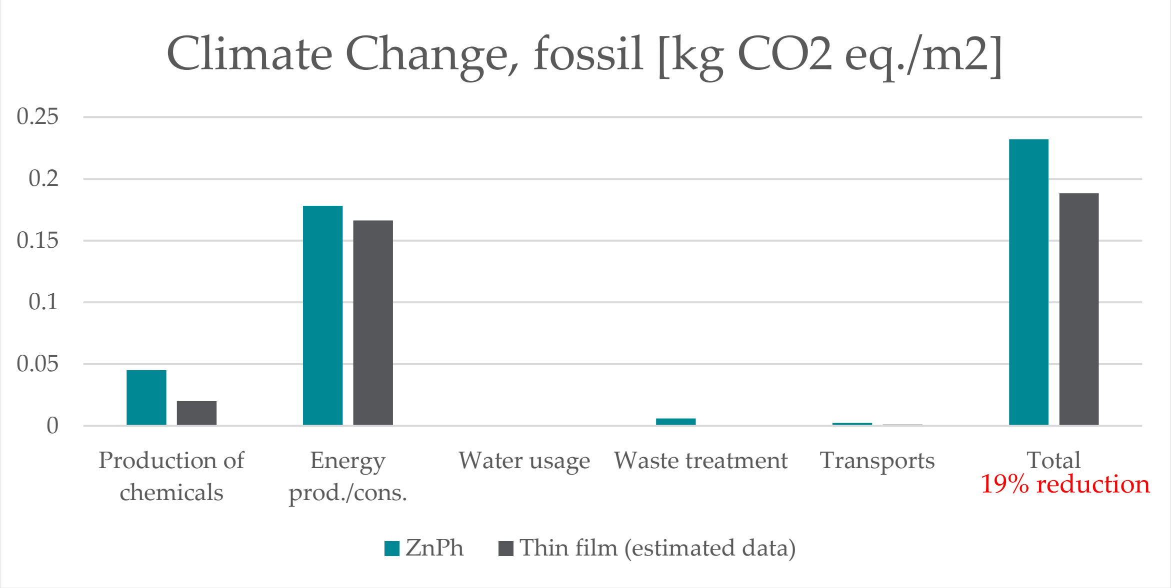


Figure 8: Climate impact, ZnPh vs. thin film, Process line 4 case.

The comparison for the two project partner 2 cases is presented in Figure 9 and Figure 10. There are similar energy reductions also here, but as the energy contributes less it is mainly the other activities (production of chemicals, waste treatment and transports) that contributes to the total impact reduction. Waste treatment is reduced as less sludge is produced and transport is reduced as less chemicals and less waste need to be transported. Also for these two cases a significant reduction in impacts from production of chemicals is noted.

