REPORT

LCA for treated timber according to BS 8417 and alternative materials – Horse, highway, and domestic fence

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Report Summary

Project title

Alternative methods for LCA toxicity assessment - applied according to BS 8417 UC 4 impregnated wood

Project sponsor

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Title and subtitle of the report

LCA for treated timber according to BS 8417 and alternative materials
– Horse, highway and domestic fence

Summary

The use of chemicals in construction products and risk mitigation is an area that is often attached to material selection. 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 by the Biocides Products Regulation and requires a national approval from the UK's Health and Safety Executive (HSE). Concerning the efficacy requirements, so far retention levels for the different wood preservatives have been stipulated by the manufacturer and given as a recommendation to the user. Currently a working group within the Wood Protection Association (WPA) is working on an independent system for data requirement and application procedure for the approval of wood preservatives.

This investigation presents a life cycle assessment (LCA) on pressure treated timber according to BS 8417 and using Wolmanit CX-10. The analysed product category in the case study are two fence designs including pressure treated timber and an alternative post and rail material of plastic, and untreated 'natural durable' wooden posts made of UK home grown European larch and Siberian larch (from Siberia).

The LCA methodology applied, including the environmental impact indicators, use the requirements prescribed by the Product Category Rules (PCR) for all construction products as defined in EN 15804. This so called Core PCR is used as guideline for environmental product declarations (EPD) and is linked to the construction products regulation (CPR). The purpose of this study is to evaluate how these requirements can be used and to evaluate the environmental performance, with respect to selected and mandatory impact indicators in the EPD.

Calculations showed that BS 8417 use class 4 treated timber, with a retention for 15 year service life and 30 year service life, has a better environmental performance, in comparison to 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 larch. These differences determine the relative ranking between the investigated Siberian larch and respective plastic fences. 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 renewable materials is not available. This impact category has therefore been excluded from the study, as it would render a comparison incomplete with respect to the plastic alternative. Consequently we find a need to develop better methods for 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 study, and here we also find a need for future developments.

Key words: BS 8417 HC 4, Construction product regulation, desired service life (DSL), domestic garden fence, durability, EN 15804, environmental assessment, European larch, fence posts, highway fences, horse fence, impregnated wood, treated wood, life cycle assessment (LCA), plastic, Siberian larch, Wolmanit CX-10.

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Context

For today's products apart from the price, aesthetics, and technical performance, ecological sustainability is now an aspect which is used for product evaluation. We find that a products environmental performance is important in assessing products and many consumers make an environmentally sound choice in relation to the options available. With this in mind, the survey have analysed two different fence designs namely a horse fence and a highway fence (with four rails and an electric wire for the horse fence) and a domestic garden fence (with three rails) 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, and 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, including fuel for energy and transports. A reoccurring question asked by consumers is the environmental difference between using a domestic treated timbers compared to a naturally durable wood which may be transported over long distances.

Red- and white wood is pressure treated for use in ground contact and to extend its service life. Impregnated wood in ground contact should be in compliance with the UC 4 class criteria to guarantee its durability. Alternatives to pressure treated pine are naturally more durable wood species like Siberian larch, 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. Domestic garden fencing and more utility fence design for horse or highway purpose were chosen for the case study. These designs are a commonly used form of fencing.

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 that this core PCR will lead to a precise and competitively neutral way to account and assess the environmental impact through a life cycle perspective. The EPDs will then be applicable in accordance with the construction product regulations, as basis for LCA on constructions works etc. The regulations now include that the environmental impact should be managed in a life cycle perspective using LCA based environmental declarations if this kind of performance is asked for. It is up to the national regulation to stipulate further mandatory use of LCA and EPD. The purpose of this study is to evaluate how these new rules can be used to analyse the alternative options, pertaining to the environmental performance of the selected environmental indicators mandatorily included in the construction product PCR EN 15804.

A common environmental assessment method for product based on LCA

Environmental performance under the CPR

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.

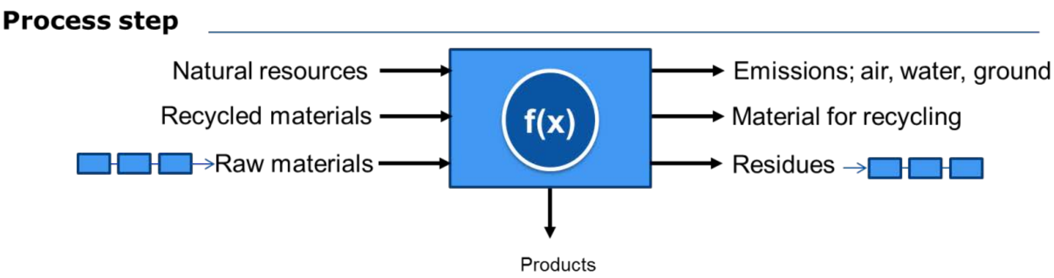


Figure 1 LCA is founded on an inventory of the flow in to and from all processes and to then divide them between the generated products.

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 analyze the products 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 *functional unit*, such as aesthetic ageing and deformations, which is not assumed critical for a fair comparison. Such 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. Ideally the PCR will bring about a similar EPD for a product inapproachable from whom that makes the LCA. The open LCA framework as described in ISO14044 will now be limited and result in a precise LCA.

PCR is one of the most fundamental demands in the international standard for EPDs (ISO 14025) (Figure 2). 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 for 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.

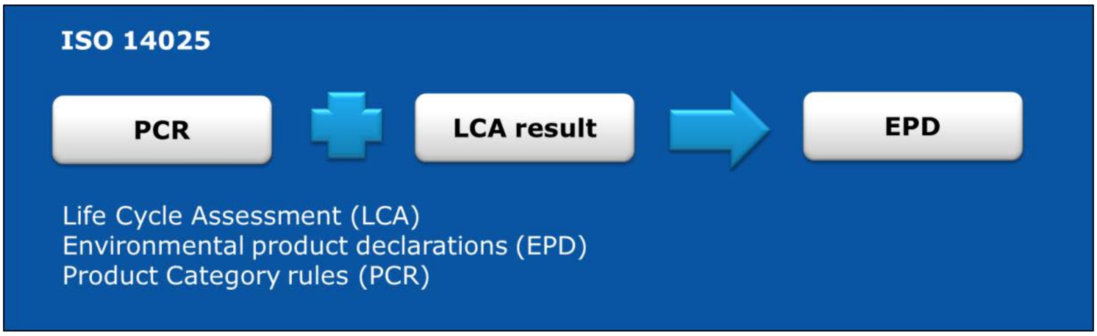


Figure 2 ISO requires the presence of a PCR that directs how to calculate and present an LCA result in an EPD.

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 same 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 as information modules. This modular construction allows that the LCA data for individual products can then be used as building blocks to calculate the environmental impact on all different kinds of construction works.

For a PCR (e.g. the standard EN 15804) it has be approved by a so-called program operator (Figure 3) to get operational, if the ISO14025 standard shall be followed. A number of program operator exists that follows EN 15804and the International EPD system has published an additional PCR for treated wood (Erlandsson 2009).

Concerning the internal European market, 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, and used within all Europe.

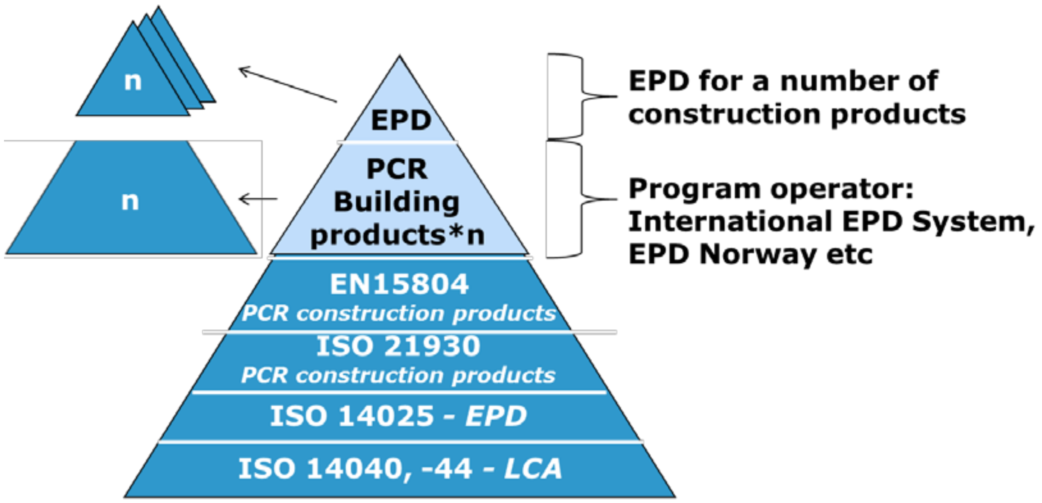


Figure 3 The hierarchical order of the standards that are needed for an EPD for construction products, where the program operator manages the PCR and publish the generated products EPDs.

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 leaving 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. Such LCA result does not need to cover a whole life cycle. EPDs of this format may be 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.

An accounting LCA compiles environmental stressors/loads that are associated with the products life cycle, without accounting for any indirect effects, as in an consequential LCA. A consequential LCA goes beyond the simple product burden perspective and includes 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 for public procurements etc. It is this robustness which has led to accounting (or attributional) LCA being used in most known EPD system or LCA based climate declarations program.

