LIFE CYCLE ASSESSMENT OF UTILITY POLES

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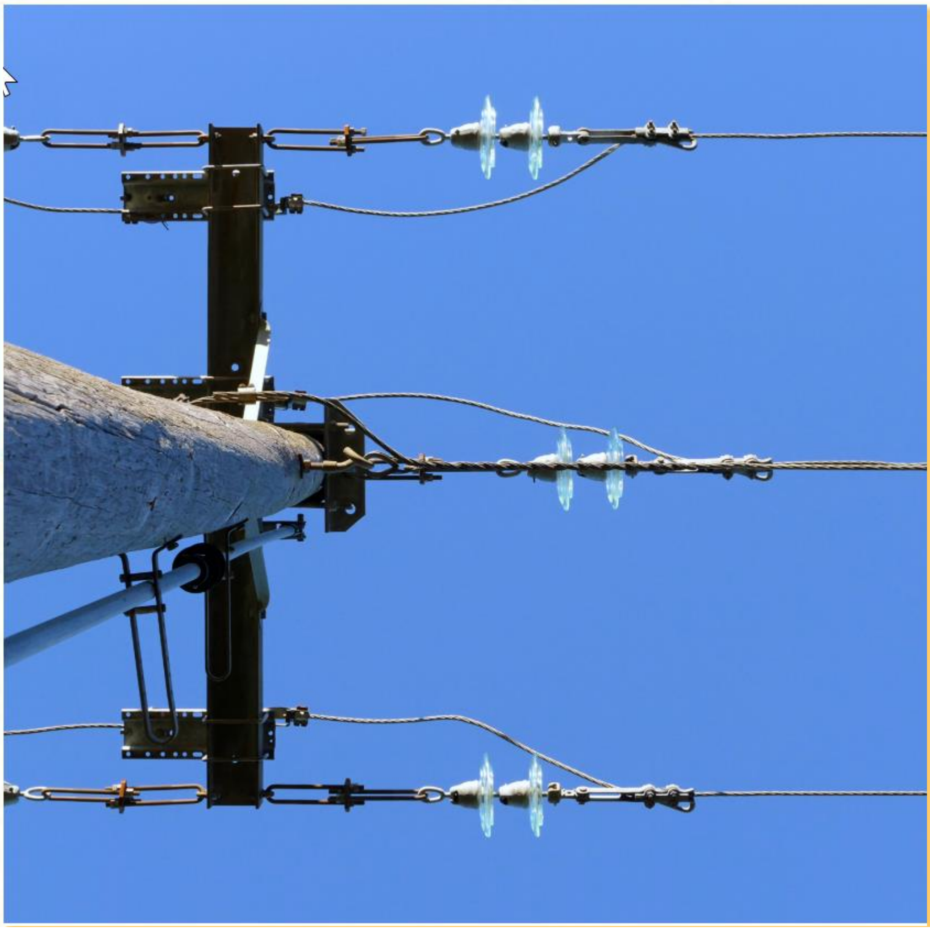
POWER GRID MAINTENANCE



Energiforsk

Life cycle assessment of utility poles

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Foreword

For a long time, a majority of Sweden's power-line utility poles were manufactured using wood impregnated with creosote. Recently, however, questions have been raised concerning the ecological and health risks of creosote, which has led to a number of manufacturers developing utility poles using other materials and impregnation other than creosote. In this project, a life cycle assessment (LCA) was conducted on a number of different utility poles that are either currently available or will soon be available in the Swedish market. The goal of this study is to provide an overview of the amount of resources that different types of utility pole materials utilise during their service life and their impact on the surrounding environment. The results of this study can be used by grid owners as part of the documentation for decisions on future purchases of utility poles.

The project was co-financed by the Foundation for IVL Swedish Environmental Research Institute (SIVL) and Energiforsk (Swedish Energy Research Centre), and carried out by IVL Swedish Environmental Research Institute. This is one of two reports that were produced as part of the project – the other report, *ProScale Assessment within life cycle assessment on utility poles*, can be downloaded at www.energiforsk.se. Both reports can also be downloaded at the IVL website, www.ivl.se with the following report numbers:

- B2392 - ProScale assessment within life cycle assessment on utility poles
- B2393 - Life-cycle assessment of utility poles

At Energiforsk, the project was carried out as part of the organisation's "Power Grid Maintenance" industry research programme, and the reference persons from the programme's steering group were:

- Kenneth Stefansson, Vattenfall Eldistribution AB
- Hans Erik Carlsson, E.ON Energidistribution AB
- Christer Gruber, EBR

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Lennart Kjellman,
Programme Manager, Power Grid Maintenance
Stockholm, 21 September 2020

This report presents the results and conclusions from a project that was part of a research program conducted by Energiforsk and co-financed by the SIVL Foundation. The author(s) of the report are responsible for its content

Summary

This report is a result of the research project "LCA of utility poles" which has been co-financed by Energiforsk and the Foundation for IVL Swedish Environmental Research Institute (SIVL) in 2019 and 2020.

The background of the project is that IVL Swedish Environmental Research Institute has previously carried out an LCA, where the environmental impact of various pole materials was reported (Erlandsson, 2011). Now, a few years later, new materials for utility poles have been introduced to the market and the results of the previous study are considered outdated and in need of an update.

The reason for developing new pole materials are mainly because there is an uncertainty as to whether the wood preservative creosote will continue to be used. Creosote contains substances with hazardous properties and is approved for restricted use for, among other things, utility poles. In order to reduce the use of creosote and to prepare the energy industry for a possible ban, grid owners and energy companies are demanding new alternatives.

The purpose of the LCA is to generate environmental impact data for different pylon materials but also that the results can be used by grid owners and pole producers in permit matters and public procurement. Furthermore, the project aims to inform pylon owners, pole producers and other actors in the affected markets about the environmental impact that the choice of different pole materials can bring.

The study covers the Swedish market and the use of poles for Swedish conditions. Four materials are evaluated using LCA: wooden pole impregnated with creosote, wooden pole with copper-based impregnation, wooden pole covered in polyethylene and composite poles. These materials are believed to be available in the short term for the Swedish market (1-3 years).

The goal of the LCA is to

1. Calculate the environmental impact of the selected pole materials from a life cycle perspective using LCA,
2. Identify the parts of the utility poles' life cycle which have a major impact on the result, and to
3. Compare the environmental impact of the different pole materials.

The results of the LCA show that the environmental impact of the studied pole materials arise in different places along their life cycle and differs depending on the material and the environmental impact category being studied. A large part of the poles' environmental impact arises from the extraction and production of raw materials. Also, the emission of metals and organic pollutants during the use phase as well as how the poles are handled after the end of life has a major impact on the total result.

The PE-clad wooden pole results in the lowest environmental impact of the studied utility pole materials, and this applies to all the environmental impact categories covered in the project, except for ozone creation potential (ground level ozone) where wooden pole with copper-based impregnation scores slightly better. One of the contributing reasons for the lower impact of a PE-cladded wooden pole is that it is made from a renewable raw material (wood) and a large proportion of recycled polyethylene. The utility pole is also designed for recycling of both wood and plastic raw material, which gives a lower overall impact at the end-of-life stage compared to incineration. The utility pole also has a low impact during the use phase as, in relation to the impregnated wooden posts, it does not emit metals or organic pollutants.

The composite poles have the highest environmental impact in all studied environmental impact categories except for eutrophication and ecotoxicity where impregnated wooden posts have a higher impact. High impact from the raw materials for the composite posts gives a higher total impact compared to impregnated wooden poles and the PE-clad wooden pole. The advantage of composite poles is that, in relation to impregnated wooden poles, it does not emit metals or organic pollutants into the surrounding environment during the use phase.

For wooden poles that are impregnated with either creosote or a copper-based impregnating agent, it is the impregnation products which mainly contributes to its environmental impact. It is the production of the impregnation products that contributes to the overall results, but also emissions during the use phase as well as emissions during waste management.

The results of the sensitivity analysis, where the expected lifespan of the poles and their environmental gains after recovery are included in the analysis, show that the PE-clad wooden pole has the lowest impact considering climate change and that the composite pole result in the highest.

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Glossary

The glossary below provides descriptions and explanations of the terms used in this study.

Term	Explanation
Functional unit	The base of calculation for the study, which is the unit the results pertain to.
Sensitivity analysis	Analysis of uncertain parameters such as assumptions and input data in order to evaluate their impact on the results.
Life cycle assessment (LCA)	Compilation and evaluation of relevant inflows and outflows from a product, process or system, and evaluation of the potential environmental effects across its life cycle (ISO 14040:2006 and 14044:2006).

1 Introduction

This chapter is intended to provide the reader with an introduction to the background of the research project, the people and/or organisations with a potential interest in the results, and how they could be used in the industry, for example. Furthermore, the methods used to calculate the environmental impact of the utility poles and their potential toxicity are briefly described.

1.1 BACKGROUND

As mentioned in the foreword to this report, IVL conducted an LCA on behalf of several grantors in the power grid industry that reported the environmental impact of various utility pole materials (Erlandsson 2011). Apart from the environmental impact, the potential toxicity to humans and the environment were also calculated. Now, more than a decade later, new utility pole materials have been introduced into the utility pole market, and the results of the 2011 study are considered outdated and in need of an update.

As a response, Energiforsk and SIVL financed a project that was carried out by IVL for the purpose of conducting a new LCA in which the list of utility pole materials encompassed by the evaluation was brought up to date in order to reflect the current market in Sweden. The 2011 study included four different utility pole materials, but some of them are no longer considered relevant for the Swedish market. Moreover, entirely new utility pole materials have been introduced into the market. These have not previously been evaluated from an environmental impact perspective, and there is interest in better understanding this from grid owners, energy companies, and others. The results are also intended to be used as documentation in conjunction with permit reviews and in communication with government bodies such as county administrative councils and municipalities.

Part of the background behind the development of new utility pole materials is the fact that there is uncertainty concerning the continued use of creosote impregnations. At present, their use is limited but creosote has been approved for impregnation of rail sleepers and utility poles. The reason for this limited use is that creosote contains various substances with properties that are hazardous to health (Swedish Chemicals Agency 2020). Grid owners and energy companies are demanding new alternatives in order to reduce the use of creosote and to prepare the energy industry for a potential prohibition. These alternatives contain, for example, wooden poles with various kinds of impregnations, and composite poles.

Apart from the evaluation of environmental impact, an additional method was included in the project. This is called ProScale, and it is used to calculate the potential toxic risk of products throughout their life cycle from a work environment perspective. The method is under development, and this research project is part of a range of other projects where ProScale is being tested from the perspective of users and results. The results from the project's ProScale assessment are presented separately in the report *ProScale assessment within LCA on utility poles*, which can be downloaded from the websites of IVL (IVL 2020) and Energiforsk (Energiforsk 2020).

Companies that supported the idea behind the project are Vattenfall Eldistribution AB, Skellefteå Kraft AB, EON, Kraftringen AB, and Telia Company.

1.2 LIFE CYCLE ASSESSMENT

A life cycle assessment (LCA) is a compilation and evaluation of relevant inflows and outflows from a product system and an evaluation of the potential environmental effects across its life cycle (ISO 14040:2006 and 14044:2006). Inflow and outflow pertain to the use of natural resources and the generation of emissions and waste products linked to the system.

The life cycle consists of processes and transportation in all stages, from extraction of natural resources to final handling of the product, as well as disposal of waste products through waste management and recycling (**Fel! Hittar inte referenskälla.**).

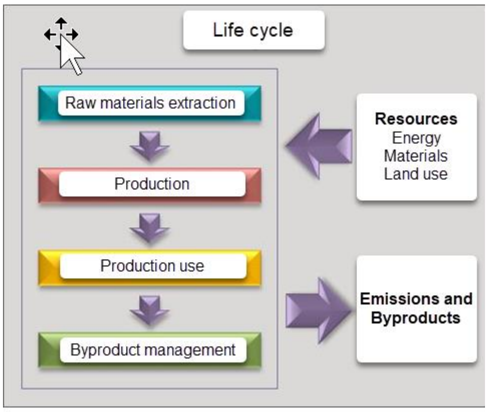

Figure 1 – Illustration of an LCA system.

A life cycle assessment consists of four phases, which under the ISO standard are designated: goal and scope; inventory analysis; impact assessment; and interpretation (**Fel! Hittar inte referenskälla.**).

