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Life cycle assessment (LCA) of railway sleepers

Comparison of railway sleepers made from

concrete, steel, beech wood and oak wood

Study in order of
Studiengesellschaft Holzschwellenoberbau e.V.
(Society for Research on Wooden Railway Sleepers)

With a text contribution to the state of affairs concerning the disposal of used sleepers
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Summary

This updated life cycle assessment (LCA) compares the environmental impacts of railway sleepers made from concrete, steel, beech wood and oak wood. In LCA, all material and energy flows related to the life cycle of a sleeper are compiled and assessed from 'cradle-to-grave': from the production of the main materials and mounting equipment, over the use phase up to its deconstruction, recycling and final disposal. In addition to that, the respective share of track bed construction and its maintenance are accounted for because the structure of the track bed differs for the sleepers under consideration.

Thus, the study compares as the functional unit:

> 1 railway sleeper including the mounting equipment, plus the respective share of the track bed over the length of 63 cm, over one year, relative to the average service life of the sleeper

This life cycle assessment was conducted in conformity with the series of international standards ISO 14040ff. The study was period was peer-reviewed externally by Dr. K. Richter, Swiss Federal Laboratories for Materials Testing and Research (Empa), Dübendorf (CH) and can thus be made publically available.

The target audience of this study are:

1. Strategic decision makers, who formulate guidelines for procurement,
2. Political decision makers, who formulate requirements for operators of railways,
3. Procurement managers of railway sleepers,
4. Experts in the fields of production, track laying and disposal of sleepers.

This study updates an LCA study on railway sleepers in Switzerland, conducted by Empa and published in 1998[1]. Relevant updates include:

- Updating of process data, mainly for the wooden sleepers (see below)
- Utilisation of the updated LCI/LCA database ecoinvent 2.0 (release November 07). For this study, relevant updates of process data include, e.g., cement and steel production, transportation processes, electricity mixes, disposal processes, etc.
- Utilisation of updated impact characterisation methods for all impact categories[2]. The methodological updates of the impact categories on human and eco-toxicity are particularly relevant for this study. Contrary to the Empa-study, these methods explicitly take into account fate and exposure of emission. This allows us to depict the impacts of chronic exposure in a much more appropriate way in LCA.
- Adaptation of the study to German conditions. This includes the use of the German electricity mix and the use of German statistics for the service life of the sleepers.
- Update of the inputs needed for the maintenance of the track bed.

For the sleepers made from concrete and steel, the process data was mainly taken over from the Empa study. According to several companies, the process data has not changed significantly for these sleepers. Its impact on the result of the LCA is hardly significant compared to the influence of the background data, e.g. for cement or steel production.

For the sleepers made from wood, the process data has been updated over the whole life cycle. Hence, some data gaps in the Empa-study could be closed with more reliable and rep-

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[1] Künniger und Richter 1998
[2] Guinée, Gorrée *et al.* 2002

resentative data and some considerable process optimizations could be taken into account. These updates include:

- Inventorying of forestry processes for beech and oak based on studies by the University of Hamburg[3],
- Update of the data for the production of creosote, including the allocation of the distillation process based on the current economic conditions of a manufacturer,
- Update of the allocation of the coking process for the tar oil production based on the current economic situation of a German coke plant.
- Update of the emissions from the impregnation process based on data from the U.S. Environmental Protection Agency[4],
- Exclusive use of creosote grade C according to EN 13991 with a reduced tendency to evaporate,
- Reduced insertion quantities of creosote according to the current application of DIN 68811:2007-01,
- Estimation of emissions during service life of the wooden sleepers based on actual insertion quantities of creosote and significantly reduced evaporation tendencies of creosote grade C[5],
- Thermal utilisation of used wooden sleepers and updating of the resulting emissions,
- Accounting of the substitution effect resulting from the thermal utilisation of wood, i.e. the combustion of railway sleepers instead of fossil fuels, based on heating values determined in laboratory tests made for this study.

