REPORT

LCA for NTR class A timber in ground contact and alternative materials – Horse fences and fence posts

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Report Summary

Project title

Alternative methods for LCA toxicity assessment - applied to NTR Class A impregnated wood

Project sponsor

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Title and subtitle of the report

LCA for NTR class A timber in ground contact and alternative materials
– Horse fences and fence posts

Summary

The use of chemicals in construction products and risk mitigation is an area that is often attached to the selection of the material. Wood preservatives are used to increase the durability of the wood so that it can be applied in fields that otherwise would not have been possible. The use of wood preservatives is regulated in the Biocides Directive and requires a national approval from the Swedish Chemicals Agency (for the Swedish market).

A life cycle assessment (LCA) on pressure treated pine according to NTR class A with a copper based agent was implemented in the project. The analysed product category in the case study is fence posts including pressure treated timber and alternative posts of; plastic, untreated wooden posts of robinia (from central Europe) and Siberian larch (from Siberia). The report reflects Swedish or Scandinavian conditions.

In the assessment, the LCA methodology and the environmental impact indicators used, as prescribed by the general Product Category Rules (PCR) for construction products (EN 15804). This so-called Core PCR is linked to the European construction products directive (CPR). The purpose of this study is to evaluate how these policies can be used and to analyse the environmental performance with respect to selected and mandatory impact indicators in the environmental product declaration (EPD).

Calculations found that NTR Class A treated pine has a better environmental performance in comparison with the alternative materials used for the assessment. Uncertainties in the choice of service life prediction data exist in relation to plastic posts, but also to some extent to posts of robinia and larch. These differences determine the relative ranking for other options. The study has taken into account all environmental impact categories, which are required to be included in accordance with EN 15804 apart from resource use, since assessment methods for resource use lack factors for renewable materials. This impact category has therefore been excluded from the study, as it else would render a comparison incomplete with respect to the plastic alternative. Thus we find a need to develop better methods to assess resource use in the future. Since human toxicity and ecotoxicity are not found among the mandatory environmental impact categories included in the LCA, in accordance with EN 15804, these aspects are not included in the assessment, and even here we find a need of future developments.

Construction product regulation, durability, EN 15804, environmental assessment, fence post, horse fence, impregnated wood, treated wood, life cycle assessment (LCA), larch, NTR class A, plastic, robinia, Siberian larch.

Bibliographic data

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Context

For today's products besides the price, aesthetics, technical performance also ecological sustainability is now an aspect which is used for product evaluation. Now we find that a product's environmental performance is important in assessing products. Many consumers make an environmentally sound choice in relation to the options available. With this in mind, the survey have analysed two different horse fences types and made of various alternative materials.

Wood is a renewable material which is viewed as an ecologically sound choice, if it comes from sustainable forestry, due to its association with aspects such as low climate impact and sustainable use of resources. Even though wood is a renewable material, fossil fuels are used in different steps of the process, for input goods as well as transports among other things. A reoccurring question asked by consumers is the environmental difference between using a domestic treated timber compared to a naturally durable wood, which is transported over long distances.

Pine is pressure treated for use in ground contact and to extend its service life. Impregnated wood in ground contact shall be in compliance with the NTR class criteria to guarantee its durability. Alternatives to pressure treated pine are naturally durable wood species like Siberian larch, robinia (Robinia pseudocacia, commonly known as the Black Locust and sometimes marketed as acacia or more precise false acacia), and other materials such as plastic or plastic composites.

The goal of this study is to compare the different alternative fence options from an environmental standpoint using LCA. Horse fences were chosen for the case study as it is a commonly used form of fence, which can be comprised of varied materials. The study comprises horse rail fences (with posts and rails and an electric wire) and an electric fence (with poles and electric steel wires). The electric fences are representative for permanent fencing for different types of livestock. Another product segment is temporary fences, but wooden poles are not used for this purpose and therefore not included in this study.

The study uses the methodological guidance for LCA calculations and environmental impact categories developed by the European standardisation (CEN TC350), to be used for the joint European market environmental product declaration (EPD). CEN has within the framework of this mandate developed so-called product category rules (PCR), to develop EPDs for all construction products (EN 15804). The ambition is to use these rules in a competitively neutral way, to account and assess the environmental impact through a life cycle perspective, and applicable in accordance with the construction product regulations. The regulations now include that the environmental impact should be managed in a life cycle perspective using LCA, based environmental declarations (EPD) if this kind of performance is asked for. The purpose of this study is to evaluate how these new rules can be used to analyse the alternative options, based on the selected environmental indicators that is mandatorily included in the construction product PCR EN 15804.

A common environmental assessment method for product based on LCA

Environmental performance under the CPD

The European Construction Products Regulation (CPR) applies to all construction products used for all kind of construction works. The CPR offers a way to assess construction materials environmental performance in a life cycle perspective by using Life Cycle Assessment (LCA) methodology. A more precise way to perform an LCA is developed as part of Environmental Product Declaration (EPD), as defined in the European standard EN 15804. The EPD describe the environmental product performance by publishing the LCA result that constitutes a number of environmental impact categories such as; climate change, ozone depletion, acidification, eutrophication, tropospheric ozone and resource use.

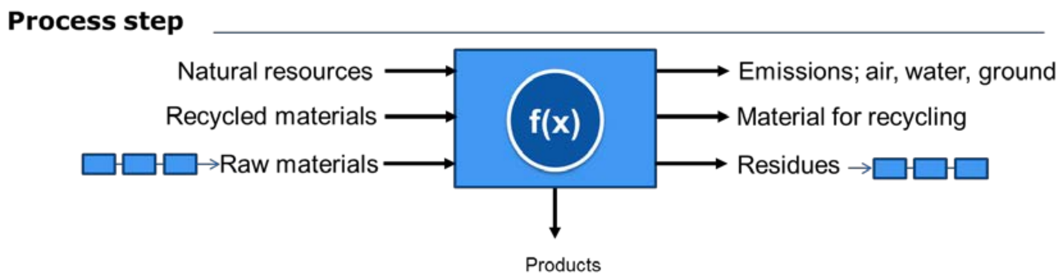


Figure 1 LCA is founded on an inventory of the flow to and from all processes that constitute the environmental impact allocated to the generated products.

The LCA is an environmental tool which enables analysis and evaluation of the environmental impact from products and services from a life cycle perspective. During the first stage of an LCA, all necessary processes needed during a product life cycle is collocated – from cradle to grave – thus constituting an inventory analysis of the environmental stresses which occur (see Figure 1). When conducting product comparisons we need to analyse the product's complete life cycle and secure that the products deliver the same or similar function. In an LCA, the so-called *functional unit* is introduced, that is a fundamental function which all compared alternatives in the comparison need to fulfil. Thus there may be other functions not investigated in the comparison such as aesthetic ageing and deformations, not assumed critical for a fair comparison. These functions will have to be managed outside the LCA as a part of the final basis for decisions.

The LCA methodology is described in international standards (ISO 14040, ISO 14044) and has received a general acceptance. The LCA methodology also belongs to the environmental management family, the ISO 14000 family.

Product Category Rules

A robust method of undertaking an LCA is by applying a so-called *accounting LCA* (also known as *attributional LCA*). The use of such a system perspective is the prerequisite for receiving LCA based modular data and minimising the LCA users' value choices. We can further strengthen the LCA by constructing a framework of rules, where different method choices for all products will be regulated within a document called Product Category Rules.

PCR is one of the most fundamental demands in the international Standard for EPDs (ISO 14025). Under this standard, a widely accepted regulatory PCR has to be developed for all product groups, describing how the LCA shall be carried out. There is more than one reason why the LCA is constructed according to a regulatory framework as in a PCR, where perhaps the most important keywords are, for example; comparability and cost efficiency. Moreover, the LCA user's value choices are guided, thus leading to calculations that are tantamount and robust.

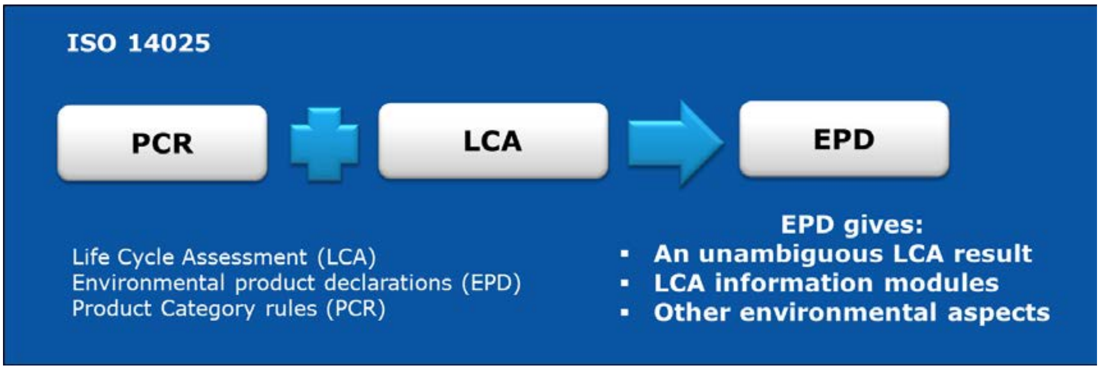


Figure 2 ISO requires the presence of a PCR that directs how to calculate and present an LCR in an EPD.

A European PCR standard (EN 15804) has currently been developed for all construction products. According to the CPR this framework of rules should be used to make sure that all EPD are done in a consistent manner. The EPD may thus allow the comparison of environmental data within the product group and intended use, if they are found on the same functional unit. Optionally, the fact that the LCA data in the EPD is modular constructed they can be used in other LCA studies. This modular construction allows that the LCA data for individual products can then be used as (information) building blocks, to calculate the environmental impact on all different kinds of construction works.

For a PCR (e.g. EN15804) to apply it must be approved by a so-called program operator (Figure 3). The largest program operator in Sweden is the International EPD system. This EPD system also publishes additional PCR for treated wood (Erlandsson 2009). It is also the legislator's ambition to avoid trading barriers, by using a harmonising declaration for all construction materials and avoiding that many different systems are set up by several counterparts in the different countries. When the program operator has accepted the PCR, the suppliers can develop a declaration which contains environmental performances calculated by LCA methodology.