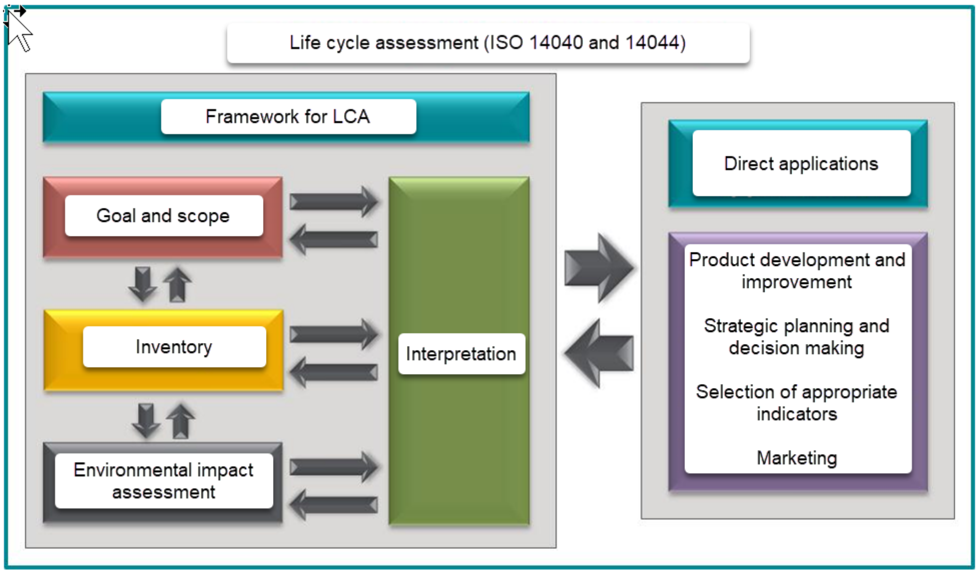

Figure 1 – Phases of the LCA study.

2 Goal and scope

This chapter presents a summary of the goal and scope of the project. The limitations of the project, and what it is not intended to contribute, are also clarified to an extent.

2.1 GOAL AND SCOPE

The intent of the project is to produce documentation on the environmental impact of power-line utility poles manufactured from different materials. It is assumed that these materials will be available to the Swedish market in the near future. Utility pole materials that are under development and that could be considered of relevance for the Swedish market within a period of one to three years are encompassed by the study.

The purpose of producing environmental impact data for various utility pole materials is for the results to be used by grid owners and producers in permit reviews and procurements. Moreover, the project is intended to inform grid owners, utility pole producers and other players in the markets concerned about the environmental impact that their choice of various utility pole materials could entail.

The study encompasses the Swedish market and the use of utility poles under Swedish conditions. In some cases, international producers deliver utility poles to the Swedish market; in these cases, the LCA reflects the actual geographical conditions such as production and transportation. The project does not encompass utility pole materials that are under development and could become relevant for the Swedish market over the medium to long term. The purpose of the project is therefore to generate information that can be used in the industry in the near future.

The service life of the various utility pole materials may be a crucial factor in the impact of the products on the environment. But there is significant uncertainty as to what should apply. That is why those of us conducting the project compromised by including the service live of the utility pole materials on a partial basis and testing them in a scenario analysis where it is assumed that the service life is in line with the number of years that utility pole producers and suppliers indicate as the benchmark for Sweden and Swedish conditions. In the overall comparison, we did not account for differences in service life among the various utility pole materials. It is assumed that the utility poles that were evaluated deliver a service life that is sufficiently long for grid owners to consider building their power-line routes using the selected utility pole materials.

In addition to testing the impact of service life on the results, alternative waste management scenarios were also tested. It is assumed that some of the utility pole materials can be recycled, while others are incinerated in combined power and heating plants.

The properties of the various utility pole materials that were studied differ. Apart from service life, the load-bearing capacities of the utility pole materials also varies, which could result in a variation among utility pole materials in the need for the number of poles for a given power-line route. But since the purpose of the LCA is to compare the impact of different utility pole materials across their life cycle, these variations were not included in the results. They are, however, discussed in the report. But the results (the environmental impact of various utility pole materials) can be used to calculate the total environmental impact from a given type of pole for a unique section of power lines. The results can also be used to evaluate the total impact of different utility pole materials for a power-line corridor. This is done by multiplying the results of one pole type with the number of utility poles required for a power line.

2.2 GOAL

The goal of the project is to:

1. Estimate the environmental impact of various utility pole materials from a life-cycle perspective by using an LCA;
2. Identify those parts of the utility poles' life cycle that have a significant impact on the results; and
3. Compare the environmental impact of the various utility pole materials.

2.3 STUDIED PRODUCT SYSTEMS

The types of utility poles included in the study, and the pole suppliers who contributed the data for the various utility pole materials, are described below. This chapter also describes the functional unit that was used as the calculation reference in the study.

2.3.1 Studied types of power-line utility poles

The utility poles that were included in the study consist of various types of materials and are manufactured by various suppliers. Compared with the previous study (Erlandsson 2011), utility poles made of concrete or steel were not included. Wooden poles impregnated with creosote are the reference product for the study. The utility pole materials compared in the study are thus impregnated wood, PE-clad wooden poles and composite poles. **Fel! Hittar inte referenskälla.** presents the utility poles that are included in the study, and the waste management alternatives that were selected in the study for the respective utility pole types. Section 3.7 presents further information on the waste management scenarios. These assumptions are also tested in a sensitivity analysis.

Table 1 – Utility poles studied.

No.	Utility pole type	Supplier	Waste management
1	Wooden pole – creosote	Rundvirke	Incineration
2	Wooden pole – copper	Rundvirke	Incineration
3	Wooden pole – copper + RVP repellent	Rundvirke	Incineration
4	Wooden pole – PoleProtect	ScanPole + Copper	Incineration
5	Wooden pole – PE coating	WOPAS	Materials recycling
6	Composite pole – epoxy	ABB Power Grids Sweden	Landfill
7	Composite pole – polyester	Jerol	Landfill
8	Composite pole – polyurethane	Melbye	Landfill

One of the purposes of this report is to compare the environmental impact of various utility pole materials, rather than utility pole suppliers. That is why utility poles of the same type or material have been pooled together, and the results show an average value of the environmental impact. The average value was calculated by totalling the environmental impact for utility poles made from the same materials and then dividing by the number of poles. The utility pole materials are presented in the results section as:

- Creosote (pole No. 1 in Table 1 above);
- Copper-impregnated wooden poles (poles Nos. 2, 3, and 4);
- PE-clad poles (pole No. 5); and
- Composite poles (poles No. 6, 7, and 8).

2.3.2 Functional unit

The functional unit serves as a base of calculation for the study and is the unit that the results refer to. A 12-metre power-line utility pole, referred to as N12 (wood distribution pole, conical, having a diameter of 25 cm 2 m from the butt end) was selected as the functional unit.

The service life of the utility poles varies depending on factors such as the utility pole materials and impregnation. In the main results of the study, the variation in service life of the utility poles has not been taken into account. To analyse the impact of service life on the results, a sensitivity analysis with regard to service life was carried out and is presented in Section 4.8.

2.3.3 LCA type

There are two types of LCA studies that differ as regards the questions they answer. An LCA study can either be an attributional LCA or a consequential LCA. An attributional LCA focuses on investigating the environmental impact of a system, while a consequential LCA investigates the environmental consequences of the switch from one system to another.

This study is an attributional LCA and focuses on investigating the environmental impact of the respective utility pole materials.

2.4 SYSTEM BOUNDARIES

This section describes the system boundaries of the LCA models, and which processes have been included or excluded for all product systems studied and for the sensitivity analysis. The term "sensitivity analysis" pertains to the analysis of uncertain parameters that could pertain to input data or assumptions that were made in the study. The impact of the analysis on the results is evaluated and presented separately after the main results of the study.

The flow chart for the utility poles is shown in **Fel! Hittar inte referenskälla.** below. The flow chart shows which processes have been included, and which have been excluded. Installation, dismantling and maintenance are not included in the study. The study only takes the utility pole into account, and not the cabling or attachment hardware. Electricity and losses are not included in the study.

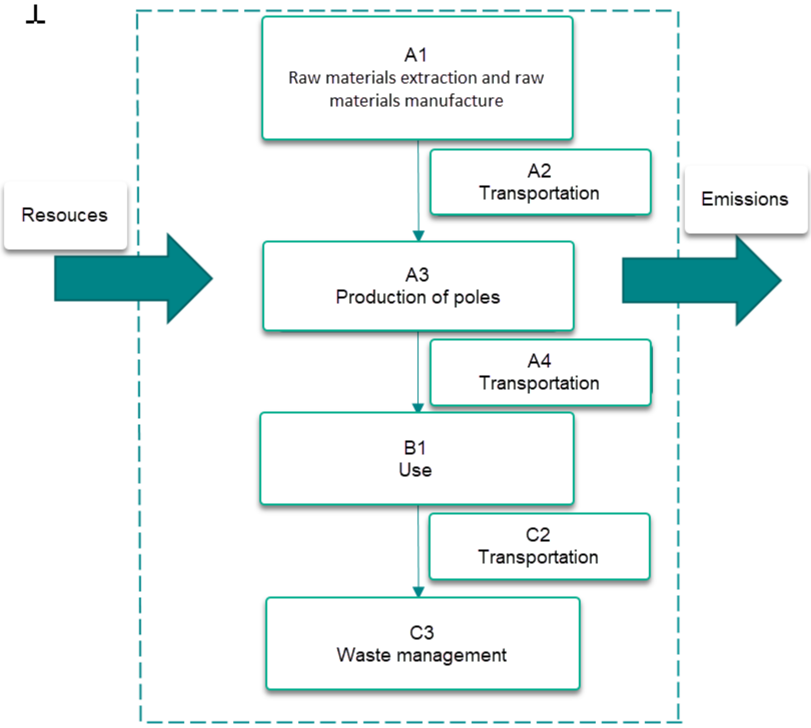

Figure 2 – Flow chart for the utility poles.

The figure above is based on modules defined in the EN15804 standard. The modules that were excluded can be seen in table 2 below.

Table 2 – Included and excluded life-cycle stages (modules) defined under EN15804. Module D has been included in a sensitivity analysis.

	Product phase			Construction phase		Use phase							End of life				D
	Raw materials extraction	Transportation	Manufacture	Transportation	Installation	Use	Maintenance	Repair	Replacement	Renovation	Energy during use	Water during use	Dismantling	Transportation	Waste management	Disposal	Gains after end of life
Module	**A1**	**A2**	**A3**	**A4**	**A5**	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**C1**	**C2**	**C3**	**C4**	**D**
Incl.	X	X	X	X		X								X	X		

2.4.1 Boundaries towards nature

This is a "cradle-to-grave" study, which means that the entire life cycle has been included from the production of fuel, electricity and raw materials all the way from the cradle – where natural resources are extracted – to the grave, meaning waste management of the utility poles. The LCA study includes all relevant transportation.

2.4.2 Geographical boundaries

This study reflects the installation and use of the utility poles in Sweden. This means that waste management of the utility poles is based on Swedish conditions. The utility poles are manufactured in different countries and is based on information from suppliers. Energy production for the manufacture of the utility poles has been assumed to represent the countries where the respective poles are produced, meaning that electricity used for the production of a utility pole in Sweden is based on data representing the average electricity mix in Sweden.

Data for production of raw materials is built on aggregate data that is based primarily on data from the EU. In cases where the EU-based data was not available, data from other countries or regions was used.

2.5 ENVIRONMENTAL IMPACT CATEGORIES

The results of the study are presented for several environmental impact categories. The environmental impact categories included in the study – and the method used – are presented in **Fel! Hittar inte referenskälla.** below. Choice of environmental impact categories and methods based on requirements from EN15804:2012+A2:2019 (CEN, 2019).

Table 3 – Environmental impact categories included in the study.

Environmental impact category	Indicator	Unit	Method
Climate impact, fossil	GWP fossil	kg CO_2 eq.	IPCC 2013
Acidification	AP	mol H^+ eq.	Accumulated Exceedance
Eutrophication	EP freshwater	kg P eq.	ReCiPe 2008
Ecotoxicity	ETP freshwater	CTUe[1]	USETox
Human toxicity, cancer	HTP-c	CTUh[2]	USETox
Human toxicity, non-cancer	HTP-nc	CTUh[2]	USETox
Ground-level ozone	POCP	kg NMVOC eq.[3]	ReCiPe 2008

The LCI indicators that were included in the study are presented in **Fel! Hittar inte referenskälla.** below.

Table 4 – LCI indicators

Parameter	Indicator	Unit
Primary energy use, renewable	PERT	MJ
Primary energy use, non-renewable	PENRT	MJ

[1] Comparative Toxic Unit (Ecotoxicity potential).
[2] Comparative Toxic Unit (Human toxicity potential).
[3] Non-Methane Volatile Organic Compounds.

3 Life cycle inventory

This chapter presents the various utility pole types that were included, and the data that was collected for the respective pole types. The life cycle inventory was conducted both to obtain an understanding of the various stages in the life cycle of the poles and in order to collect data to conduct the calculations for the study in the next step.

Since the manufacturing data for the poles is confidential (the property of the various manufacturers), it is not presented in the report. The manufacturing processes for the respective poles is therefore described at a general level, without detailed data on specifically which raw materials are included or their amounts. Key assumptions for the study are also presented in this section. Appendix B: Data sources used provide an account of the data sources and the procedures used in GaBi, the LCA software, in order to calculate the environmental impact of the pole types. Data sources are presented only for the materials and resources that are not confidential.