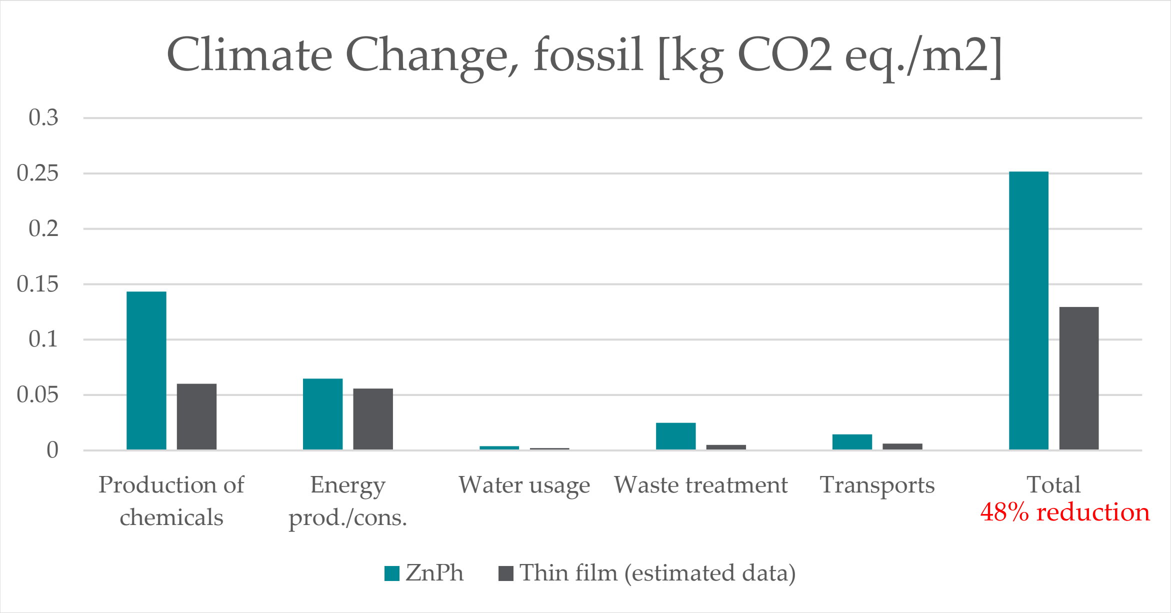


Figure 9: Climate impact, ZnPh vs. thin film, Process line 2 case. Here components are shot blasted before pre-treatment which leads to a significantly higher consumption of process chemicals compared to the other cases.

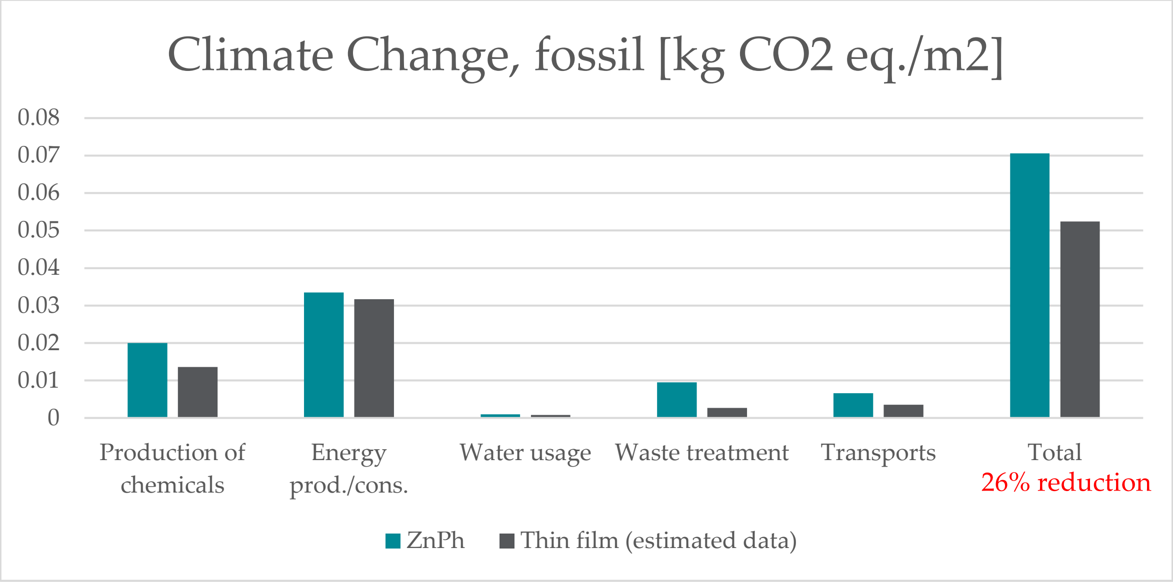
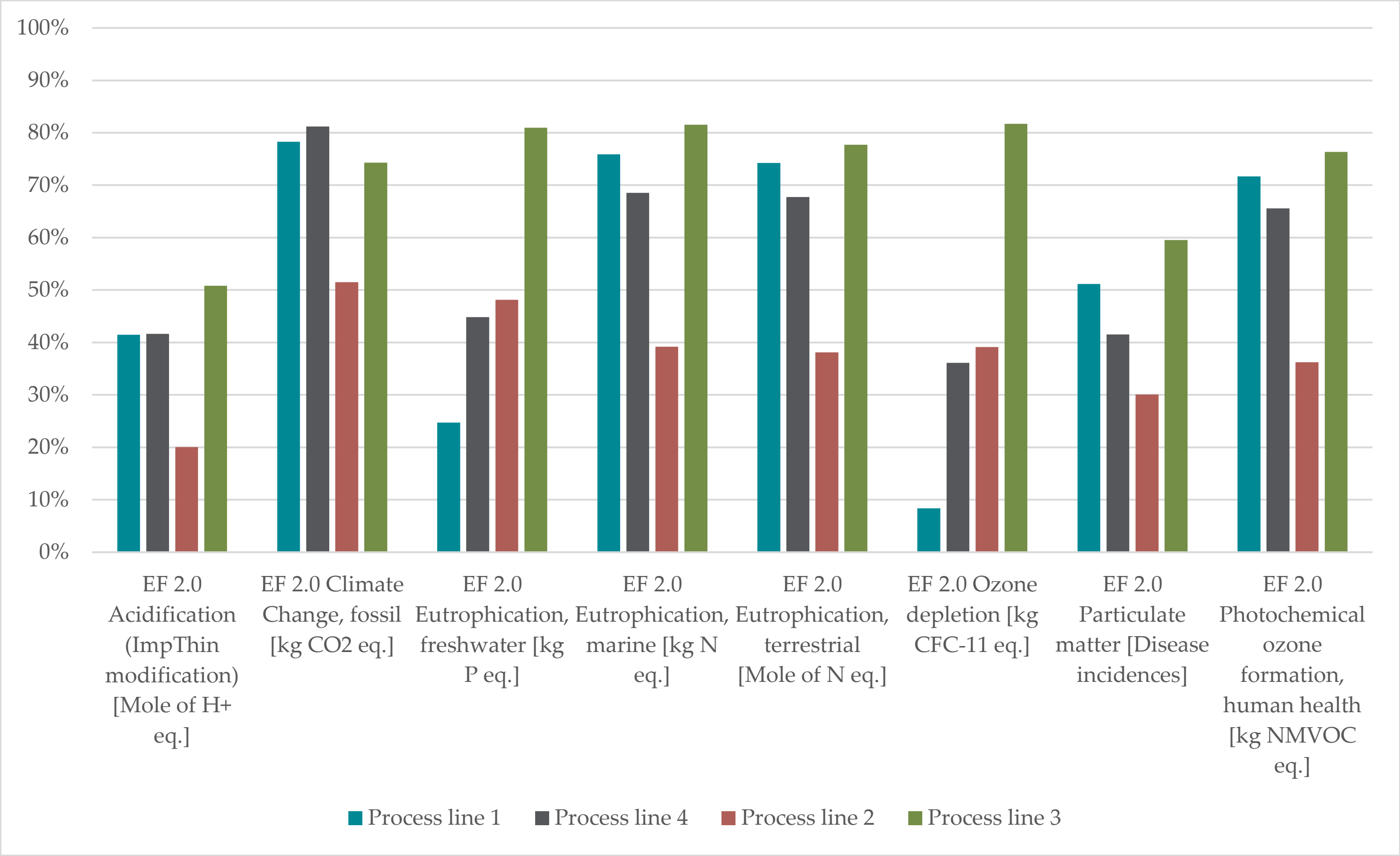