From inventory to environmental impact assessment

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

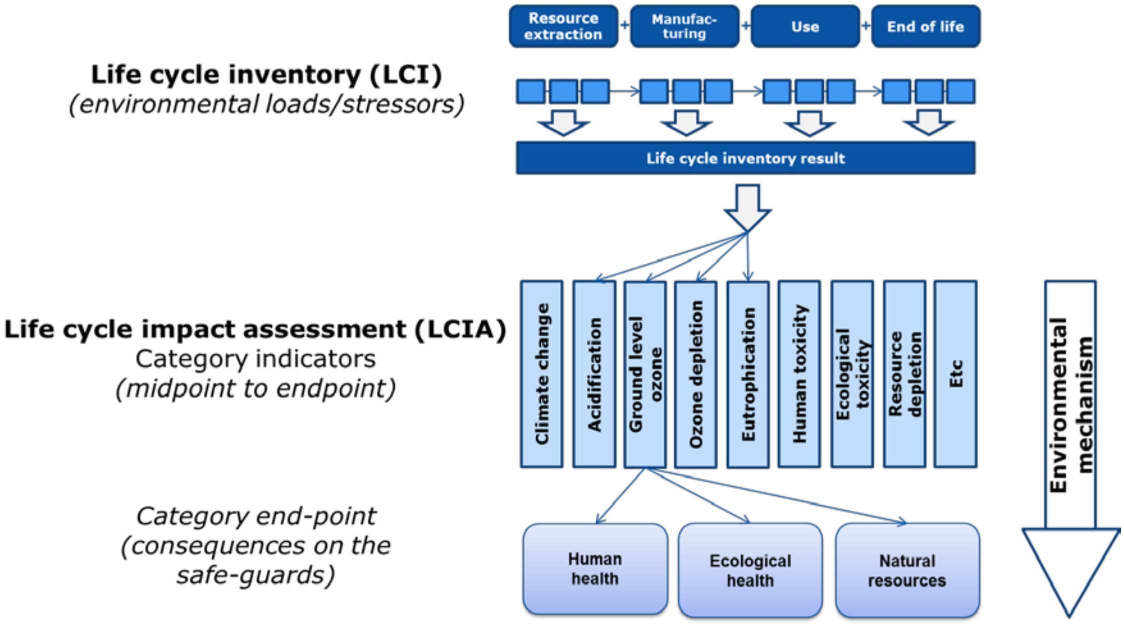


Figure 4 The two main stages of an LCA describe the progression from environmental loads to environmental impact i.e. the Inventory (LCI) and Environmental Impact Assessment (LCIA) stage.

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 profile for the whole life cycle can be established.

The LCA-method for the case study

The outlined LCA calculations follow the LCA methodology employed here follows the core PCR EN 15804. It is viewed of importance to use of the LCA result in an EPD that is divided into a number of information modules, which describe common parts of a products 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 impact of different processes are to be allocated to the manufactured products.

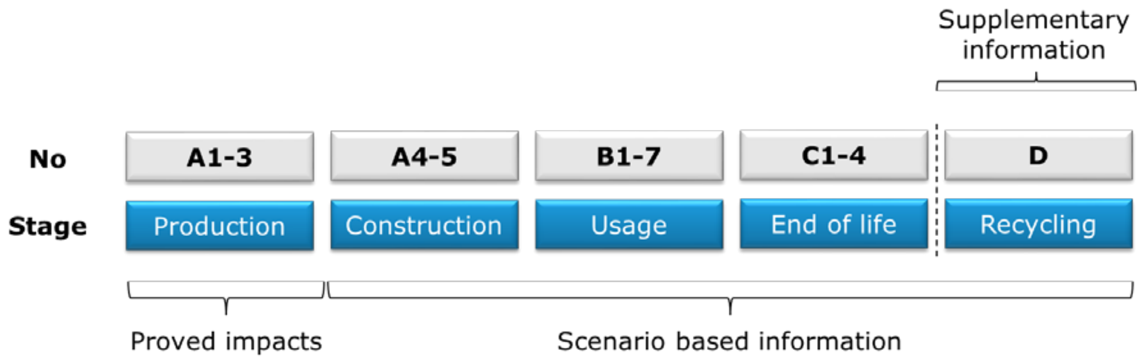


Figure 5 The construction material life cycle is divided into a number of stages, from A to C, in accordance with EN 15804 that represent LCA-information modules. A1-3 is the cradle-to-gate termed phase, which can be validated. Module D consists of additional information describing the consequences of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

To calculate and report the environmental impact as determined in the EN 15804 includes 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, since it does 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 such 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 include the scarcity of different resources. The currently utilized impact methods of resource depletion consider various mineral resources and the scarcity of fossil fuels and evaluated by its availability and consumption.

Furthermore, in EN 15804 there are currently no generally accepted methods on how to assess toxic emissions, as specified in the impact categories; human toxicity and ecological toxicity. A general acceptance of such methods 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. However, the Biocidal Products Directive (BPD) requires an 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 HSE. 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:

- ***Running meter*** - a running meter of a fence that includes the posts and rails. This definition allows different center-to-center (c.t.c.) distance between the two posts..
- ***Average per annum*** - the environmental impact of each sub-component divided by the predicted service life of the sub-component. The service life of the electric wire (if applied) respectively post and rails are handled separately. Exchanges of these two sub-components (the structural material and the electric wire) 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, which is 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 shall 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 service life data.

The same type of electric wire is used for the wooden as for the plastic alternatives. Therefore, the electric consumption is equal in this case that an electric wire is used, and the LCA does therefore not include the electric consumption and its environmental impact. The potential difference when different electric wire systems are 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 use classes (UC) are defined by the BS 8417. The penetration and retention requirements for preservatives which had been tested in accordance with BS EN 599-1 are listed in BS 8417 (Table 1). The requirements for the use classes 1-5 differ for 15 years, 30 years and 60 years Desired Service Life (DSL). The DSL can be defined as the estimated mean value for the life time of treated timber.

Table 1. BS 8417 Use class and typical service situations

Use class	Service situation	Principal Biological Agency	Typical Service Situation	Examples
1[1]	Above ground, covered. Permanently dry.	Insects	Internal, with no risk of wetting.	All timbers in normal pitched roofs except tiling battens and valley gutter members Floor boards, architraves, internal joinery, skirtings. All timbers in upper floors not built into solid external walls.
2	Above ground, covered. Occasional risk of wetting.	Fungi / Insects	Internal, with risk of wetting.	Tiling battens, frame timbers in timber frame houses, timber in pitched roofs with high condensation risk, timbers in flat roofs, ground floor joists, sole plates (above dpc), timber joists in upper floors built into external walls.
3	**Coated**[3] Above ground, protected, e.g. by a coating. Exposed to frequent wetting. If wood becomes wet, drying out may be delayed by a coating.	Fungi[4]	External, above damp proof course (dpc)	External joinery including roof soffits and fascias, bargeboards, etc., cladding, valley gutter timbers, external structural load bearing timbers
	Uncoated Above ground, not protected. Exposed to frequent wetting.	Fungi[4]	External, above damp proof course (dpc) uncoated	Fence rails, gates, fence boards, agricultural timbers not in soil / manure contact and garden decking timbers that are not in contact with the ground.
4[5]	In contact with ground or fresh water. Permanently exposed to wetting.	Fungi[4]	Timbers in permanent contact with the ground or below dpc. Timbers in permanent contact with fresh water Cooling tower packing Timbers exposed to the particularly hazardous environment of cooling towers.	Fence posts, gravel boards, agricultural timbers in soil / manure content, poles, sleepers, playground equipment, motorway & highway fencing and garden decking timbers that are in contact with the ground. Lock gates and revetments. Cooling tower packing (fresh water).
5	Permanently exposed to wetting by salt water.	Marine borers, Fungi	All components in permanent contact with sea water.	Marine piling, piers and jetties, dock gates, sea defenses, ships hulls, and cooling tower packing (sea water)

Concerning the efficacy requirements, so far retention levels for the different wood preservatives have been stipulated by the manufacturer and given as a recommendation to the user.

Currently a working group within the Wood Protection Association (WPA) is working on an independent system for data requirement and application procedure for approval of wood preservatives. Table 2 shows the minimum requirements for the efficacy data which shall be submitted in support of claims for the desired service life of treated timber in the relevant Use Class according to the WPA approval scheme

Table 2. Minimum requirement for efficacy data acc. to WPA approval scheme (draft)

UC	DSL	
	15 years	30 years
3 (uncoated)	Laboratory	Laboratory Field-to validity[1]
4	Laboratory Field-10 yrs[2, 3]	Laboratory Field-10 yrs[4]

Laboratory = Laboratory data only required.

Field = Field trial data required – with number of years. The Independent Panel will be looking for evidence of substantial decay in untreated controls during the field trial.

The following notes are valid for the use classes given in Table 2:

1. Where a product has been approved for use in UC4, and field-tested appropriately, further testing to above ground field tests is not required. For 30 year DSL the retention may be set at 50% of that approved for UC4 15-year DSL. However, the retention for 30 years DSL derived from field trial data (UC3 uncoated or UC4) may not be less than the critical value from laboratory tests x 1.25.

2. Data from field trials for the period shown in the table must normally be submitted but an application for approval may be submitted with fewer years (but not less than 5 years) data with an argued case that supports the recommended retentions for the relevant use class/DSL combination. If an approval is granted where less than 10 years data is submitted the approval is conditional on further data being submitted at 1 year intervals until the 10 year period is achieved.

3. Retention equivalent to 9 kg CCA reference stakes is required.

4. Retention equivalent to 9 kg CCA reference stakes x 1.5 multiplication factor. The Retention may not be less than the critical value from laboratory tests x 1.5.

In order to define the Service Life more precisely, this LCA takes preservative retentions in account which predict a minimum service life time of 15 years respective 30 years. Therefore, the retention is higher compared to the ones for 15 y and 30 y DSL.

Spruce (Picea sitchensis) and Pine (Pinus sylvestris) are the predominant timber treated in Great Britain. According to the Forestry Commission (2011) the standing timber volume of Sitka Spruce is ca. 170,012 tm^3 and for Scots Pine 50,662 tm^3. Apart from these species a considerable amount of European Larch (Larix decidua: standing volume: 36,122 tm^3) and Douglas Fir (Pseudotzuga menziesii: standing volume - 15,055 tm^3) is used for timber treatment.

Timber in ground contact, like fencing posts, are treated according to BS 8417 HC 4 and the range currently consists of joists, i.e. sawn and planed timber larger than 75 x 125 mm small-posts (50 to 140 mm in diameter and in lengths up to 3 meters), large poles (telephone and electricity poles) and sleepers. Small-posts and sawn products are usually treated with a copper-based preservative in Great Brittan.

