FACULTY OF CIVIL ENGINEERING CTU IN PRAGUE

LCC Wooden track sleepers

Comparative Economic Assessment between **wooden track sleepers** made from Beech and Oak and **Urethane track sleepers**

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Railway Sleepers - Life Cycle Costs

This study deals with the direct comparison of **wooden track sleepers** compared to **urethane track sleepers**. The examined wooden sleepers are made of Beech and Oak. The scope of the presented Life Cycle Cost Analysis (LCC) is to evaluate the influence of certain cost affecting factors by following scenarios:

1. Life cycle costs depending on different analysed periods
2. Life cycle costs depending on decreased service life durations
3. Life cycle costs depending on increased replacement costs
4. Life cycle costs depending on increased disposal costs

The cost of railway sleepers made from various materials may be assessed from the point of view of their effective use throughout their entire life cycle. A life cycle costs analysis of the structure is a suitable tool for this assessment. Quantifying the life cycle costs of sleepers on the basis of relevant input data regarding technical parameters should be an important part of an investor's groundwork for decision making when selecting the optimal technical solution, considering also its **environmental aspects** and especially long-term **economic consequences**.

1. Introduction to Life Cycle Costs

Life cycle costs (LCC) comprise the total costs incurred during the entire life cycle, including costs of acquisition, maintenance and restoration, operation, and life cycle termination [1]. Often, only acquisition costs are considered during a selection process, while the costs of operation, maintenance, restoration, and disposal are disregarded. However, costs incurred in the use phase and during eco-friendly disposal comprise a significant portion of total life cycle costs. A LCC analysis is most beneficial in the preparatory stage of construction, where it can be instrumental to selecting effective solutions [2]. It is important to stress the fact that whole life costs are significantly influenced already in the pre-investment phase of the structure's life cycle, when the structure is being designed and its material characteristics are being considered.

Life cycle costs (LCC) comprise the total costs incurred in the entire life cycle of the structure - which is to say costs incurred in all four phases of the life cycle, pre-investment, investment, operation, and disposal phases. If the analysed period is shorter than the life of the structure, the residual value of the structure is substituted in place of life termination costs**. Life cycle costs (*LCC*)** can be outlined as the sum of the costs of **acquisition (*AC*)**, **operation (*OP*), restoration, maintenance (*MC*)**, and **disposal costs (*DC*)** – see (1) and Fig.1.

$$LCC = AC + OP + MC + DC \quad (1)$$

where

LCC … life cycle costs of the structure in €
AC … acquisition costs of the structure in €
OP … operation costs of the structure in €
MC … maintenance costs of the structure in €
DC … disposal costs of the structure in €

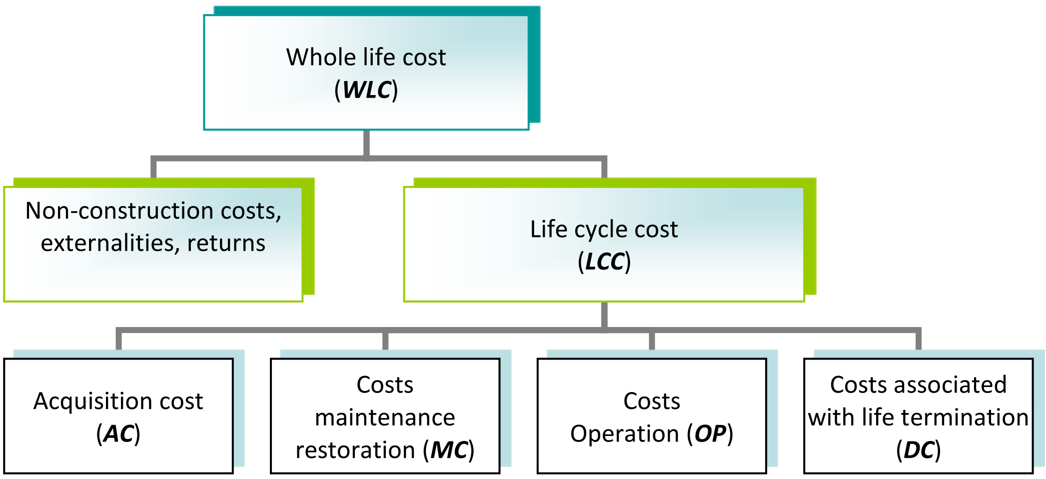

Fig. 1 Life cycle costs structure of the project (in accordance with [1])