Figure 10: Climate impact, ZnPh vs. thin film, Process line 3 case.

The comparison has also been made for the other selected impact categories, see Figure 11. A reduction can be seen for all the impact categories when comparing thin film pre-treatment against zinc phosphating pre-treatment.



5 Discussion on resource depletion and toxicity aspects

5.1 Resource depletion

In this chapter the abiotic resource depletion aspect is discussed. Abiotic resources include natural resources which are non-living, such as metal ore. Several methods for measuring resource depletion in LCA are available, however debated since quantitative methods cannot be verified since they depend on future technologies as well as resource demand and availability (Guinée, et al., 2001).

In the life cycle impact assessment method CML2001, three different cases for assessment of metals are available. A baseline abiotic depletion method involves ultimate resource reserves. A second method is based on economic reserves, the part of a natural reserve which can be extracted economically with available technologies. The third method is in addition to the economic reserves also including "reserve bases" which are identified resources which has potential of being available to extract with current technologies and economy. Looking at the extraction of metals, the result will indicate the resource depletion potential of a reserve related to annual use (van Oers & Guinée, 2016).

Since no data is available for making a quantitative assessment of abiotic resource depletion, results are presented for individual elements measured in kg Antimony (Sb) equivalents per kg extracted material in Figure 12 - Figure 14 to evaluate if the technologies involve any limited or critical elements. The depletion of the element Antimony is used as a reference and the choice is arbitrary since other substances would not affect relative sizes of characterization factors (van Oers & Guinée, 2016).

A list of relevant elements used in zinc phosphating and thin film pre-treatment has been retrieved from one of the project partners. For zinc phosphating, green bars, the relevant elements include zinc, manganese, nickel, phosphorous and fluorine. For thin film, grey bars, the elements include zirconium, silicon, copper and fluorine. Iron is included as a common element for comparison purposes.