According to the Construction Product Regulation (CPR) construction classified strength graded treated wood need to be CE-marked.

Case study – fences

Keeping the animals in or shutting them out

In general, fences can be separated into fences which are used for keeping the animals in or out (i.e. game/wildlife fences, highway fences). Furthermore it can be then distinguished between permanent and temporary fences. Considering the range of temporary fences, for example narrow plastic posts, composites and spring-steel can be found. 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.

According to our investigations only a few material alternatives exist in the market for permanent livestock posts such as naturally durable wood, according to BS 8417 treated wood posts, 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 different larch species. These natural 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 1.8 meters and for horse rail fences it is 1.8 to 2.1 m meters. A standard domestic garden fence should have typically three rails (dimension 3.6 m x 38 x 99 mm) and a fence for horses or highways stuff typically have 4 rails (dimension 3.6 m x 38 x 100 mm). The post length for standard domestic wooden fence is 1.8 m and has a dimension of 75 x 125 mm. The more robust fence used for horses or highway fence should have a length of 1.8 m to 2.1 m and a dimension of 75 x 150 mm.

Permanent plastic-fences[1] 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.

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

Table 3. Typical mounting options for permanent horse fences and domestic garden fence used in the case study.

	Timber	**Plastic**
Domestic garden fence		
Wire and rails	Loose electric wire, 3 rails	Embedded electric wire, 3 rails
C.t.c. post	1.8	2.0
Dimensions, mm	posts: 75x125 rails: 38x88	posts: ø 90 rails: ø 75
Post-length, totally (above ground)	1.8 (1.2)	2.0 (1.4)
Robust horse or railway fence		
Wire and rails	Loose electric wire, 4 rails	Embedded electric wire, 4 rails
C.t.c. post	1.8	2.0
Dimensions, mm	posts: 75x150 rails: 38x88	posts: ø 90 rails: ø 75
Post-length, totally (above ground)	1.8 to 2.1 (1.2 to 1.4)*	2.0 (1.4)

* The 2.1 m post alternative is used when installed in soft ground or if a higher fence is wanted. The 2.1 alternative is chosen for the calculations.

Copper treated timber rails are equipped with a 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. Also the plastic fence has an electric wire, but this might be embedded.
This wire is assumed to have the same diameter as the wooden option. Whence replacing the wire in the plastic embedded option, it needs to be mounted with almost exactly the same fixings as the timber post. Our study therefore assumes 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 make sure they are more stably fastened. It is important not to skimp on the depth regardless of the post materials choice. 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 Table3):

Horse fence: 2.1 meter wooden post set with c.t.c. distance of 1.8 meters and four rails including one electric wire. The highway fence has the same design except that it has no electric wire.

Domestic garden fence: 1.8 meter plastic or wooden posts mounted with c.t.c distance of 2 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 on the wires service life. 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[2]. In addition to these types of wire we have the strong galvanized wire with an with a coating at least 36 µm, performed with double or triple galvanisation which provide an estimated life span of 8-16 years and 15-30 years[3]. 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.

[2] http://www.bmsab.se/subdet37.htm
[3] 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 a modern plastic fence. Examples of alternative plastics are PP, PVC or ABS. Furthermore, the analysis assumes that the plastic is made of 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 supplier 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 problem will not appear if rails are shaped like boards instead of round timber. This kind of deformation valid for circular plastic rails is a known problem with all plastic fencing panels, and may occasionally result in the posts coming out of the 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 gray plastic alternative that do not have these problems. However, with regard to dark plastic material higher temperature related shrinkage can be expected which might shorten the service life. A foreign manufacturer indicates that the plastic (made from quality assured production waste) has a technical service life of 50 years[4]. 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 analysing alternative results were 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.

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

Decay index and service life prediction

The investigation of the durability of timber in ground contact can be done by field tests and laboratory tests. The advantage of lab experiments is that they are easier to reproduce and faster to implement. In general 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 for reference. This material is regarded as a reliable reference, with adequate historical documentation.

The most common test method for evaluating the durability of timber in ground contact is the EN 252 field test method. This test method stipulates the exposition of standardised test pieces (stakes) of 500 x 500 x 25mm. It is reasonable to assume an increased durability of posts with bigger dimensions, compared to the standardised smaller test pieces. Moreover, it is relevant when assessing the durability of small-posts in ground contact to use field data with the correct dimension, but in the absence of such data, information from the standardised test pieces have been used.

Figure 6 Visualisation of the decay index, in compliance with the European field testing standard EN 252, used for timber in ground contact.
(Reference: Råberg, Terziev 2006)

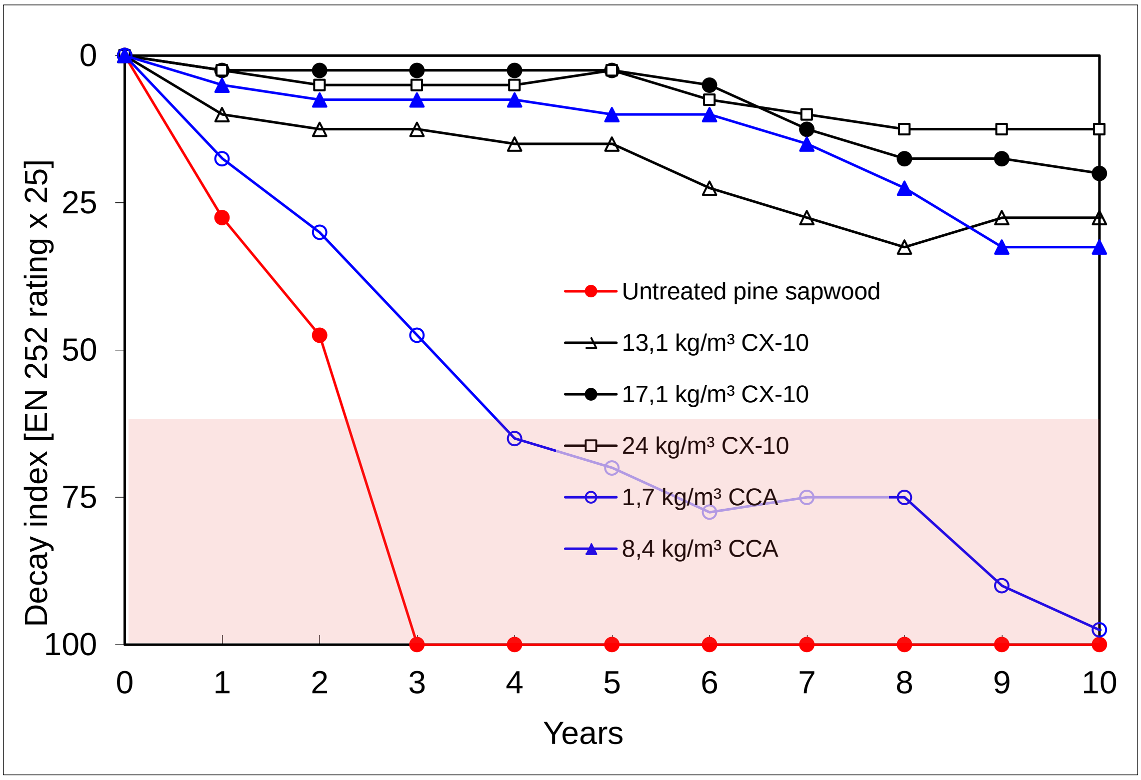
The degradation of timber in field tests are evaluated according to a four-point scale[5], as shown in Figure 6, where an index of 100 means that the post is totally rotten and is no longer fit for purpose.

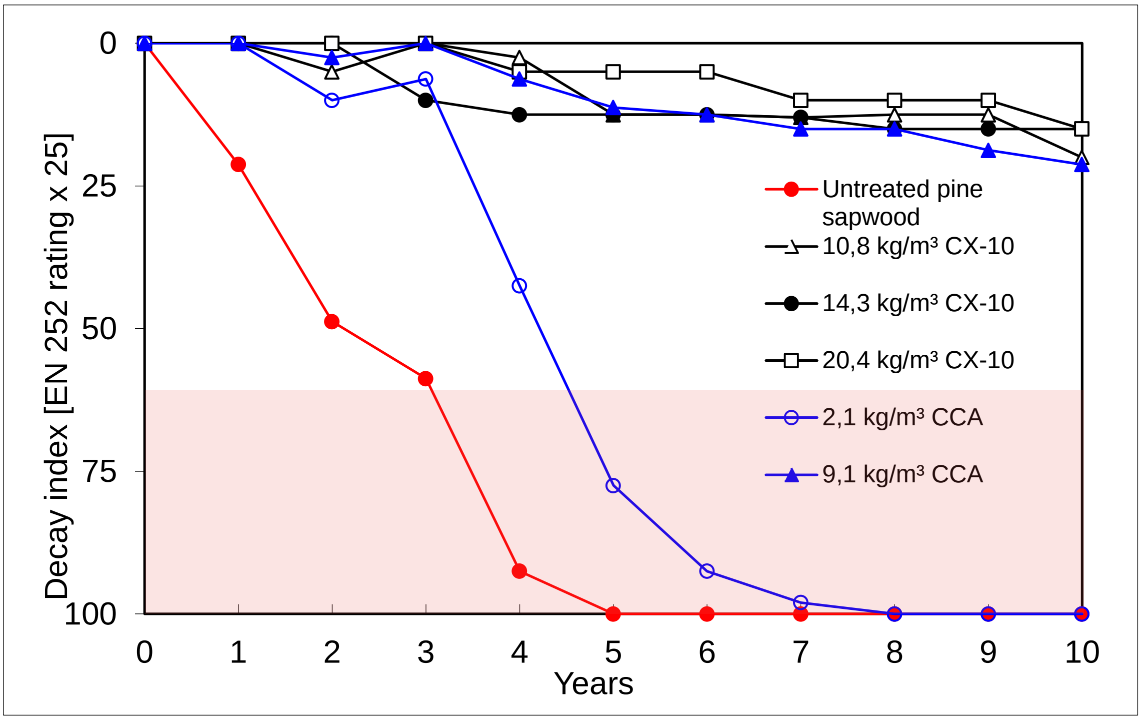
[5] A description of the rot index scale is; Healthy-no visible attack 0, Weak attack 25, Moderately Difficult attack 50, difficult attack 75 and very difficult infestation, sample condemned 100.