The life cycle cost calculation is an economic evaluation method that accounts for all relevant costs incurred in the defined time period while also taking into consideration the time value of money by calculating the net present value (PV). The LCC indicator structure derives from the calculation of the net present value of cash flows. The basic premise of this method is the fact that one monetary unit in the present has more value than the same unit in the future.

The net present value for the analysed period constitutes the present value of future costs incurred during the life cycle of the project. Because the life cycle cost calculation is concerned with costs rather than revenues, it is easier in this case to express costs as positive values. The LCC indicator calculation can be expressed using the following general relationship [2]:

$$LCC = \sum_{t=0}^{T} \frac{C_t}{(1+r)^t} \tag{2}$$

where

LCC	life cycle costs of the structure in €
C_t …	yearly cost in each year of the life cycle of the project in € after subtracting positive cash flows, e.g. residual values of the structure or the value of the land for sale,
r …	discount rate in %/100 (p.a.),
t …	the year of evaluation taking values from *0* to *T*,
T…	the length of the evaluated period in years.

When calculating LCC, it is recommended to use the real discount rate, which excludes the influence of future inflation. Discount rate in the private sector should represent the opportunity costs of capital investment, which may be the interest on an investment loan, lost interest due to a decrease in the total amount in an account, the lost proceeds from an investment, the true return of a capital investment, or the required return rate of business. In the public sector, discount rate may be set centrally for evaluation of public investments, usually between 0% and 4%. A higher discount rate discourages long-term investments, while a lower discount rate supports them. Discount rate is commonly the subject of sensitivity analysis. The value of the discount rate may be derived for instance from the financial bank rate recommended by the European Commission for public project evaluation

The LCC indicator is a cost criterion, a lower value is favourable to the investor. Information key to LCC modelling includes information about the development of costs in each phase of the life cycle, the possibilities and ways of influencing them, and information about the life of the structure and equipment. Publicly funded construction project investors are aided by optimised life cycle costs of structures in achieving a greater value for money and observing the 3E principle (effectiveness, efficiency, economics), which are key for public finances. The current version of the public procurement act [3] specifies life cycle costs as one possible application of the basic indicator “economic advantageousness of tenders” for the selection of a public procurement supplier.

2. Analysis of life cycle cost of railway sleepers

Life cycle costs must be quantified with knowledge of the technical parameters of structures and equipment, because the choice of materials affects not only acquisition costs but also operating costs, restoration costs, and disposal costs.

A. Determining the goal of the LCC analysis

The aim of the LCC is to illustrate the increased economic efficiency of using impregnated wooden sleepers in comparison to urethane sleepers.

B. Determining the scope of the LCC analysis

It is a detailed analysis of the life cycle costs for material variants of key construction, i.e. railway sleepers. Therefore, the life cycle costs of the entire construction project are not evaluated. Commonly used impregnated wood sleepers made from beech and oak are evaluated, as well as a relatively new option, urethane sleepers. Only a few specific costs comprise the bulk of the total life cycle cost of sleepers, mainly acquisition costs, removal and installation costs when replacing a sleeper, and disposal costs. These cost items are relevant to the evaluation. Other cost items are irrelevant.

C. Definition of key parameters

Key parameters are the life of the evaluated sleepers, the acquisition costs, removal and installation costs when replacing a sleeper, and disposal costs. The acquisition and disposal costs differ significantly between the evaluated variants. Therefore, they warrant increased consideration even during the design phase of the project.