Data and information used as a basis for the study have been collected from various sources such as:

- Manufacturer and supplier of power-line utility poles (**Fel! Hittar inte referenskälla.**)
- Literature
- Personal communication.
- LCA databases – for example, the database in GaBi (Thinkstep AG 2018) or data published by industry organisations (PlasticsEurope)

3.1 WOODEN POLES INCLUDED

The study includes five wooden poles with various impregnations or coatings, and three composite poles. A brief description of the respective suppliers and poles is presented below.

Rundvirke

Rundvirke Poles AB manufactures impregnated wooden poles that are used for telephone and transmission lines. The company has two manufacturing plants in Sweden, in Ludvika and Kälarne. The poles are manufactured from Swedish forestry products, and Rundvirke manufactures utility poles with various impregnations. Rundvirke has been manufacturing impregnated wooden poles for 121 years (Rundvirke Poles 2020).

Three of Rundvirke's wooden poles are included in this study. The reference for this study are wooden poles impregnated with creosote. In addition, wooden poles impregnated with copper salts and a pole impregnated with copper followed by an oil-based impregnation (RVP repellent) are also included.

The creosote pole has a service life of approximately 55 years; the copper salt-impregnated pole has a service life of approximately 35 years; and the oil-treated, copper salt-impregnated pole has a service life of approximately 45 years (Freij 2020).

ScanPole

ScanPole manufactures wooden poles for purposes such as power lines and illumination. The company has production plants in Norway, Finland and the UK, and has been manufacturing utility poles for 70 years. The company supplies several different kinds of impregnation for wooden poles – for example, creosote and copper salt impregnation – but the focus in this LCA was on a copper oil impregnation called PoleProtect that has been in the market since 2020 (ScanPole 2020).

According to tests, ScanPole's pole with PoleProtect has a service life of over 40 years (Basic 2020).

WOPAS

WOPAS AS, established in 2016, manufactures unimpregnated wooden poles with PE coating. The wood raw material is Swedish or Norwegian spruce or pine, which is turned to the right measurements and dried to a suitable moisture content. The plastic raw material corresponds to approximately 25% of the total weight of the pole, and consists of half recycled and half virgin polyethylene. The service life of the pole is believed to be around 80 years (WOPAS 2020).

3.2 COMPOSITE POLES INCLUDED

Three different glass fibre composite poles were included in the study. A brief description of the respective poles follows below.

ABB Power Grids Sweden

ABB Power Grids Sweden develops composite poles that are to be used as alternatives to wooden poles. The trunk of the composite pole is constructed of glass fibre and epoxy plastic, and has a thermoplastic external cover. It is maintenance-free and has an expected service life of 80 years (ABB 2020).

Jerol

Jerol Industri AB manufactures composite poles for uses including power-line utility poles. They have been manufacturing poles at their plant in Tierp outside Uppsala, Sweden since 2001. The pole consists of a polyester core reinforced with glass fibre, inside a shell of polyethylene. The service life of the Jerol pole is believed to be 80 years or more (Jerol 2018).

Melbye

Melbye Skandinavia provides solutions for infrastructure in energy and fibre optic networks. Melbye delivers products including composite poles produced by RS. The composite poles consist of glass fibre and polyurethane (PU) and have an estimated service life of 100 years in Swedish weather conditions (Fecht 2020).

3.3 MANUFACTURE OF RAW MATERIALS (A1)

Data pertaining to types and amounts of material per manufactured pole type was collected in partnership with the suppliers. For wooden poles, data pertaining to both wood raw materials and impregnation was included. For the composite poles, both primary raw material and any chemicals and additives needed for production were included. Material for caps and bottoms is included for all composite poles.

The data used to calculate the impact of the production of material and resources was taken from generic data from Thinkstep AG (2018).

3.4 MANUFACTURE (A3)

Pole manufacturing data was collected from the suppliers. The energy reported in conjunction with manufacture is primarily electricity. For upstream data from electricity production, generic data for country-specific average electricity production was used based on where production occurred. Internal transportation for manufacture was included in the study.

The information regarding waste and direct emissions from production is insufficient, and was therefore included only to a certain extent and based on the data provided by the producers.

3.5 USE (B1)

No maintenance work during the use phase of the poles – or any environmental impact that arose during installation and dismantling – was included. Leaching of impregnation that occurred during the use of the wooden poles was included in the study. Information regarding leaching is based on information from literature and data documentation from the suppliers.

3.6 TRANSPORTATION (A2, A4, C2)

Information on mode and distance of transportation for raw materials used for the poles was collected from the pole manufacturers. These are not presented in the report on the grounds of confidentiality. The environmental impact from these transport activities are reported in Module A2, which is described in **Fel! Hittar inte referenskälla.** above.

This study encompasses the use of power-line utility poles in the Swedish market, and the average transport of finished poles within Sweden, or to Sweden if the poles were manufactured abroad, has been assumed. **Fel! Hittar inte referenskälla.** below presents the transport distances to an average customer in Sweden that were used in the study (Module A4) and the distances used for transport from the location where the pole was installed to the incineration plant or landfill (Module C2).

Table 5– Transportation distance.

Utility pole type	Distance to customer	Distance to waste management
Wooden pole – Creosote	200 km	100 km
Wooden pole – Copper	200 km	100 km
Wooden pole – Copper + RVP repellent	200 km	100 km
Wooden pole – PoleProtect	600 km	100 km
Wooden pole – PE coating	600 km	100 km
Composite pole – Epoxy	200 km	100 km
Composite pole – Polyester	200 km	100 km
Composite pole – Polyurethane	5,000 km + 200 km[4]	100 km

3.7 WASTE MANAGEMENT (C3)

The study covers “cradle to grave” and waste management is therefore included. For wooden poles, waste management has been modelled based on incineration of wood, and – in one case – polyethylene. No credit for manufactured energy in the form of electricity and heating was included.

For composite poles there are several alternatives for waste management. The pole can be sent to landfill or used as filler, and it is assumed that in the future the pole can be recycled for materials. In this study, the waste management for composite poles has been calculated based on landfill. The poles cannot be incinerated since they largely contain glass fibre. Data for incineration and landfill is based on generic data from Thinkstep AG (2018).

3.8 RECYCLING (D)

The sensitivity analysis evaluated the impact of any recycling for the various pole types. For impregnated wooden poles, energy reclamation has been included, where an average mix of Swedish electricity and district heating is assumed to be replaced in conjunction with incineration. It is expected that the poles can be incinerated in a conventional combined power and heating plant together with household waste, where the division between electricity and heat generated is modelled as 10% electricity and 90% heat.

For composite poles, it is assumed that the PE coating could replace newly manufactured PE and that the composite could be used as filler, thereby replacing crushed stone. It is assumed that the PE-clad wooden pole could also replace newly manufactured PE and that the core wood could replace particle board.

[4] The distance of 5,000 km pertains to transportation by boat, and the distance of 200 km pertains to transportation by truck.

4 Results

The results of the LCA are presented and described in this chapter. It includes four different categories of pole material for pole type N12. The results for wooden poles with copper-based impregnation is shown as an average value of the poles impregnated with substances other than creosote – copper, copper/RVP repellent and PoleProtect. The results for the three composite poles studied (epoxy, polyester and polyurethane) are presented in a similar manner.

The environmental impact categories presented are listed in **Fel! Hittar inte referenskälla.** and the impact is shown as total impact, but is also distributed throughout the life cycle according to **Fel! Hittar inte referenskälla.**, which is a selection of modules described in EN15804. The results can also be found in table form in Appendix C.

4.1 CLIMATE IMPACT

The climate impact for the various pole materials is presented in **Fel! Hittar inte referenskälla.** and shows the impact that arises primarily from fossil-based carbon dioxide. The biogenic net contribution of the climate impact from renewable raw materials over 100 years is assumed to be zero (capture during cultivation and emissions during waste management) since the service life of the products is shorter than a century.

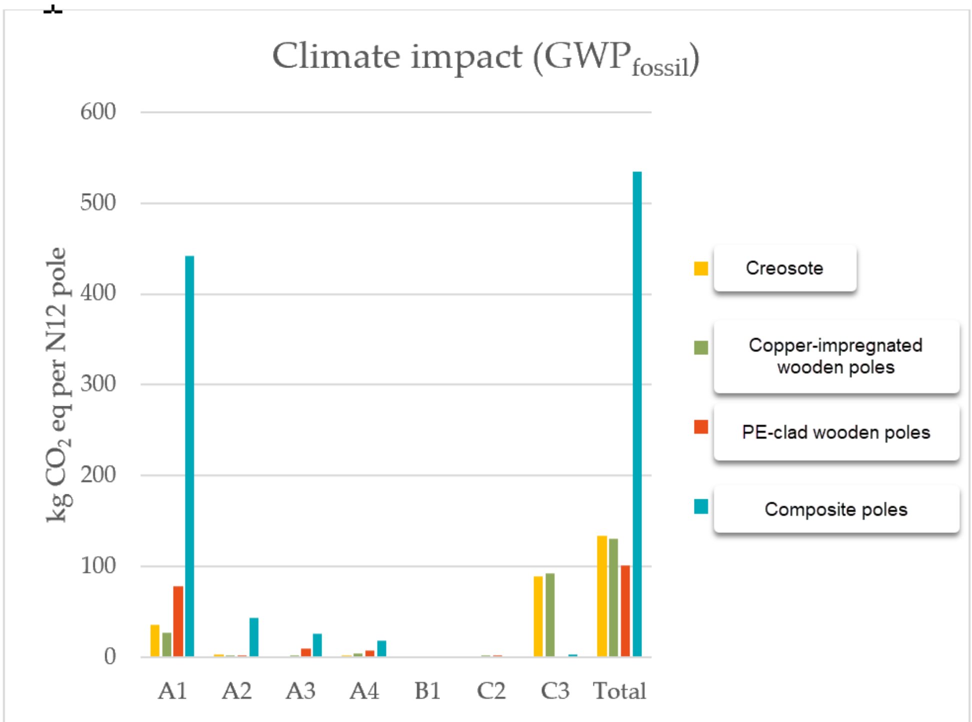

Figure 3 – Climate impact for the respective pole materials, in kg CO_2 eq per pole.

The pole materials that have the greatest climate impact over their service life are the composites. The primary impact arises when resources are extracted and the pole material (primarily glass fibre and polymers) are produced (A1). Relative to the impact from the raw materials, the impact from production of the poles (A3) and transportation of pole material (A2) and completed pole (A4) is quite small, despite the fact that one of the three composite poles studied is produced in North America. Waste management (C3) has relatively no impact since it is assumed that the pole will be put into landfill after use, resulting in limited emissions of greenhouse gases.

PE-clad wooden poles are the type that have the least climate impact over their life cycle out of all the pole materials studied. The impact arises primarily during extraction and production of the raw materials used. But since half of the plastic raw materials (PE) are produced from recycled materials, this has a lower impact compared with manufacture from virgin materials instead. Waste management has nearly no climate impact since both wood and plastic raw materials are recycled and used to manufacture new products.

The climate impact for wooden poles impregnated with creosote and copper-based impregnations is somewhat higher than PE-clad wooden poles. The primary impact arises when the poles are incinerated during waste management, but some impact also arises during the extraction and manufacture of the raw materials. Even for these raw materials, incineration of wood raw materials does not contribute to the results in C3 since they are renewable.

Generally, the results show that manufacturing and transporting poles has relatively little climate impact, while the greatest impact comes from the choice of pole material (raw materials and waste management). The reason for the impact from transportation of composite poles being somewhat higher compared to the other poles is that the raw materials are purchased by global entities and then transported over significantly longer distances (A2).

4.2 ACIDIFICATION

The potential impact of the pole materials on acidification is shown in **Fel! Hittar inte referenskälla.** below. It shows that poles that are manufactured from composite materials have the greatest impact, while poles that are manufactured from treated or PE-clad wood have a significantly lower total impact.

In a manner similar to the one for climate impact, extraction and manufacture of raw materials for composite poles have the greatest impact. The impact for transportation is also significant, due largely to the fact that the raw materials are sent over significantly longer distances than for the wooden poles studied (A2), and that one of the manufacturers produces poles in North America instead of the Nordic region (A4).

For wooden poles impregnated with creosote and copper-based impregnation, it is primarily the manufacture of impregnation products that contributes to their acidification potential in A1. For PE-clad wooden poles, polyethylene makes the greatest contribution. The impact in C3 arises when the impregnated wooden poles are incinerated during waste management.

