# Life cycle assessment of high-performance railway infrastructures

Analysis of superstructures in tunnels and on open tracks

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**ABSTRACT:** Almost 25 % of environmental pollution, measured by the indicator of global greenhouse emissions, is emitted by transport. A change in the mobility behavior of the population seems inevitable so that the 17 UN sustainable development goals (SDGs) or the goals of the EU commission's green deal can be achieved. Accordingly, the existing infrastructure must transform into a sustainable transport infrastructure in the long term. The modern railway transport systems and the emerging Trans-European Transport Network (TEN-T) at the Brenner-Corridor and across whole Europe, respectively, make a significant contribution to achieving a future-proof and sustainable built environment. However, such projects place great requirements on engineers, the construction, the materials used and the maintenance. Therefore, continuous improvements and optimizations of designs, materials, construction and maintenance processes are essential to achieve long term sustainability.

This master thesis analyzes different railway superstructures with the method of a life cycle assessment using the example of the emerging high-performance infrastructure at the Brenner base tunnel and the Brenner corridor in the tunnel and on the open track. The study investigates all relevant life cycle stages from production (A1-A3) to the disposal of the superstructure components in the stage (C1-C4).

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**KEYWORDS:** life cycle assessment, construction operation, railway, superstructures, slab track, ballasted track, transport infrastructure

## 1 INTRODUCTION

The idea of sustainability has also taken part in the construction industry. The call for sustainable development from an ecological, economic and social point of view is becoming louder and louder. [1]

But how does sustainable building work? Sustainable building means that the entire building is investigated, every detail/ every building product is analyzed and considered over the entire life cycle from the procurement of raw materials through the construction and the use to the stage of disposal and removal of the object and therefore resources and energy quantities can be optimally used, reduced and saved in every life cycle stage. [2, 3]

However, sustainability does not only play an essential role in the building sector, but also in the infrastructure sector, where ecological, economic and social assessment is applied and will play an even more important role in the future in view of the expectations with regard to climate change, energy transition, mobility transition, decarbonization, etc. The thematically range of today's sustainable infrastructure reaches from traditional points of contact such as transport and resource consumption to the issues of environmental quality and human health. [4-6]

## 2 THE LIFE CYCLE ASSESSMENT

The Life Cycle Assessment (LCA) tool is an internationally standardized method for assessing the environmental effects of products and product systems over their life cycle. The LCA-method offers a transparent, verifiable and comprehensible system for describing and evaluating environmental impacts.

## 3 INVESTIGATED SUPERSTRUCTURES

In the course of this study, different railway track systems were analyzed. Three ballasted tracks with different concrete sleepers (K1, L2 & L17) and one slab track system (STA ÖBB-PORR) from Austrian manufacturers were evaluated from an ecological point of view on the open track and in the tunnel.

### 3.1 Superstructures

The superstructure includes all components of the track (rail- and switch-linkage, rails, sleepers/ track supporting plates, rail fastenings, underlay plates and intermediate layers), the bedding of the track grid (e.g. ballasted track) and the protective layers. [7]

### 3.2 Differences between ballasted track and slab track

The differences between the two railway superstructures lie in the bedding. At the ballasted track, the track grid is floating in the ballast bed. This means that there is no fixed anchoring of the sleepers to the ballast. The loads caused by the rolling wheel are transferred to the subgrade via the rails, sleepers and ballast. [7]

In contrast, the slab track counterpart uses concrete slab tracks to transfer the load. The load ablation is therefore more areal and homogeneous. A durable and low-maintenance track is therefore guaranteed. [7, 8]

The different properties of the superstructures result in different applications in practice. The ballasted track is mainly used on open tracks due to its simple manufacture and maintenance. The slab track is in Austria only used in tunnels of greater length due to its more complex construction. [7, 8]

## 4 LIFE CYCLE ASSESMENT OF SELECTED SUPERSTRUCTURES

### 4.1 General

The mentioned superstructures above were analyzed from an ecological point of view for different periods of time (80 and

200 years) over the entire life cycle (cradle to grave) using the methodology according to EN 15804 + A2 and the procedure according to the ISO standards. The results were broken down to the component level in order to show the optimization potentials in the best possible way. In addition, a variation of minimum and maximum lying times was carried out for a better illustration of different route conditions.

The global warming potential (GWP), acidification potential (AP) and nonrenewable cumulative energy demand (NRCED) were used as impact indicators. For the sake of clarity, the presentation of results in this form is limited to the GWP.

## 4.2 Results

The results have shown that there is potential for optimization above all in the stage of utilization, since more frequent modernization cycles and the associated rebuilding of superstructure elements account for a significant proportion of the overall environmental impact (see Fig. 4-1).

The environmental impact could be reduced by optimizing the products for a longer service life, thus resulting in longer maintenance intervals. I.e., in stage B2-B5 there is a reduction of new production.

The possible increase in environmental impact in the stage of production (A1-A3) due to the changes in design will be compensated in the longer term in the stage of use (B2-B5) and would result in overall savings.