The number of sleepers replaced during a track overhaul is also a key parameter.

D. Determining variants for analysis

Three material variants of railways sleepers with comparable bulk density and mechanical parameters are analysed. Commonly used impregnated wooden sleepers made from beech and oak and urethane sleepers are evaluated.

E. Gathering data pertaining to the evaluated variants

Only a few specific costs comprise the bulk of the total life cycle cost of sleepers, mainly acquisition costs, removal and installation costs when replacing a sleeper, and disposal costs.

The costs of replacing an element are comparable for all material variants being evaluated, predominantly wage expenses and compensations for track closures (EUR 150 – 500 apiece, depending on location and closure conditions).

The acquisition costs of a single impregnated wood sleeper are EUR 70 for beech and EUR 100 for oak. Urethane sleeper acquisition costs are significantly higher, EUR 400 apiece.

Disposal of impregnated wood sleepers constitutes a cost in summer (EUR 50 per ton) and an earning in winter (EUR 30 per ton), depending on supply and demand; in the long-term, with a time horizon of 10 years, disposal costs can be considered to be zero. Urethane sleeper disposal costs are higher, EUR 180 per ton. The evaluated variants have a comparable bulk density, 10 – 11 pcs per ton.

The life of the evaluated variants is key for the life cycle cost analysis. High-quality impregnated beech and oak sleepers can be considered to have a technical life of 25 - 30 years, in accordance with the life of the rail and baseplates (30 years), evidenced in completed construction projects. The planned technical life of urethane sleepers is 50 years. Due to the short history of use of these products, data indicating their true technical life in use is not available.

F. Economic evaluation of the variants

Table 1 shows LCC (life cycle costs) of one railway sleeper with a life of 30 years for impregnated wood sleepers and 50 years for urethane sleepers across an analysed period of 50 years.

Table 1 LCC for an analysed period of 50 years

Variant	Impregnated Beech sleeper	Impregnated Oak sleeper	Urethane sleeper
Acquisition costs (€)	70	100	400
Replacement costs (€)	150	150	150
Disposal costs (€)	0	0	18
Service life (years)	*30*	*30*	*50*
LC (years)	*50*	*50*	*50*
LCC (€)	**587**	**667**	**1,118**
As a percentage	**52%**	**60%**	**100%**

It becomes apparent, for an analysed period of 50 years with **equal replacement costs** in combination with **usual disposal costs** the LCC (life cycle costs) of wooden sleepers are **48 %** (Beech) respectively **40 %** (Oak) **less** compared to the LCC of urethane sleepers.

Table 2 shows LCC (life cycle costs) of one railway sleeper with a life of 30 years for impregnated wood sleepers and 50 years for urethane sleepers across an analysed period of 75 years.

Table 2 LCC for an analysed period of 75 years

Variant	Impregnated Beech sleeper	Impregnated Oak sleeper	Urethane sleeper
Acquisition costs (€)	70	100	400
Replacement costs (€)	150	150	150
Disposal costs (€)	0	0	18
Service life (years)	*30*	*30*	*50*
LC (years)	*75*	*75*	*75*
LCC (€)	**770**	**875**	**1,402**
As a percentage	**55%**	**62%**	**100%**

It becomes apparent, for an analysed period of 75 years with **equal replacement costs** in combination with **usual disposal costs** the LCC (life cycle costs) of wooden sleepers are **45 %** (Beech) respectively **38 %** (Oak) **less** compared to the LCC of urethane sleepers.

Table 3 shows LCC (life cycle costs) of one railway sleeper with a life of 30 years for impregnated wood sleepers and 50 years for urethane sleepers across an analysed period of 100 years.