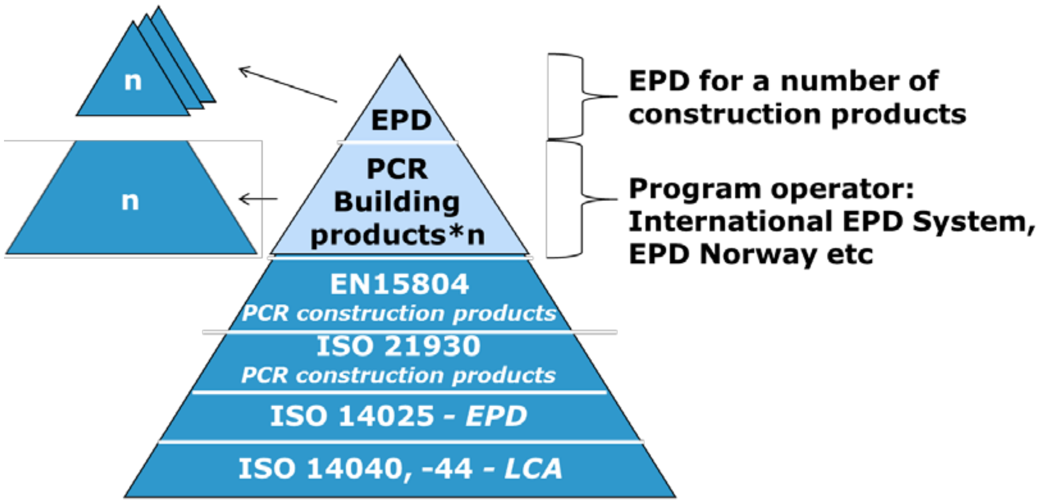


Figure 3 The hierarchical order of the standards that are needed for an EPD for construction products, where the program operator manages the PCR and publish the generated products EPDs.

The lowest requirement concerning the scope of the LCA in an EPD covers a so-called "cradle-to-gate" inventory. This inventory covers the processes from raw material extraction to the finished product clearing the factory gates. The environmental impact in an EPD is typically defined as a *declared unit*, which is often conveyed per kg or m^3. EPDs of this format are used to compare different products within the same product group (sawn timber, Portland cement etc.) and as an information module for an extended LCA.

An EPD can also be developed that covers a whole life cycle, cradle-to-grave, and if the technical function of the product is accounted for, the LCA result will be reported based on a *functional unit*. However, note that this kind of EPD cannot be used as a means of comparing products (sourced from different materials), unless they are based on the same mutual functional unit.

Two major different methodical LCA system perspectives exist, namely attributional and consequential LCA. An attributional, or also called accounting LCA, compiles environmental stressors[1] that are univocally associated with the products life cycle, without accounting for any indirect effects as in a consequential LCA. A consequential LCA goes beyond the simple product burden perspective and includes additional product system in the same analysis, which typically leads to many uncertain choices. As a methodology, accounting LCA, is therefore considered to be very robust and the preferable system perspective for a fair product comparison and selected for EPD according to EN 15804. It is this robustness which has led to accounting (or attributional) LCA being used in most known EPD systems or LCA based climate declaration programmes.

[1] Pressure on the environment caused by human activities (such as generation of pollution and resource use).

From inventory to environmental impact assessment

In all LCAs an inventory analysis is conducted covering all environmental stressors, which is related to the product and results finally in the LCA in an environmental impact overview, an environmental performance profile, see Figure 4.

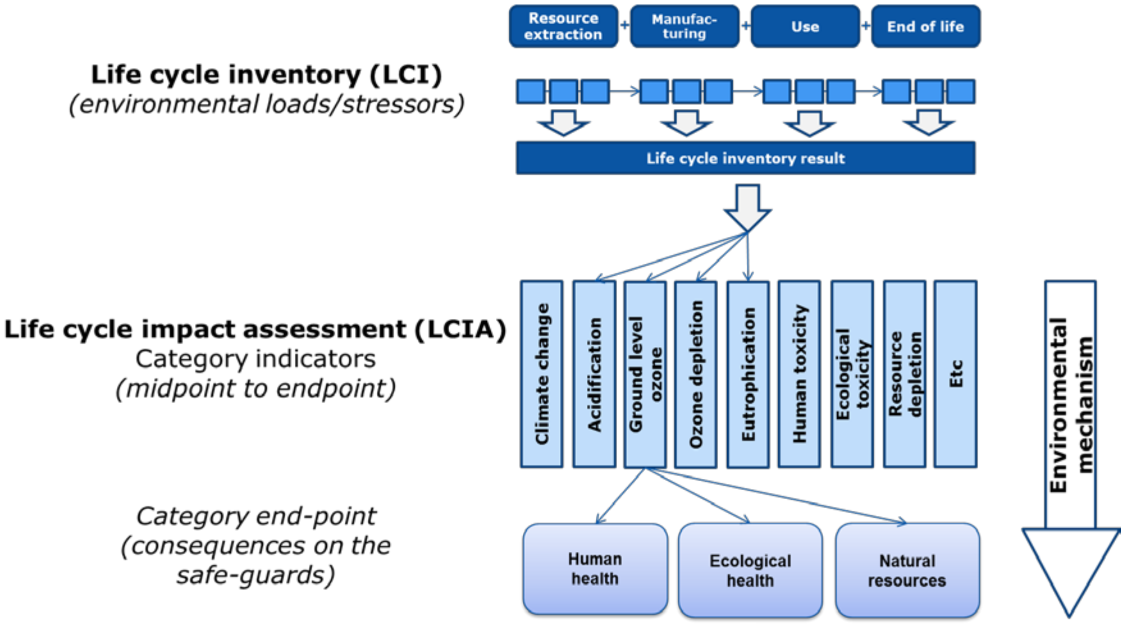


Figure 4 The two main stages of an LCA describe the progression from environmental loads to environmental impact i.e. the Inventory (LCI) and Environmental Impact Assessment (LCIA) stage.

In order to interpret the significance of generated emissions and use of resources, these stressors are converted into contributions to various environmental impact categories. This stage of an LCA is designated a Life Cycle Impact Assessment, LCIA. An environmental impact defines a potential effect such as; climate change, acidification, eutrophication, tropospheric ozone and ozone depletion. All LCIA methods used include a set of so-called characterisation factors. These characterisations factors are defined for all relevant emissions divided in different recipient (emission to air, water and ground) or for a given resource. By multiplying the stressors from the inventory with the characterisations factors, valid for each impact category, an aggregated environmental impact for the whole life cycle can be established.

The LCA-method for the case study

The outlined LCA-calculations follow the LCA methodology employed in the EPD in accordance with the Construction Products Regulation as defined in the core PCR EN 15804. In this LCA approach it is important that the EPD result is divided into a number of information modules, which describe common parts of a product's life cycle (see Figure 5). Other important factors handled in the PCR are the choice of system boundaries and allocation methods, i.e. how the environmental impacts of different processes are to be allocated to the manufactured products.

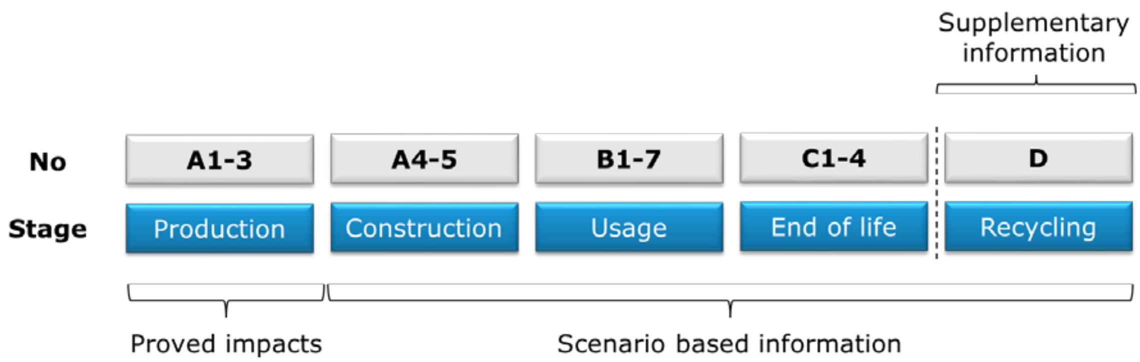


Figure 5 **The construction material life cycle is divided into a number of stages, from A to C (in accordance with EN 15804) that represent LCA-information modules. A1-3 is the cradle-to-gate termed phase, which can be validated. Module D consists of additional information describing the consequences of recycling.**

How to calculate and report the environmental impact as determined in the EN 15804, including the following mandatory environmental impact categories (and referenced in turn the characterization factors according to CML 2001):

- Global Warming Potential (GWP), in kg CO_2 equiv.
- Eutrophication Potential (EP), in kg PO_4 equiv.
- Acidification Potential (AP), in kg SO_2 equiv.
- Ozone Depletion Potential (ODP), in kg CFC-11 equiv.
- Photochemical Ozone Formation Potential (POFP), in kg ethylene equiv.
- Abiotic Depletion Potential (ADP), elements in kg Sb equiv. and fossil in MJ.

According to EN 15804 two environmental impact categories should be used for Abiotic Depletion Potential (ADP), namely abiotic resource depletion fossil and abiotic resource depletion minerals. Please note that the current case study does not include these impact categories, which do not hold any factors for renewable resources providing an incomplete picture favouring products using renewable resources. The EN 15804 is aware of this and states that there is a need to develop the methods used for Abiotic Depletion Potential. Interestingly, factors like the primary energy are not considered to be an LCIA method as no consideration is taken to the scarcity of different resources. The currently utilized impact methods of resource depletion consider various storage resources and the scarcity of fossil fuels as shaped by its availability and consumption.

Furthermore, in EN 15804 there are currently no generally accepted method on how to assess toxic emissions, as specified in the impact categories; human toxicity and ecological toxicity. A general acceptance of such method is in great demand. As there is no generally accepted method for toxicity, they are not included in the mandatory environmental impact categories according to the core construction product PCR EN 15804. The case study, therefore, excludes the assessment of toxic aspects.

The Biocidal Products Directive requires a national approval for the use of the active substances found in wood preservatives. These acts include aspects related to human toxicity and ecotoxicity and a national approval according to the Swedish Chemicals Agency. All the current wood preservatives on the market have undergone such an assessment and meet these requirements.

Declared and functional Unit

In this study the so-called ***functional unit,*** which is used in an LCA to compare alternatives, is reported per:

- ***Section*** - a section of a fence that includes the post and potential rails and the corresponding center-to-center (c.t.c.) distance between the two posts. The analysis uses a c.t.c. distance of 2 meters for the horse rail fence or 4 feet for horse electric wire fence.
- ***Average per annum*** - the environmental impact of each sub-component divided by the applied life of the sub-component; where the service life of wire respectively posts and rails is handled separately (exchanges of these two sub-components are assumed to occur independently of each other).

The alternative to a functional unit is a so called declared unit (according to EN15804). In this specific case study the declared unit covers all life cycle stages and therefore coincides with the scope of the functional unit, except for durability not being taken into account. The declared unit displays the environmental impact of manufacturing the alternative materials for fences, the use stage and when it is subsequently demolished and disposed of. The option to report the LCA based on a declared unit is a common way to account for the environmental performance in an EPD. This type of LCA result based on a declared unit should not be used for comparisons, since durability aspects are not accounted for, but instead as a basis for EPD readers themselves, to make a fair assessment possible by adding different predicted service life.

