Sustainability in Conventional Tunnelling

An LCA-Based Assessment of Austrian Transport Infrastructure Tunnels

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ABSTRACT: This master's thesis presents a life cycle assessment (LCA) of conventional tunnelling according to the New Austrian Tunnelling Method (NATM) to address the lack of environmental benchmark data for Austrian transport infrastructure tunnels. Based on the analysis of life cycle stages A1–A5, environmental benchmark values are derived for different tunnel types, and key material- and process-related optimisation potentials are identified. The results provide a basis for simplified sustainability assessments and life cycle-based decision support during early project phases.

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KEYWORDS: Conventional Tunnelling, New Austrian Tunnelling Method, Life Cycle Assessment, Sustainability

1 INTRODUCTION

The sustainability performance of transport infrastructure projects is largely determined during the early project phases. In particular, alignment and design-related decisions regarding the location and implementation of transport routes or tunnel structures influence the required material consumption, construction and excavation processes, as well as maintenance efforts throughout the entire life cycle. As the transport sector is responsible for around 30% of Austria's national greenhouse gas (GHG) emissions and more than half of the annual domestic material consumption of approximately 143 million tonnes is attributed to the construction sector, tunnelling represents a significant opportunity for reducing environmental impacts, accounting for an estimated share of around 4.2% of national GHG emissions [1, 2].

However, the early integration of sustainability assessments is often hindered in practice by the high complexity of tunnelling, geotechnical uncertainties, and the currently limited availability of applicable and representative data bases for Austrian conditions.

2 OBJECTIVE AND METHODOLOGY

This master's thesis addresses this research gap through a life cycle assessment (LCA) of conventional tunnelling according to the New Austrian Tunnelling Method (NATM). The aim is to develop environmental benchmark values for Austrian transport infrastructure tunnels in order to enable a simplified life cycle-oriented sustainability assessment during early project phases.

To achieve a representative assessment, averaged parameters for construction processes, construction and auxiliary materials, as well as logistics chains were applied. Since detailed geological information is often unavailable during early project phases, the geotechnical conditions were simplified into three categories: "difficult excavation conditions", "moderate excavation conditions" and "easy excavation conditions". This classification is based on the matrix-based categorisation of excavation classes according to ÖNORM B 2203-1 and represents different requirements regarding excavation, support measures and inner lining.

Typical Austrian transport infrastructure tunnels with the following cross-sections were investigated:

- double-track and single-track railway tunnels,
- two-lane and single-lane road tunnels,
- walkable and vehicle-accessible cross-passages.

The assessment was carried out in accordance with ÖNORM EN 17472 and includes the life cycle modules A1–A5. All relevant tunnel construction activities from excavation to the construction of the inner lining were considered, including the associated transport, energy and disposal processes.

The permanent material input of the future structure is assigned to the material production stages A1–A3, while the transport of these materials to the construction site is considered within transport stage A4 [3]. Temporary materials, auxiliary materials, process-related energy consumption and associated transport processes are assigned to construction stage A5. In addition, A5 includes the construction site energy supply through lighting and ventilation, the operation of the tunnel construction equipment, its mobilisation and demobilisation, as well as the disposal of excavated material (see Fig. 2-1).

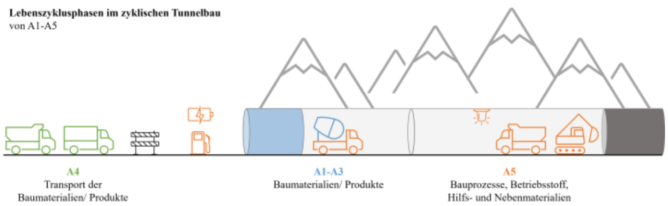

Fig. 2-1: Life cycle stages in conventional tunnelling

3 RESULTS

The results show that the material production stage (A1–A3) and the construction stage (A5) represent the main contributors to the environmental impacts of tunnelling. The distribution of impacts is significantly influenced by the geological conditions and the respective tunnel type. On average, approximately 56–73% of the environmental impacts are attributed to material production, while the construction stage accounts for 25–42%. In contrast, the transport stage (A4) contributes only a minor share of approximately 1–3%.

With increasing geotechnical challenges, the required excavation effort, the extent of support measures and the required concrete volumes for the inner lining increase (see Fig. 3-1). The inner lining represents the largest individual contributor, accounting for approximately 40–52% of the total global warming potential (total GWP) across the analysed life cycle stages. This is mainly attributed to the high quantities of structural concrete and the required steel reinforcement under more demanding geological conditions. In addition, shotcrete used for support measures represents a significant influencing factor, particularly under easily excavatable geological conditions due to the increased support requirements.

GWP-gesamt [t CO_2-Äq.] pro Meter Tunnel je Geologie und Tunnelart

Bahntunnel				
schwer lösbar		9,7		7,5
mittel lösbar		14,0		10,3
leicht lösbar		19,6		13,7
Mittelwert		14,4		10,5
Straßentunnel				
schwer lösbar		9,6		7,4
mittel lösbar		13,8		10,2
leicht lösbar		19,4		13,6
Mittelwert		14,3		10,4
Querschläge				
schwer lösbar		5,3		3,2
mittel lösbar		6,6		4,5
leicht lösbar		7,8		5,5
Mittelwert		6,6		4,4

Fig. 3-1: Results for total GWP by geology and tunnel type

The analysis of excavation processes further shows that environmental impacts depend on the applied excavation method. While drill-and-blast excavation is primarily influenced by diesel consumption and explosives, mechanical excavation is increasingly affected by the energy demand of the equipment used.

The results demonstrate that material- and process-related optimisation measures, such as improved concrete mixtures and enhanced utilisation of excavated material, offer significant potential for reducing environmental impacts [4, 5]. The derived benchmark values for the investigated tunnel types enable a comparative assessment of different transport infrastructure tunnels under Austrian conditions.

4 CONCLUSION

The results of this master's thesis demonstrate that an early integration of life cycle assessment can make a significant contribution to the sustainable planning of transport infrastructure tunnel structures. The developed benchmark values provide a practical basis for estimating environmental impacts during early project phases and for comparing different design options with regard to their sustainability performance.

Through the systematic assessment of various tunnel types and geotechnical conditions, it was demonstrated that the environmental performance of tunnel structures strongly depends on project-specific boundary conditions. The derived indicators enable a simplified evaluation of future projects and support life cycle-oriented decision-making in Austrian tunnelling practice.

At the same time, the study highlights that a comprehensive sustainability assessment requires the consideration of additional aspects beyond the construction of the tunnel structure itself (A1–A5). The results therefore provide a basis for further investigations and future optimisation approaches in the field of sustainable tunnelling.

5 OUTLOOK

Future studies should extend the assessment to additional life cycle stages, such as operation, maintenance and end-of-life, in order to enable a comprehensive evaluation of tunnel infrastructure. Furthermore, a complete environmental assessment of transport infrastructure projects should include the modelling of road or railway superstructure elements as well as the technical equipment of the tunnel. This would allow the entire life cycle of a transport facility to be represented and enable a more comprehensive evaluation of the interactions between the structure, operation and use.

In addition, material circularity through the reuse of excavated material, as well as material- and process-related optimisation measures (e. g. clinker-reduced concrete mixtures), offer significant potential for reducing environmental impacts.

For practical application, further automation of LCA approaches and their integration with digital models should be pursued. The combination of environmental impacts and life cycle costs (LCA and LCC) represents another important future approach to planning sustainable tunnel structures in accordance with evolving European sustainability assessment requirements.

6 REFERENCES

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