Many reports describe service life data for comparisons of different types of timber and wood preservative agents, where a decay index of 100 is reached and the post has completely rotted and broken off. In this state the timber does not meet its required technical performance as a fence post. For this report a simplified assumption has been used instead here, stating that when the decay index reaches 60 (this means significantly exceeded index of decay 50), this is assumed to correspond with the technical service life of a wooden fence post in ground contact that fulfills the function as a fence post.

Durability according to BS 8417 HC 4 treated timber

Timber treated according to BS 8417 HC 4 treated timber is not a precise product concerning durability aspects. A number of HSE-approved preservatives with different retentions 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) has been used. Due to environmental reason, in 2006 the use of CCA-preservatives in UK was banned. Modern wood preservatives are typically based on copper and an organic fungicide. Referring to the EN 252 test method, their efficacy is evaluated by comparing the result for CCA treated reference samples (higher retention) with the efficacy of the test product at a certain retention.





Figures 7 and 8 EN 252 Field test evaluations of two different north European field tests. (Reference: BASF 2012)

Figures 7 and 8 present EN 252 field test data for Wolmanit CX-10 treated timber in ground contact at two different Northern European test sites. Both trials clearly demonstrate that Wolmanit CX-10 has the same or better efficacy as CCA at the respective retentions (13.1 kg/m^3 CX to 8.4 kg/m^3 CCA in Fig 7) and (10.8 kg/m^3 CX to 9.1 kg/m^3 CCA).

BS 8417 states a desired service life of 15 years needs to be met, however in this study we are looking for a minimum service life of 15 years, so a strong safety margin needs to be applied. Therefore, a retention of 16.0 kg/m^3 has been applied to this study to ensure that all treated timbers pass the 60% rot index threshold, beyond the 15 year stated target. BS 8417 then states that to meet a 30 year service life a factor of 1.5 is applied to the 15 year service life hence 16 x 1.5 equals 24.0 kg/m^3. In the calculations the amount of sapwood is set at 50%.

Larch

According to Wagenführ (1985), approximately 17 different types of larch are known.

In accordance with EN 350-2 the European Larch (Larix decidua) is classed as 3-4, i.e. “moderate durable to slightly durable”. Practical experiences have shown that the Siberian larch have a better natural resistance in a 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).

European larch

UK home grown larch consists mainly on Larix decidua. 2011 the National Forest Inventory reports in total in Great Britain 36,122 tm^3 standing timber volume (England: 12,823 tm^3; Scotland: 17,420 tm^3; Wales: 5.879 tm^3).

Due to the on-going Larch pest in certain parts of UK an increasing amount of larch timber has to be harvested and will be used in near future.

In the public mind larch timber has the fame to have significant higher resistance compared to spruce and even pine heartwood in ground contact. Even if the higher durability of larch timber cannot be confirmed by EN 350-2, architects and communal decision maker often specify untreated larch timber for in ground and above ground use.

Siberian larch

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[6]. The Siberian larch has a slow growing rate and requires up to 250-years until its fully grown[6]. In our case study, we therefore include posts are made of Siberian larch from Siberia as an example of natural durable wood that are imported.

Efficacy of larch in ground contact

Field studies evaluating larch posts have not been found in literature. The identified data presents results from EN 252 field trials (using standardized test samples), which show the durability for different types of larch, while also including information on 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 test sites (Ultuna and Simlångsdalen). Keeping in account the evaluation of 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 field trial 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.

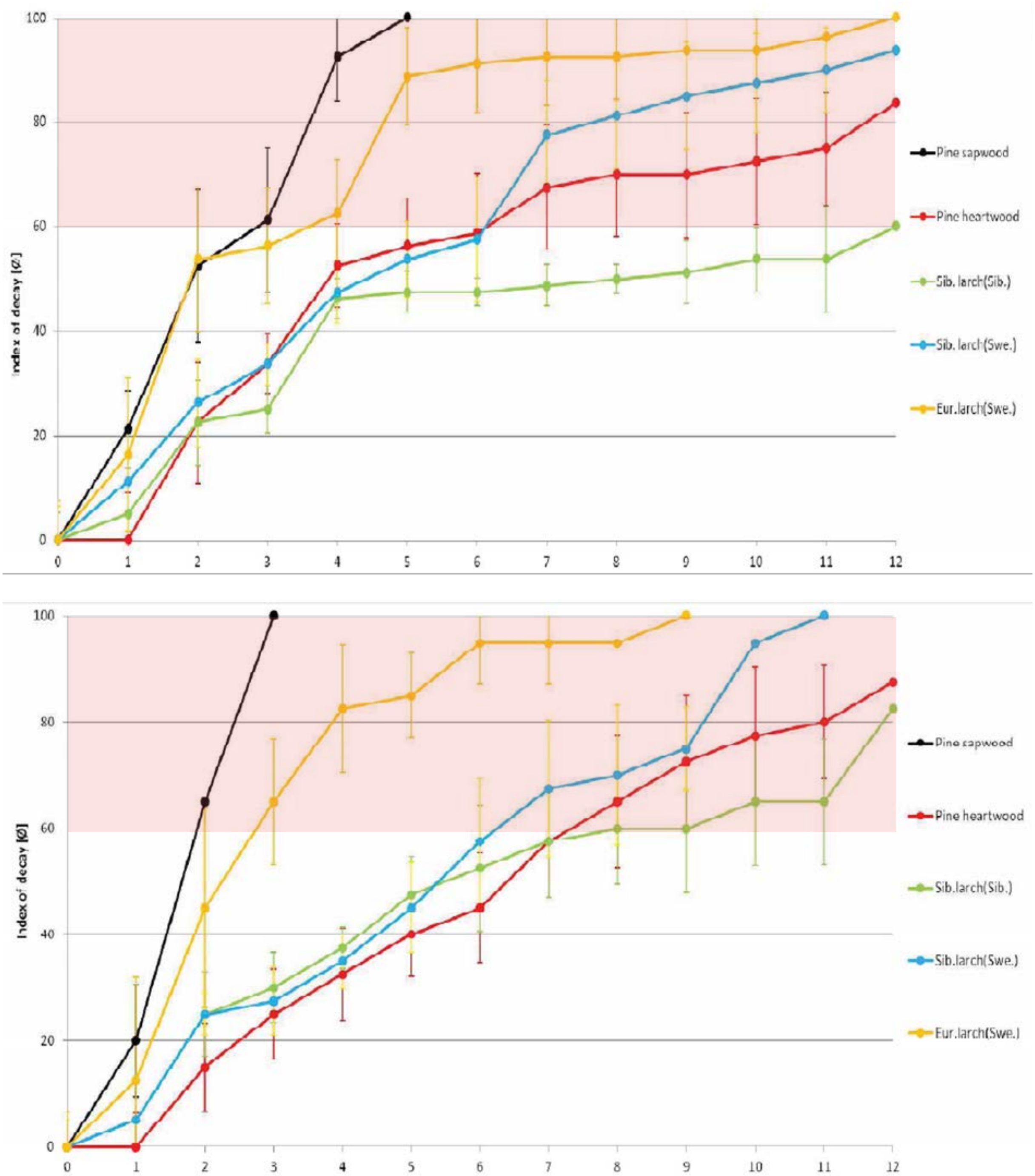


Figure 9 Durability results according to EN 252 field trials in Simlångsdalen (top) and Ultuna (bottom), where the heartwood (red) and sapwood (black) from pine compared two types of larch (Larix sibirica, Larix decidua) from two plant locations Larix sib. from Siberia (green) and from Sweden (blue) and Larix dec. from Sweden (yellow).
(Reference: Pockrandt 2012)

The field tests which are represented in Figure 9 had been started on the same year (time series), but from two different locations with different climate and soils, etc. From literature it is known that the field trials geographical placement and conditions may results in different service life. Further, 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 or 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 durability, with a service life of about 6 years compared to European Larch with 3 to 4 years.

Figure 10 presents the results of another Swedish field test trial (test site SP Borås: Larsson Brelid et al. 2011) with larch from Denmark and test pieces with a size of 22 x 95 mm. Unfortunately the report does not indicate what kind of larch has been tested.

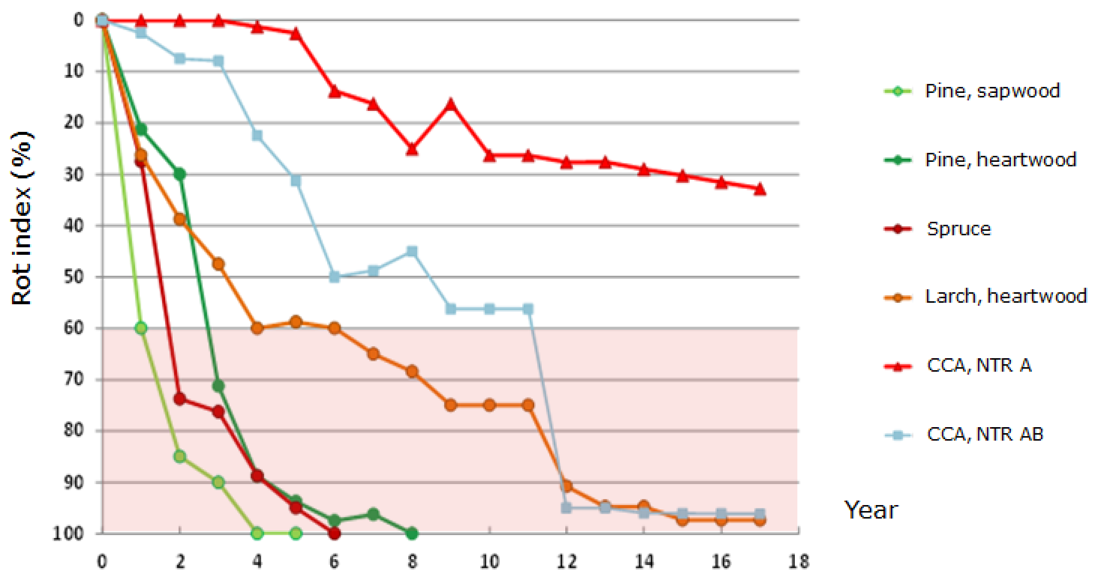


Figure 10 Durability results for sample boards 22x95 mm for various wood species and CCA treated timber for above (CCA-AB) and in ground contact (CCA-A). The red area indicates when a rot index of 60% have been achieved, the estimated technical-life extension in this study. (Reference: Larsson Brelid et al. 2011)

Figure 10 shows the assessment of the field trails after 15 years exposure. The dashed line shows the assumed technical service life of pine and spruce heart wood of about 3 years and about 5 years for heartwood larch of Danish origin.