The same type of electric wire is used for the comparisons and since the electric consumption is equal for all alternatives, the LCA does not include the electric consumption and its environmental impact. The potential difference when different electric wire systems are applied and generate different energy use is therefore not included in the functional unit (or in the LCA).

Pressure treated timber

Pressure treated timber can be divided into different categories according to their intended uses. These durability and use classes are in Scandinavia defined by NTR. Then, the quality control is conducted by a control body approved by the NWPC. NTR class M treated timber is primarily used when there is a possibility of aquatic timber pests being present, e.g. shipworms. NTR class A treated timber is relevant for use in ground and freshwater contact, or in particular cases above ground when a significant risk of rotting in combination with personal safety is present. NTR class AB is intended for the use of weather exposed surface based timber structures such as decking, fences and wind boards etc. Joinery products for use above ground, i.e. windows, doors, garden furniture are impregnated with class B.

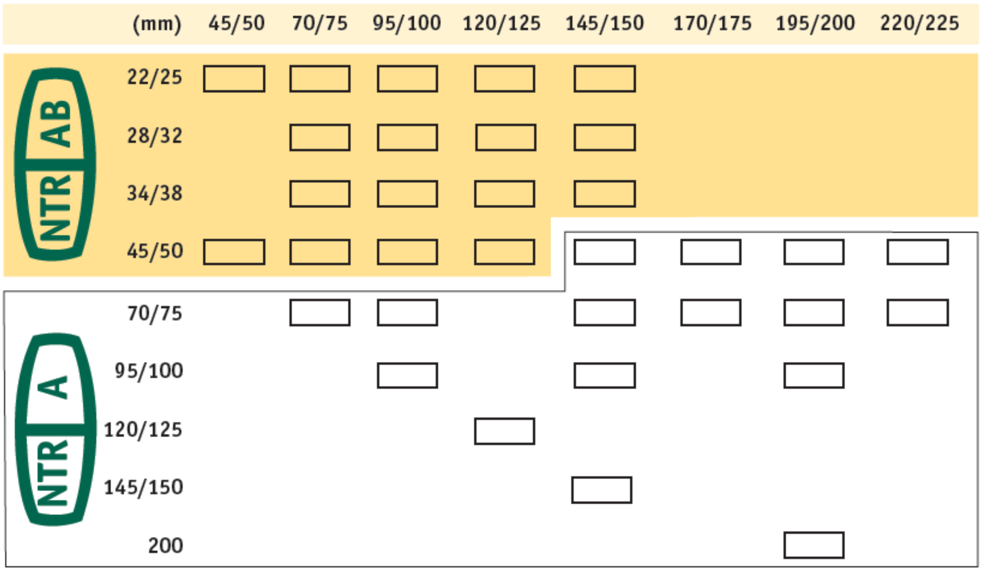


Figure 6 Dimensional stock range allocations of NTR A and NTR AB treated timber available in Swedish timber yards.

Pine (*Pinus sylvestris*) is the predominant timber treated in Scandinavia. Timber in ground contact is treated according to NTR A and the range currently consists of joists, i.e. sawn and planed timber larger than 45x145 mm (see Figure 6), small-posts (50 to 140 mm in diameter and in lengths up to 3 meters), large-posts (telephone and electricity posts) and sleepers. Thin dimension sawn goods smaller than 45x45 has to be ordered in NTR class A if needed. However, timber in ground contact is not normally found in these dimensions and is therefore not present in the store-kept stock range. Small-posts and sawn products are usually treated with a copper-based preservative.

In Scandinavia 90% of the timber production is treated following the NTR regulations. According to the Construction Product Regulation (CPR) construction classified treated wood need to be CE-marked.

In Sweden the manufacturers introduced a 20 year guarantee of NTR treated pine timber. This warranty guarantees that posts or other products are not so affected by rot that the wood loses its intended function. Warranty rules apply to all timber intended for consumer use.

Case study – fences

Keeping the animals in or shutting them out

We can separate fences which are used for keeping the animals in or out (i.e. game/wildlife fences), where the first category is the most common. Furthermore we can then distinguish between permanent and temporary fences. When we consider the range of temporary fences we find for example narrow plastic posts, composites and spring-steel. These fences are placed relatively sparsely (5-10 meters). These temporary fence posts do not withstand cold well and should therefore not be used outdoors all year around.

We have found that it only exists a few material alternatives in the market for permanent livestock posts such as naturally durable wood, salt NTR treated wood posts, creosote treated class NTR A and plastic posts. More recently, there have been requests for certain items such as untreated timber, which is why alternative types of wood are included in the case study i.e. represented by larch and robinia. These naturally durable wood, alternative types of timber are used as the basis for the environmental comparison.

Mounting options

The length of the timber wire posts for animals are in general 1.75-1.8 meters and for horse rail fences it is 2.1-2.2 meters. The slope impact varies in between 0.5 to 1 meter, with a recommendation of 0.7 meter. The timber posts show a variation in diameter of 8 to 10 centimetres, where the thicker diameter is utilized for corners stakes, gates and other categories where reinforcements are needed. Permanent plastic-fences[2] are sturdier than the provisional options and are therefore comparable with the timber posts. A more exclusive horse fence option has two rails. The distance between posts for horse multiline wire is typically 4 meters, while the distance between posts when rails are used is 2 meters. Fence posts used for sheep and bovine animals vary from 3 to 4 meters.

[2] Delivered Plastic fences, such as; the A-fence/SE (http://equisafe.se/bilder/monteringsanv.pdf) or Poda (http://www.poda.se/).

Table 1 An example of a typical mounting option for permanent animal fences (other options exist).

	Wire setting	Timber	Plastic
Sheep			
Wire (example*)	15+50+80	—	—
C.t.c. post		3.5	3.5
Diameter, mm		80	76
Post-length, totally (above ground)		1.8 (1.3)	1.8 (1.3)
Bovine		3	
Wire (example)	40+40	—	—
C.t.c. post		3.5	3.5
Diameter, mm		80	76
Post-length, totally (above ground)		1.8 (1.3)	1.8 (1.3)
Horse, electric wire			
Wire (example)	60+90+120	—	—
C.t.c. post		4	4
Diameter, mm		80	76
Post-length, totally (above ground)		1.8 (1.3)	1.8 (1.3)
Horse, rail fences			
Wire and rails	One electric wire (and 2 to 3 rails)	Loose electric wire	Embedded electric wire
C.t.c. post		2	2
Diameter, mm		100	90
Post-length, totally (above ground)		2.1 (1.4) 2.5 (1.8)	2.0 (1.4) 2.4 (1.7)

* The data regarding fence-wire is taken from www.lantbutiken.se

Copper treated timber rails are equipped with an electric wire to prevent horses gnawing on it. Thus these options will in principle always consist of the same amount of wire, which also applies to untreated timber.

To better enable a comparison we will assume that the electric wire, with accessories, in principle is the same regardless of what material is used for the post. The exception of this case is the horse rail fence, where the plastic option has an embedded electric wire. This wire is assumed to have the same diameter as the wooden option. When replacing the wire in the plastic option, it needs to be mounted exactly as the timber post. In our study, we therefore assume that the electrical wire fixing elements over time is the same, regardless of the choice of posts and rails.

The plastic post is inserted into a drilled hole which is backfilled with shingle. When the timber posts are pounded into the ground they are "wedged" into the existing soil, which assures that they are more stably fastened. It is important not to skimp on the depth regardless of the choice of post materials. If one follows the supplier's instructions it is presumed that all alternatives will equally perform their functions in an equivalent way.

The case study uses the following data (for further details see Table 1):

Horse fence: 2.5 meter wooden post or a 2.4 meter post set with c.t.c. distance of 2 meters and two rafts including two electric wires.

Horse Fencing: 1.8 meter plastic or wooden posts mounted with c.t.c. distance of 4 meters and three electric wires.

Materials and durability

Electric-wire

The so-called iron-wire (soft-wire) or HT-wire (high tensile/hard-wire) from steel has a significantly longer service life than the conventional wires. The climate has a major impact of the service life of the wires. Zinc oxidizes at normal conditions by about 2 my a year and more in the vicinity of the sea. The market consists mainly of the normal galvanized wire of approximately 8 microns of zinc providing a service life of 4 to 5 years. A more durable option is sought, for permanent fences or electric fences that are durable with a minimum of maintenance recommended of 2.5 HT-wire, with heavy insulators and traction springs, which would provide more financial operational benefits.

Normal iron-wire has a service life of 4-8 years. HT-wire has a service life of 15-20 years according to the suppliers[3]. In addition to these types of wire we have, the strong galvanized wire with a coating of at least 36 µm, performed with double or triple galvanisation which provides an estimated service life of 8-16 years and 15-30 years[4]. The galvanisation in this case consists of an aluminium and zinc mixture consisting of 95 % zinc and 5 % aluminium.

It is assumed in the case study that a steel wire of 2.5 mm is used and that an improved galvanizing is undertaken, which is calculated to provide a service life of 15 years for the electrical wire. Electrical wire is assumed to be replaced regularly and therefore would not affect the function of the fence or fences. This assumption applies to all options including the plastic posts.

3 http://www.bmsab.se/subdet37.htm
4 http://www.arcelormittal.com/distributionsolutions/wiresolutions/industrialwire/products/crapal_wire

Plastic

Plastic posts are made of different polymers and in this case study polyethylene (PE) is selected, which is considered to be representative of the modern plastic fence. Examples of alternative plastics are PP, PVC or ABS. Furthermore, the analysis assumes that the plastic is 100% recycled production waste. Production spill seems to be by far the most common raw material for plastic posts (as well as the raw material for wood composites). The use of production waste is justified by the fact that it is easy to guarantee the quality of this raw material unlike the quality of recycled plastic. In the context of LCA we find from an environmental standpoint that this pre-consumer waste essentially holds the same environmental impact as virgin plastic 'as it never has been used in a product' (i.e. compared to post-consumer waste from scrapped products).

No documented service life information on plastic posts was found in the literature or provided by the suppliers asked. However, we have found a manufacturer who has provided an example of a fence installed at the end of 1989/1990 which is still standing today (Karlsson 2012), thus providing an example of a service life of more than 20 years. The owner of this fence turns the rail 180 degrees each year as they otherwise will bend. This kind of deformation is a known problem with all plastic fencing rail and may occasionally result in the rail coming out of the posts hole (but can be managed by annually turning them as described above). Although growth on white plastic fence is an aesthetic problem, we now have black or dark grey plastic alternative that do not have these problems. A foreign manufacturer indicates that the plastic (made from quality assured production waste) has a technical service life of 50 years[5]. The manufacturer does not comment on how the fence mechanical properties change and when the fence as such is no longer serviceable.