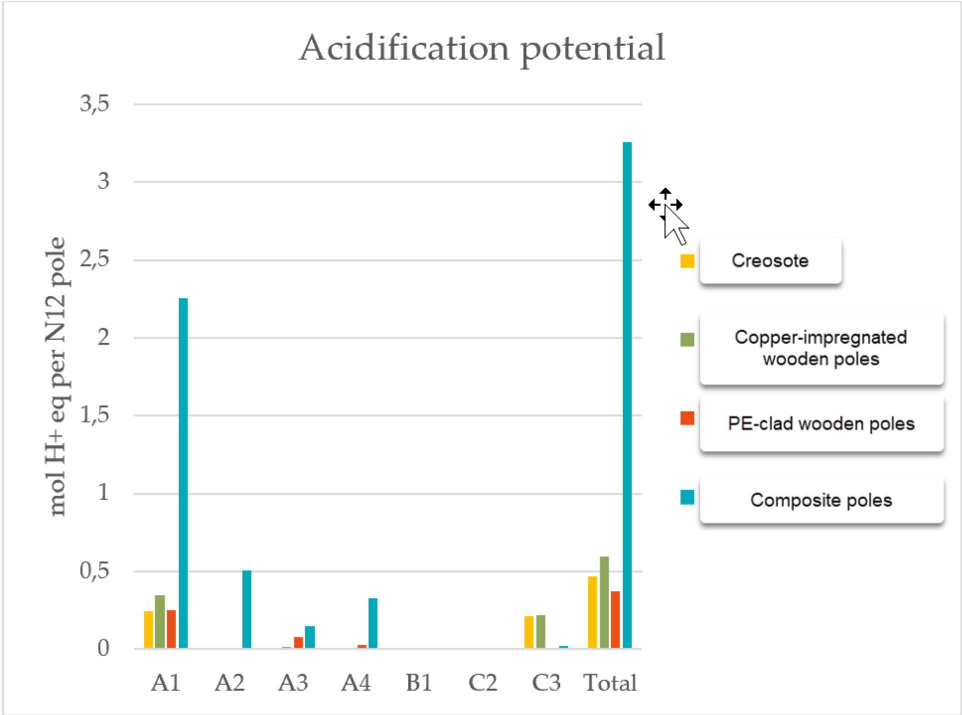

Figure 4 – Acidification potential for the respective pole materials, in mol H+ per pole type.

4.3 EUTROPHICATION

Fel! Hittar inte referenskälla. shows the impact of the poles studied on eutrophication. Poles impregnated with creosote and copper-based substances have a significantly greater total impact than PE-clad wooden poles and composite poles. The primary impact arises with extraction and manufacture of raw material, and for wooden poles impregnated with both creosote and copper-based products, the impregnations are what contribute to the result. The impact from the other phases of the life cycle can be assumed to be negligible in relation to those from the production of raw material.

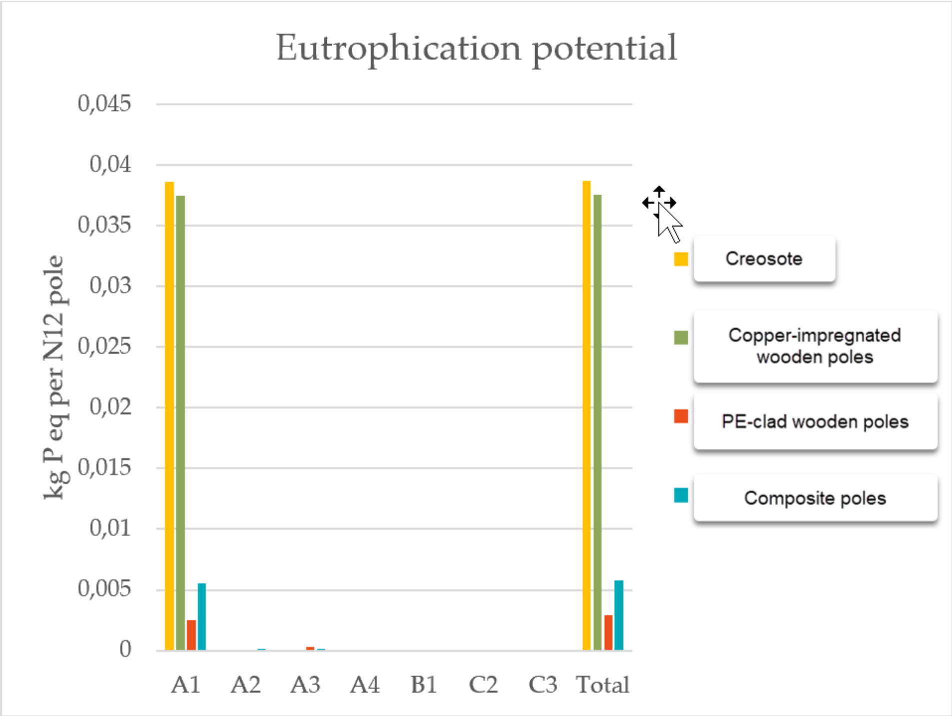

Figure 5 – Eutrophication potential for the respective pole materials, in kg P eq per pole type.

4.4 GROUND-LEVEL OZONE

Fel! Hittar inte referenskälla. shows the impact of the pole materials on the formation of ground-level ozone. Of the poles studied, composite poles have the greatest impact, and it is primarily the manufacture of raw materials (A1) and transportation that have an impact. Transportation – primarily transportation of raw material – has a significant impact for this impact category as well.

The wooden pole with creosote impregnation proved to have a greater impact on the formation of ground-level ozone than the poles impregnated with various copper-based substances. One of the reasons for this is that volatile substances are used in the formulation of creosote impregnation, while the copper-based impregnations are largely water-based.

Wooden poles with copper-based impregnation and PE-clad wooden poles are the alternative that have the lowest formation of ground-level ozone over their life cycle.

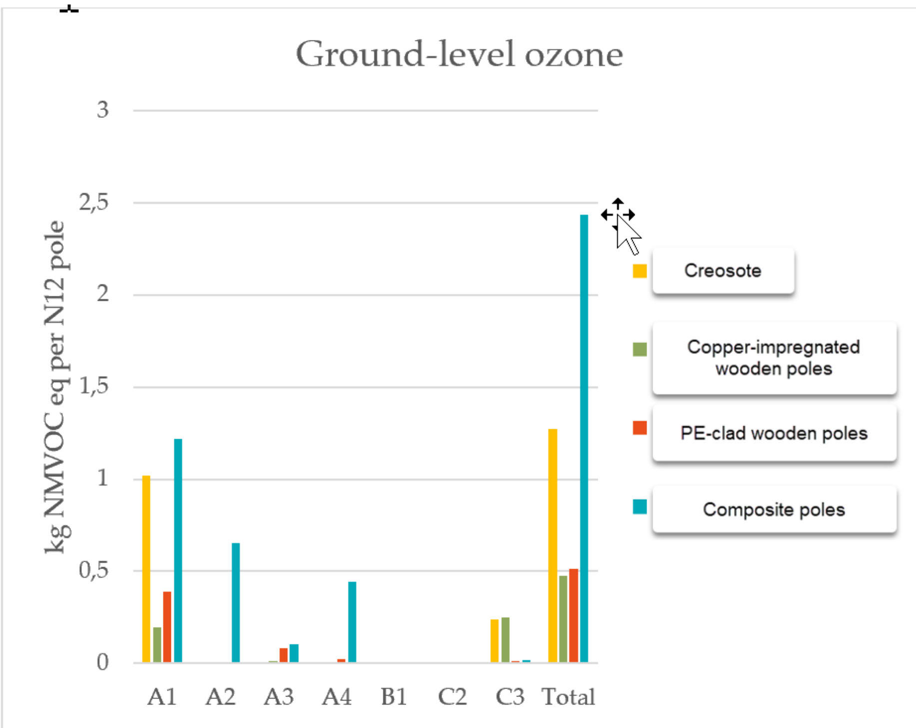

Figure 6 – Ground-level ozone for the respective pole materials, in kg NMVOC eq per pole type.

4.5 HUMAN TOXICITY

In the results, the impact on human toxicity is divided between the impact from carcinogenic and non-carcinogenic substances, and is indicated in Comparative Toxic Units (Human), or CTUh, and is reported for the poles studied in **Fel! Hittar inte referenskälla.**, **Fel! Hittar inte referenskälla.** and **Fel! Hittar inte referenskälla.**. The sum total of both impacts indicates the total human toxicity for the poles studied over their life cycle.

The results of the LCA show that composite poles have the greatest total potential impact on human toxicity over their life cycle, and that it is primarily the impact from non-carcinogenic substances that contribute to the result (**Fel! Hittar inte referenskälla.**). Wooden poles that are impregnated with creosote are the ones with the greatest impact on human toxicity concerning carcinogenic substances (**Fel! Hittar inte referenskälla.**), while composite poles have the greatest impact where non-carcinogenic substances were studied (**Fel! Hittar inte referenskälla.**). PE-clad wooden poles are the type with the least total impact on human toxicity over their life cycle, as regards impact from both carcinogenic and non-carcinogenic substances.

Furthermore, the results from the LCA show that wooden poles with copper-based impregnation, PE-clad wooden poles and composite poles primarily give rise to human toxicity from non-carcinogenic substances (more than 95% of the impact). Wooden poles with creosote, on the other hand, have an impact through emissions of both carcinogenic and non-carcinogenic substances.

Table 6 – Human toxicity, total over life cycle from carcinogenic and non-carcinogenic substances, and the percentage of impact from carcinogenic and non-carcinogenic substances per pole material.

	Wooden pole with creosote	Wooden pole with copper-based impregnation	PE-clad wooden pole	Composite poles
Human toxicity, total [CTUh]	3.88E-06	2.16E-06	8.28E-07	8.80E-06
Human toxicity – Carcinogenic substances [%]	46%	2%	4%	4%
Human toxicity – Non-carcinogenic substances [%]	54%	98%	96%	96%

4.5.1 Human toxicity – Carcinogenic substances

The results for human toxicity that focus on carcinogenic substances show that the PE-clad wooden pole and the wooden poles that are impregnated with copper-based products are the best alternatives when a total low potential impact is sought after (**Fel! Hittar inte referenskälla.**). Composite poles also have a relatively low total impact compared to wooden poles with creosote, but it is higher than the other two pole types. Creosote is the pole with the greatest impact, which arises primarily during the use phase, but extraction and production of the raw materials used for producing creosote also have a significant impact.

PE-clad wooden poles, copper-impregnated wooden poles and composite poles have a low impact on human toxicity during the use phase (B1) compared with creosote poles. This means that it emits or leaches a lesser amount of harmful substances during its useful life compared with wooden poles impregnated with creosote.

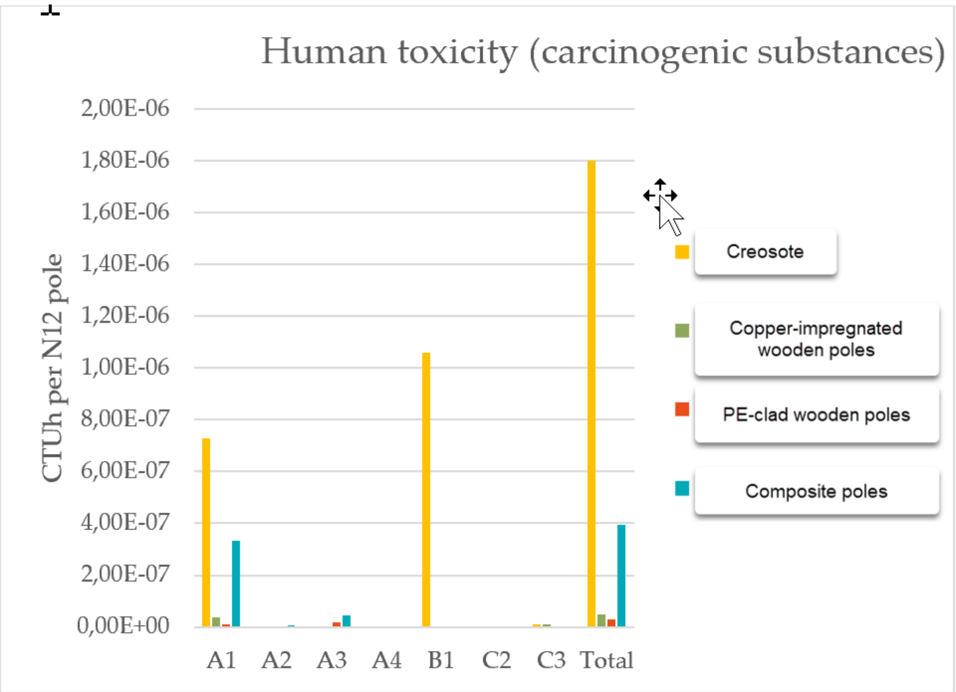

Figure 7 – Human toxicity (carcinogenic substances) for the respective pole types, in CTUh per pole type.

4.5.2 Human toxicity – Non-carcinogenic substances

Fel! Hittar inte referenskälla. shows the potential impact of the pole materials on human toxicity that arises from emissions of non-carcinogenic substances. The results show that the category of composite poles has the greatest potential impact and that the PE-clad wooden pole has the least. Wooden poles with creosote and copper-based impregnations have an equal total impact and a total lower impact than composite poles but higher than PE-clad wooden poles.

Above all, it is the impact from extraction and production of raw materials (A1) that give rise to the impact of the composite poles on human toxicity. The use of glass fibre yields roughly the same impact as the use of different types of polymers in the pole material.