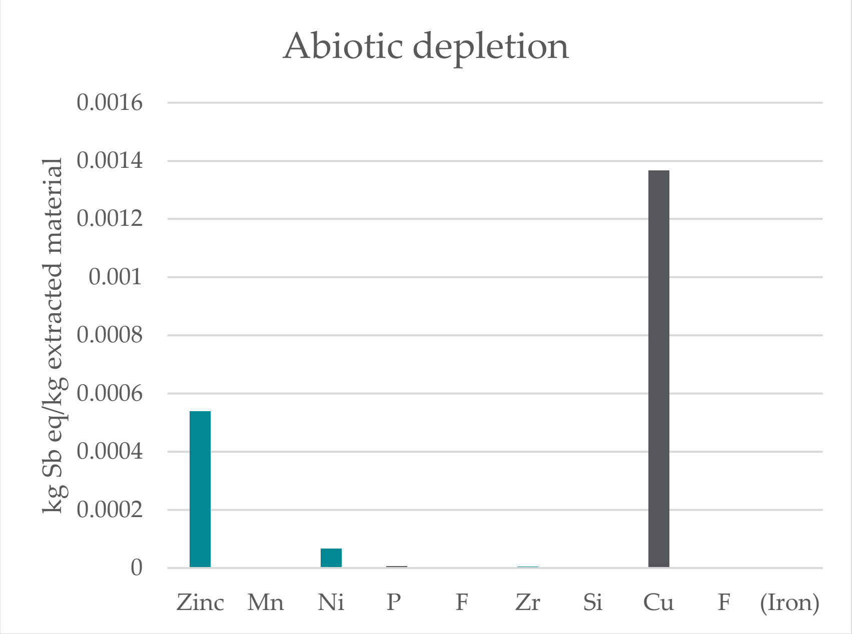


Figure 12: Baseline abiotic depletion potential based on rates of extraction and ultimate resource reserves for 1 kg of elements relevant in the two pre-treatment processes. Green represents ZnPh and grey thin film elements.

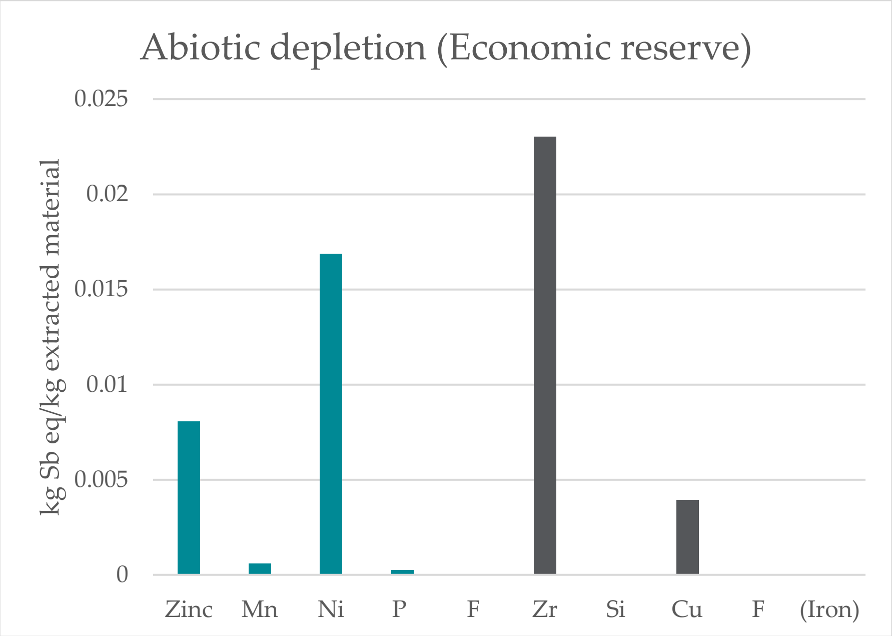


Figure 13: Abiotic depletion potential based on current economic reserves and rates of extraction for 1 kg of elements relevant in the two pre-treatment processes. Green represents ZnPh and grey thin film elements.