Figure 2.1 compares the environmental impacts of the railway sleepers relative to each other. The environmental are thus normalised relative to the respective indicator values of the sleeper made from concrete (indicator value = 1).
For the wooden sleepers, heat recovery is assumed as the practical implementation of by European and German law. Negative values indicate that the heat recovery from the combustion of the wooden sleepers, substituting for the combustion of fossil fuels, avoids more emissions than are released during the life cycle of the wooden sleeper before its combustion.

Based on this figure and on more in-depth analysis of the environmental profiles of all sleepers, the results of the study can be summarized as follows:

- Generally, the environmental profile of all sleepers is dominated by the environmental impacts from track bed construction and maintenance.
- New steel sleepers cause the largest contributions in all impact categories. This is independent of the allocation procedure applied to steel (see below).
- The environmental impacts associated with repaired steel sleepers lie below the impacts of the concrete sleeper in all categories and above the impacts of wooden sleepers.
- Compared to the repaired steel sleepers and to the concrete sleeper, the wooden sleepers cause (sometimes very significantly) the lowest impacts in all impact categories, except in eutrophication. The contributions to eutrophication do not differ significantly for all sleepers.
- For some impact categories, the avoided emissions from the energetic substitution, i.e. the avoidance of the combustion of fossil fuels due to the thermal utilisation of

[3] Schweinle 2000
[4] EPA 1999
[5] compared to creosote W.E.I. type B, the share of evaporated creosote is reduced from 45% to approximately 5% for creosote grade C (Künniger & Richter 1998)

wood, can be higher than the direct emissions over the life cycle of the wooden sleepers, particularly in the case of climate change (if used for co-generation), but also for the depletion of abiotic resources, for stratospheric ozone depletion or for photosmog.