The potential impact from the use of the poles (B1) is relatively low in comparison with the impact from production. Wooden poles with creosote have the greatest impact in the use phase of the pole types studied, but the impact is lower than the one that arises when the pole is produced.

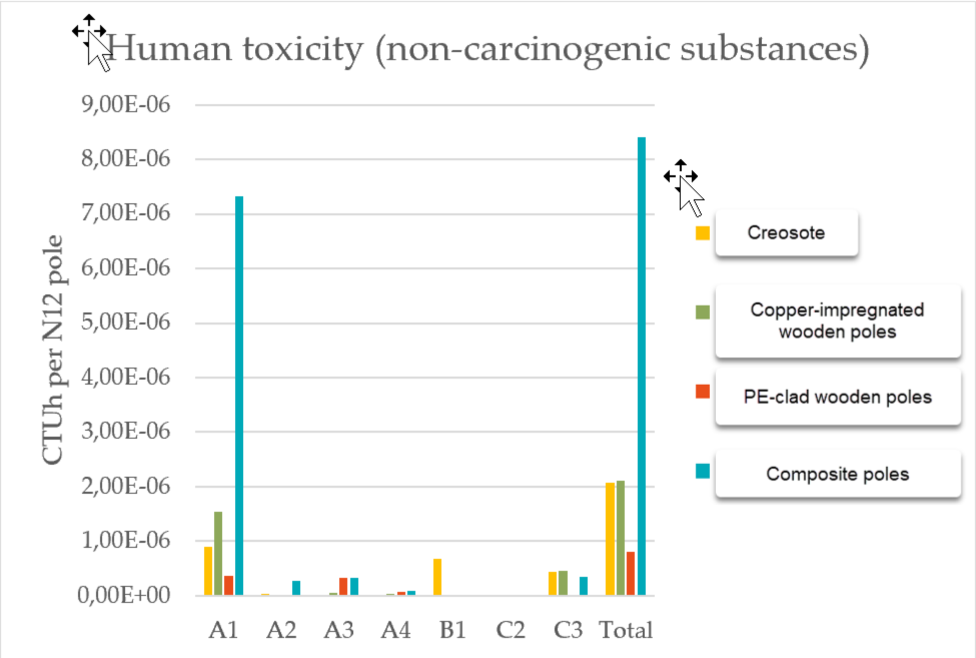

Figure 8 – Human toxicity (non-carcinogenic substances) for the respective pole types, in CTUh per pole type.

4.6 ECOTOXICITY

The potential impact of the poles studied on ecotoxicity is shown in **Fel! Hittar inte referenskälla.**. Over the life cycle of the poles, PE-clad wooden poles have the lowest total impact, and this pole type has significantly lower impact than the other three pole types

For creosote- and copper-impregnated wooden poles, and composite poles, it is primarily the extraction and production of raw materials used in manufacturing the poles that represent the greatest impact. On the whole, it can be seen from the results below that the greatest ecotoxic environmental impact arises in raw materials production, and that only a lesser part arises during the use phase itself.

PE-clad wooden poles and composite poles have a low impact on ecotoxicity during the use phase (B1), due to the fact that emissions and leaching of hazardous substances is assumed to be negligible. On the other hand, the results show that both creosote- and copper-impregnated poles have an impact on ecotoxicity during the use phase. For copper-impregnated poles, leaching of copper is the primary contributing factor.

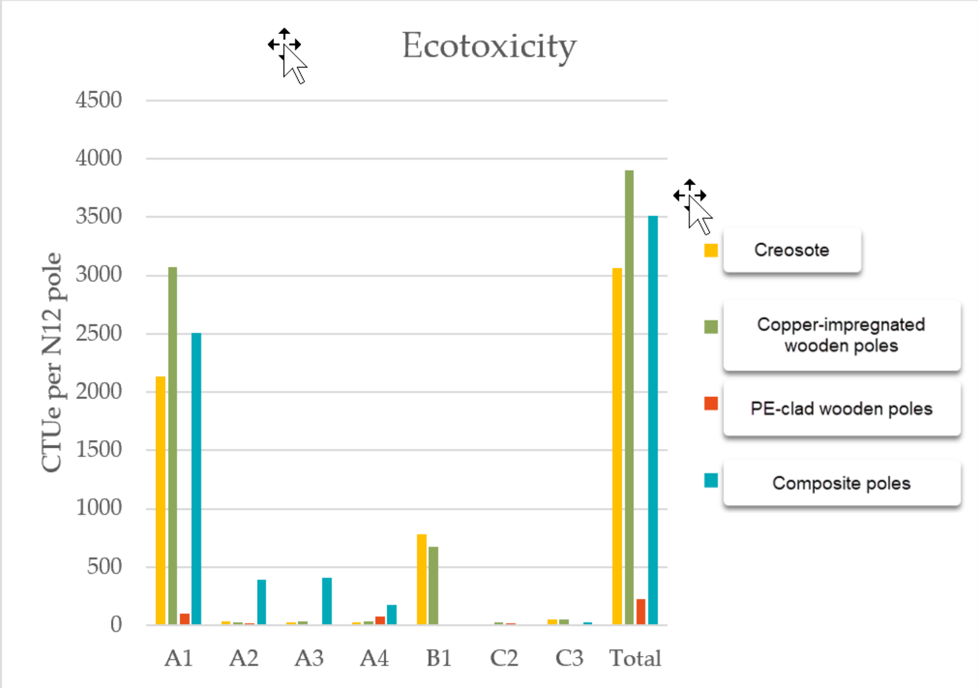

Figure 9 – Ecotoxicity for the respective pole materials, in CTUe per pole type.

4.7 PRIMARY ENERGY

Primary energy is a measurement of the amount of energy resources required for a system being studied. For this study, it is a useful standard for measuring resource efficiency among the various pole materials since both wooden poles and different types of polymers have energy-bearing properties. The results presented in **Fel! Hittar inte referenskälla.** show total primary energy use divided between non-renewable energy (fossil energy resources) and renewable energy.

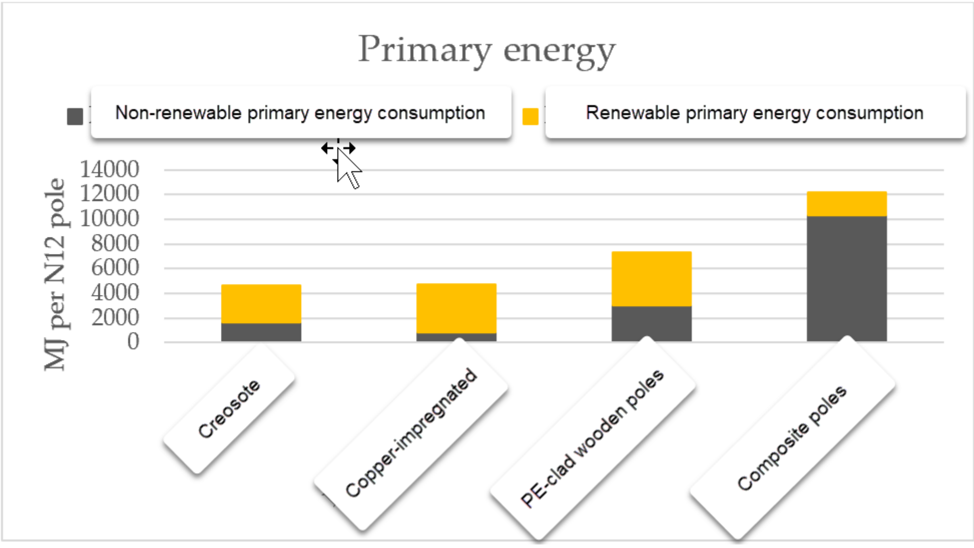

Figure 10 – Primary energy for the respective pole materials, in MJ per pole type.

The results show that impregnated wooden poles require the least amount of primary energy, and that wooden poles impregnated with creosote or copper salts use similar amounts of energy where more than half comes from renewable sources.

The poles that require the most energy resources are composite poles, where the need is more than twice as large compared to wooden poles impregnated with creosote or copper-based substances. Fossil-based resources are the primary contributor to the total result from the manufacture of glass fibre and polymers as raw materials.

In the case of the PE-clad wooden poles, the wood raw material promotes an equally significant need for renewable energy as for the impregnated poles. The difference between them is due primarily to a greater need for polyethylene during production compared to creosote and copper salt impregnations.

4.8 SENSITIVITY ANALYSIS

This chapter presents and describes the results of the sensitivity analyses. Two assumptions have been tested:

- alternate waste scenarios in which the recycling potential of the poles are presented and [credited?]; and
- the expected service life of the poles.

4.8.1 Alternate waste scenarios

In the main analysis, assumptions were made regarding which waste management approach for the various pole materials was most likely under current conditions. It was assumed that all wooden poles except the WOPAS plastic-clad poles would be incinerated, and that composite poles would go to landfill. These assumptions were tested in a sensitivity analysis, and potential recycling scenarios in the foreseeable future were formulated in the project group. These can be seen in **Fel! Hittar inte referenskälla.** below.

Table 7 – Scenario analysis for alternate waste management methods and recycling potential for the various poles.

No.	Utility pole type	Waste management	Module D / Gains after end of life
1	Wooden pole – creosote	Incineration	District heating and electricity
2	Wooden pole – copper	Incineration	District heating and electricity
3	Wooden pole – copper + RVP repellent	Incineration	District heating and electricity
4	Wooden pole – PoleProtect	Incineration	District heating and electricity
5	Wooden pole – PE coating	Materials recycling of wood poles and PE coating	Particle board and newly manufactured PE granulate
6	Composite pole – epoxy	Materials recycling of composites and PE	Crushed stone and newly manufactured PE granulate
7	Composite pole – polyester	Materials recycling of composites and PE	Crushed stone and newly manufactured PE granulate
8	Composite pole – polyurethane	Materials recycling of composites	Crushed stone

A quality factor of 0.5 is applied to the recycling of PE in this analysis. No quality factor is applied to recycling of crushed composites such as crushed stone – the assumption is that 1 kilogram of composite can replace 1 kilogram of crushed stone.

The PE-clad wooden poles contain 50% recycled polyethylene; only the content of newly produced polyethylene is therefore credited in order to avoid double counting. If the quality factor of 0.5 is also included for the recycling of polyethylene, it is assumed that 25% of the total content of the pole could be replaced by newly produced polyethylene.

The results of the sensitivity analysis are presented in **Fel! Hittar inte referenskälla.** below. For the composite poles, the total savings potential with regard to greenhouse gas emissions released is low. This is due primarily to a low level of climate impact from the production of crushed stone. The PE-clad wooden pole displays the largest recycling potential of all poles, where the greatest factor is the replacement of newly produced particle board. Since the wood core of the pole is untreated, there is potential for using the raw material as wood chips for manufacturing particle board. The emissions avoidance from the manufacturing of new polyethylene also promote a reduced climate impact for the pole. The composite poles are also coated with polyethylene, which can be recycled, but there are smaller amounts than in the PE-clad wooden poles so the recycling potential is therefore somewhat lower.

In this analysis, all impregnated wooden poles are incinerated and it is assumed that the energy produced replaces an average Swedish electricity mix and district heating mix. The emissions avoidance from production of district heating is greater than the emissions avoidance from production of electricity, the primary reason being that combined power and heating plants produce a greater proportion of heating than electricity.

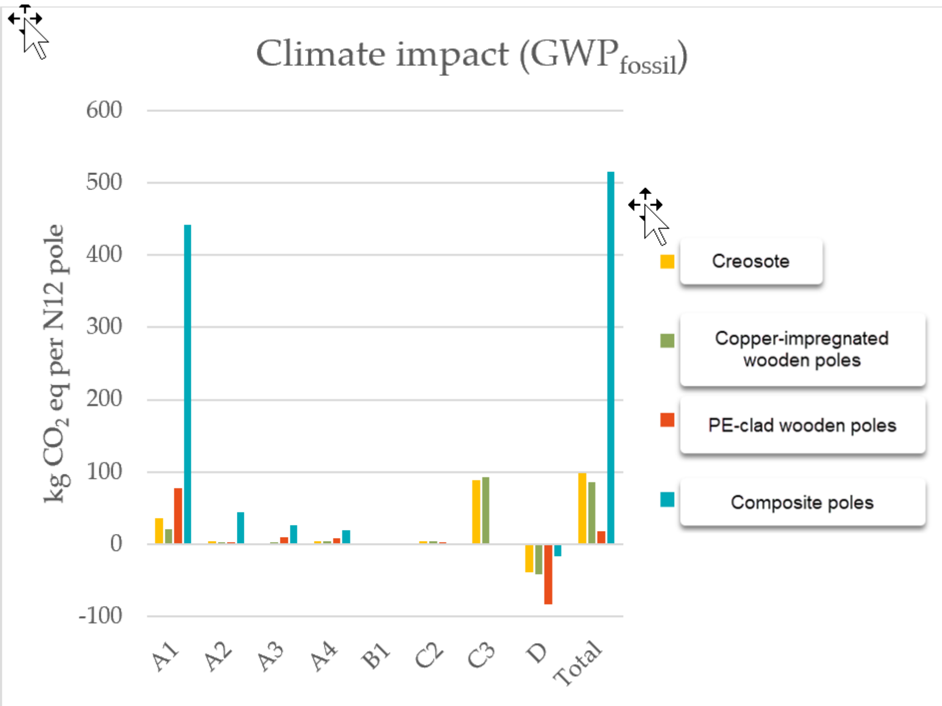

Figure 11 – Climate impact for the pole materials, accounting for recycling potential for the respective poles (Module D according to EN15804).