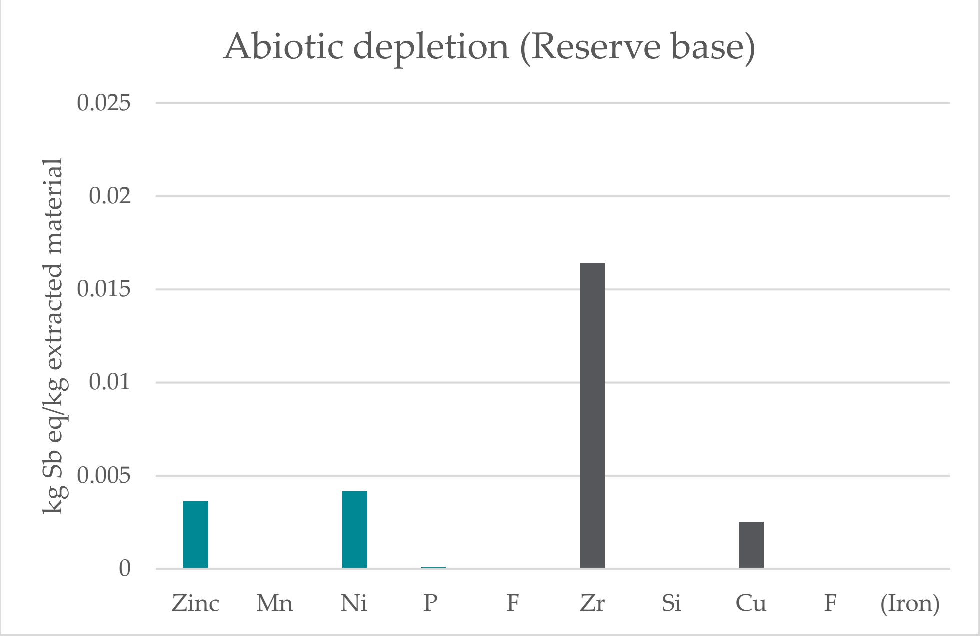


Figure 14: Abiotic depletion potential based on current and potential economic reserves and rates of extraction for 1 kg of elements relevant in the two pre-treatment processes. Green represents ZnPh and grey thin film elements.

The diagrams in Figure 12, Figure 13 and Figure 14 indicate that no critical or limited metals according to current extraction technologies and economy are used in neither zinc phosphating nor thin film. The reference substance Antimony (Sb) represents 1 kg Sb eq. per kg extracted material, whereas more rare and critical metals have factors larger than 1. Hence, the values for these elements are very small. No comparison between zinc phosphating or thin film can be made without knowing and multiplying by the used quantities of elements.

5.2 Toxicity assessment

The studied process consists of heated water tanks or spray chambers with different mixes of zinc phosphating or thin film chemicals. The area is kept well ventilated, and the wastewater is processed before leaving the facility. Chemicals, which some are classified as toxic and discussed further below, are handled in the process, and may end up in air, soil, and water. As explained above, main elements in zinc phosphating include zinc, manganese, nickel, phosphorous and fluorine. For thin film, the elements include zirconium, silicon, copper, and fluorine.

5.2.1 Data and methodological limitations

The current LCA impact assessment methods for toxicity should be used with caution since they are not sufficiently robust for decision making and lack experience in applying toxicity categories to LCA databases.

In addition, limited access to chemical and process data as well as lack of data for the thin film technology in general, makes it hard to perform quantitative assessments on toxicity with sufficient quality. Toxicity is instead evaluated in a qualitative manner below.

5.2.2 Chemicals used in zinc phosphating and thin film pre-treatment

Both zinc phosphating and thin film involve corrosive chemicals in treatment and cleaning steps which cause damage on skin and eyes, as well as on aquatic ecosystems if released directly into the environment. Chemicals used in the zinc phosphating process are also classified with additional hazard phrases for human toxicity and ecotoxicity, mainly due to nickel compounds. Direct toxicity and exposure of the concentrated or diluted chemicals might occur during preparations, maintenance, or cleaning of the tanks.

Based on data collected for the LCA it could be seen that a smaller total amount (in weight) of process chemicals is used in thin film pre-treatment compared to zinc phosphating. Also the amount of chemicals used for cleaning equipment and waste water treatment are estimated to be heavily reduced for thin film pre-treatment.

5.2.3 Emissions to indoor air, outdoor air, water and soil

In this study, literature on emissions and waste treatment for the zinc phosphating process is used for assessing toxic emissions to air, water, and soil. Since no data or studies on thin film technology is available, such as chemical composition of waste or sludge, it is not possible to make a representative comparison.