Wood species	short cut
Spruce sapwood	FiS
Spruce heartwood	FiK
Douglas Fir Heartw	Dou
Larch heartwood	Lä
Black locust heartw	Rob
English oak heartw	Ei
Pine heartwood	KiK
Pine sapwood	KiS
Fir	Ta
CCB treated pine sapw	CKB

* IRG/WP 06-10598: The Natural Durability of Wood i Different Use classes

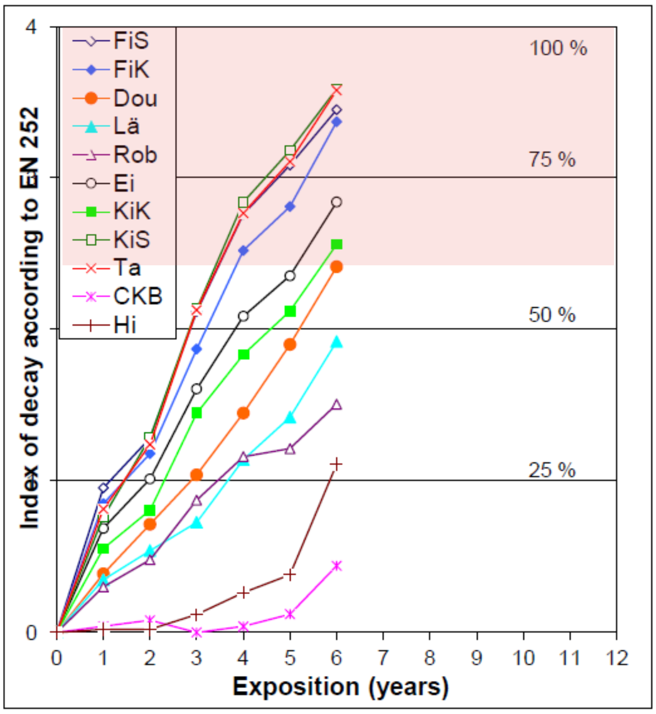


Figure 11 Durability results according to EN 252 field tests for Larch heartwood and other wood species based on 150 test samples of (500 x 50 x 25 mm) per wood type, as well as five German field trial sites (a rating of 1 corresponds to a rot index of 25%, 2 a rot index of 50%, 3 a rot index of 75% and 4 a rot index of 100%).
(Reference: Rapp et al. 2006)

Figure 11 shows the mean durability of Larch heartwood (Larix decidua) in ground contact after 6 years of exposure. By exploiting the durability line for larch heartwood an index of decay of 60 can be expected after 7 year of exposure.

In all cases the test samples in the studies mentioned above were made of 100 % larch heartwood. Under practical conditions, this cannot be assumed for the posts used in practice. On the other hand, a board in comparison with a post holds a more extensively exposed ground contacting surface. In subsequent calculations regarding ground contacting posts from European Larch a technical service life of 6 years is applied and 8 for Siberian larch cultivated in Siberia. This value represents a post containing a high percentage of heartwood. Moreover, a relatively favorable assumption apply, which is why the service life of 8 years for European Larch and 10 years for Siberian Larch is used for sensitivity assessments.

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). In an LCA a distinction is made between post-consumer recycled material that comes from scraped products that then is recycled (end-of life products), and pre-consumer waste that is never used for any product (i.e. normally production waste). 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). No environmental impact from the manufacturing process that produces the plastic waste has been added to the wastes environment impact.

The case study calculations assume 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 why 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 production total, were we found that the plastic raw materials dominates, this is why the data used are assumed as representative and useful for the present comparison.

BS 8417 treated timber

The generic data for preservative treated coniferous wood is based on UK average values. The LCA calculations are based on Wolmanit CX-10 treated pine timber with 50% heartwood. The LCA information regarding the production of the wood preservative

Wolmanit CX-8/CX-10 has been obtained from BASF (2013). Wolmanit CX-8/10 is at the present the most used copper wood preservative in Scandinavia and is under way to increase its use in UK. 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 retention comply with the UC 4 requirements for 15 and 30 year service, respectively.

The production data for the timber are mean values from different manufacturers (including BSW, M&M Timber) at varying degrees on manufacturing capacity. Information regarding the impregnation stage has also been compared with data from additional Scandinavian manufacturers. Thus this data facilitates a comparative evaluation of the differences between the various manufacturers. The differences between the compared manufacturers are viewed to of minor importance as long as the same type of fuel and industrial drying process is used (i.e. an artificial wood drying). Compared to the Scandinavian sawmills that only use bio-based fuels in the process to generate thermal energy, the UK sawmills use an energy mix with significant part of fossil fuels in the process. This will result in an increased contribution to climate change.

The transport from the forest to the impregnation plants are set to be 63 km based on reported figures from sawmills included in the UK inventory. The transportation by road from impregnation plants to the end user 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 it is sent via an 80 km transport 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 is therefore based on the following assumption:

- The same data used for Swedish forestry is also used for Russian larch forestry and is in the same range as literature data valid for Finnish forestry
- The same data per m^3 for the manufacturing of sawn timber from Sweden 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)[6] than for pine, the impact on weight basis will be lower than for pine, in respect to the figures used in this case study. The following transport data are used: 80 km from the forest to the sawmill by truck, 100 km truck on average from various sawmills suppliers in Siberia to a central transshipment sort (probably Irkutsk), 5500 km of railway from Irkutsk to Europe (applied 50 % electrified, 50 % diesel), 750 km boat from Europe to any seaport in UK, and then 150 km transport to the installation site by truck and finally at 80 km from the installation site to 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 made is considered as acceptable for the comparison.

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

Results

The results of the LCA calculations are based on a number of conditions and assumptions where the applied durability data reported in Table 4 including the 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 regards to the production of Siberian larch posts. However, we find that it is the transportation, which significantly contribute to the environmental performance, thus this is why said data nevertheless is deemed to provide a reasonable and adequate comparison.

Table 4. 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
BS 8417 treated poles	15[1)] respective 30[2)]	15 respective 30	Domestic coniferous wood. The field data on posts and others in accordance with EN 252
Siberian larch	8[3)]	10	From Siberia. The field data for samples in accordance with EN 252
European larch	6[3)]	8	From UK. The field data for samples in accordance with EN 252
Polyethylene (PE)	20	30	Pre-consumer recycled PE. No published field-data identified

1) 16.0 kg/m^3 retention to meet no lower than a 60% rate on the rot index, with a minimum service life of 15 years.

2) 24.0kg/m^3 retention to meet no lower than a 60% rate on the rot index, with a minimum service life of 30 years.

3) The service life is based on a decay index of 60%.

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 and rails, without taking into account the varying service life, but including the end-of-life stage, see Figure 12. These figures are 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 informative purpose.

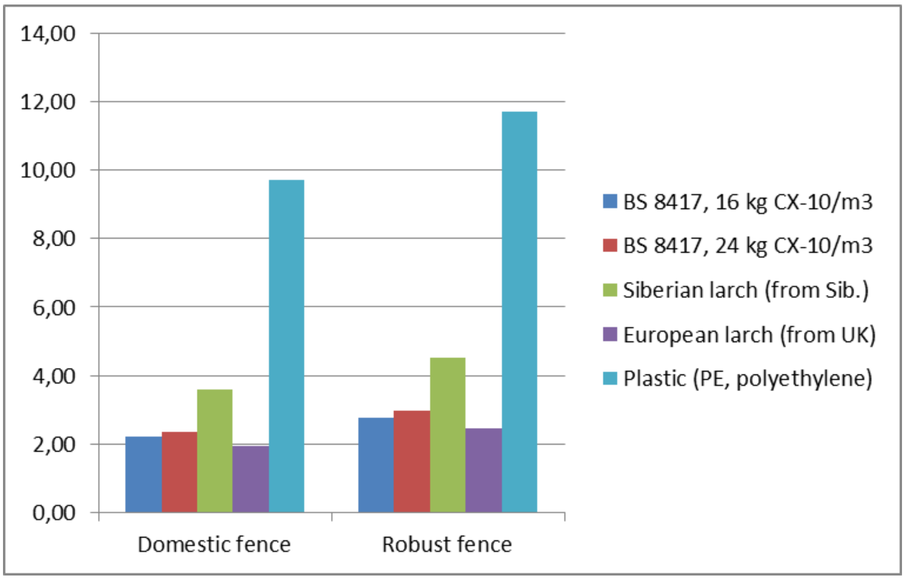


Figure 12 Contributions to climate change, kg CO_2e, according to the declared unit, i.e. during the life cycle with an equal service life and per running meter fence for two alternative fence design, where the center to center distance between the posts in each section is 1.8 and 2 meters for wood respective the plastic alternative.