To carry out the assessment an average service life of 20 years is applied to the plastic fence. A sensitivity analysis is carried out, namely analyzing alternative results where uncertain assumptions are varied. The sensitivity analysis examines the consequences if the plastic fence were to last for 30 years. This in itself does not state that it in reality will last that long, just how it would affect the environmental impact if it did last for 30 years. In the future an extensive inventory should be undertaken to obtain more secure information, especially since the documentation for the product alternative has been found to be lacking.

[5] http://www.plasmar.com.au/fence-posts

The rot index and the service life of timber in ground contact

Field tests and laboratory tests are used to determine the resistance of timber in ground contact. The advantage of lab experiments is that they are easier to reproduce and faster to implement. The field tests provide a more reality-based result and can thus be perceived as a more reliable method. In order to relate different measurement series with each other CCA-treated timber is typically used as reference. This material is regarded as a reliable reference, with an adequate historical documentation.

Figure 7 Rot index visualisation in compliance with the European field testing standard EN 252, used for analysing the degradation of timber in ground contact. (Reference: Råberg, Terziev 2006)

The degradation of timber in field tests are evaluated according to a four-point scale[6], as shown in Figure 7, where an index of 100 % means that the post may have rotted off and is no longer operational. Many durability evaluation tests define comparative durability data for different types of timber and wood preservative agents, based on a rot index of 100 %. In this state the timber does not meet its required technical performance as a fence post. A simplified assumption has instead been used in this report. When the rot index reaches 75%, it is here assumed to correspond with the technical service life of a wooden fence post in ground contact, when it is still operational.

According to the most common test to evaluate wood decay resistance, EN 252, standardised test pieces of 500 x 500 x 25 mm are used. It is reasonable to assume that the resistance of small-posts are relatively better than the resistance of the standardised test pieces. Moreover, it is relevant when assessing the resistance of small-posts to use field data

[6] A description of the rot index scale is; Healthy-no visible attack 0 %, Weak attack 25 %, Moderately Difficult attack 50 %, difficult attack 75 % and very difficult infestation, sample condemned 100 %.

with the correct dimension, but in the absence of such data, information from the standardised test pieces is also useful.

NTR A treated timber

NTR A treated pine is not a precise product. However, a number of NTR-approved agents with different uptake can be used to meet the requirements. Historically, a well proven wood preservative with good properties against rot, consisting of copper, chromium and arsenic (CCA) have been used. CCA-preservatives are not used today due to environmental reasons. Modern wood preservatives are typically based on copper and an organic fungicide.

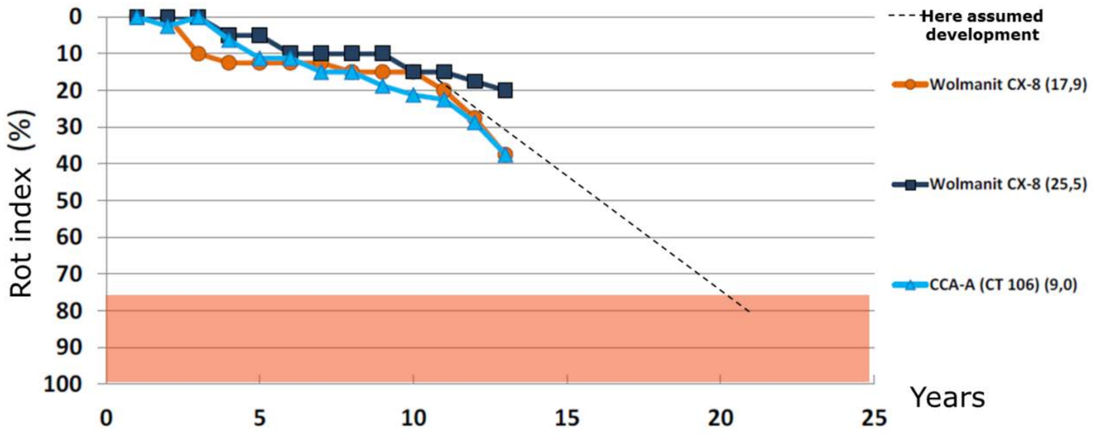


Figure 8 **Field test evaluations of NTR class A copper treated fence post in ground contact. The values in parentheses indicate the preservative uptake per cubic meter. The dashed line shows the 20-year estimated development done in this report. (Reference: BASF 2012)**

In Figure 8 the accessed field studies data for a typical and representative, copper based substance according to NTR class A in ground contact is presented. The estimated service life of a CCA-post (rot index 100 %) based on the above result is more than 25 years. The figure shows that even development of the lower absorption copper-agent initially follows the same trend as the CCA. A supposed extrapolation from the field data reported in Figure 8 indicates that a rot index of maximum 75 % after 20 years exposure should be managed with a good safety margin. This should be realistic, especially if we add the fact that the nominal absorption (for this preservative) at 22 kg/m^3 is higher than the current 17.9 kg/m^3, which shows the same trend as the CCA-reference (see Figure 8).

It is assumed in the calculations that no difference in efficacy exists between the different NTR approved copper-agents.

It is assumed that a service life of 20 years is reasonable for NTR A treated post in ground contact. Given that the field trials show that the absorption and actual preservative follows the CCA development, it is therefore deemed unnecessary in the case study to use any alternative service life estimations for the sensitivity analysis.

It is assumed that 20 years are a reasonable service life for NTR A treated post in ground contact. Given that the field trials show that the absorption and actual preservative follow the CCA development, it is therefore deemed unnecessary in the case study to use any alternative service life estimations for the sensitivity analysis.

Siberian larch

There are approximately 17 different types of larch. In accordance with EN 350-2 the European Larch (Larix decidua) is classed as 3-4, i.e. “moderate durable to slightly durable”. The practical experiences have shown that the Siberian larch has a better natural resistance in comparison with the European larch especially if it is cultivated in Siberia. An on-going study of the reasons for this is carried out by the Swedish University of agricultural sciences (SLU) in Uppsala (Terziev 2013).

Siberian larch actually consists of different types where Larix Sibirica and Larix Sukaczewij dominate the primary areas of eastern Siberia from the river Yenisej, Bajkals Island towards the pacific coast, representing 40 % of the stock[7]. The Siberian larch has a slow growing rate and requires up to 250 years until it is fully grown[7]. In our case study, we therefore assume that the posts are made of Siberian larch from Siberia.

We have not found any field studies evaluating small larch posts. However, we did find results from EN 252 field durability trials (using standardized test samples) presented in literature including information on species and their origin. One of the studies included pine (heartwood and sapwood) and two kinds of species of larch (Larix sibirica, Larix decidua) from two plant locations in Sweden and Norway. The tests were conducted at two different experimental fields (Ultuna and Simlångsdalen). By using these field trials Pockrandt (2012) draws the conclusion that the Siberian larch from Siberia is the most durable larch.

Inferring larch natural resistance without precise knowledge of the species or origin is thus difficult. The experimental results presented in Figure 9 show that European larch grown in Sweden has the inferior durability among the analysed alternatives and in simplification has a similar durability as pine sapwood from Sweden. Another conclusion is that the Siberian larch from Sweden and pine heartwood has a similar resistance.

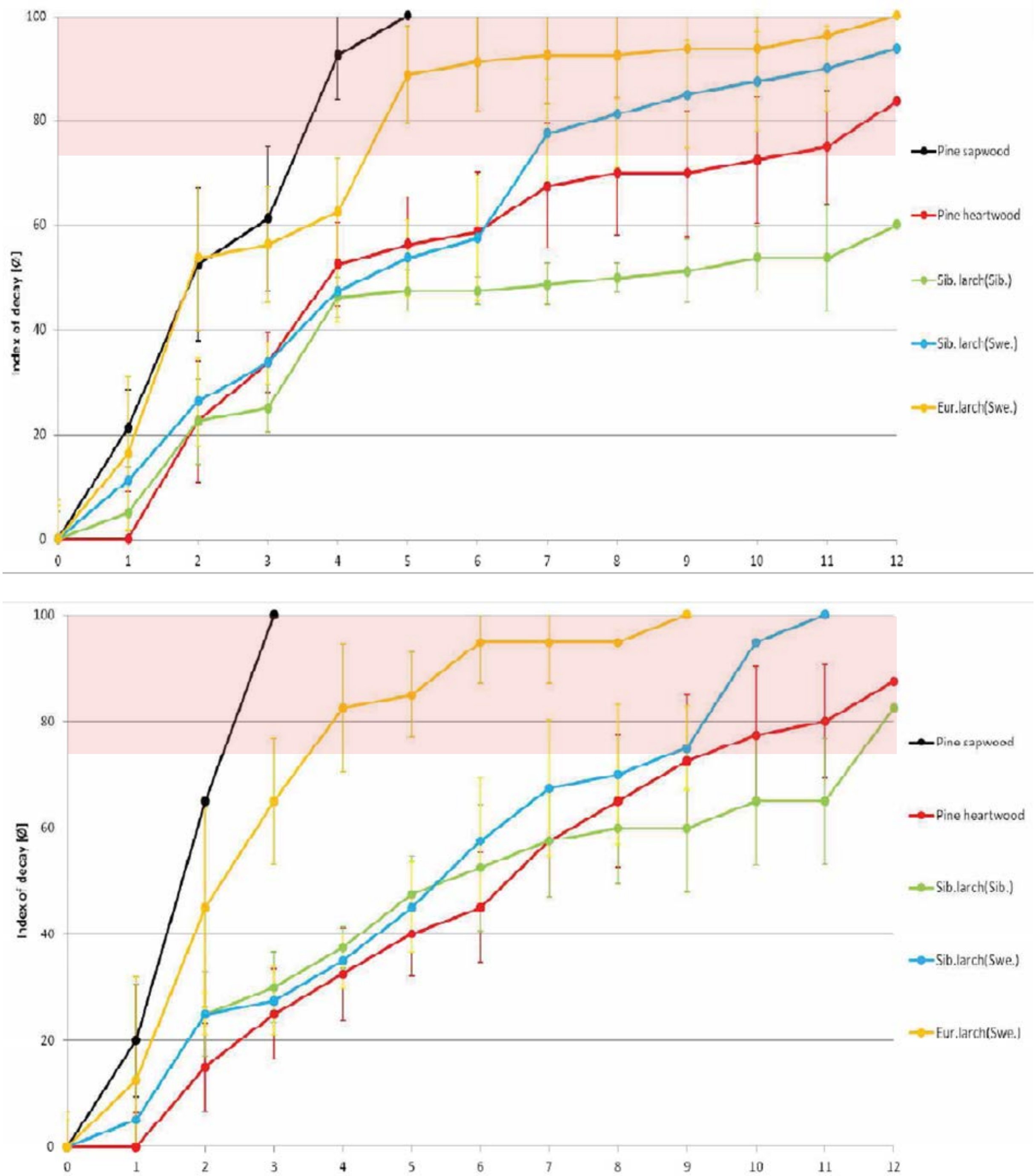


Figure 9 **Rot index (or index of decay)for test samples in the ground in accordance with EN 252 from field trials in Simlångsdalen (top) and Ultuna (bottom), where the heartwood (red) and sapwood (black) from pine compared two types of larch (Larix sibirica, Larix decidua) from two plant locations Larix sib. from Siberia (green) and from Sweden (blue) and Larix dec. from Sweden (yellow).**
(Reference: Pockrandt 2012)

The field trial results found in Figure 9 are from the same year (time series) but from two different locations with different weather and soils, etc. We find that the field trials geographical placement and conditions may result in differences. However, the individual dispersion in the wood-materials is also a reason for variations. An evaluation of this particular study demonstrates a difference between Siberian larch from Siberia and from Sweden, which in simplification corresponds to a difference in the technical service life (as defined here) of 2 or more than 5 years! Regardless of location the Siberian larch from Siberia shows the best resistance with a service life of about 12 years.