For indoor air, fumes from tanks which might involve corrosive or toxic chemicals are relevant. This depends on ventilation, temperature and open or closed tanks (European Commission, 2006). If released to the environment, compounds might end up in the compartments air, water, and soil.

During the zinc phosphating procedure, wastewater will be generated, as well as waste in form of sludge. Previous studies have shown that zinc represents a dominant pollutant in phosphating sludge with regard to concentration (Uçaroğlu & Talinli, 2012). For wastewater, the dominating element is nickel (European Commission, 2006). The wastewater requires treatment before release into the environment, such as filtering methods or chemical techniques, to not exceed concentration threshold limits for toxic compounds according to legislation.

Due to the characteristics of the zinc compounds, they tend to end up in soil or sludge rather than air or water. If released to the environment, the result could be local contamination of soil near the emission source with risk for leachate in surrounding water systems. Zinc in larger complexes does not tend to volatilize from soil or water. The same applies to zinc in landfills, it will mainly appear in soil but leaching might occur (U.S. Department of Health and Human Services, Public Health Service, 2005).

Sludge from zinc phosphating processes which contains toxic heavy metals is classified as hazardous waste with toxic and reactive properties. In general, phosphating sludge includes iron and zinc phosphate compounds as well as traces of other elements which can be copper, nickel, chromium, and lead. Treatment in form of for example solidification and stabilization is required before landfilling to prevent toxic leachate. Conversion and immobilization of metals in the sludge can be performed by using additives such as lime, clay or cement, with the aim to make the metal compounds less toxic. If sludge is treated properly, studies show that it will probably not be required to classify it as hazardous waste (Uçaroğlu & Talinli, 2012).

The sludge from thin film will contain hazardous metals, however the sludge composition will differ based on chemicals involved and rest products. According to collected information from project partners, the amount of sludge from thin film treatment will be less than for traditional zinc phosphating. In this LCA study, the assumption that a thin film process will generate 80-90% less sludge waste compared to traditional zinc phosphating along with a less toxic chemical composition, will result in lower risks for toxic emissions.

6 Conclusions

6.1 Climate change

Thin film pre-treatment is likely the better technology in terms of climate impact. This study estimates reductions in impact of between 19% and 48%. The figures for the project partner 2 cases might be subject to higher uncertainties as the waste treatment, which is judged to be modelled less accurate, is contributing more to the reduction here.

Less energy is needed for heating the baths in a thin film pre-treatment process and less sludge is generated, so it is obvious that impacts from these activities are reduced. What is less obvious is how the usage of other chemicals in different amounts would change the climate impact. In this study the impact from production of chemicals is reduced in all the four analyzed cases.

The LCA also shows that it is important to take into account the impact from production of chemicals and not just focusing on energy consumption when assessing a total climate impact. Especially when using low carbon energy, it is important to carefully consider all the activities.

6.2 Other LCA impact categories

Also when looking at the other impact categories, see Figure 11, thin film pre-treatment seems to perform better than zinc phosphating. For all cases and all categories there is reduction in impact of at least around 20%. It is important to note that some of the included categories here might be of less importance when comparing the two technologies. One example is Ozone depletion, where no obvious emissions occur in the analyzed system.

6.3 Resource depletion

It is not possible to obtain which one of the two technologies that performs best here based on the provided data. However, based on the provided list of elements typically contained in the process chemicals, and the methods used for assessing resource depletion, it could be seen that none of these elements are considered rare or critical. This indicates that resource depletion is likely of less importance when comparing the technologies.

6.4 Toxicity

To make a proper assessment of toxicity more data would be needed, especially regarding thin film pre-treatment. Thin film pre-treatment looks promising though, as less toxic chemicals are generally used and less sludge is generated which might lower risks for toxic emissions.

References

European Commission, 2006. *Reference Document on Best Available Techniques for the Surface Treatment of Metals and Plastics,* s.l.: s.n.

European Commission, December 2017. *PEFCR Guidance document, - Guidance for the 13 development of Product Environmental Footprint Category Rules (PEFCRs), version 6.3,* s.l.: European Commission.

Guinée, J. et al., 2001. *Universiteit Leiden.* [Online]
Available at:
https://www.universiteitleiden.nl/binaries/content/assets/science/cml/publicaties_pdf/new-dutch-lca-guide/part2a.pdf
[Accessed 19 January 2022].

International Organization for Standardization, 2006a. *ISO 14040:2006 Environmental management - Life cycle assessment - Principles and framework,* s.l.: s.n.