The figure above, which is based on the declared unit, does not account for the diverse service life predictions of the alternative options. The electric wire used for the horse fence has a contribution to the overall impact that is less than 3%. The fence called 'robust fence' in the figure 12 is, therefore, representative for the horse fence and highway fence (that do not have an electric wire). According to the declared unit the climate impact contribution of the two BS 8417 treated alternatives and European Larch are low in comparison with the Siberian Larch, and significant lower than the plastic alternative, which has the highest climate impact contribution of the three alternatives.

In the next step we include the durability and take into account the service life prediction (see Table 1), to facilitate a more accurate comparison. The *functional unit* is now used as the base for the assessment. 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 and rails 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. The posts and rails are assumed to be replaced at the same time and in practice determined by the service life of the posts.

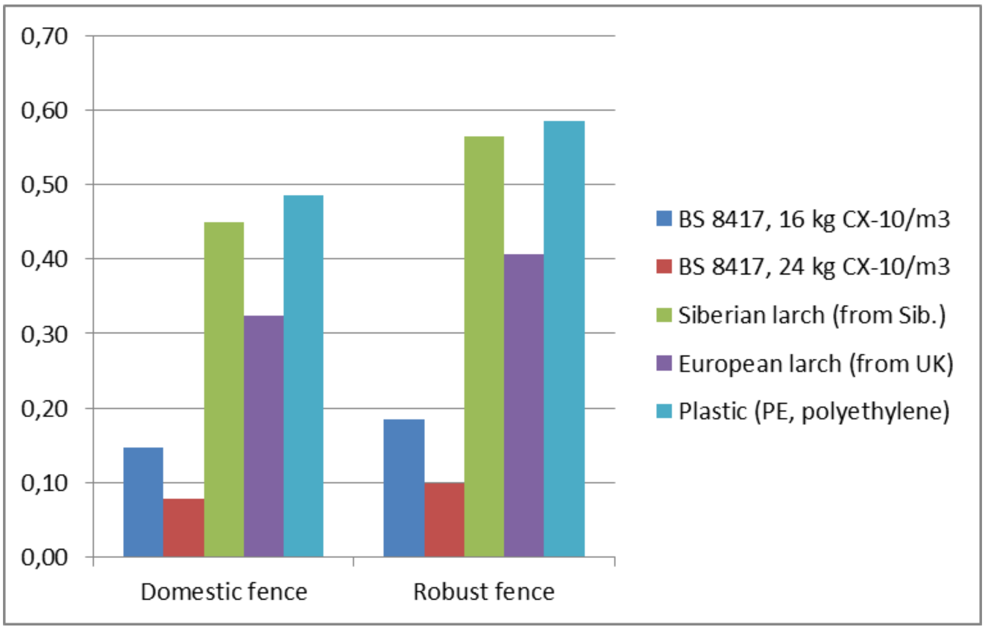


Figure 13 Contributions to climate change, kg CO_2e, during an average life cycle per running meter fence and per annum for the two alternative fence designs, where the center to center distance between the posts in each section is 1.8 and 2 meters for wood respectively the plastic fence. The following service life data are applied in the Base scenario; 15 and 30 years for BS 8417 with 16 kg CX-10 respectively 24 kg Wolmanit CX10 per m3 sapwood, Siberian Larch from Siberia 8 years, European Larch from UK 6 years and plastic 20 years.

In Figure 13, the different alternatives supply the same function, that is, an equivalent service life and technical performance. Analyzing the result given in Figure 3 gives that the contribution to climate impact is lowest for BS 8417/ 30 y DSL followed by the same fence with the 15 y DSL retention fences either of the domestic or robust fence design. The plastic material alternative has the highest environmental impact found in this study when contribution to climate change is analysed.

So far, we have only analysed the impact on the climate change. Figure 14 and Figure 15 show the relative contribution of all analysed impact categories for the domestic garden respective the robust fence design. 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.

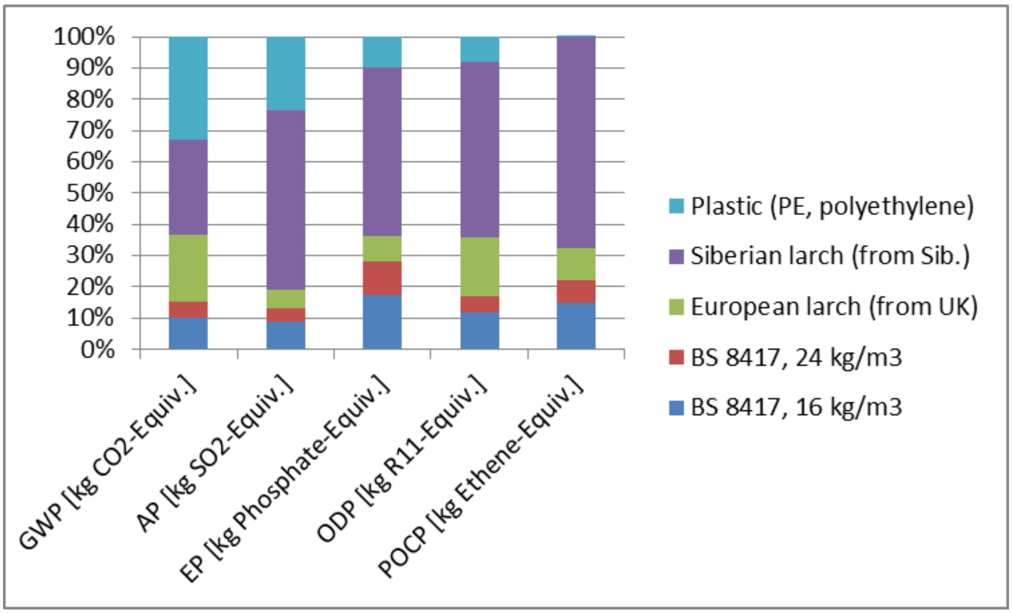


Figure 14 The relative contribution of different environmental categories from different domestic garden fencing material options during an average life cycle per section and per running meter according to the baseline scenario[7]
Abbreviations: GWP – global warming potential, AP – acidification potential, EP – eutrophication potential; ODP – ozone depletion potential, POCP – photochemical ozone potential

[7] The following service life are used for the baseline scenario; BS 8417, DSL 30 y rsp. 15 y years, plastic 20 years, larch 12 years.

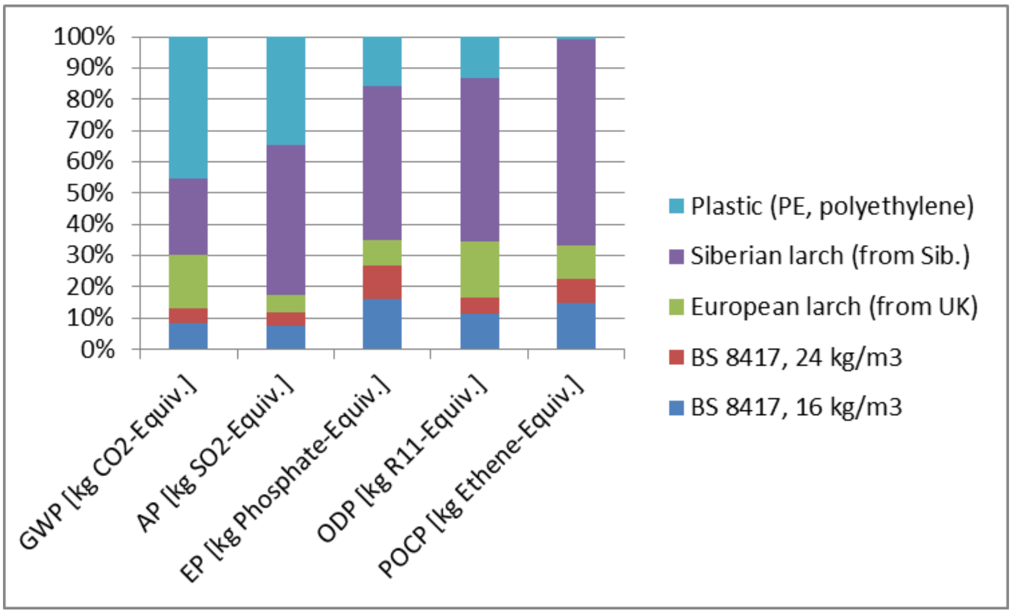


Figure 15 The relative contribution of different environmental categories from a robust fence (in this case the horse fence including an electric wire), during an average life cycle per running meter and per annum according to the baseline scenario[7]
Abbreviations: GWP – global warming potential, AP – acidification potential, EP – eutrophication potential; ODP – ozone depletion potential, POCP – photochemical ozone potential

The service life for plastic posts is uncertain and as an alternative to 20 years 30 years is examined. The same uncertainty does not apply to the wooden alternatives. Nevertheless, in order to evaluate the robustness the service life is increased for Larch in the sensitivity analysis. The contribution to climate change according to both the baseline scenario and the sensitivity scenario can be found in Figure 16.

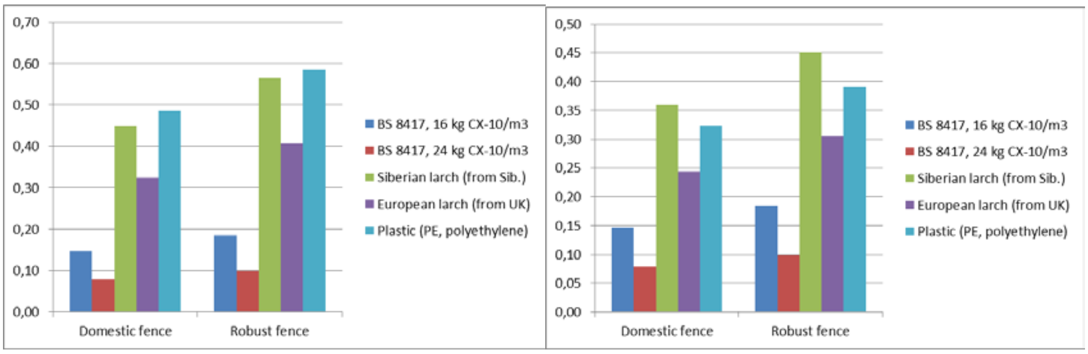


Figure 16 Contributions to climate change, kg CO_2e, during an average life cycle per running meter and per annum for alternative fence designs. The baseline service life prediction data for the Base line scenarios in the figure on the left are; 15 and 30 years for BS 8417 with 16 kg CX-10 respectively 24 kg Wolmanit CX-10 per m3 sapwood, Siberian Larch from Siberia 8 years, European Larch from UK 6 years and plastic 20 years. The figure on the right presents the results from the sensitivity analysis in which the following service life prediction data have been applied; 15 and 30 years for BS 8417 with 16 kg CX-10 respectively 24 kg Wolmanit CX-10 per m^3 sapwood, Siberian Larch from Siberia 10 years, European Larch from UK 8 years and plastic 30 years.