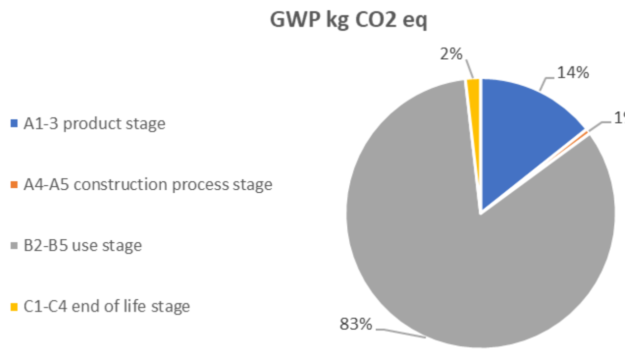
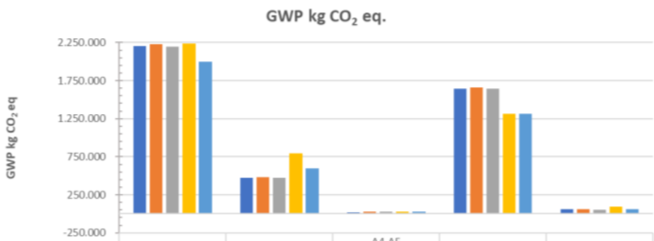



Fig. 4-1: percentage distribution of GWP over the life cycle of a concrete sleeper

Fig. 4-2 illustrates the effects on the environment for each superstructure variant once again. It can be seen that, due to its design, the slab track initially emits significantly more kg CO2 eq. than the ballasted track. However, it is evident that the durability of the product results in fewer environmental impacts over time.

In view of the long period under consideration, the life cycle stages of construction and disposal account for only a marginal share of the environmental impacts and amount to about 3 % overall.




| | Total absolute | A1-3 product stage | A4-A5 construction process stage | B2-B5 use stage | C1-C4 end of life stage |
|---|---|---|---|---|---|
| Leube K1 | 2.200.496 | 473.670 | 20.209 | 1.646.498 | 60.119 |
| Maba L2 | 2.228.231 | 482.591 | 24.728 | 1.659.845 | 61.066 |
| Maba L17 | 2.197.628 | 475.725 | 24.994 | 1.640.767 | 56.143 |
| FF STA freie Strecke | 2.237.571 | 798.656 | 29.342 | 1.311.703 | 97.870 |
| FF STA Tunnel | 2.000.844 | 599.166 | 28.754 | 1.311.703 | 61.222 |

Fig. 4-2: GWP of the superstructures per life cycle stages

There is also potential for improvement at the component level. This includes, for example, the rails, which have considerable impact on the environment during the stage of production. Ecological improvements in steel production would be conceivable.

The concrete structures could be optimized in terms of cement content and clinker content, provided that the same strength and durability can be guaranteed. For further information on potentials, please refer to the long vision.

# 5 CONCLUSION

In summary, it can be claimed that the present study shows the basic optimization potentials and outlines the most diverse topics. Of course, not all questions could be answered in detail or all possible relevant facts/ findings could be analyzed in detail in course of this work, as they would go beyond the scope of this master thesis. However, these findings would have to be further verified in one or more follow-up studies. In addition, it would be interesting to include the monetary and social impacts in a further analysis in order to be able to present a holistic sustainability assessment.

# 6 OUTLOOK

In conclusion, any change that contributes to a future-proof and sustainable built environment is valuable for generations in the future and our living space. In this respect, the railway as an environmentally friendly means of transport already plays a major role in a sustainable European transport infrastructure and will continue to do so in the foreseeable future.

# 7 REFERENCES

[1] S. Friedrichsen, Nachhaltiges Planen, Bauen und Wohnen: Kriterien für Neubau und Bauen im Bestand, 2. Aufl. Berlin: Springer Vieweg, 2018. [Online]. Verfügbar unter: http://www.springer.com/

[2] P. Indinger, „Nachhaltiges Bauen: Die grüne Revolution", Redshift, 13. Mai 2021, 2021. [Online]. Verfügbar unter: https://redshift.autodesk.de/nachhaltiges-bauen/. Zugriff am: 12. April 2022.

[3] IBU - Institut Bauen und Umwelt e.V., Nachhaltiges Bauen | Nachhaltigkeit im Bauwesen. [Online]. Verfügbar unter: https://ibu-epd.com/nachhaltiges-bauen/ (Zugriff am: 12. April 2022).

[4] NGS Global, Infrastruktur und Nachhaltigkeit. [Online]. Verfügbar unter: https://www.ngs-global.com/index.php/de/expertise/branchen/infrastruktur-und-nachhaltigkeit?dt=1649763540427 (Zugriff am: 12. April 2022).

[5] S. Langsdorf, M. Hinzmann, A. Araujo, M. Hirschnitz-Garbers und I. Merbold, „Transformation hin zu nachhaltigen, resilienten Infrastrukturen (TRAFIS II)", 2022. [Online]. Verfügbar unter: https://www.ecologic.eu/de/17171

[6] T. Zinke, „Nachhaltigkeit von Infrastrukturbauwerken". Dissertation, Fakultät für Bauingenieur-, Geo- und Umweltwis-senschaften; Karlsruher Institut für Technologie, Karlsruher Institut für Technologie (KIT).

[7] Univ.-Prof. Dipl.-Ing. Dr. Günter Prager, „Infrastruktur Schiene: Studienblätter zur Vorlesung", Universität Innsbruck, 2021.

[8] Univ.-Prof. Dipl.-Ing. Dr. Günter Prager, „Hochleistungsbahnen: Studienblätter zur Vorlesung", Universität Innsbruck, 2021.