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Environmental Impacts of Railway Tunnel Construction & Operation

Tunnel Cross-Section vs. Traction Energy Demand

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Introduction

A strong increase in demand for rail transportation of goods and passengers could be observed in Switzerland during the past decades, with several lines having reached their capacity limit. The Swiss Federal Railways have launched several infrastructure projects to address these capacity constraints and the expected further increase [1, 2, 3].

The planned railway tunnel between the cities of Zurich and Winterthur represents a central element within these projects. Figure 1 provides a schematic overview of the projected tunnel.

The construction of concrete intensive infrastructure such as tunnels or bridges is connected to high material consumption and emissions.

- 9 km of tunnel between Winterthur and Zurich
- parallel single-track tubes
- branch-off towards Zurich Airport
- excavation diameter Ø = 10 m
- 20 cross-cuts connecting the tubes
- 3 infrastructure buildings (IB)
- main tubes excavated by tunnel boring machine (TBM)
- branch-off conventionally excavated
- 100 years of projected operation
- construction: 2026 - 2035

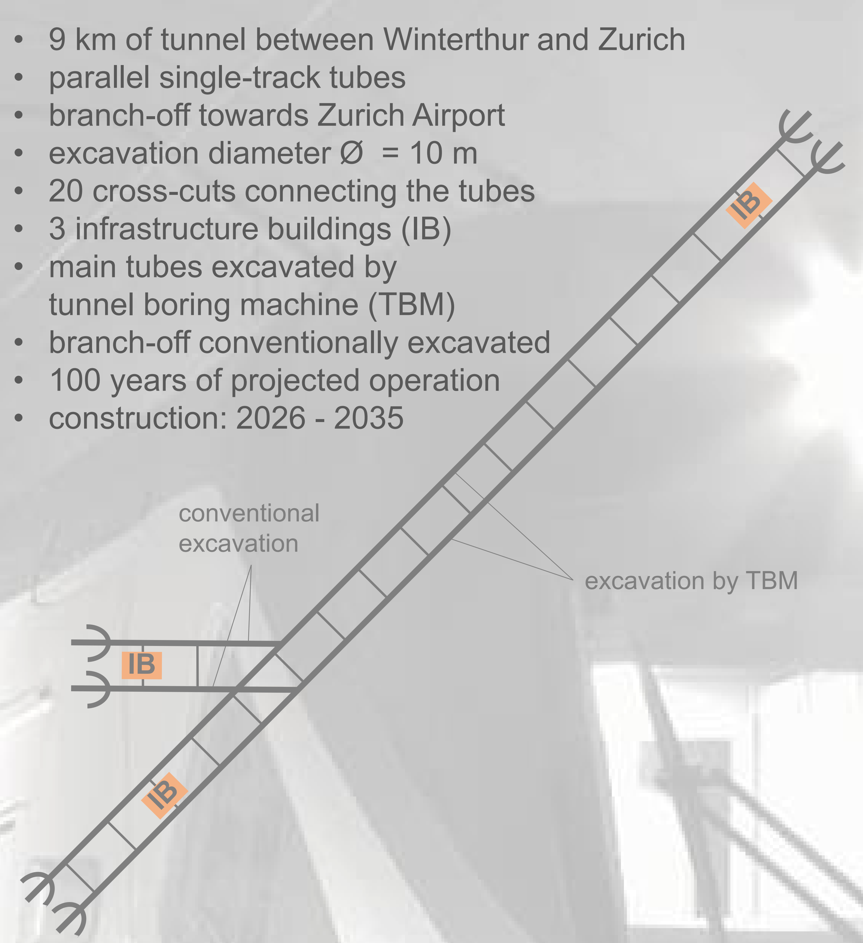

Figure 1. Schematic representation of the tunnel system based on [4, 5].

However, not only the construction of the tunnel but also its operating phase is associated with considerable demand for resources and energy. Infrastructure components require regular maintenance and replacement, ventilation, lighting and drainage systems consume electricity. In addition, trains on tunnel tracks consume significantly more electricity than on open tracks due to the increased air resistance inside the tunnel [6]. A life cycle assessment was carried out in order to investigate the potential environmental impacts of tunnel construction and operation.

Goal and Scope

The goal of this study was the assessment of potential environmental and human health impacts of tunnel construction and operation in order to identify the main drivers and hotspots. In addition, the effects of different excavation and construction methods were investigated, as well as the influence of the size of the tunnel cross section and the impact of the electricity mix used to power the trains crossing the tunnel.

System modelling was based primarily on project-specific plans, reports, concepts and information provided by project management. Tunnel and railway infrastructure components were modelled based on product data sheets or technical literature. Maintenance and component replacement were considered according to the corresponding concepts. The same applies for the modelling of the energy demand of lighting, ventilation and drainage system. The energy demand of the trains crossing the tunnel during the projected 100 years operating phase was calculated on the basis of the project-specific aerodynamics concept and estimations of future traffic volumes.