Even allowing for this uncertainty regarding service life on the plastic fence and an improved durability on Larch, the environmental performance is favour to BS 8417 DSL 30 and followed by the DSL 15 y alternative. The figure also illustrates the resource efficiency of impregnated wood according to BS 8417 with copper preservative, when an increased amount of preservative is used. The home-grown Larch is then preferable compared to imported and the more durable alternative that origin from Siberia. The plastic alternative may compete with Siberian Larch if the base scenario service life of 8 years competes with the service life of 30 years for the plastic alternative.

The study's result when considering different types of fences generalise that; irrespective of any fence or post design, it is reasonable to assume that the BS 8417 UC 4 posts have the lowest environmental impact for the environmental impacts categories used in the assessment. The LCA performed does not include human and ecological toxicity due to the lack of generally accepted impact assessments within this area. 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 heavily depend on its durability and the proximity of forest raw materials. The naturally resistant wood species analyzed as options in this study are European and Siberian larch. Siberian larch from Siberia has long distances of imported to the UK, which stresses these options negatively in an environment correlation due to their relatively high transport mileage and its significant contribution. Durability and service life prediction is another important factor to be considered as well as the lack of experience data for field posts for all alternatives apart from BS 8417 UC 4. The plastic alternative is particularly sensitive to this. When compared to the options above, the plastic alternative with a lifespan of 30 years is a potentially interesting option compared to the naturally durable materials, if they have a service life of 6 to 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 factor affects the resistance in practicality and is a prerequisite 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 60 % according to EN 252, were 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 of this aspect in the literature.

The treated post according to BS 8417 and a retention that result in a DSL for 30 years has the best environmental performance, irrespective of the implemented lifespans of the alternative materials, and with regards to the analysed environmental impact categories. 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 the standard that governs how an environmental product declaration shall be made for all construction products in the European market. At presently we do not know which countries that 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 the near future, the environmental classification system for different construction works already complies with EN 15804, which why this standard already has an impact on how an LCA must be calculated and reported.

Acknowledgement of support

Thank you to all suppliers and manufacturers for the details of each manufacturing process. A special thank to the companies BSW and M & M Timber for supplying us with production data and to Richard Gulland/BASF plc for the final review of the report.

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Appendix: LCA-results

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

Domestic garden fence — baseline scenario

per meter and year	BS 8417, 16 kg/m3			15	years	BS 8417, 24 kg/m3			30	years
	Total	Product stage	Construction	Use	End of life	Total	Product stage	Construction	Use	End of life
GWP [kg CO2-Equiv.]	0,15	0,12	0,02	0	0,01	0,08	0,06	0,01	0	0,00
AP [kg SO2-Equiv.]	6,1E-04	4,7E-04	1,1E-04	0,0E+00	3,0E-05	3,0E-04	2,4E-04	5,7E-05	0,0E+00	1,5E-05
EP [kg Phosphate-Equiv.]	2,8E-04	2,4E-04	3,5E-05	0,0E+00	9,4E-06	1,7E-04	1,6E-04	1,8E-05	0,0E+00	4,7E-06
ODP [kg R11-Equiv.]	9,1E-09	4,2E-09	3,8E-09	0,0E+00	1,0E-09	4,0E-09	2,1E-09	1,9E-09	0,0E+00	5,1E-10
POCP [kg Ethene-Equiv.]	1,0E-04	7,8E-05	1,9E-05	0,0E+00	5,0E-06	5,0E-05	4,0E-05	9,3E-06	0,0E+00	2,5E-06
ADP elements [kg Sb-Equiv.]	1,4E-06	1,3E-06	5,4E-08	0,0E+00	1,4E-08	1,0E-06	9,9E-07	2,7E-08	0,0E+00	7,2E-09
ADP fossil [MJ]	2,4E+00	1,9E+00	3,7E-01	0,0E+00	9,9E-02	1,3E+00	1,1E+00	1,8E-01	0,0E+00	4,9E-02

per meter and year	Siberian larch (from Sib.) 8 year					European larch (from UK) 6 year				
	Total	Product stage	Construction	Use	End of life	Total	Product stage	Construction	Use	End of life
GWP [kg CO2-Equiv.]	0,45	0,41	0,03	0	0,02	0,31	0,24	0,06	0	0,003
AP [kg SO2-Equiv.]	4,0E-03	3,8E-03	1,4E-04	0,0E+00	7,6E-05	4,4E-04	7,6E-05	2,8E-04	0,0E+00	7,6E-05
EP [kg Phosphate-Equiv.]	8,8E-04	8,1E-04	4,4E-05	0,0E+00	2,3E-05	1,3E-04	2,3E-05	8,8E-05	0,0E+00	2,3E-05
ODP [kg R11-Equiv.]	4,4E-08	3,6E-08	4,8E-09	0,0E+00	2,5E-09	1,5E-08	2,5E-09	9,5E-09	0,0E+00	2,5E-09
POCP [kg Ethene-Equiv.]	4,7E-04	4,3E-04	2,3E-05	0,0E+00	1,2E-05	7,1E-05	1,2E-05	4,6E-05	0,0E+00	1,2E-05
ADP elements [kg Sb-Equiv.]	2,5E-07	1,5E-07	6,7E-08	0,0E+00	3,6E-08	2,1E-07	3,6E-08	1,3E-07	0,0E+00	3,6E-08
ADP fossil [MJ]	6,7E+00	6,0E+00	4,6E-01	0,0E+00	2,5E-01	1,4E+00	2,5E-01	9,2E-01	0,0E+00	2,5E-01

per meter and year	Plastic (PE, polyethylene) 20 year				
	Total	Product stage	Construction	Use	End of life
GWP [kg CO2-Equiv.]	0,49	0,48	0,01	0	0,002
AP [kg SO2-Equiv.]	1,6E-03	1,6E-03	3,9E-05	0,0E+00	1,0E-05
EP [kg Phosphate-Equiv.]	1,6E-04	1,5E-04	1,2E-05	0,0E+00	3,2E-06
ODP [kg R11-Equiv.]	6,2E-09	4,9E-09	1,3E-09	0,0E+00	3,5E-10
POCP [kg Ethene-Equiv.]	6,2E-09	4,9E-09	1,3E-09	0,0E+00	3,5E-10
ADP elements [kg Sb-Equiv.]	7,5E-08	5,7E-08	1,8E-08	0,0E+00	4,9E-09
ADP fossil [MJ]	1,7E+01	1,7E+01	1,3E-01	0,0E+00	3,4E-02

Robust fences type highway or horse — baseline scenario

per meter and year	BS 8417, 16 kg/m3			15	years	BS 8417, 24 kg/m3			30	years
	Total	Product stage	Construction	Use	End of life	Total	Product stage	Construction	Use	End of life
GWP [kg CO2-Equiv.]	0,11	0,09	0,02	0	0,004	0,06	0,05	0,01	0	0,002
AP [kg SO2-Equiv.]	4,5E-04	3,5E-04	8,0E-05	0,0E+00	2,1E-05	2,3E-04	1,9E-04	4,0E-05	0,0E+00	1,1E-05
EP [kg Phosphate-Equiv.]	2,1E-04	1,8E-04	2,5E-05	0,0E+00	6,5E-06	1,3E-04	1,2E-04	1,2E-05	0,0E+00	3,3E-06
ODP [kg R11-Equiv.]	6,6E-09	3,3E-09	2,7E-09	0,0E+00	7,1E-10	3,1E-09	1,8E-09	1,3E-09	0,0E+00	3,5E-10
POCP [kg Ethene-Equiv.]	7,4E-05	5,8E-05	1,3E-05	0,0E+00	3,5E-06	3,8E-05	3,2E-05	6,5E-06	0,0E+00	1,7E-06
ADP elements [kg Sb-Equiv.]	1,0E-06	9,9E-07	3,7E-08	0,0E+00	1,0E-08	7,7E-07	7,5E-07	1,9E-08	0,0E+00	5,0E-09
ADP fossil [MJ]	1,7E+00	1,4E+00	2,6E-01	0,0E+00	6,9E-02	9,6E-01	8,3E-01	1,3E-01	0,0E+00	3,4E-02

per meter and year	Siberian larch (from Sib.)			8	year	European larch (from UK)			6	year
	Total	Product stage	Construction	Use	End of life	Total	Product stage	Construction	Use	End of life
GWP [kg CO2-Equiv.]	0,32	0,29	0,020	0	0,011	0,22	0,17	0,04	0	0,011
AP [kg SO2-Equiv.]	2,8E-03	2,7E-03	9,9E-05	0,0E+00	5,3E-05	3,3E-04	7,3E-05	2,0E-04	0,0E+00	5,3E-05
EP [kg Phosphate-Equiv.]	6,3E-04	5,8E-04	3,1E-05	0,0E+00	1,6E-05	1,1E-04	2,8E-05	6,1E-05	0,0E+00	1,6E-05
ODP [kg R11-Equiv.]	3,1E-08	2,6E-08	3,3E-09	0,0E+00	1,8E-09	1,0E-08	2,1E-09	6,6E-09	0,0E+00	1,8E-09
POCP [kg Ethene-Equiv.]	3,3E-04	3,0E-04	1,6E-05	0,0E+00	8,7E-06	5,3E-05	1,2E-05	3,2E-05	0,0E+00	8,7E-06
ADP elements [kg Sb-Equiv.]	2,4E-07	1,7E-07	4,7E-08	0,0E+00	2,5E-08	2,1E-07	8,6E-08	9,4E-08	0,0E+00	2,5E-08
ADP fossil [MJ]	4,8E+00	4,3E+00	3,2E-01	0,0E+00	1,7E-01	1,1E+00	2,4E-01	6,5E-01	0,0E+00	1,7E-01

per meter and year	Plastic (PE, polyethylene)		20	year	
	Total	Product stage	Construction	Use	End of life
GWP [kg CO2-Equiv.]	0,59	0,58	0,010	0	0,0008
AP [kg SO2-Equiv.]	2,0E-03	2,0E-03	4,7E-05	0,0E+00	4,0E-06
EP [kg Phosphate-Equiv.]	2,0E-04	1,9E-04	1,5E-05	0,0E+00	1,2E-06
ODP [kg R11-Equiv.]	7,9E-09	6,2E-09	1,6E-09	0,0E+00	1,3E-10
POCP [kg Ethene-Equiv.]	3,5E-06	3,5E-06	1,6E-09	0,0E+00	1,3E-10
ADP elements [kg Sb-Equiv.]	1,5E-07	1,3E-07	2,2E-08	0,0E+00	1,9E-09
ADP fossil [MJ]	2,1E+01	2,0E+01	1,5E-01	0,0E+00	1,3E-02