Table 3 LCC for an analysed period of 100 years

Variant	Impregnated Beech sleeper	Impregnated Oak sleeper	Urethane sleeper
Acquisition costs (€)	70	100	400
Replacement costs (€)	150	150	150
Disposal costs (€)	0	0	18
Service life (years)	*30*	*30*	*50*
LC (years)	100	100	100
LCC (€)	**953**	**1,083**	**1,686**
As a percentage	**57%**	**64%**	**100%**

It becomes apparent, for an analysed period of 100 years with **equal replacement costs** in combination with **usual disposal costs** the LCC (life cycle costs) of wooden sleepers are **43 %** (Beech) respectively **36 %** (Oak) **less** compared to the LCC of urethane sleepers.

In Tables 1, 2 and 3, the LCCs are aliquoted according to the length of the analysed period. This means, for example, in Table 3 (analysed period of 100 years), for both wooden sleepers (service life 30 years), a proportional part of the costs for the acquisition and replacement of the sleeper corresponding to 10 years is added.

In the following graphs, in contrast to Tables 1, 2 and 3, only the costs that are likely to be incurred are plotted (i.e. without the addition of aliquot costs).

All following analyses are considered with an analysed period of 100 years.

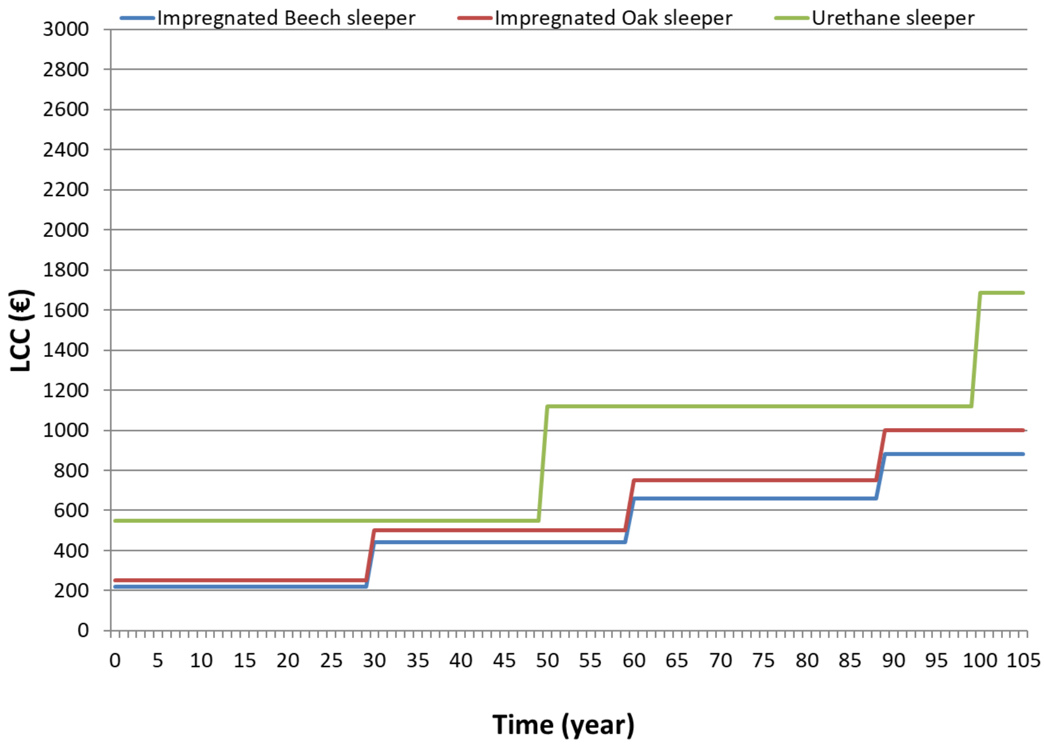

Figure 2 LCC for an analysed period of 100 years

Figure 2 shows, with the parameters above, the LCC (life cycle costs) of impregnated wooded sleepers made of Beech and Oak are **below** the LCC (life cycle costs) of urethane sleepers for the **whole duration** of the analysed period of 100 years.