4.8.2 Significance of the pole's service life

The different pole materials have different service lives, and a sensitivity analysis was carried out in order to illustrate the effects of this on the results. The manufacturers of utility poles stated the expected service life of the respective poles, which are presented in **Fel! Hittar inte referenskälla.** below.

Table 8 – Expected service lives of the various utility poles, according to manufacturer information

No.	Utility pole type	Expected service life
1	Wooden pole – creosote	55 years
2	Wooden pole – copper	35 years
3	Wooden pole – copper + RVP repellent	45 years
4	Wooden pole – PoleProtect	45 years
5	Wooden pole – PE coating	80 years
6	Composite pole – epoxy	80 years
7	Composite pole – polyester	80 years
8	Composite pole – polyurethane	100 years

For all pole types, we have used the service lives indicated by the suppliers. On average, the wooden poles have a service life of 35–55 years and the composite poles have a service life of 80–100 years. The plastic-clad wooden poles have an expected service life of 80 years – the same order of magnitude as the composite poles.

The results of the sensitivity analysis are presented in **Fel! Hittar inte referenskälla.** and **Fel! Hittar inte referenskälla.** below. The figures present the results of the climate impact from the main analysis, but are shown per N12 pole and year instead of solely per N12 pole. The results show that on average, composite poles have a greater climate impact than the other pole materials, even accounting for the longer service life. As previously mentioned, the greatest climate impact arises in the manufacture of the raw materials.

The PE-clad wooden poles show the least climate impact in the analysis, which is due primarily to the poles having the least climate impact in the basic analysis as well, and this is boosted with a long expected service life (80 years). The impregnated wooden poles, as well as the creosote poles, demonstrate the second-lowest climate impact despite having on average half the service life of the composite poles.

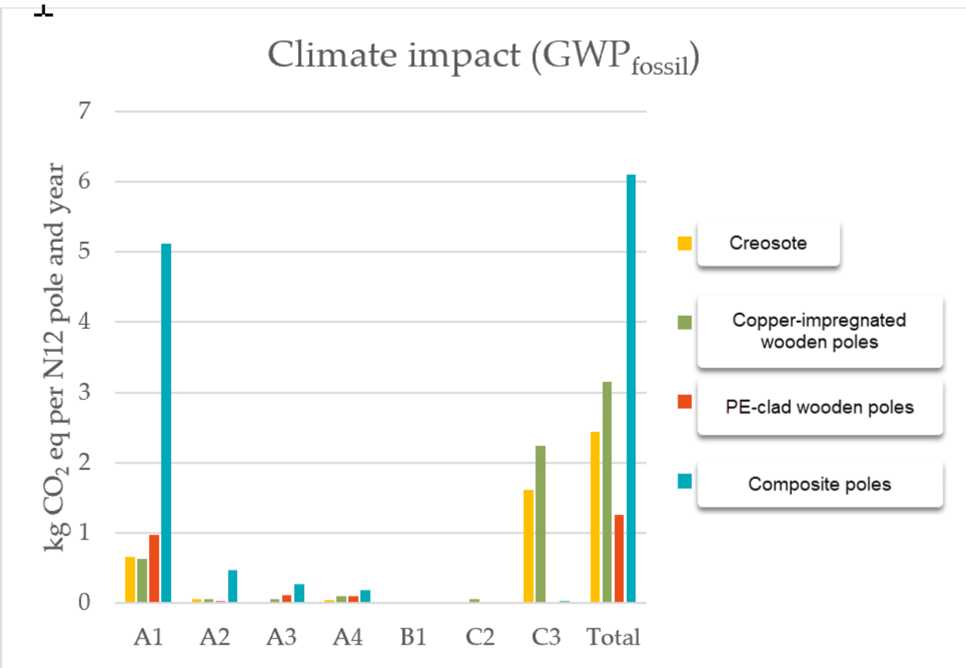

Figure 12 – Climate impact for the respective pole materials, per pole and year. The expected service life of all poles is based on suppliers' own information (see Table 8 above).

If the recycling potential for all poles is taken into account, the results of the climate impact per pole and year is a bit different; this is presented in **Fel! Hittar inte referenskälla.** below. Since the PE-clad poles proved to have the greatest recycling potential in the previous sensitivity analysis, the total climate impact is even lower than the other poles if expressed as results per year. The impregnated wooden poles also have a greater savings potential than the composite poles when recycling potential is included, and therefore have a lower climate impact per pole and year.

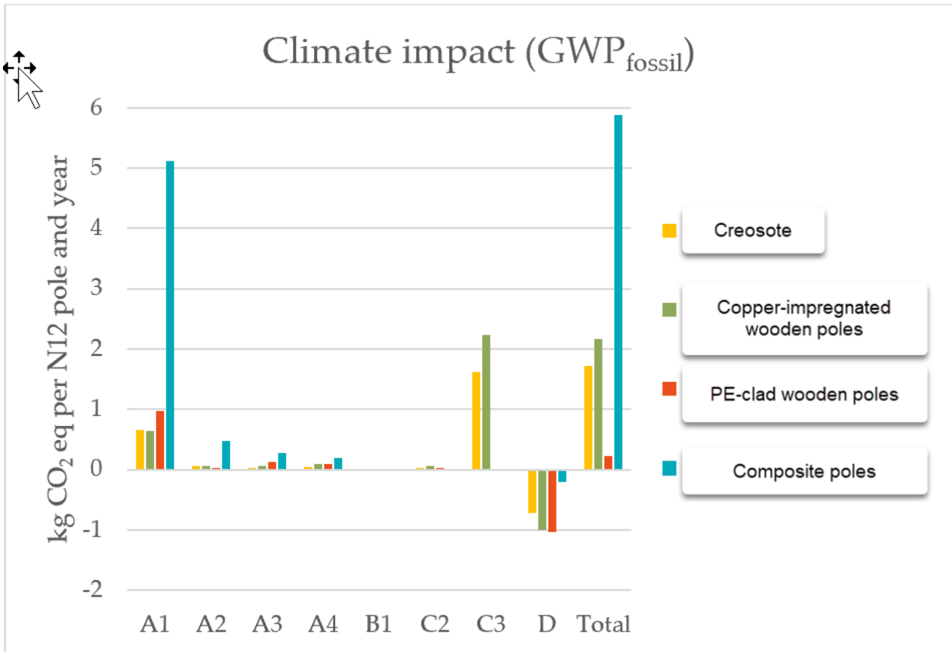

Figure 13 – Climate impact for the respective pole materials, per pole and year, accounting for recycling potential for the respective poles. The expected service life of all poles is based on suppliers' own information (see Table 8 above).

4.8.3 Environmental impact from electricity production

To place the LCA results in a broader perspective, the environmental impact of the poles is compared with the environmental impact that arises as a result of electricity production. The environmental impact of the poles is compared with the environmental impact of 1 MWh of average European electricity production (ENTSO-E). The mix consists of nuclear power (26%), coal (25%), natural gas (13.5%), hydroelectric power (18%), wind power (7%), solar power (3%), biomass (2.5%) and other energy sources (5%), and corresponds to the production mix for 2015. In Sweden alone, approximately 164 TWh of electricity (164,000,000 MWh) is produced annually (Ekonomifakta 2020).

The results of the comparison are presented for a number of selected environmental impact categories in Figures 15–17 below. For the climate impact, **Fel! Hittar inte referenskälla.** below shows that 1 MWh of European electricity production is at approximately the same order of magnitude as a utility pole that is available in the Swedish market.

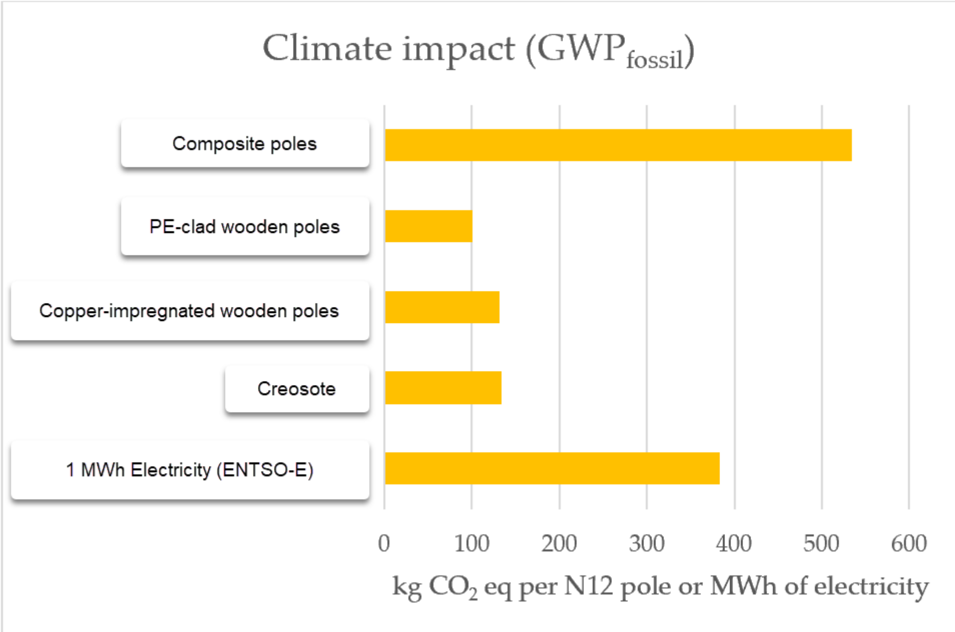

Figure 14 – Comparison of total climate impact of utility poles over their life cycles with the production of 1 MWh of European electricity.

The results of the human toxicity analysis are presented in **Fel! Hittar inte referenskälla.** below. The graph below shows that for the carcinogenic substances, the creosote pole stands out, even in the comparison with electricity production. The bars below show the total human toxicity for the poles, and the use phase corresponds to approximately 60% of the total value of the creosote poles with regard to the carcinogenic substances.

For the non-carcinogenic substances, the composite poles stand out in the comparison. This environmental impact arises during the production of the poles, and no toxic substances leach out during the use phase. For the creosote pole, approximately 30% of emissions arise during the use phase, and the remainder during the production and end-of-life phases. 1 MWh of electricity production has largely the same effective output as the impregnated poles (copper and creosote) relative to the non-carcinogenic substances. The major differences exist for the carcinogenic substances.

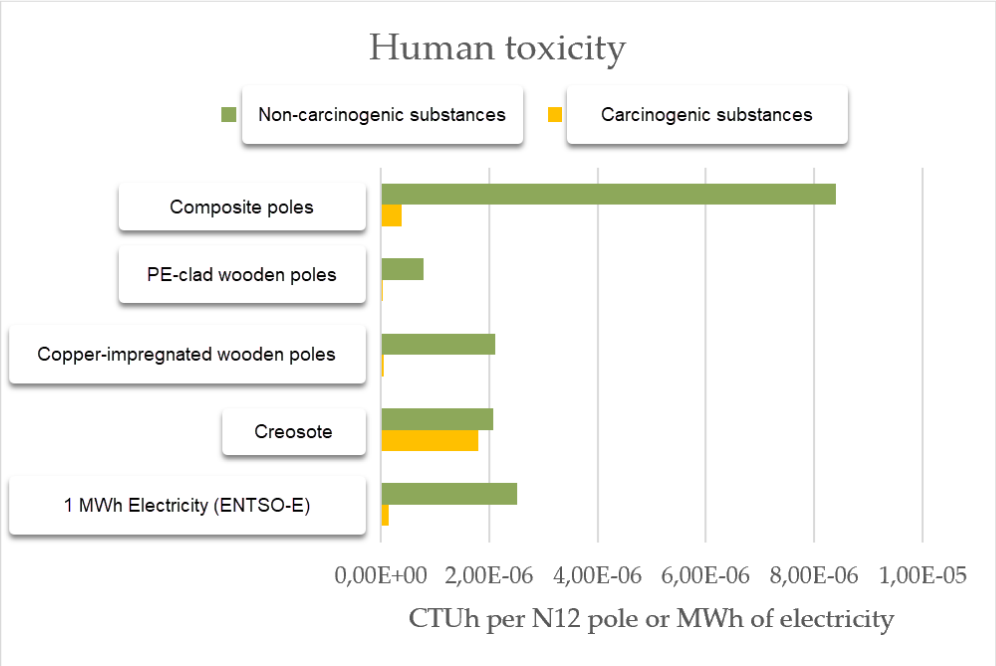

Figure 15 – Comparison of human toxicity potential of the utility poles with the production of 1 MWh of European electricity.