Furthermore, Swedish field trails are shown in Figure 10 (Larsson Brelid et al. 2011) with larch from Denmark and test pieces with size of 22 x 95 mm (the report does not indicate what kind of larch).

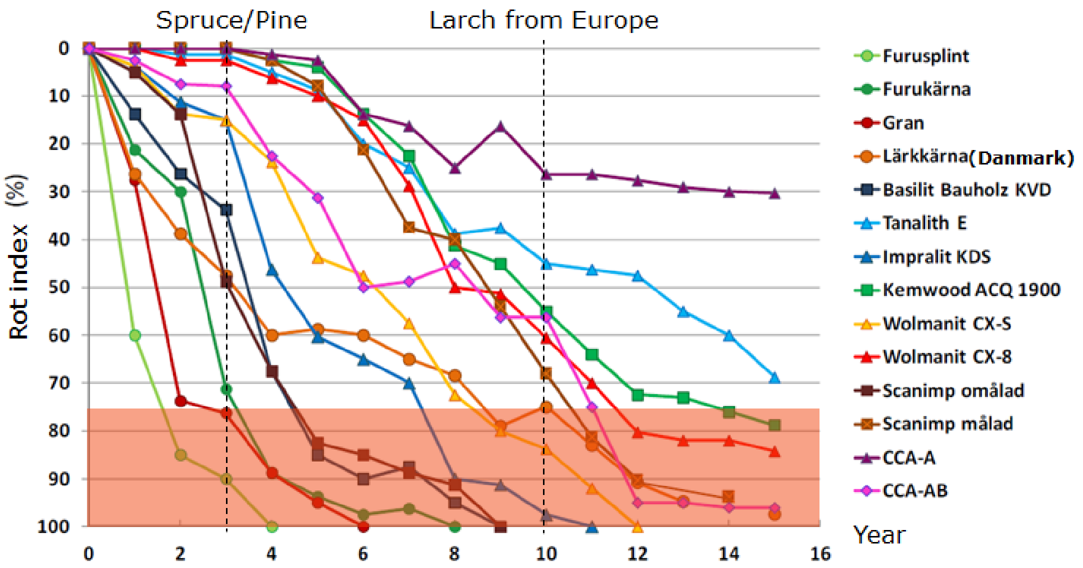


Figure 10 **Rot index for sample boards 22x95 mm for various wood preservatives in ground contact impregnated according to class AB (i.e. not intended for ground contact) and different types of wood in ground exposure from a Swedish field trail evaluation. The dashed lines are examples of estimated technical service life extension, namely when a rot index of 75 % has been achieved.**
(Reference: Larsson Brelid et. al 2011)
Keys for translation**: Omålad=unpainted, furusplint=pine sapwood, furukärna=pine heartwood, gran=spruce, lärkkärna=larch heartwood and the remaining tests samples are pine impregnated with the named wood preservatives.**

The field trails which were assessed after 15 years exposure focused on the effectiveness of NTR AB-medium in ground contact (NTR AB class has a lower uptake than NTR A). We use this survey as a basis for setting a technical service life on a larch fence post. The dashed lines in Figure 10 show the estimated technical service life of pine and spruce core of about 3 years and about 10 years for heartwood larch of Danish origin.

The referenced test pieces used in this study have 100% heartwood. However, this is not matched by the posts used in practice. On the other hand, a post in comparison with a rail holds a more extensively exposed ground contacting surface. In subsequent calculations regarding ground contacting posts from Siberian larch cultivated in Siberia a technical average service life of 12 years was applied. This value represents a post containing a high percentage of heartwood. Moreover, a relatively favorable assumption applies, which is why the 8 years' service life is used for sensitivity assessments. Furthermore, other types of larch are likely to have a lower resistance.

Robinia (Robinia pseudoacacia)

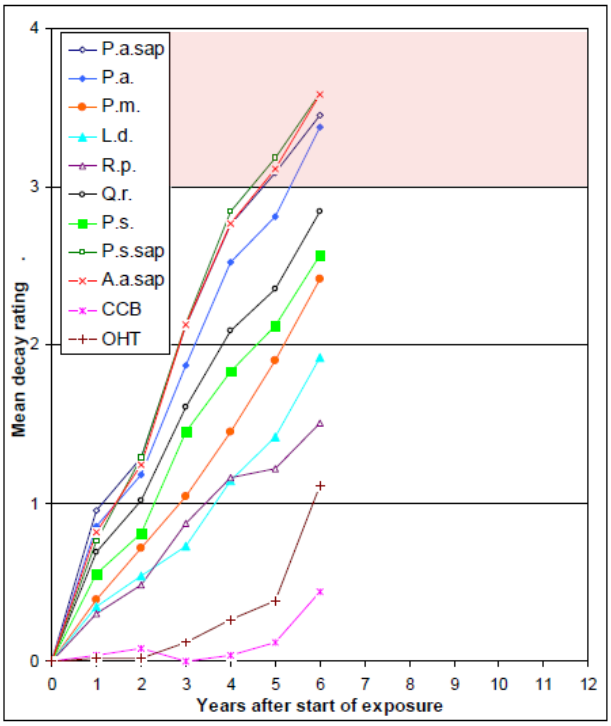
Robinia pseudoacacia (black locust or false Acazia) is according to EN 350-2 classed with a natural resistance of 1-2 (very durable to durable). However, the classification is applied to slow growing timber (i.e. no plantation wood).

When cultivating robinia for posts the tree is permitted to grow until the heartwood has matured. A technique for production of posts is to turn down small logs leaving only the heartwood. An easier way to obtain a post is to use a larger heartwood log and from that log cleave the substances suitable for (split) posts (see Figure 11).

Figure 11 Squared posts from cleaven robinia wood stacked for shipment to customers. (Photo: FX Hardy OctoWood France, 2013)

A European supplier of robinia indicates that the raw material and the posts primarily come from different Eastern European countries; Bulgaria, Romania, Moldova and Hungary but also from France (Hardy 2013). The same supplier indicates that an average service life in France is 8 to 10 years. A New Zealand evaluation classified Robinia with the highest resistance and durability (Class 1) and with a resistance of over 25 year in construction purposes (refers to 100% heartwood and above ground). The same article states that when used in ground contact such as for fence post, it has a shorter service life (WNFR 1997).

Robinia was, in Swedish/Norwegian field trials in accordance with EN 252, classified with the durability class of 2-3 (durable to moderately durable). After 3 years of field trials in Borås, Simlångsdalen and Ås (Norway), robinia achieved a rot index of 28, 38 and 30 %, respectively. In a comparison between robinia values of resistance (above) and larch values (from field trials in Simlångsdalen and Ultuna, see Figure 9) we find that robinia has a lower resistance than larch, i.e. in this case, robinia has a slightly higher degradation. However, it is uncertain whether this study actually used robinia exclusively from heartwood.



Description of material	Latin name	Abbrev.
Norway spruce sapwood	*Picea abies Karst.*	P.a. sap
Norway spruce heartwood	*Picea abies Karst.*	P.a.
Douglas fir heartwood	*Pseudotsuga menziesii* Franco	P.m.
Larch heartwood	*Larix decidua* Mill./ *Larix jap.*	L.d.
Black locust heartwood	*Robinia pseudoacacia* L.	R.p.
English oak heartwood	*Quercus robur* L.	Q.r.
Scots pine heartwood	*Pinus sylvestris* L.	P.s.
Scots pine sapwood	*Pinus sylvestris* L.	P.s. sap
White fir mostly sapwood	*Abies alba* Mill	A.a. sap
CCB 6 kg/m³ Scots pine sapwood (steeping for 2,5 hours in 5% Impralit-CKB-solution)	*Pinus sylvestris* L.	CCB
Oil Heat Treatment of Norway spruce (>200°C temp., minimum oil retention)	*Picea abies* Karst..	OHT

Figure 12 The mean durability in ground contact for Robinia etc. measured according with EN 252, based on 150 test samples of (500 x 50 x 25 mm) per wood type, as well as five German field trials (a rating of 1 corresponds to a rot index of 25 %, a rating of 2 a rot index of 50 %, a rating of 3 a rot index of 75 % and a rating of 4 a rot index of 100 %).
(Reference: Rapp et al 2006)

The resistance for different types of wood is reported in extensive German field trials as per EN 252, which includes five locations (see Figure 12). This study shows that European larch and robinia has a similar degradation pattern. However, the performance of robinia is superior to that of the European larch. In comparing larch data to that of pine heartwood (Pinus sylvestris) we find that larch has a superior resistance. In an evaluation of this study, after 6 years exposure we find that pine heartwood is inferior in comparison to robinia (termed Rp in the figure) and larch (termed Ld in the figure).

To carry out the calculations a technical average service life of 12 years is applied to robinia, which then is assumed to mainly consist of heartwood. An alternative service life of 8 years is set for a robinia post with a lower proportion of heartwood to illustrate that value is used in sensitivity calculations.

Other assumption for LCA calculations

Below is information compiled that will have significant impact on the LCA calculations.

Plastic

Plastic posts are made from polyethylene (PE) pre-consumer plastic waste. In this case it means that the plastic consists of product manufacturing waste (or the equivalent origin). In an LCA a distinction is made between post-consumer recycled material that comes from scrapped products that is recycled (end-of life products), and pre-consumer waste that is processed or manufacturing waste that is never used for any product. A product that uses pre-consumer waste will have to carry the environmental impact upstream to produce the plastic raw material. In an LCA the merit of using production waste is therefore relatively limited, following the allocation rules in EN15804 or the main principle for allocation in LCA (i.e. ISO14044).