G. Sensitivity analysis

a) Sensitivity analysis of the sleeper replacement cost value

Table 4 shows LCC (life cycle costs) of one railway sleeper with a life of 30 years for impregnated wooden sleepers and 50 years for urethane sleepers across an analysed period of 100 years. In this case the replacement costs are considered to be at the upper limit, i.e. EUR 500 apiece, to determine the **influence of replacement costs** on the LCC.

Table 4 LCC for increased replacement costs

Variant	Impregnated Beech sleeper	Impregnated Oak sleeper	Urethane sleeper
Acquisition costs (€)	70	100	400
Replacement costs (€)	***500***	***500***	***500***
Disposal costs (€)	0	0	18
Service life (years)	*30*	*30*	*50*
LC (years)	100	100	100
LCC (€)	**2,470**	**2,600**	**2,736**
As a percentage	**90%**	**95%**	**100%**

It becomes apparent, for an analysed period of 100 years with **replacement costs at the upper limit** in combination with usual disposal costs and a usual service life the LCC (life cycle costs) of wooden sleepers are **10 %** (Beech) respectively **5 %** (Oak) **less** compared to the LCC of urethane sleepers.

In Table 4, the LCC are aliquoted according to the length of the analysed period. This means, for both wooden sleepers (service life 30 years), a proportional part of the costs for the acquisition and replacement of the sleeper corresponding to 10 years is added. In the following Figure 3, only the costs that are likely to be incurred are plotted (i.e. without the addition of aliquot costs).

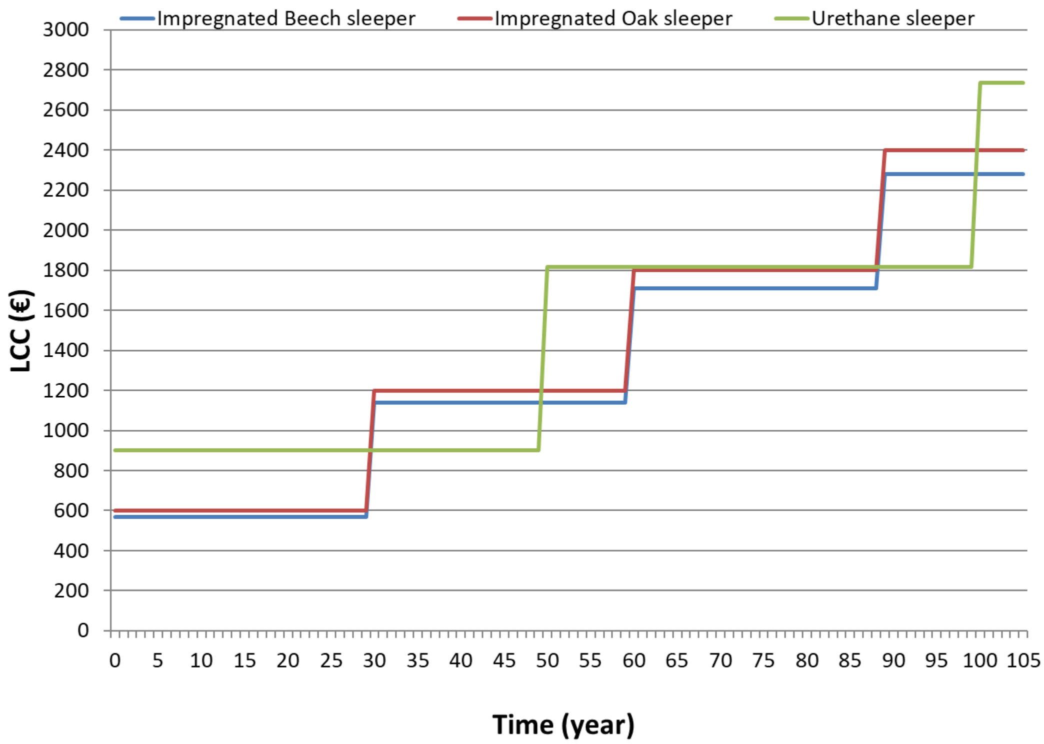

Figure 3 LCC for increased replacement costs

Figure 3 shows, with the parameters above, the LCC (life cycle costs) of impregnated wooded sleepers made of Beech and Oak are **below** the LCC (life cycle costs) of urethane sleepers for the whole duration of the analysed period of 100 years except for the time between the first replacement of wooden sleepers and the first replacement of urethane sleepers (year 30 – 49).