In the comparison of ecotoxic environmental impact between pole materials and electricity production, it can be seen that they are largely the same order of magnitude except for the PE-clad wooden pole, which is much lower. The copper-impregnated wooden poles demonstrated the greatest effective output, with only 17% of the emissions occurring during the use phase and the remainder during production. The creosote pole had greater emissions during the use phase (26% of total emissions) but was otherwise on the same order of magnitude as the production of 1 MWh of European electricity.

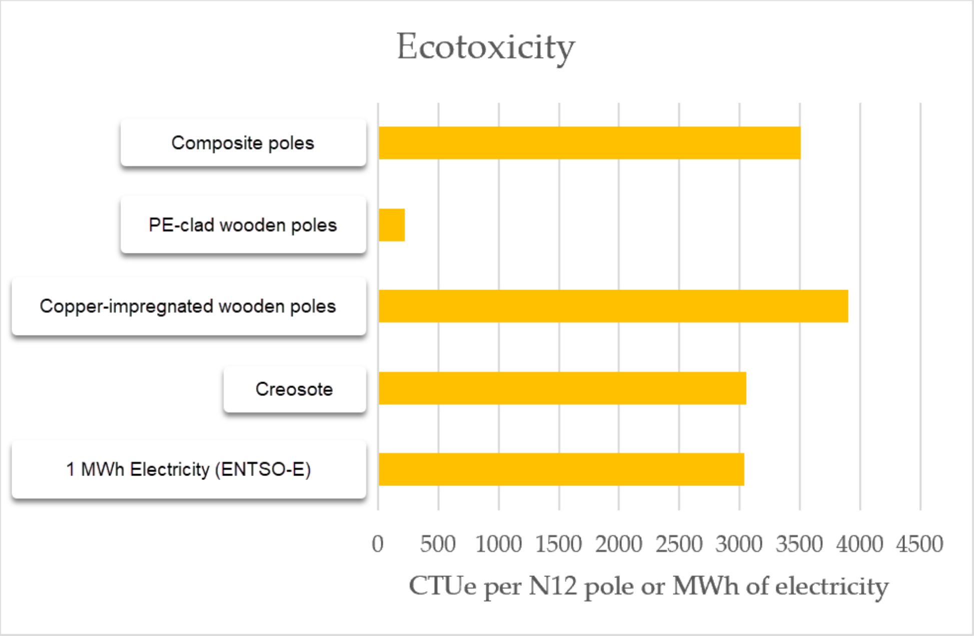

Figure 16 – Comparison of ecotoxicity potential of the utility poles with the production of 1 MWh of European electricity.

5 Discussion and conclusions

This chapter presents a discussion of the results and the conclusions that can be drawn from this study. The results are compared with previous studies in the same field, proposals for how the results are to be interpreted are described, and some of the limitations of the study are presented. We also present proposals for potential future studies and activities targeted towards pole suppliers and the industry.

5.1 COMPARISON WITH SIMILAR STUDIES

On two previous occasions, the Swedish Environmental Research Institute (IVL) published reports concerning the environmental impact of utility poles from a life cycle perspective: Erlandsson & Almemark 2009 and Erlandsson 2011.

Erlandsson & Almemark 2009 investigated the environmental impact of three pole materials: steel, concrete and creosote-impregnated poles. The normalised results showed both that the steel pole had the greatest environmental impact of all categories, and that the human toxicity potential that arises throughout the life cycle of the poles had a relatively greater impact than the other categories (including ecotoxicity and climate impact).

These results are also found in Erlandsson 2011. That analysis carried out a new comparison of steel, concrete and creosote poles, but with the addition of a composite pole. The normalized results again showed that the steel pole had the greatest environmental impact out of all categories except ground-level ozone, and that the human toxicity potential for the steel pole had a greater impact than the other categories. Setting aside the results of the steel poles in Erlandsson 2011, it can be seen that the climate impact of the composite poles was measured relatively highly in the normalisation of the results compared to the human toxicity potential of the creosote poles.

The changes applied in this study compared with the previous ones include the LCA largely following the recommendations in EN15804, the latest standard for environmental product declarations; the inclusion of more pole types (PE-clad wooden poles and copper-impregnated wood poles); broader documentation for composite poles (three suppliers instead of one); the use of a 12-metre pole as the functional unit instead of a 9-metre pole; and the study of the recycling potential of the poles.

5.2 INTERPRETATION OF RESULTS

The service life of the utility poles varies between 35 and 100 years, based on manufacturer information. The service life was included in a sensitivity analysis and can be seen in **Fel! Hittar inte referenskälla.** and **Fel! Hittar inte referenskälla.**. In these results, it can be seen that despite the service life of the composite poles being double that of impregnated wooden poles, they have a greater climate impact. According to the information from Jerol (Bryant-Meisner 2020), testing indicates that the pole could remain standing for twice as long (160 years) without its properties becoming impaired. If this assumption could be applied to all composite poles, it would mean that the climate impact per pole and year would end up at around the same order of magnitude for composite poles as for wooden poles. If the service life of composite poles could thus be extended, composite poles would not be a worse alternative than wooden poles from a climate perspective. At present, the manufacturers of composite poles assume service lives of 80 to 100 years, which is the assumption made in this study.

Improving the climate performance of the composite poles requires, for example, an increased service life through re-use of the poles, or alternately choosing raw materials with lower climate impact. By working with their raw materials suppliers and actively selecting materials with a low environmental impact, pole producers can reduce their climate footprint.

The emissions that occur during the use phase from creosote- and copper-impregnated poles give rise to human toxic and ecotoxic effects, in contrast to composite poles and the PE-clad pole, which release negligible emissions during their use phase. The creosote pole has the highest results of all poles in the category of human toxicity with carcinogenic substances, owing to the volatile substances that evaporate into the air. This effect has also been demonstrated in previous studies (Erlandsson 2011).

The ecotoxicity results were impacted to an extent by the emissions that arise during the use phase, but to the greatest extent were from the manufacture of the raw materials. During the use phase, it is primarily copper that gives rise to ecotoxic emissions from the copper-impregnated wooden poles. Different suppliers have indicated different levels of leaching of copper during the use phase. The average value of the copper-impregnated poles yielded ecotoxic effects that were 2–3 times greater than the creosote poles. But since the indicated levels of copper leaching vary among different suppliers, some caution should be exercised in drawing conclusions based on the results of ecotoxicity during the use phase. For the creosote poles, it is primarily leaching of anthracene – a polycyclic aromatic hydrocarbon (PAH) into the ground – that contributes to the ecotoxicity potential during the use phase. By creating more inert impregnations that do not leach metals or organic pollutants into the surrounding environment, the toxic footprint of wooden poles can be reduced.

The basic analysis assumed that impregnated wooden poles are currently incinerated, that composite poles are sent to landfill, and that the PE-clad poles can be recycled for materials. The manufacturing company Wopas has been able to demonstrate interest from the furniture industry in re-using these materials, and incineration has therefore not been assumed in the basic case.

A sensitivity analysis tested the recycling potential of the poles, in which all the wooden poles were “credited” with electricity avoidance and district heating production, the PE-clad pole with production avoidance of particle board and PE granulate, and the composite poles with construction materials and PE granulate avoidance. The analysis did not result in any greater relative changes among the various poles with regard to the category of climate impact. The production avoidance of construction material, crushed stone, does not give rise to any major climate savings for the composite poles since the material has a low climate impact.

In interpreting the results, it is important to keep in mind that the results are valid for the assumptions that were made in the study and the system limitations that have been defined. Other assumptions could affect the results. However, the impact from key assumptions such as waste management have been investigated through sensitivity analysis in the study in order to demonstrate possible alternatives for the future.

The study is based on robust documentation. All pole suppliers have provided information to the project group on raw materials, transportation, manufacturing of poles, service lives and emissions during the use phase.

The background data for the study was retrieved primarily from the LCA databases Thinkstep (2018) and Ecoinvent (Wernet et al. 2016). The majority of the dataset used is originally from 2016 to 2018, which can be considered as representative of current manufacturing.

5.3 LIMITATIONS

Part of the main purpose of this study is to investigate the differences in environmental impact among various pole materials. That is why the number of poles required for power lines in a given section has not been taken into account, since this can vary depending on the type of utility pole and material selected. The results of this LCA can be used to calculate and compare the total environmental impact from a unique power line where N12 poles are used. This task is left as an exercise for the reader in planning power-line corridors.

The data that forms the basis for production of raw materials for composite poles was discussed in partnership with the pole suppliers over the course of the projects. The IVL project group has studied the data that was recommended for use in LCAs of composite materials by the European Composites Industry Association (EuCIA). The impact of the data that was recommended for composites was compared with the data that was used in this LCA. The conclusion of the analysis is that the main results and the conclusions of the study are not expected to be appreciably impacted if the recommended data sets are used instead.

Including several parts of the life cycle for the poles – for example, maintenance, installation and uninstallation – can be of interest in obtaining a holistic view of the total environmental impact of the poles, despite the fact that they may be equivalent in comparison with one another. The environmental impact that arises as a result of remediation after removal of creosote poles has not been captured in this study.

Toxicity assessments in LCAs are associated with a number of uncertainties. This may be due on the one hand to input data of uncertain quality, and on the other to inbuilt uncertainties in the methods used for toxicity assessments. The USEtox method was used in this study; it is the method recommended in the EN15804 standard for environmental impact assessments of construction products. USEtox indicates characterisation factors for metals as "indicative" rather than "recommended", and caution should be exercised in interpreting the results (USEtox 2020). Any emissions of microplastics from the poles during the production and use phase are not included in this LCA. This is due primarily to the fact that there is currently no carefully developed method for assessing what impact to health and the environment could arise as a result of emissions of microplastics.

The results of this study have not been weighted or normalised, which means that no conclusions may be drawn as to which environmental impact category or categories are most significant in assessing the environmental impact of the poles. Normalisation and weighting have been excluded since both methods contain inbuilt estimations and uncertainties. Nor is the publication of results from normalisation and weighting permitted in EPDs, since these indications can be considered to be arbitrary and misleading (EPD International 2020).

5.4 SUGGESTIONS FOR FUTURE STUDIES

This study encompasses four types of pole material (creosote- and copper-impregnated wooden poles, PE-clad wooden poles and composite poles) from six different manufacturers. No conclusions regarding other pole materials such as steel – which is a common material for high voltage levels in power grids – may be drawn based on this study. Including more materials for more voltage levels in power grids in order to draw conclusions on what environmental impact the poles will have in the Swedish power grid will be of interest for future studies.

It may also be of interest in future studies to calculate the environmental impact of power lines, thereby capturing the inherent properties of various pole materials such as the impact of pole density on a power line.

Producing environmental product declarations (EPDs) for utility poles is a useful tool for communicating verified, transparent and comparable information on the current environmental impact of the products over their life cycles. Apart from communication, EPDs can be used to identify significant environmental aspects and, in partnership with suppliers, to improve the environmental performance of the products throughout the chain (EPD International, undated). By developing specific Product Category Rules (PCRs), the industry can make it possible for pole producers to develop environmental impact information that is in demand and comparable.

5.5 CONCLUSIONS

The main purpose of this study is to calculate the environmental impact of various pole materials and to identify those stages of the life cycle of the poles that bear a large part of the environmental impact – as well as to compare impacts among the various pole types.

The results of the LCA show that the environmental impact of the utility pole materials studied arise at different points along their life cycles, and differ depending on which pole material and environmental impact category is being studied. A large part of the total environmental impact of the utility poles arises in the extraction and manufacture of raw materials. But leaching of chemicals during the use phase and waste management of the poles have a major impact on the results.

PE-clad wooden poles are the ones that result in the least environmental impact of the utility poles studied, and this applies to all the environmental impact categories encompassed by the project except for the “ground-level ozone” category, where the impact of copper-impregnated poles is marginally lower. One of the contributing factors to the lower impact is that it is manufactured from renewable wood raw materials and a large share of recycled polyethylene. The pole is also designed so that both wood and plastic raw materials could be reused, which yields a greater impact compared with incinerating the pole after use. The pole also has a low level of anticipated toxicity impact during the use phase as it – relative to the impregnated wooden poles – does not leach metals or organic pollutants.

The composite pole is the type with the greatest environmental impact in all impact categories studied apart from eutrophication and ecotoxicity, where impregnated wooden poles have a greater impact. A high level of impact from the production of raw materials for composite poles yields a greater total impact compared to impregnated wooden poles and PE-clad wooden poles. The advantage of composite poles is that – relative to the impregnated wooden poles – they are not expected to leach metals or organic pollutants during the use phase.

For wooden poles that have been impregnated with either creosote or copper-based substances, the impregnation products are the primary contributor to the environmental impact. The production of impregnation products is a partial contributor to the results, but leaching during use and emissions during waste management also have an impact. Compared with PE-clad wooden poles and composite poles, these pole types enable the use of the least amount of natural resources (primary energy) over the life cycle. The largest portion of energy raw materials comes from renewable materials (wood raw materials). The impregnated wooden poles promote a low level of climate impact relative to the composite poles.