Domestic garden fence — sensitivity analysis with alternate service life

per meter and year	BS 8417, 16 kg/m3			15	years	BS 8417, 24 kg/m3			30	years
	Total	Product stage	Construction	Use	End of life	Total	Product stage	Construction	Use	End of life
GWP [kg CO2-Equiv.]	0,15	0,12	0,02	0	0,01	0,08	0,06	0,01	0	0,00
AP [kg SO2-Equiv.]	6,1E-04	4,7E-04	1,1E-04	0,0E+00	3,0E-05	3,0E-04	2,4E-04	5,7E-05	0,0E+00	1,5E-05
EP [kg Phosphate-Equiv.]	2,8E-04	2,4E-04	3,5E-05	0,0E+00	9,4E-06	1,7E-04	1,6E-04	1,8E-05	0,0E+00	4,7E-06
ODP [kg R11-Equiv.]	9,1E-09	4,2E-09	3,8E-09	0,0E+00	1,0E-09	4,0E-09	2,1E-09	1,9E-09	0,0E+00	5,1E-10
POCP [kg Ethene-Equiv.]	1,0E-04	7,8E-05	1,9E-05	0,0E+00	5,0E-06	5,0E-05	4,0E-05	9,3E-06	0,0E+00	2,5E-06
ADP elements [kg Sb-Equiv.]	1,4E-06	1,3E-06	5,4E-08	0,0E+00	1,4E-08	1,0E-06	9,9E-07	2,7E-08	0,0E+00	7,2E-09
ADP fossil [MJ]	2,4E+00	1,9E+00	3,7E-01	0,0E+00	9,9E-02	1,3E+00	1,1E+00	1,8E-01	0,0E+00	4,9E-02

per meter and year	Siberian larch (from Sib.)			10	year	European larch (from UK)			8	year
	Total	Product stage	Construction	Use	End of life	Total	Product stage	Construction	Use	End of life
GWP [kg CO2-Equiv.]	0,36	0,32	0,02	0	0,01	0,23	0,18	0,04	0	0,003
AP [kg SO2-Equiv.]	3,2E-03	3,0E-03	1,1E-04	0,0E+00	6,1E-05	3,3E-04	5,7E-05	2,1E-04	0,0E+00	5,7E-05
EP [kg Phosphate-Equiv.]	7,0E-04	6,5E-04	3,5E-05	0,0E+00	1,9E-05	1,0E-04	1,8E-05	6,6E-05	0,0E+00	1,8E-05
ODP [kg R11-Equiv.]	3,5E-08	2,9E-08	3,8E-09	0,0E+00	2,0E-09	1,1E-08	1,9E-09	7,1E-09	0,0E+00	1,9E-09
POCP [kg Ethene-Equiv.]	3,7E-04	3,4E-04	1,9E-05	0,0E+00	9,9E-06	5,3E-05	9,3E-06	3,5E-05	0,0E+00	9,3E-06
ADP elements [kg Sb-Equiv.]	2,0E-07	1,2E-07	5,4E-08	0,0E+00	2,9E-08	1,5E-07	2,7E-08	1,0E-07	0,0E+00	2,7E-08
ADP fossil [MJ]	5,4E+00	4,8E+00	3,7E-01	0,0E+00	2,0E-01	1,1E+00	1,8E-01	6,9E-01	0,0E+00	1,8E-01

per meter and year	Plastic (PE, polyethylene)			30	year
	Total	Product stage	Construction	Use	End of life
GWP [kg CO2-Equiv.]	0,32	0,32	0,01	0	0,001
AP [kg SO2-Equiv.]	1,1E-03	1,1E-03	2,6E-05	0,0E+00	6,9E-06
EP [kg Phosphate-Equiv.]	1,1E-04	9,8E-05	8,0E-06	0,0E+00	2,1E-06
ODP [kg R11-Equiv.]	4,1E-09	3,2E-09	8,7E-10	0,0E+00	2,3E-10
POCP [kg Ethene-Equiv.]	4,1E-09	3,2E-09	8,7E-10	0,0E+00	2,3E-10
ADP elements [kg Sb-Equiv.]	5,0E-08	3,8E-08	1,2E-08	0,0E+00	3,3E-09
ADP fossil [MJ]	1,1E+01	1,1E+01	8,4E-02	0,0E+00	2,3E-02

Robust fences type highway or horse — sensitivity analysis with alternate service life

per meter and year	BS 8417, 16 kg/m3			15	years	BS 8417, 24 kg/m3			30	years
	Total	Product stage	Construction	Use	End of life	Total	Product stage	Construction	Use	End of life
GWP [kg CO2-Equiv.]	0,11	0,09	0,02	0	0,004	0,06	0,05	0,01	0	0,002
AP [kg SO2-Equiv.]	4,5E-04	3,5E-04	8,0E-05	0,0E+00	2,1E-05	2,3E-04	1,9E-04	4,0E-05	0,0E+00	1,1E-05
EP [kg Phosphate-Equiv.]	2,1E-04	1,8E-04	2,5E-05	0,0E+00	6,5E-06	1,3E-04	1,2E-04	1,2E-05	0,0E+00	3,3E-06
ODP [kg R11-Equiv.]	6,6E-09	3,3E-09	2,7E-09	0,0E+00	7,1E-10	3,1E-09	1,8E-09	1,3E-09	0,0E+00	3,5E-10
POCP [kg Ethene-Equiv.]	7,4E-05	5,8E-05	1,3E-05	0,0E+00	3,5E-06	3,8E-05	3,2E-05	6,5E-06	0,0E+00	1,7E-06
ADP elements [kg Sb-Equiv.]	1,0E-06	9,9E-07	3,7E-08	0,0E+00	1,0E-08	7,7E-07	7,5E-07	1,9E-08	0,0E+00	5,0E-09
ADP fossil [MJ]	1,7E+00	1,4E+00	2,6E-01	0,0E+00	6,9E-02	9,6E-01	8,3E-01	1,3E-01	0,0E+00	3,4E-02

per meter and year	Siberian larch (from Sib.)			10	year	European larch (from UK)			8	year
	Total	Product stage	Construction	Use	End of life	Total	Product stage	Construction	Use	End of life
GWP [kg CO2-Equiv.]	0,26	0,23	0,016	0	0,009	0,17	0,13	0,03	0	0,008
AP [kg SO2-Equiv.]	2,3E-03	2,1E-03	8,0E-05	0,0E+00	4,2E-05	2,5E-04	6,0E-05	1,5E-04	0,0E+00	4,0E-05
EP [kg Phosphate-Equiv.]	5,0E-04	4,6E-04	2,5E-05	0,0E+00	1,3E-05	8,2E-05	2,4E-05	4,6E-05	0,0E+00	1,2E-05
ODP [kg R11-Equiv.]	2,5E-08	2,1E-08	2,7E-09	0,0E+00	1,4E-09	7,9E-09	1,6E-09	5,0E-09	0,0E+00	1,3E-09
POCP [kg Ethene-Equiv.]	2,6E-04	2,4E-04	1,3E-05	0,0E+00	6,9E-06	4,1E-05	1,0E-05	2,4E-05	0,0E+00	6,5E-06
ADP elements [kg Sb-Equiv.]	2,0E-07	1,4E-07	3,7E-08	0,0E+00	2,0E-08	1,7E-07	8,0E-08	7,0E-08	0,0E+00	1,9E-08
ADP fossil [MJ]	3,8E+00	3,4E+00	2,6E-01	0,0E+00	1,4E-01	8,1E-01	2,0E-01	4,8E-01	0,0E+00	1,3E-01

per meter and year	Plastic (PE, polyethylene)		30	year	
	Total	Product stage	Construction	Use	End of life
GWP [kg CO2-Equiv.]	0,39	0,39	0,006	0	0,0005
AP [kg SO2-Equiv.]	1,3E-03	1,3E-03	3,1E-05	0,0E+00	2,7E-06
EP [kg Phosphate-Equiv.]	1,4E-04	1,3E-04	9,7E-06	0,0E+00	8,2E-07
ODP [kg R11-Equiv.]	5,4E-09	4,2E-09	1,0E-09	0,0E+00	8,9E-11
POCP [kg Ethene-Equiv.]	3,5E-06	3,5E-06	1,0E-09	0,0E+00	8,9E-11
ADP elements [kg Sb-Equiv.]	1,2E-07	1,1E-07	1,5E-08	0,0E+00	1,3E-09
ADP fossil [MJ]	1,4E+01	1,4E+01	1,0E-01	0,0E+00	8,6E-03