b) **Sensitivity analysis of sleeper life**

Table 5 shows LCC (life cycle costs) of one railway sleeper with a life of 15 years for impregnated wooden sleepers and 30 years for urethane sleepers across an analysed period of 100 years, to determine the **influence of service life** on the LCC.

It becomes apparent, for an analysed period of 100 years with **equal replacement costs** in combination with **usual disposal costs** and a **decreased service life** the LCC (life cycle costs) of wooden sleepers are **31 %** (Beech) respectively **22 %** (Oak) **less** compared to the LCC of urethane sleepers.

Table 5 LCC for decreased service life

Variant	Impregnated Beech sleeper	Impregnated Oak sleeper	Urethane sleeper
Acquisition costs (€)	70	100	400
Replacement costs (€)	150	150	150
Disposal costs (€)	0	0	18
Service life (years)	***15***	***15***	***30***
LC (years)	100	100	100
LCC (€)	**1,687**	**1,917**	**2,443**
As a percentage	**69%**	**78%**	**100%**

In Table 5, the LCC are aliquoted according to the length of the analysed period. This means, for both wooden sleepers (service life 15 years), a proportional part of the costs for the acquisition and replacement of the sleeper corresponding to 10 years is added. For urethane sleeper (service life 30 years), a proportional part of the costs for the acquisition, replacement, and disposal of the sleeper corresponding to 10 years is added. In the following Figure 4, only the costs that are likely to be incurred are plotted (i.e. without the addition of aliquot costs).