The results of the sensitivity analysis, where the expected service life of the poles and possibility of materials recycling are included in the analysis, show that PE-clad wooden poles have the lowest climate impact and that the composite poles have the greatest impact despite the expectation of being in use for nearly twice as long as the impregnated wooden poles.

To place the results in a broader perspective, the environmental impact of the poles was compared over the life cycle of the poles with the environmental impact from electricity production. In the comparison, the conclusion can be drawn that the climate impact, human toxicity and ecotoxicity of the poles are roughly in the same order of magnitude as the production of 1 MWh of electricity of a European mix.

This study highlights the manufacture and service life of the poles based on current conditions. Any future process improvements or new materials could have a greater or lesser environmental impact.

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Appendix A: Primary energy

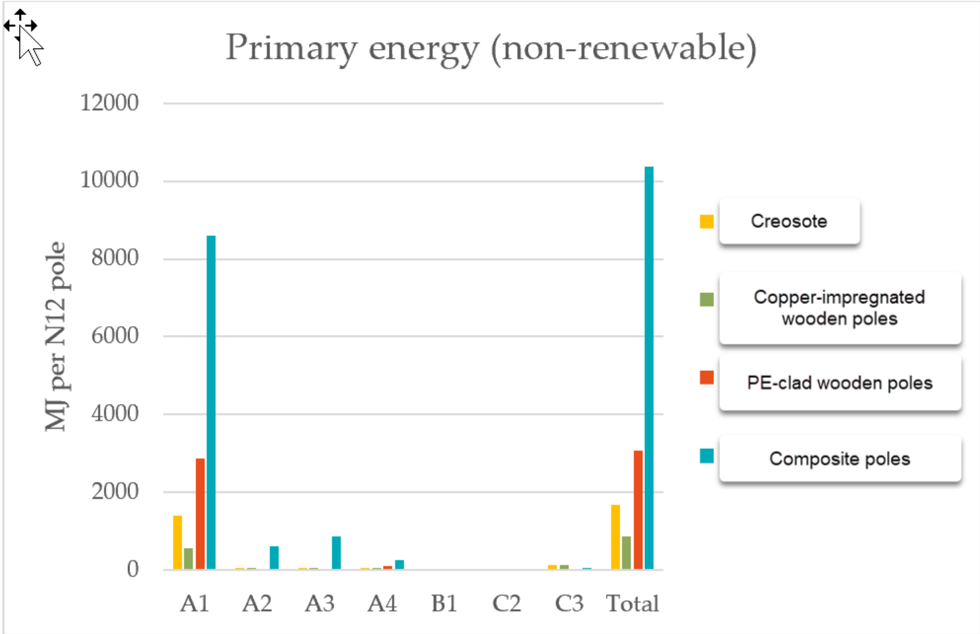

Figure 17 – Results for non-renewable primary energy for the various pole materials, distributed among modules A1–C3. The results are presented in MJ per functional unit.

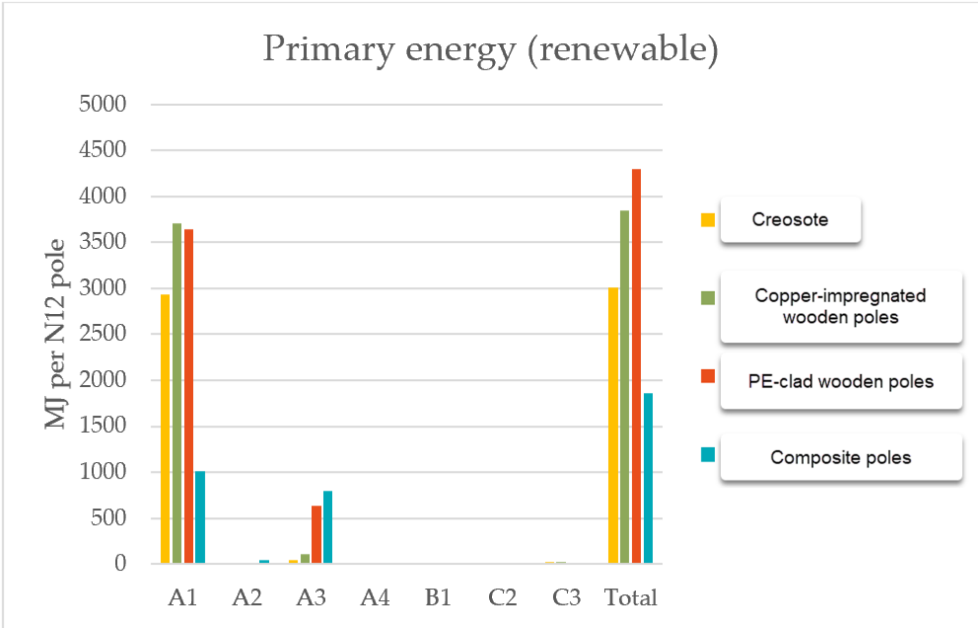

Figure 18 – Results for renewable primary energy for the various pole materials, distributed among modules A1–C3. The results are presented in MJ per functional unit.

Appendix B: Data sources used

Table 9 – Table 9. A selection of the data sets used in the LCA modelling in GaBi.

Resource type	Resource	LCI data set	Reference year	Source
Raw materials	Wood	DE: Spruce log with bark (44% H_2O content) ts	2018	Thinkstep AG (2018)
Raw materials	Wood	DE: Pine log with bark (79% moisture; 44% H_2O content) ts	2018	Thinkstep AG (2018)
Raw materials	Glass fibre	DE: Glass fibres ts	2018	Thinkstep AG (2018)
Raw materials	Epoxy resin	DE: Epoxy resin (EP) mix ts	2018	Thinkstep AG (2018)
Raw materials	Polyester	DE: Polyester resin unsaturated (UP)	2018	Thinkstep AG (2018)
Raw materials	Polyethylene	RER: Polyethylene low density granulate (PE-LD)	2014	PlasticsEurope
Raw materials	Polyurethane	EU-28: Aromatic Polyester Polyols (APP) production mix PU Europe EU-28: Aliphatic Isocyanates ALIPA	2014 2010	Thinkstep AG (2018)
Fuel	Diesel	EU-28: Diesel mix at refinery ts	2016	Thinkstep AG (2018)
Energy	Electricity, Sweden	SE: Electricity grid mix ts	2016	Thinkstep AG (2018)
Energy	Electricity, Norway	NO: Electricity grid mix ts	2016	Thinkstep AG (2018)
Energy	Electricity, Germany	DE: Electricity grid mix ts	2016	Thinkstep AG (2018)
Energy	Electricity, Europe	ENTSO: Electricity grid mix ts	2015	Thinkstep AG (2018)
End of life	Incineration of wood	SE: Processed wood in waste incineration plant ts	2018	Thinkstep AG (2018)
End of life	Construction material, replaces composites	DE: Crushed stone 16/32	2018	Thinkstep AG (2018)
End of life	Particle board, replaces wood from PE-clad wooden poles	EU-28: Particle board	2018	Thinkstep AG (2018)

Appendix C: Results

The results for all pole materials are presented below in table form. The results for all environmental impact categories studied are divided into life cycle stages A1–A3 (production phase), A4 (transportation to customer), B1 (use phase), C2 (transportation to waste management), C3 (waste management) and a total value. The results below encompass the results of the main analysis and are given per N12 pole. The service life of the poles and gains after end of life are not included here.

Table 10 – Results for creosote poles for all environmental impact categories studied, divided into life-cycle stages A1–A3, A4, B1, C2 and C3.

Category	Unit	A1-A3	A4	B1	C2	C3	Total
Ecotoxicity	CTUe	2189	24.1	784.0	12.0	50.2	3060
Acidification potential	Mol H^+ eq.	0.26	0.0030	0	0.0015	0.21	0.47
Human toxicity (carcinogenic substances)	CTUh	7.29E-07	4.83E-10	1.06E-06	2.41E-10	8.34E-09	1.80E-06
Human toxicity (non-carcinogenic substances)	CTUh	9.48E-07	1.93E-08	6.69E-07	9.66E-09	4.35E-07	2.08E-06
Climate impact (fossil)	kg CO_2 eq.	41.0	2.69	0	1.35	89.0	134.0
Ground-level ozone	kg NMVOC eq.	1.03	0.0023	0	0.0012	0.24	1.27
Primary energy (non-renewable, PENRT)	MJ	1475	35.7	0	17.9	127	1660
Primary energy (renewable, PERT)	MJ	2983	2.07	0	1.04	21.3	3010
Eutrophication potential	kg P eq.	0.039	1.29E-05	0	6.46E-06	1.67E-05	0.039

Table 11 – Results for copper-impregnated poles for all environmental impact categories studied, divided into life-cycle stages A1–A3, A4, B1, C2 and C3.

Category	Unit	A1-A3	A4	B1	C2	C3	Total
Ecotoxicity	CTUe	3124	37.7	672.2	22.6	46.1	3902
Acidification potential	Mol H^+ eq.	0.36	0.0093	0	0.0042	0.22	0.59
Human toxicity (carcinogenic substances)	CTUh	3.91E-08	7.55E-10	0	4.54E-10	8.59E-09	4.89E-08
Human toxicity (non-carcinogenic substances)	CTUh	1.61E-06	3.33E-08	1.88E-10	1.91E-08	4.49E-07	2.11E-06
Climate impact (fossil)	kg CO_2 eq.	32.2	4.21	0	2.53	92.3	131.2
Ground-level ozone	kg NMVOC eq.	0.21	0.0080	0	0.0035	0.25	0.47
Primary energy (non-renewable, PENRT)	MJ	646.2	55.9	0	29.1	123.3	854.5
Primary energy (renewable, PERT)	MJ	3825	3.24	0	1.69	21.7	3851
Eutrophication potential	kg P eq.	0.037	2.02E-05	0	1.21E-05	1.40E-05	0.038

Table 12 – Results for PE-clad poles for all environmental impact categories studied, divided into life-cycle stages A1–A3, A4, B1, C2 and C3.

Category	Unit	A1-A3	A4	B1	C2	C3	Total
Ecotoxicity	CTUe	125.4	71.8	0	18.6	9.29	225.1
Acidification potential	Mol H^+ eq.	0.33	0.025	0	0.0064	0.0073	0.37
Human toxicity (carcinogenic substances)	CTUh	2.79E-08	1.44E-09	0	3.74E-10	2.11E-10	3.00E-08
Human toxicity (non-carcinogenic substances)	CTUh	7.03E-07	6.80E-08	0	1.76E-08	9.48E-09	7.98E-07
Climate impact (fossil)	kg CO_2 eq.	90.0	8.05	0	2.09	0.74	100.9
Ground-level ozone	kg NMVOC eq.	0.48	0.021	0	0.0056	0.010	0.51
Primary energy (non-renewable, PENRT)	MJ	2913	107.0	0	27.7	14.4	3062
Primary energy (renewable, PERT)	MJ	4290	6.19	0	1.61	1.02	4299
Eutrophication potential	kg P eq.	0.0028	3.86E-05	0	1.00E-05	3.20E-06	0.0029

Table 13 – Results for composite poles for all environmental impact categories studied, divided into life-cycle stages A1–A3, A4, B1, C2 and C3.

Category	Unit	A1-A3	A4	B1	C2	C3	Total
Ecotoxicity	CTUe	3303	174.3	0	8.68	21.6	3508
Acidification potential	Mol H^+ eq.	2.90	0.33	0	0.0029	0.021	3.26
Human toxicity (carcinogenic substances)	CTUh	3.87E-07	3.01E-09	0	1.74E-10	3.78E-09	3.93E-07
Human toxicity (non-carcinogenic substances)	CTUh	7.92E-06	9.48E-08	0	8.20E-09	3.51E-07	8.41E-06
Climate impact (fossil)	kg CO_2 eq.	511.4	19.06	0	0.974	3.09	534.4
Ground-level ozone	kg NMVOC eq.	1.98	0.44	0	0.0026	0.0167	2.44
Primary energy (non-renewable, PENRT)	MJ	10061	258.1	0	12.9	41.8	10360
Primary energy (renewable, PERT)	MJ	1853	2.18	0	0.749	5.29	1864
Eutrophication potential	kg P eq.	0.0058	1.24E-05	0	4.67E-06	7.00E-06	0.0058

Search terms

Life cycle assessment; utility pole; environment; power grid

Life cycle assessment of utility polesLife cycle assessment of utility poles

At present, a large majority of power-line utility poles in every country are manufactured from creosote-impregnated wood. In recent years, sales of poles developed from other materials have begun since the continued use of creosote as wood impregnation is uncertain.

A life cycle assessment for a number of different materials for utility poles has been conducted for this report. A report on the life cycle assessment for several of these materials provides grid owners with the opportunity to compare their properties. This also means that this information can be used as documentation for decisions on future purchases of poles.

The results show that the impact of the various pole materials varies, both as regards the scope and where in the life cycle it is greatest. The material that has the least impact in all categories except one is PE-clad wood.

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