Results

- **Concrete structures, cement-based auxiliary measures, and steel** used during excavation and construction were identified as main drivers affecting the overall environmental impacts of the construction phase (Figure 2).
- **Lower impacts found for excavation and construction by tunnel boring machine** compared to other tunnel construction methods such as drilling & blasting or excavation and construction by conventional machinery.
- **Tunnel and Railway infrastructure components** dominate the potential impacts related to freshwater eutrophication and use of minerals and metals (Figure 2).
- **Electricity consumed by the trains crossing the tunnel was identified as main driver** of the potential environmental impacts of the operating phase (Figure 3).
- **Impacts of tunnel construction may outweigh those of the operational phase**, but only if an electricity mix with very low carbon-intensity is used for infrastructure and train operation (Figure 3).
- **Construction of larger tunnel cross-sections can be beneficial** from an environmental perspective. However, this is highly project-specific and dependent on various factors such as the electricity mix used for traction, the speed of the trains inside the tunnel or the aerodynamic properties of the trains (Figure 3).

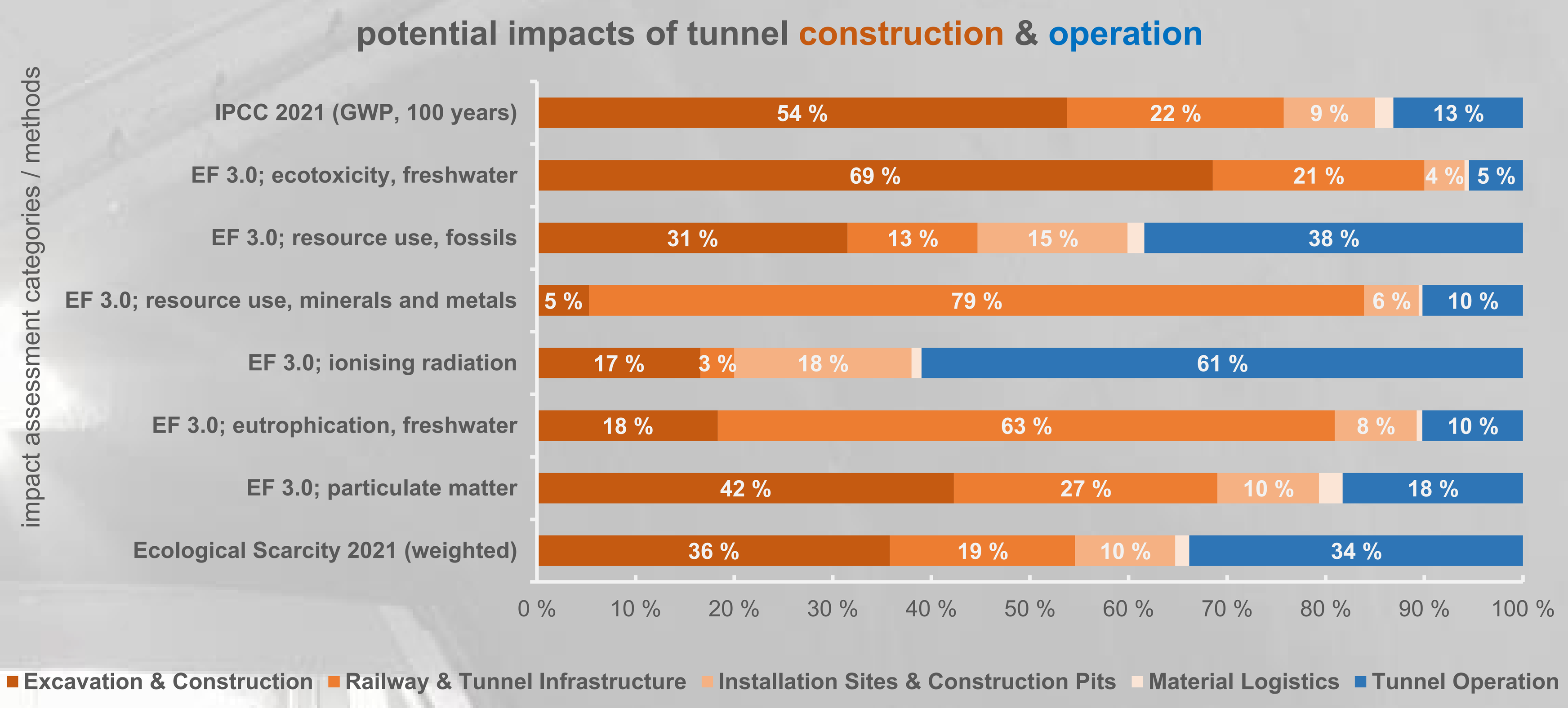

Figure 2. Overview of the potential environmental and human health impacts of tunnel construction and operation with regard to selected impact categories. Impacts related to tunnel construction, tunnel infrastructure (including component replacement), installation sites and material logistics are shown in shades of orange. Impacts related to the 100 years operation phase of the tunnel are depicted in blue. Impact assessment methods: IPCC 2021, Global Warming Potential (GWP); Environmental Footprint EF 3.0; Ecological Scarcity 2021.