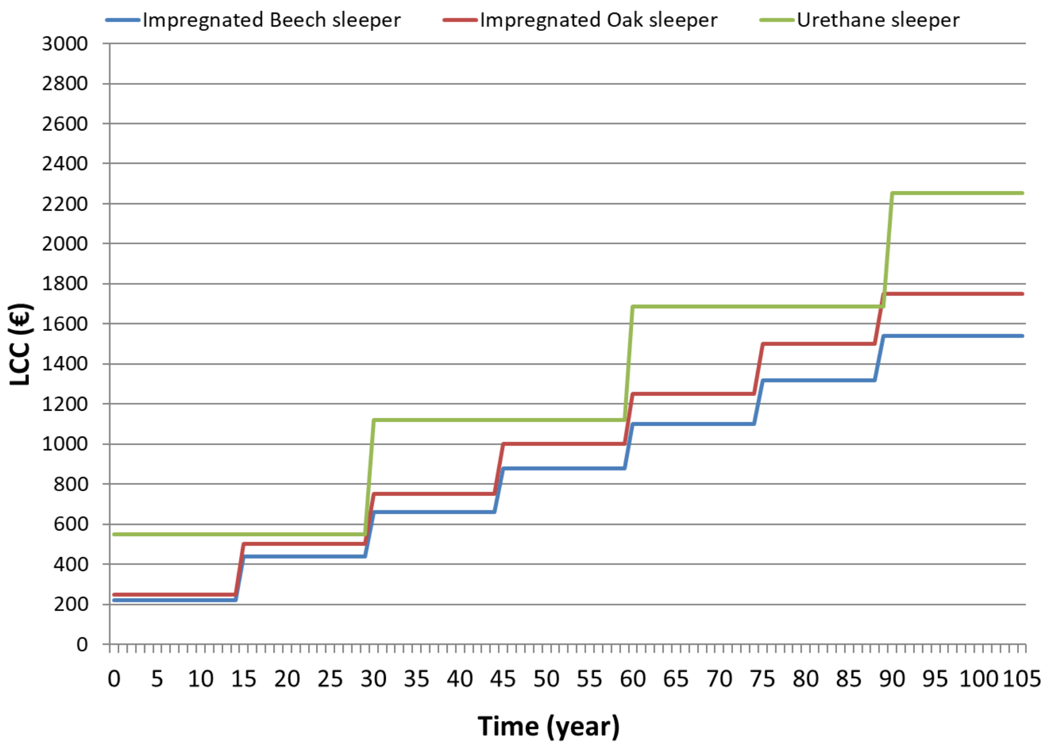

Figure 4 LCC for decreased service life

Figure 4 shows, with the parameters above, the LCC (life cycle costs) of impregnated wooded sleepers made of Beech and Oak are **below** the LCC (life cycle costs) of urethane sleepers for the **whole duration** of the analysed period of 100 years.

c) **Sensitivity analysis of disposal costs**

Table 6 shows LCC (life cycle costs) of one railway sleeper with a life of 30 years for impregnated wooden sleepers and 50 years for urethane sleepers across an analysed period of 100 years. Disposal costs of impregnated wooden sleepers are considered to be the summer value, i.e. EUR 5 apiece. Disposal costs of urethane sleepers are considered to be double, i.e. EUR 36 apiece, to determine the **influence of disposal costs** on the LCC.

Table 6 LCC for increased disposal costs

Variant	Impregnated Beech sleeper	Impregnated Oak sleeper	Urethane sleeper
Acquisition costs (€)	70	100	400
Replacement costs (€)	150	150	150
Disposal costs (€)	***5***	***5***	***36***
Service life (years)	30	30	50
LC (years)	100	100	100
LCC (€)	**970**	**1,100**	**1,722**
As a percentage	**56%**	**64%**	**100%**

It becomes apparent, for an analysed period of 100 years with equal replacement costs in combination with **increased disposal costs** and a usual service life the LCC (life cycle costs) of wooden sleepers are **44 %** (Beech) respectively **36 %** (Oak) **less** compared to the LCC of urethane sleepers.

In Table 6, the LCC are aliquoted according to the length of the analysed period. This means, for both wooden sleepers (service life 30 years), a proportional part of the costs for the acquisition, replacement, and disposal of the sleeper corresponding to 10 years is added. In the following Figure 5, only the costs that are likely to be incurred are plotted (i.e. without the addition of aliquot costs).

Figure 5 shows, with the parameters above, the LCC (life cycle costs) of impregnated wooded sleepers made of Beech and Oak are **below** the LCC (life cycle costs) of urethane sleepers for the **whole duration** of the analysed period of 100 years.