International Organization for Standardization, 2006b. *ISO 14044:2006 Environmental management — Life cycle assessment — Requirements and guidelines,* s.l.: s.n.

Khodayari, R., 2021. *Miljövärdering av fjärrvärme.* [Online]
Available at: https://www.energiforetagen.se/statistik/fjarrvarmestatistik/miljovardering-av-fjarrvarme/

Risberg, F., 2021. [Interview] 2021.

U.S. Department of Health and Human Services, Public Health Service, 2005. *Agency for Toxic Substances and Disease Registry (ATSDR) - Toxicological profile for Zinc.* [Online]
Available at: https://www.atsdr.cdc.gov/ToxProfiles/tp60.pdf
[Accessed 21 02 2022].

Uçaroğlu, S. & Talinli, I., 2012. Recovery and safer disposal of phosphate coating sludge by solidification/stabilization. *Journal of Environmental Management,* Issue 105, pp. 131-137.

van Oers, L. & Guinée, J., 2016. *The Abiotic Depletion Potential: Background, Updates, and Future,* Leiden: MDPI.

Appendix A – Data collection template

Data collection: Zinc phosphating	
Reference unit:	The data should be collected based on a reference unit e.g. 1 year or per tonne of product output. Please state the reference unit below.
Reference unit:	
Enter the use of raw materials, energy etc. per reference unit. Energy such as e.g. electricity, natural gas etc. Note that we need to know the fuel input and not energy in terms of "heat" or "steam" (internally produced from a fuel). If you use externally produced heat such as district heat this should be entered as well. Apply the unit you prefer e.g. kWh, MJ, Nm3 etc. Auxiliary materials are materials which are not part of the final product, but used in the production e.g. chemicals. Emissions to air could either be from combustion of fuels or process specific.	

	Unit	**Zinc phosphating** Amount [Unit/ Reference unit]	**Data provided by**	**Process step**	**Comment**
Process chemicals					
Chemical 1	kg				
…	kg				
…	kg				
…	kg				
…	kg				
Chemical N	kg				
Other chemicals (e.g. for cleaning or used in waste water treatment)					
Chemical 1	kg				
…	kg				
…	kg				
…	kg				
Chemical N	kg				
Water use					
Tap water	m3				
Other water	m3				
Energy use					
Electricity	kWh				
LPG					
Natural gas					
District heat					
Other (specify)					

Emissions					
AIR					
- From combustion of fuels					N/A?
CO2					
CO					
NOx					
SO2					
Non-methane-VOC (specify)					
CH4					
N2O					
Particles (specify sizes)					
Other (specify)					
- Process specific emissions (specify)					A small amount of chemicals is assumed to evaporate with the water from the hot pretreatment baths (ENABLE)
					Water vapour?
WATER					
COD					
BOD					
Tot-N					
Tot-P					
Other (specify)					
Waste					
Sludge					
Oil emulsions					
Metal particles					
Other					
Waste water					
Production: Main product					
Pre-treated area	**m2**				

Appendix B – List of used generic data sets

Table 5: Datasets included in the study

Production related chemicals		
Region	**Dataset name**	**Database**
DE	Hydrochloric acid (32%)	Sphera
DE	Hydrogen fluoride	Sphera
RoW	iron (III) chloride production, product in 40% solution state	ecoinvent 3.7.1
EU-28	Lubricants at refinery	Sphera
DE	Nitric acid (98%)	Sphera
EU-28	Phosphoric acid (H3PO4, 54% P2O5)	Fertilizers Europe
RER	potassium hydroxide production	ecoinvent 3.7.1
GLO	sodium fluoride production	ecoinvent 3.8
EU-28	Sodium hydroxide (caustic soda) mix (100%)	Sphera
RER	sodium nitrite production	ecoinvent 3.7.1
EU-28	Sulphuric acid (96%)	Sphera
EU-28	Water (desalinated; deionised)	Sphera
Energy, water and waste management		
Region	**Dataset name**	**Database**
SE	Electricity grid mix 1kV-60kV	Sphera
SE	Electricity, 100% hydro power	Sphera
EU-28	Municipal waste water treatment (mix)	Sphera
DE	Sludge (acid/basic)	Sphera
DE	Sludge (hazardous low level, encapsulation and landfill)	Sphera

DE	Sludge (high moisture)	Sphera
SE	Tap water from groundwater	Sphera
EU-28	Thermal energy from LPG	Sphera

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