The case study assessment assumes that recycled plastic is allocated with a reduced transport distance in contrast with buying the primary raw material. An option for future development, which is appealing from an environmental perspective, is to use post-consumer recycled plastic from discarded products, provided that the technical requirements are met.

The LCA data used for plastic post comes from Plastic Europe and is among other alternatives available in the EU funded LCA database ELCD. These data are from 1999, which is relatively old. However, they are currently the best data we have been able to identify. This data has been compared with other sources and they are found to be on the same level as the data from Plastics Europe. Furthermore, as the production process is unchanged, we can assume that the data used is also viewed as representative for the present day production. Generally we found that the contribution to the overall environmental impact from plastic post transportations is relative small, and by no means as significant as for the timber alternative. However, the production of plastic raw materials account for the dominant share of environmental impacts, such as climate change, acidification, eutrophication, and more. Manufacturing statistics for fence posts are based on data received from a manufacturer of plastic pipes with accessories. These manufacturing data are of minor importance in relation to the total production, where we found that the plastic raw materials dominate. This is why the data used are assumed as representative and useful for the present comparison.

NTR A treated pine

The generic data for pine is based on Swedish average values. The LCA calculations are based on pine treated with a copper agent. LCA information regarding the production of the wood preservative Wolmanit CX-8 has been obtained from BASF (2013). Wolmanit CX-8 is at present the most used copper agent in Sweden. These LCA calculations assume that 70% of the copper is composed of post-consumer recycled materials and reflect the current manufacturing situation. In a comparison we find that a high percentage of recycled copper provides a better environmental performance than using primary raw materials. Data regarding preservative uptake comply with the NTR class A requirements. Furthermore, we assume that data regarding preservatives agents are market representative for the most common NTR Class A products, in other words, are to be regarded as a general value for all copper-based wood preservatives.

Three different manufacturers (Derome, OctoWood/Bräcke posts, Fyrås Wood & Impregnation) provided information on production are various levels of production capacity. Information regarding the impregnation stage has also been compared with data from three additional manufacturers (Martinson Trä, SCA Timber and Ingarps Wood Impregnation). Thus this data facilitates a comparative evaluation of the differences between the various manufacturers. The differences between the compared manufacturers are of minor importance, as long as the same type of fuel and industrial drying process is used (i.e. an artificial wood drying).

The transport from the forest to the impregnation plants are set to be 120 km on average as opposed to the common sawmill where an average distance of 80 km is considered to be reasonable. The longer distances account for that subcontracting occurs, which requires further transportation. When posts are included in the production, raw materials are assumed to have a larger catchment area than usual lumber. The transportation distance by road from impregnation plants to the site, is assumed to be approximately 300 km, whether it goes directly there or via a timber yard, etc. It is assumed that when the posts, after service, are sent via an 80 km transport distance to a district heating plant (with a permit to burn treated wood). All trucking is conservatively estimated with a blank return.

Siberian larch

Specific information for Russian forestry, sawing and processing is not available and to fill these gaps the following assumptions are made:

- The same data used for Swedish forestry is also used for Russian larch forestry
- The same data per m^3 for the manufacturing of treated wood of pine is used for a Siberian sawmill. The drying process is not assumed to be as effective as in Sweden. However, a higher proportion of heartwood (with lower moisture content) is assumed to balance out the difference so that the need for thermal energy will be calculated at the same level per m^3. The electricity consumption per m^3 has been reduced to 2/3 in comparison to Swedish conditions.

The above information is based on the environmental impact per m^3. Consider also that the density of larch is higher (550 to 770 kg/m^3)[7] than for pine. Furthermore, there is a significant difference, as follows: 80 km from the forest to the sawmill by truck, 100 km by truck on average from various sawmills suppliers in Siberia to a central transhipment depot (probably Irkutsk), 5,500 km of railway from Irkutsk to St. Petersburg (applied 50 % electrified, 50 % diesel), 750 km boat from St Petersburg to Stockholm, 150 km transport to the site by truck and finally at 80 km from the district heating plant. The transport is a significant part of the overall environmental performance of Siberian larch. This is why assumptions regarding the forestry and sawmill portion is of lesser importance and also why these assumptions are considered as acceptable for the comparison.

Robinia

We do not have any specific information regarding forest management and further processing. In the absence of such information from the supplier the following assumptions are made:

- The same data used for Swedish forestry is also used for robinia forestry
- The same data per m^3 for the manufacturing of treated wood of pine is used for the treatment of robinia. In relation to the Swedish conditions the electricity consumption ratio has been reduced to 38%, bio-based thermal energy to 10%, and 23% increase in energy use for different manufacturing machines at the sawmill. Production is believed to largely be manually facilitated and dried by the sun and transport is weight based, which ultimately results in that the internal transport work counted per m^3 increases compared to pine. If the figures are given per kg instead of per m^3 this results in a reduction for all energy use, (including the internal transport-labour) for the manufacturing of robinia posts (which has a higher density than pine). The low use of thermal energy requires that all the wood will be naturally dried.

Transport data have been obtained from a supplier (Hardy 2013). The density of green wood is set at 1,100 kg/m^3 and 800 kg/m^3 for supply density. This supplier indicates that the former Central European countries accounts for 70% of production and 30% is produced in France. Trucks are used as the actual/effective transport option for imports to Sweden. The transports go from Central Europe to Rotterdam, where it is then shipped to various ports in Europe such as Stockholm. By using electrified trains running directly to Sweden the transport can be reduced. In the analysis this (improved) option is therefore used as follows; truck from post supplier in Bulgaria/Bucharest to Stockholm, corresponding as 2,800 km by train and 200 km by boat transportation, 150 km transportation to site by truck and finally at 80 km to a district heating plant. Nonetheless, transport is a significant part of the overall environmental performance of Robinia. This is

[7] http://www.moelven.com/se/Produkter-och-tjanster/Produktsidor-Wood-AB/Produktsidor-Fasad--Utemiljo/Sibirisk-lark/

the reason why assumptions made regarding forest management and sawmills are of less importance and are hence considered as acceptable for the case study comparison.

Results

The results of the LCA calculations are based on a number of conditions and assumptions where the applied durability data reported in Table 2 function as a base scenario (most probable outcome) as well as a sensitivity analysis. The sensitivity analysis indicates that we receive varied results with regard to certain uncertain assumptions. Inadequate inventory data have been used in describing the environmental impact of LCA with regard to the production of Siberian larch posts and robinia posts. However, we find that it is the transportation labour, which significantly contributes to the environmental performance, thus this is why said data nevertheless are deemed to provide a reasonable and an adequate comparison.

Table 2 **Conceptual data for service life of the analysed post materials and alternative service life used for the sensitivity analysis.**

Materials	Basic scenario for practical service life, years	Sensitivity analysis, years	Notes
Pine treated with NTR A	20	20	Domestic wood. The field data on posts and others in accordance with EN 252
Siberian larch	12	8	From Siberia. The field data for samples in accordance with EN 252
Robinia (false Acacia)	12	8	From Central Europa. The field data for samples in accordance with EN 252
Recycled polyethylene (PE)	20	30	No published field-data identified

At first we purely analyse the climate impact of the various alternatives. The first interesting comparison is the environmental impact of manufacturing the various posts (without and with electric wire), without regard to the varying service life, but with residual environmental impact over its life cycle, see Figure 13. This comparison is done based on the so-called *declared unit* and <u>should not</u> be used for product comparison (i.e. comparative assertion). It is only used here for analysis with regard to the contribution by the electrical wire in relation to the total.

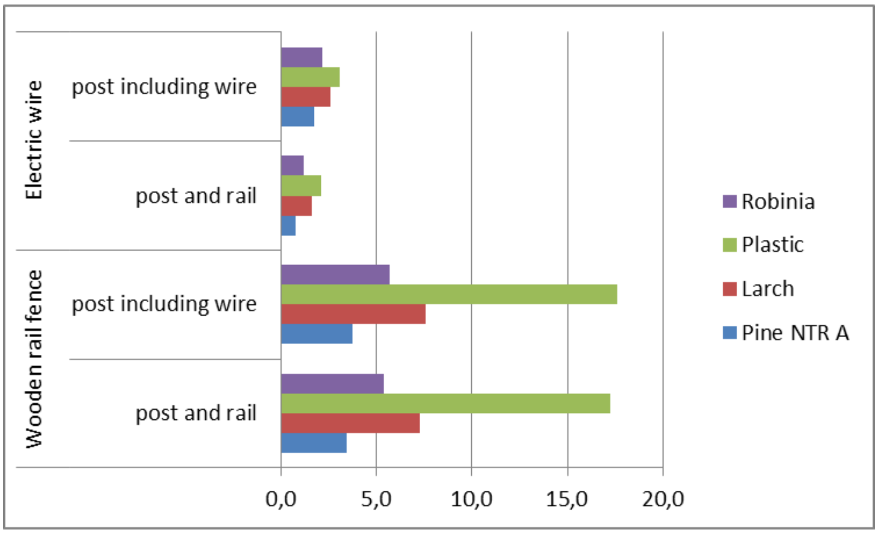


Figure 13 Contributions to climate change, kg CO_2e, according to the declared unit, i.e. during the life cycle per fence section for alternative fence materials where the center to center distance between the posts in each section is 2 and 4 meters. The provided data include respective exclude the contribution from the electric wire to clearly show the contribution of this impact. Furthermore, irrespective of materials, the same amount of electric wire is used with two wires for horse rail fences and 3 wires for electric wire fences.

The figure above, which is based on the declared unit, does not account for the diverse service life predictions of the alternative options. We note that the electric wire contribution is more significant for wire fences than for the rail fencing. In view of wire fencing, using posts and wires, it is interesting to consider how its function may be resolved by using alternative means or using alternative materials for the electric wire (like electric tape or rope). According to the declared unit the climate impact contribution of the two NTR A treated alternatives are low in comparison with the plastic alternative, which has the highest climate impact contribution of the three alternatives.

In the next step we take into account the service life prediction to facilitate a more accurate comparison (see Table 2), and the *functional unit* is now used as the base for the calculations. The service life for an electrical wire is set at 15 years, and it is assumed that it will be replaced regardless of when the posts are replaced (i.e., the fence wire is replaced regardless of when the posts are replaced). A more sophisticated calculation method would be to combine the fixed replacement intervals for fences and electrical wires. However, this option is viewed to result in further errors due to the uncertainties in assumed life expectancies, which is why this option is not applied.