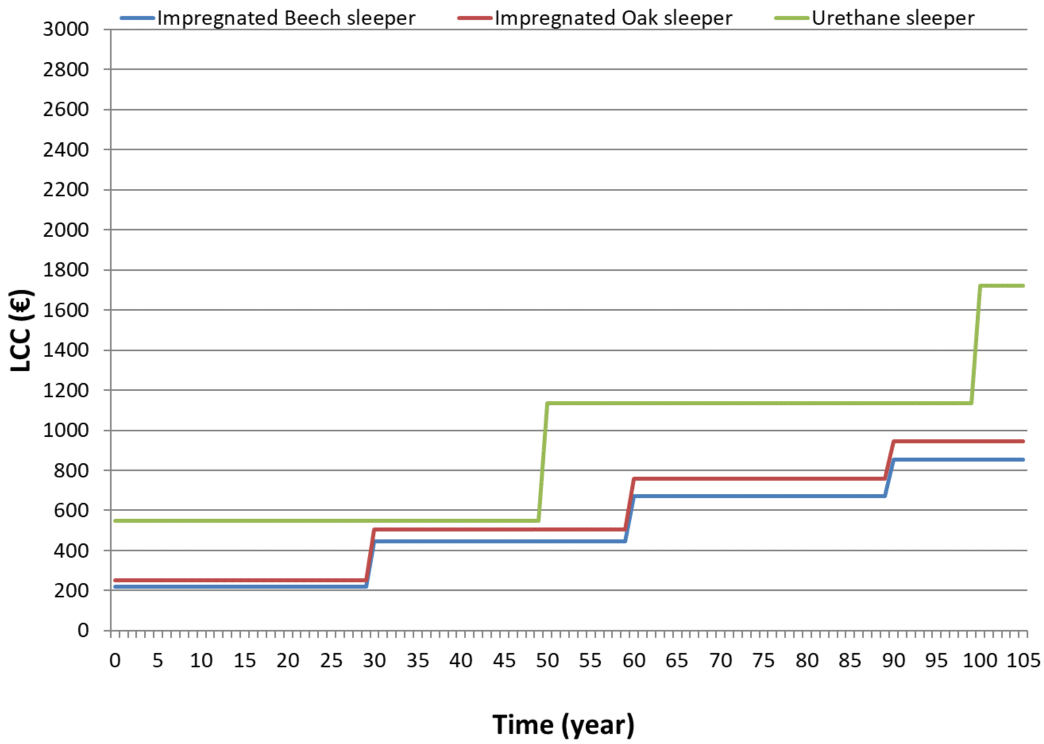

Figure 5 LCC for increased disposal costs

3. Conclusion

Based on the results of the implemented LCC following conclusions can be made:

- Only a few specific costs comprise the bulk of the total life cycle cost of sleepers, mainly acquisition costs, removal and installation costs when replacing a sleeper, and disposal costs. The costs of replacing an element are comparable for all material variants being evaluated, predominantly wage expenses and compensations for track closures (EUR 150 – 500 apiece, depending on location and closure conditions).
- The acquisition and disposal costs differ significantly. Acquisition costs of urethane sleepers are significantly higher; quadruple in comparison to impregnated wood oak sleepers and nearly six times higher than for impregnated beech sleepers.
- The disposal of impregnated wood sleepers constitutes a negligible cost in comparison to the disposal of urethane sleepers.
- The use of wooden sleepers is for all evaluated scenarios more cost effective, than the use of urethane sleepers.
- With a life time (life) of 30 years, the installation of wooden sleepers (both beech and oak) over a LC up to 100 years, is more cost effective compared to urethane sleepers with a life time of 50 years
- At increased replacement costs of 500€, the installation of wooden sleepers is still more cost effective compared to the use of urethane sleepers.

- Even at a reduced life span of 15 years, the installation of wooden sleepers (both beech and oak) is more cost effective, compared to urethane sleepers with a reduced life span of 30 years.
- Even after increasing disposal costs for wooden sleepers and urethane sleepers, the wooden sleepers remained more cost efficient for low as well as high replacement costs

On average, over all evaluated scenarios, the use of wooden sleepers (beech and oak) is 34% more cost efficient than using urethane sleepers.

The service life of the evaluated variants is key for the life cycle cost analysis. High-quality impregnated beech and oak sleepers can be considered to have a technical life of 25 - 30 years. The service life of the track surface is about 30 years. The stated time depends on the frequency of operation and the axle load. After this time, the rails are often changed due to wear and the baseplate is also replaced or reconstructed.

The planned technical life of urethane sleepers is 50 years. Due to the short history of use of these products, there is no data available indicating their true technical life in use. To this day, the system of ecological disposal of urethane sleepers is still not known.

[1] ISO 15686-5 (730951) Buildings and constructed assets - Service-life planning. part 5: Life-cycle costing, Prague: ÚNMZ, October 2018

[2] Schneiderová Heralová, R.: *Sustainable procurement of construction (economic aspects)*. 1st edition. Prague: Wolters Kluwer ČR, a. s., 2011. 256 s. ISBN 978-80-7357-642-4.

[3] Act No. 134/2016 Coll., on public procurement, as amended