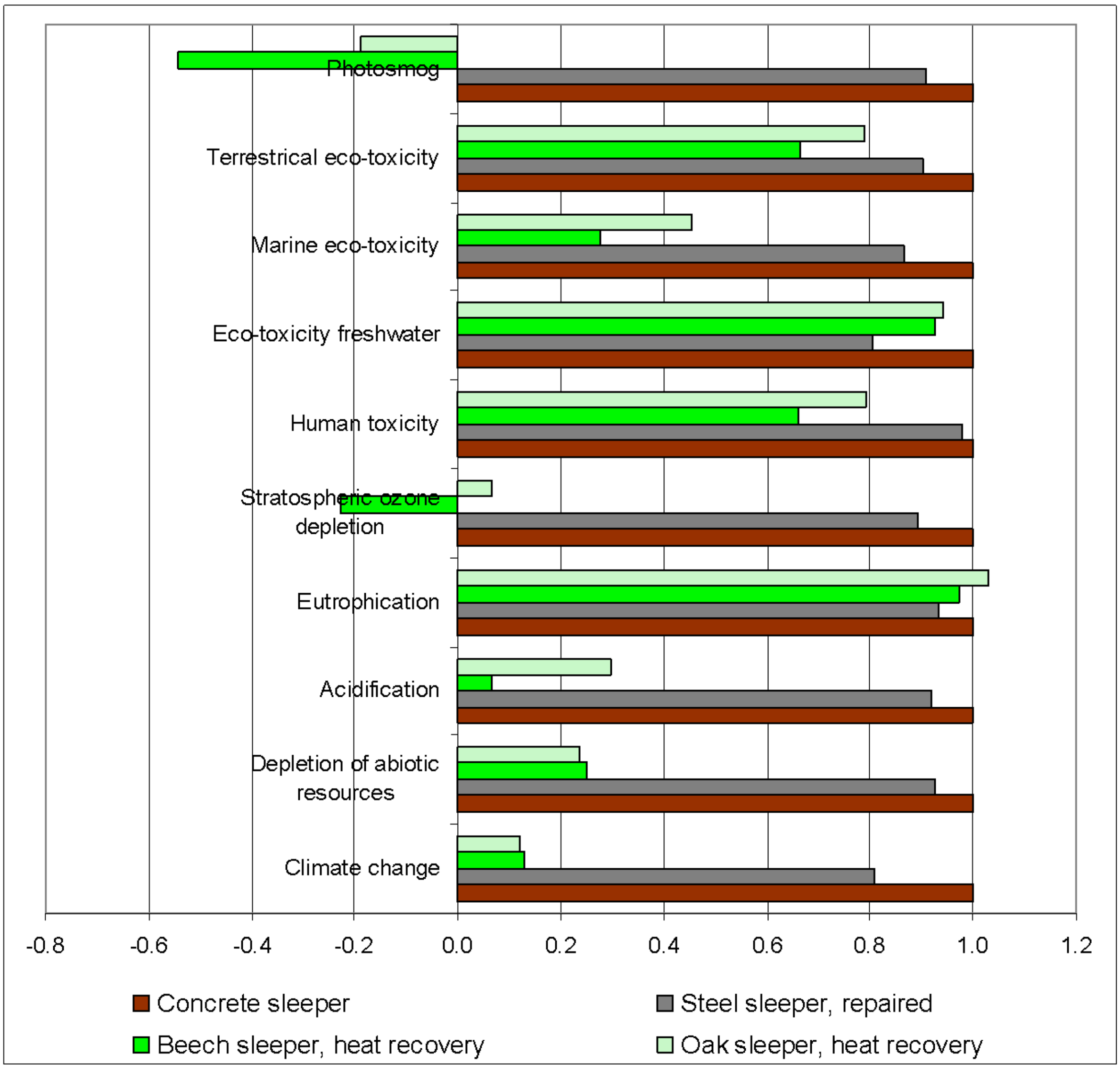

Figure 2.1: Comparison of the environmental impacts of railway sleepers relative to the impacts of the sleeper made from concrete; heat recovery fort he wooden railway sleepers (without the sleeper newly made from steel)

- The environmental impacts of beech and oak wood sleepers do not differ significantly. The slightly lower (oven-dry) weight of oak sleepers and the lower insertion of creosote is compensated with a lower heating value per sleeper and accordingly with a lower substitution effect resulting from thermal utilisation and heat recovery.
- Altogether, switching to the use of creosote grade C according to EN 13991, applied according to DIN 68811:2007-01, has led to a very significant decrease of the environmental impacts of wooden railway sleepers. Under these conditions, the use of creosote now plays a minor role for the ecological profile of wooden railway sleepers.
- The thermal utilisation of wooden sleepers as required by law has turned out to be essential for the favourable environmental characteristics of wooden sleepers.