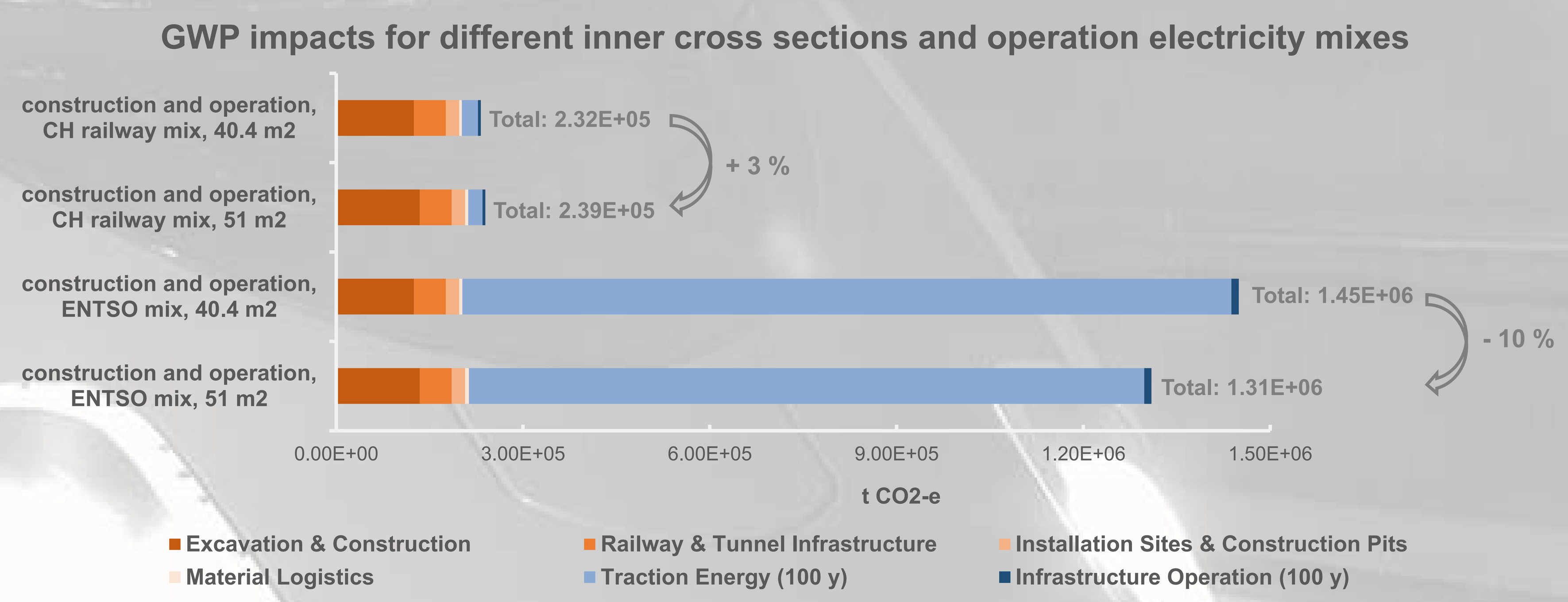

Figure 3. Comparison of four tunnel construction and operation scenarios. The top bar represents the global warming potential (GWP) attributed to the tunnel as projected with an aerodynamically free inner cross section (A_{ae}) of 40.4 m² and a fossil-free electricity mix used for traction and tunnel operation. The second bar shows the potential emissions for the scenario with an A_{ae} = 51 m² using the same electricity mix during the 100 years operation phase. The bottom two bars represent the emissions of the same tunnel construction scenarios (A_{ae} = 40.4 m² and A_{ae} = 51 m²), but with the European grid electricity mix (ENTSO mix) used for traction and infrastructure operation. GWP impact assessment method: IPCC 2021.

Discussion and Conclusion

Concrete and cement are the main drivers of potential impacts related to tunnel construction. This applies regardless of the used excavation and construction method. From an environmental point of view, it is advisable to minimize the clinker content of concrete structures and other cement-based materials wherever possible. New low carbon concrete and cement types could help reduce the construction-related impacts in the future, provided they manage to meet the required safety and durability requirements.

Tunnel construction using tunnel boring machine (TBM) was found to be associated with lower impacts compared to other tunneling methods like drilling & blasting and tunnel construction by conventional machinery. If rock conditions permit, TBM should therefore be preferred from an environmental point of view.

Construction of larger tunnel cross-sections inevitably leads to higher impacts during the construction phase for all impact categories. These additional construction-related impacts must be weighed against the reduction in impacts resulting from reduced traction energy demand.

Electricity used by the trains crossing the tunnel is by far the most relevant driver of environmental impacts related to the operation phase. Even moderate shares of fossil-based electricity lead to a dominance of the impacts associated with the operating phase over those related to tunnel construction. Using renewable electricity like hydropower is therefore of utmost importance. The construction of larger tunnel cross-sections should be considered for tunnel projects that will not have renewable electricity available for operation in the foreseeable future.

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