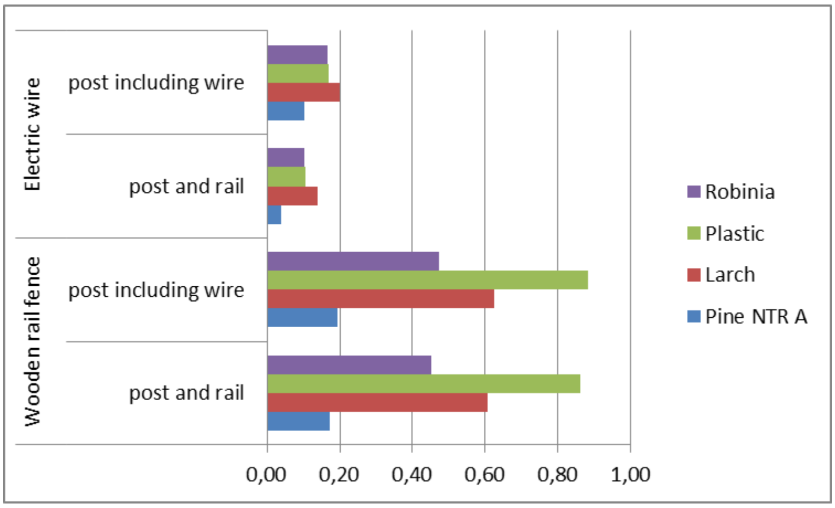


Figure 14 Contributions to climate change, kg CO_2e, during an average life cycle per section and per annum for alternative horse fence materials, where the center to center distance between the posts in each section is 2 and 4 meters. The provided data include respective exclude the contribution from the electric wire to clearly show the contribution impact. Furthermore, irrespective of materials the same amount of electric wire is used with two wires for horse rail fences and 3 wires for electric wire fences. The following service life data are applied; NTR A 20 years, plastic 20 years, larch 12 years and Robinia 12 years.

In Figure 1, the different alternatives supply the same function, that is, an equivalent service life and technical performance. During analysis of contribution to climate impact we find that the NTR A option works best for horse fences either of wire or wooden rail design. For wire fence, larch is the option with the highest climate impact contribution, plastic and robinia has a very similar performance. With regard to horse rail fences we found that NTR A has the lowest contribution to climate change, followed by robinia, after which larch and plastic follow as the higher environmental impact options found in this study.

So far, we have only analysed the impact on the climate change. Figure 15 and Figure 16 show the relative contribution of all analysed impact categories. The same information is presented in the appendix as absolute values. We have found that contributions to different environmental impact categories do not differ greatly, and they seem to have the same "pattern" as the climate impact of the alternatives included in this study. In other words, in our study's climate impact result renders a good picture which is applicable for all environmental impact categories.

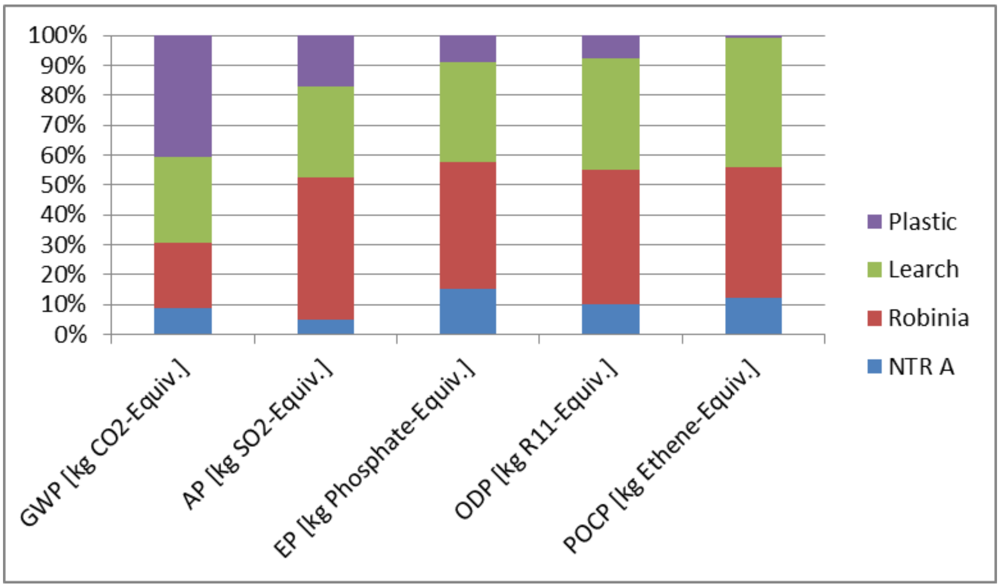


Figure 15 The relative contribution of different environmental categories from different horse fencing material options during an average life cycle per section and per annum according to the baseline scenario[8]
Abbreviations: GWP - climate impact, AP - acidification, EP- eutrophication; POCP climate impact.

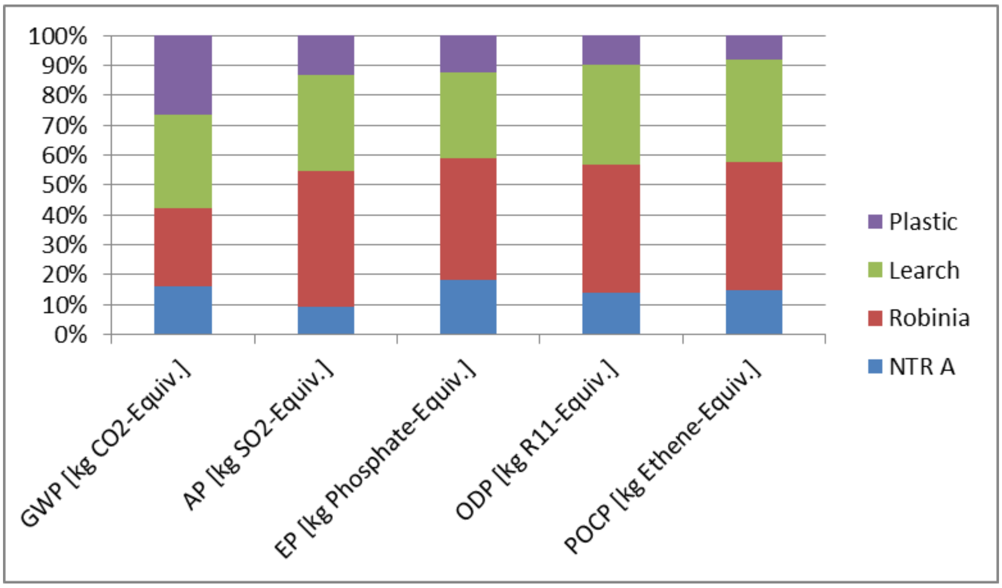
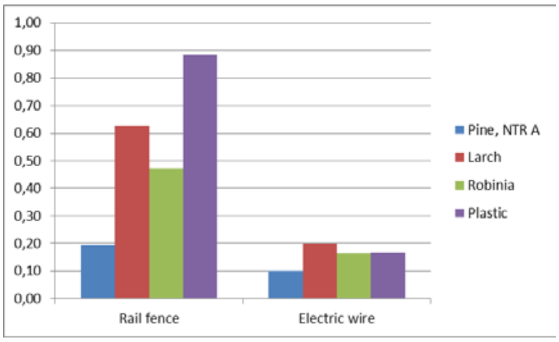


Figure 16 The relative contribution of different environmental categories from different options of horse fencing materials during an average life cycle per section and per annum according to the baseline scenario[7]
Abbreviations: GWP - climate impact, AP - acidification, EP- eutrophication; POCP climate impact.

[8] The following service lives are used for the baseline scenario; NTR A 20 years, plastic 20 years, larch 12 years and robinia 12 years.

The service life for plastic posts is uncertain. The same applies to a certain degree regarding the choice of service life prediction for larch and robinia that are also viewed to hold certain uncertainties. The main scenario contribution to climate impact and the sensitivity analysis result can be found in Figure 17. Thus indicating what alternative service life has for significance in the comparison.



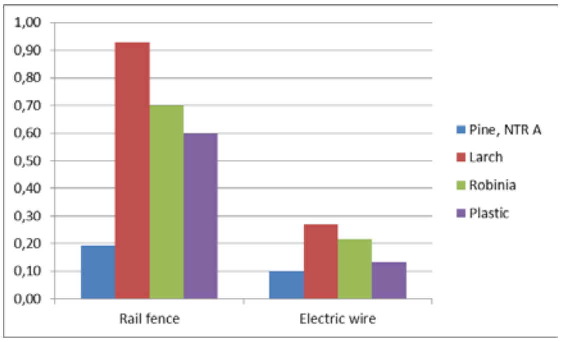


Figure 17 Contributions to climate change, kg CO_2e, during an average life cycle per section and per annum for alternative horse fence materials, where the center distance between the posts in each section is 2 and 4 meters. The provided data include (left figure) respective exclude the contribution from the electric wire to clearly show the contribution impact. Furthermore, irrespective of materials the same amount of electric wire is used with two wires for horse rail fences and 3 wires for horse electric wire fences. The baseline service life scenarios in the figure on the left are for NTR A 20 years, plastic 20 years, larch 12 years and for robinia 12 years. The figure on the right presents the results from the sensitivity analysis in which the following service lives have been applied: NTR A 20 years, plastic 30 years, larch 8 years and Robinia 8 years.

Even allowing for this uncertainty, regarding service life prediction data, the NTR class A is the alternative which works best. The other alternatives face further uncertainties and their results rather depend on assumptions about service life. The plastic rail fence with a service life of 30 years is a comparable alternative to robinia and larch with a lifespan of 12 years. However, if the robinia service life is restricted to 8 years then plastic becomes the preferred alternative in terms of the climate impact contribution. Even when considering an extended service life for horse rail fencing we find that the option of plastic is viewed as superior to robinia and larch, but not superior to pine impregnated according to NTR A and copper preservative.

The study's result, when considering different types of fences, generalise that; a larger amount of fencing mesh or wire used has a greater contribution on the fence total environmental impact and the choice of post will have a relative lesser impact. However, the choice of the post is still of importance and the post alternatives are important. If only a minor part of the fence consist of fencing wire (steel) as in the rail fence case, then we find that the choice of post material has a larger part in determining the overall environmental impact. Irrespective of any fence or post choices, it is reasonable to assume that the pine NTR class A posts have the lowest environmental impact. In considering the ranking between the other options we find that it depends on the assumed service life predictions.

Conclusions and further development

The selection of the best wood for fence posts and fences strongly depend on its durability and the proximity of forest raw materials. The naturally resistant wood species analysed as options in this study are robinia (black locust) and Siberian larch. The robinia and Siberian larch are both long distant materials imported to Sweden, which stress these options negatively in an environment context, due to their relatively high transport mileage and its significant contribution. However, the two alternatives become more competitive when found in other neighbouring countries, or in countries which have a domestic production of naturally durable wood.