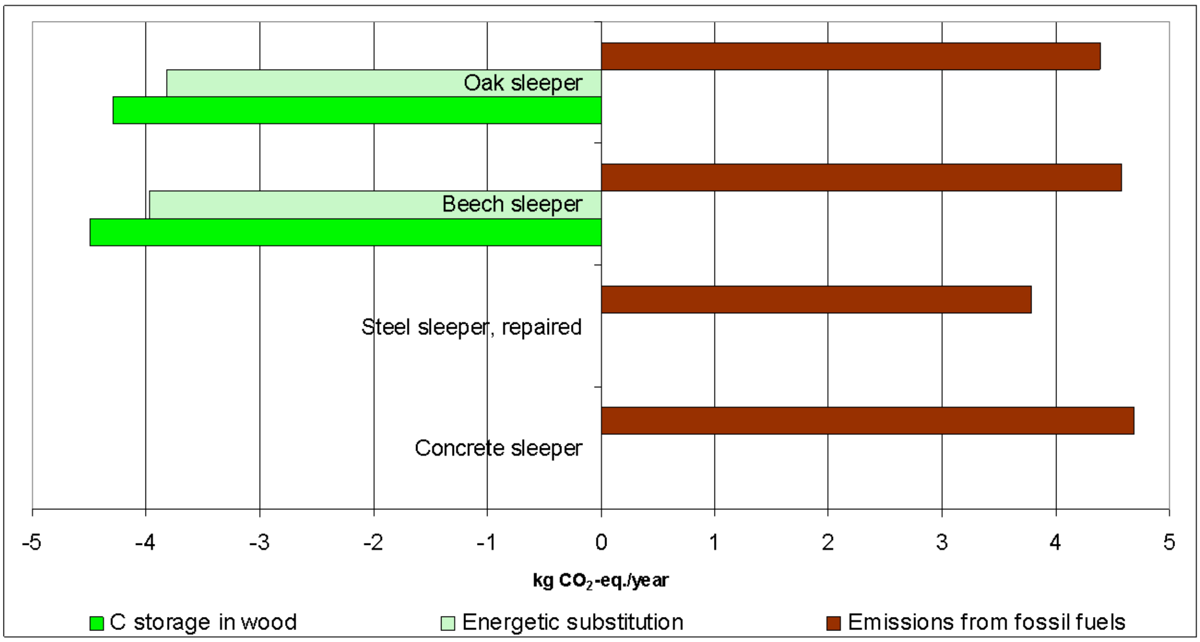

Figure 2.2: **Impacts on climate change of the railway sleepers (without newly produced steel sleepers; carbon storage in wood, energetic substitution and fossil emissions over the life cycle (per year)**

- Over their life cycle, wooden sleepers store about as much CO_2 as carbon, as greenhouse gases are released from fossil sources over the life cycle of a sleeper, including track bed construction and maintenance (Figure 2.2).
- When used consequently for thermal heat recovery – or even preferably in combined heat and power plants – the thermal utilisation of wooden sleepers substitutes for as much CO_2 as is released over the entire life cycle of the wooden sleepers, including track bed construction and maintenance. This means that wooden sleepers made from wood from sustainably managed forests are not only C-neutral with regard to biogenic carbon, but also with regard to CO_2 from fossil sources.

The following strategies can be derived from the results of this LCA for a further improvement of the environmental profile of the sleepers:

- Due to the dominance of the track bed construction and maintenance, every technical measure is suitable for an improvement of the environmental profiles of sleepers that reduce the use of new ballast and its transportation.
- Service life is a decisive factor for the environmental profile of all sleepers. The development and implementation of technical possibilities for prolonging service life or for prolonging the intervals for maintenance is a key strategy for further environmental improvements for all sleepers.
- Several process optimizations have reduced successfully the environmental profile of wooden sleepers. Switching to impregnation oil grade C according to EN 13991 and reducing insertion quantities according to DIN 68811:2007-01 as well as the incineration and energy recovery from wooden sleepers resulting from the German ordinance for waste wood are paying off. As a consequence, the environmental impacts from the mounting material have come into the focus of attention. The reduction of steel quantities, an increased reuse of mounting equipment or even the development of mounting equipment more suited for reuse could help to improve the environmental profile of the wood sleepers further.
- For steel sleepers, recovery is still the key strategy. The production of new sleepers from primary steel or even from recycled steel is associated with a worse environ-

mental profile. Possibilities of reducing steel quantities per sleeper via a change in design could be investigated. Material reductions should, however, not result in a reduced service life.

- Also in the case of concrete sleepers, a reduced use of concrete and reinforcement steel via an adapted design could be investigated. As in the case of steel sleepers, reducing material input should not result in a reduced service life, in a reduced possibility for reuse or in higher maintenance intervals. Also the use of recycled concrete as a substitute for gravel could be investigated, at least in a life cycle assessment.

Various sensitivity analyses have been conducted to test the impact of several methodological decisions and assumptions on the over-all result:

- Steel production and recycling was modelled based on the actual share of recycled steel on the total steel marked, resulting in 37% recycled metal content for steel. As an alternative, the product-specific recycling rate was used, taking into account the recycling efficiency of steel construction products, resulting in a recycled metal content of 85%.
- Swiss electricity mix was used instead of the German electricity mix.
- Carbonatisation of concrete was taken into account as a long-term effect, i.e. the re-absorption of geogenic CO_2 emissions originating from the production of clinker,
- Modified assumptions for the impregnation of wooden sleepers:
    - Mass-based allocation of the coking process, i.e. the coking of 1.38 kg coal is allocated to 1 kg of raw tar (instead of 0.714 kg according to the economic allocation),
    - Filtering efficiency of the air filters in the impregnation plants are assumed to be 95% (instead of 99%),
    - Evaporation of 10% of the inserted creosote over the service life is assumed (instead of 5%).

Based on these sensitivity analysis, the results and conclusions of this study can be considered as robust.