Durability and service life prediction are other important factors to be considered, as well as the lack of experience data for field posts, for all alternatives apart from NTR A. The plastic alternative is particularly sensitive to this. When compared to the options above, the plastic alternative with a service life of 30 years is an interesting option, if the naturally durable materials have a service life of 8 years.

When it comes to the durability for timber in ground contact (e.g. based on EN 252), there are currently no methods that allow for the generalisation of the durability data from various field experiments, so it can to be used for a generic normalised benchmark. Distinctions during the test's time series could be to make corrections for; shifting soil conditions, weather and moisture exposure and a natural and physical scale factor between the standard sample and the actual product. The posts/structures physical scaling factors affect the resistance in practice and determine the possibility for achieving a high proportion of heartwood. In order to rationally assess a technical service life of a post, to be used for a wire fence or rail fence, a simplification has been made in the report where a rot index of 75 % according to EN 252, was equated to be the technical service life where the post still fulfils its performance as a post. This study has not identified any such widely accepted methods concerning this aspect in the literature.

The NTR Class A treated pine posts and horse fences have the best environmental performance irrespectively of the implemented service life and with regard to the analysed environmental impact categories. The horse rail fences show the greatest difference between competing materials. This comparison applies to the environmental impact categories analysed that is in accordance with EN 15804. At present we lack a widely accepted impact assessment methodology in LCA for human toxicity and ecological toxicity, and therefore, this study does not include these aspects in the LCA result and following comparison. This prevents the possibility for a complete environmental comparison. Currently we also lack methods that consider the use of resources from renewable resource contributions, which precludes a completely fair comparison with the plastic option. On the other hand, the contribution from the use of renewable resources should be low, which thus should encourage the use of non-fossil resources.

The study has applied and analysed the mandatory environmental impact categories, according to EN 15804, except for the use of resources. In other words, in accordance with the assumed optional national implementation in accordance to CPD. EN 15804 is a so-called core PCR, and a standard that governs how an environmental product declaration shall be made for all construction products in the European market. At present, we do not know which countries will implement the requirements of reporting LCA performance-based information for products in the context of an EPD, public procurement etc. Even though we do not assume that this will happen in a near future, the environmental classification system for different construction works already comply with EN 15804, why this standard already have an impact on how an LCA must be calculated and reported.

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Appendix: LCA-results

Compilation of LCA results divided into stages, different environmental impact categories and service life.

Horse fence – baseline scenario

	Pine NTR A 20 years					**Robinia** 12 years				
	Total	Product stage	Construction	Use	End of life	Total	Product stage	Construction	Use	End of life
GWP [kg CO_2-Equiv.]	0.19	0.15	0.04	0.0E+00	0.01	0.47	0.35	0.08	0.0E+00	0.04
AP [kg SO_2-Equiv.]	0.00090	0.00068	0.00017	0.0E+00	0.00005	0.00230	0.00190	0.00040	0.0E+00	0.00022
EP [kg Phosphate-Equiv.]	0.00056	0.00049	0.00005	0.0E+00	0.00001	0.00101	0.00089	0.00012	0.0E+00	0.00007
ODP [kg R11-Equiv.]	1.6E-08	9.0E-09	5.8E-09	0.0E+00	1.5E-09	4.2E-08	2.8E-08	1.4E-08	0.0E+00	7.2E-09
POCP [kg Ethene-Equiv.]	1.8E-04	1.4E-04	2.8E-05	0.0E+00	7.5E-06	3.3E-04	2.6E-04	6.6E-05	0.0E+00	3.5E-05

	Larch 12 years					**Plastic** 20 years				
	Total	Product stage	Construction	Use	End of life	Total	Product stage	Construction	Use	End of life
GWP [kg CO_2-Equiv.]	0.63	0.57	0.04	0.00	0.02	0.88	0.87	0.01	0.00	0.00
AP [kg SO_2-Equiv.]	0.00545	0.00516	0.00019	0.00000	0.00010	0.00301	0.00294	0.00007	0.00000	0.00002
EP [kg Phosphate-Equiv.]	0.00123	0.00114	0.00006	0.00000	0.00003	0.00033	0.00031	0.00002	0.00000	0.00001
ODP [kg R11-Equiv.]	6.0E-08	5.0E-08	6.4E-09	0.0E+00	3.4E-09	1.2E-08	9.9E-09	2.3E-09	0.0E+00	6.2E-10
POCP [kg Ethene-Equiv.]	6.4E-04	5.9E-04	3.1E-05	0.0E+00	1.7E-05	1.4E-05	1.4E-05	2.3E-09	0.0E+00	6.2E-10

Fences – baseline scenario

	Pine NTR A 20 years					Robinia 12 years				
	Total	Product stage	Construction	Use	End of life	Total	Product stage	Construction	Use	End of life
GWP [kg CO_2-Equiv.]	0.10	0.09	0.01	0.0E+00	0.00	0.17	0.14	0.02	0.0E+00	0.01
AP [kg SO_2-Equiv.]	0.00	0.00	0.00	0.0E+00	0.00	0.00	0.00	0.00	0.0E+00	0.00
EP [kg Phosphate-Equiv.]	0.000255	0.000240	0.000012	0.0E+00	0.000003	0.000358	0.000330	0.000028	0.0E+00	0.000015
ODP [kg R11-Equiv.]	7.1E-09	5.4E-09	1.3E-09	0.0E+00	3.5E-10	1.3E-08	9.7E-09	3.1E-09	0.0E+00	1.6E-09
POCP [kg Ethene-Equiv.]	8.0E-05	7.2E-05	6.4E-06	0.0E+00	1.7E-06	1.1E-04	9.8E-05	1.5E-05	0.0E+00	8.0E-06

	Larch 12 years					Plastic 20 years				
	Total	Product stage	Construction	Use	End of life	Total	Product stage	Construction	Use	End of life
GWP [kg CO_2-Equiv.]	0.20	0.19	0.01	0.00	0.00	0.17	0.17	0.00	0.00	0.00
AP [kg SO_2-Equiv.]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
EP [kg Phosphate-Equiv.]	0.000407	0.000386	0.000013	0.000000	0.000007	0.000172	0.000170	0.000003	0.000000	0.000000
ODP [kg R11-Equiv.]	1.7E-08	1.5E-08	1.5E-09	0.0E+00	7.8E-10	5.0E-09	4.7E-09	2.8E-10	0.0E+00	7.1E-13
POCP [kg Ethene-Equiv.]	1.8E-04	1.7E-04	7.1E-06	0.0E+00	3.8E-06	4.2E-05	4.2E-05	2.8E-10	0.0E+00	7.1E-13

Horse fence – sensitivity analysis with alternate service life

	Pine NTR A 20 years					Robinia 8 years				
	Total	Product stage	Construction	Use	End of life	Total	Product stage	Construction	Use	End of life
GWP [kg CO_2-Equiv.]	0.19	0.15	0.04	0.0E+00	0.01	0.70	0.51	0.12	0.0E+00	0.07
AP [kg SO_2-Equiv.]	0.00090	0.00068	0.00017	0.0E+00	0.00005	0.00341	0.00281	0.00061	0.0E+00	0.00032
EP [kg Phosphate-Equiv.]	0.00056	0.00049	0.00005	0.0E+00	0.00001	0.00150	0.00131	0.00019	0.0E+00	0.00010
ODP [kg R11-Equiv.]	1.6E-08	9.0E-09	5.8E-09	0.0E+00	1.5E-09	6.2E-08	4.1E-08	2.0E-08	0.0E+00	1.1E-08
POCP [kg Ethene-Equiv.]	1.8E-04	1.4E-04	2.8E-05	0.0E+00	7.5E-06	4.8E-04	3.8E-04	9.9E-05	0.0E+00	5.3E-05

	Larch 8 years					Plastic 30 years				
	Total	Product stage	Construction	Use	End of life	Total	Product stage	Construction	Use	End of life
GWP [kg CO_2-Equiv.]	0.93	0.84	0.06	0.00	0.03	0.60	0.58	0.01	0.00	0.00
AP [kg SO_2-Equiv.]	0.00814	0.00770	0.00029	0.00000	0.00015	0.00203	0.00199	0.00005	0.00000	0.00001
EP [kg Phosphate-Equiv.]	0.00182	0.00168	0.00009	0.00000	0.00005	0.00023	0.00022	0.00001	0.00000	0.00000
ODP [kg R11-Equiv.]	8.9E-08	7.5E-08	9.6E-09	0.0E+00	5.1E-09	8.5E-09	7.0E-09	1.5E-09	0.0E+00	4.1E-10
POCP [kg Ethene-Equiv.]	9.5E-04	8.8E-04	4.7E-05	0.0E+00	2.5E-05	1.4E-05	1.4E-05	1.5E-09	0.0E+00	4.1E-10

Fences - sensitivity analysis with alternate service life

	Pine NTR A 20 years					Robinia 8 years				
	Total	Product stage	Construction	Use	End of life	Total	Product stage	Construction	Use	End of life
GWP [kg CO_2-Equiv.]	0.10	0.09	0.01	0.0E+00	0.00	0.22	0.17	0.03	0.0E+00	0.02
AP [kg SO_2-Equiv.]	0.00	0.00	0.00	0.0E+00	0.00	0.00	0.00	0.00	0.0E+00	0.00
EP [kg Phosphate-Equiv.]	0.000255	0.000240	0.000012	0.0E+00	0.000003	0.000468	0.000426	0.000043	0.0E+00	0.000023
ODP [kg R11-Equiv.]	7.1E-09	5.4E-09	1.3E-09	0.0E+00	3.5E-10	1.7E-08	1.3E-08	4.6E-09	0.0E+00	2.5E-09
POCP [kg Ethene-Equiv.]	8.0E-05	7.2E-05	6.4E-06	0.0E+00	1.7E-06	1.5E-04	1.3E-04	2.3E-05	0.0E+00	1.2E-05

	Larch 8 years					Plastic 30 years				
	Total	Product stage	Construction	Use	End of life	Total	Product stage	Construction	Use	End of life
GWP [kg CO_2-Equiv.]	0.27	0.25	0.01	0.00	0.01	0.13	0.13	0.00	0.00	0.00
AP [kg SO_2-Equiv.]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
EP [kg Phosphate-Equiv.]	0.000541	0.000510	0.000020	0.000000	0.000011	0.000161	0.000159	0.000002	0.000000	0.000000
ODP [kg R11-Equiv.]	2.4E-08	2.0E-08	2.2E-09	0.0E+00	1.2E-09	4.5E-09	4.3E-09	1.9E-10	0.0E+00	4.7E-13
POCP [kg Ethene-Equiv.]	2.6E-04	2.4E-04	1.1E-05	0.0E+00	5.7E-06	4.2E-05	4.2E-05	1.9E-10	0.0E+00	4.7E-13