Railway transport systems’ contribution to sustainable development

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Abstract. Transport is one of the main contributors to global environmental pollution and in particular greenhouse gas emissions (approx. 24% in 2015). Modern railway transport systems enhance the future environmental performance of transport through i) optimized construction materials, ii) improved construction and refurbishment processes, iii) evolving monitoring and maintenance management and iv) network development. This paper demonstrates a variety of studies investigating the sustainability of the construction, maintenance and operation of railway transport systems. The presented results underline the key role of railway transports systems within a future-proof sustainable built environment. As an example for an investment into a sustainable transport system the Trans-European Transport Network (TEN-T) can be named, with which the European Union aims to offer an attractive, comprehensive and sustainable transport infrastructure and in which railway transport plays the leading role.

1. Introduction
The 17 UN Sustainable Development Goals (SDGs) address global challenges related to poverty, inequality, climate, environmental degradation, prosperity as well as peace and justice. The European Green Deal promoted by the EU-Commission in December 2019 includes the issue of shifting to sustainable and smart mobility. A sustainable built environment is one of the prerequisites for the realization of the SDGs and the European Green Deal. Sustainable transport infrastructure and systems are a core part of a future-oriented built environment. This is demonstrated for example in the SDGs detailed targets and specifications.

For example, SDG 9 “Industry, Innovation and Infrastructure” states in 9.1 development of quality, reliable, sustainable, and resilient infrastructure including regional and trans-border infrastructure and in 9.4 sustainable upgrade of infrastructure with increased resource-use efficiency and greater adoption of clean and environmentally sound technologies as core targets for the goal achievement. SDG 11 “Sustainable Cities and Communities” specifies in 11.2 access to safe, affordable, accessible and sustainable transport systems for all as a relevant SDG target [1].

Modern railway transport systems can contribute their part to enhance the future environmental performance of transport in the sense of the UN SDGs through
In Austria and Germany, a variety of studies investigating the sustainability of the construction, maintenance and operation of railway transport systems were carried out in recent years. In the following chapters a selection of these studies is presented to underline railway transport systems’ sustainability potentials.

2. Sustainable Optimization of Shotcrete at the Brenner Base Tunnel
During the ongoing construction of the Brenner Base Tunnel (BBT) (a flat railway tunnel of 64 kilometers length, crossing the central Alps between Tulfes (Austria) and Fortezza (Italy)) about 15.5 million cubic meters of tunnel excavation material (crushed rock) have to be deposited. In order to reduce the volume for landfills, a primary objective is the reuse of this tunnel spoil. Feasibility studies demonstrated the possibility to apply tunnel spoil consisting of central gneiss, Brixen granites and Bündner schists (three of four main lithologies the BBT is crossing through) for concrete production [2, 3]. At the lot E 52 (access tunnel of the BBT site “Wolf”) 100% of the demand on mineral aggregates (for concrete, shotcrete, filter gravel, etc.) were produced out of tunnel spoil directly on site. The following Life Cycle Assessment (LCA) analyzes the environmental improvements of two shotcrete mixtures applied at the lot E 52 produced with 100% processed tunnel spoil (Bündner schist) and further optimized mixtures (lower overall clinker content). The results are compared to the environmental performance of two “standard” shotcrete mixtures with primary mineral aggregates (Table 1) [4].

| Table 1. Investigated shotcrete mixtures BBT lot E 52 [4] |
|---------------------------------|-----------------|-----------------|-----------------|-----------------|
|                                 | Standard shotcrete | Optimized shotcrete applied at BBT lot E 52 | |
|                                 | SSc1 [kg/m³] | SSc2 [kg/m³] | OSc1 [kg/m³] | OSc2 [kg/m³] |
| Cement                          |               |               |               |               |
| CEM I 52,5 R                   | 400           | 360           | 208           | 320           |
| CEMII/A-M(S-L) 42,5 R          |               |               |               |               |
| Additives                       |               |               |               |               |
| Latent hydraulic additions      | 20            | 60            | 49            | 100           |
| Water                           | 200           | 200           | 219           | 216           |
| Aggregates                      |               |               |               |               |
| Primary aggregates              | 1650          | 1819          | 1607          | 1607          |
| Processed spoil                 |               |               |               |               |
| Admixtures                      |               |               |               |               |
| Hardening accelerator           | 24            | 21.6          | 24            | 24            |

The investigated shotcretes are similar in terms of strength and durability. Therefore, for all investigated shotcretes, all life cycle phases after the mixing process (except from the disposal phase) can be defined as equal and not significant for the study [4].

The LCA demonstrates that (as expected) the avoiding of the tunnel spoil disposal and the saving of primary mineral aggregates has a minor influence on the Global Warming Potential GWP results due to the great impact of the clinker content, which is mainly driven by the cement type and the amount of
latent hydraulic additions in the optimized shotcretes. However, the LCA shows that for other environmental indicators (e.g. non-renewable Cumulative Energy Demand – nr-CED) the tunnel spoil reuse has a relevant influence (Figure 1).

**Figure 1.** Non-renewable Cumulative Energy Demand results shotcrete mixtures BBT site “Wolf” [4]

To allow the reuse of the tunnel spoil at the BBT lot E 52, a specific material management including concepts for material flows, processing and quality control was developed. From an economic point of view, it was determined that the reuse of the tunnel spoil is beneficial for longer tunnels (as for example the analyzed lot E 52 of the BBT with about 3 km). In general, the necessary length of a tunnel to finally amortize the investment into spoil processing depends on the specific tunnel construction and the particular lithology [5].

3. Improved refurbishment processes of railway lines
A study carried out for the Austrian Federal Railways (ÖBB) analyzes the environmental potentials of railway superstructure and substructure refurbishments with heavy construction equipment (excavating machine, track renewal train and track tamping machine), wherefore a comparative LCA to a refurbishment with conventional earthworks (excavator, bulldozer, roller and truck) is carried out. The study object (Figure 2) is a refurbishment section of the ÖBB large-scale project “Lustenau – Lauterach” (Vorarlberg, Western Austria) [6].
The LCA analyzes relevant processes until the completion of the refurbishment. Thereby, differences regarding fuel consumption of the construction equipment, the shares on equipment production (ratio of construction duration to equipment lifetime), material recycling possibilities for unbound base courses, material transport, transport logistics and replacement bus services depending on necessary route closures are examined in detail.

Figure 2. Refurbishment of railway superstructure and substructure “Lustenau – Lauterach” (excerpt)

The comparison of the LCA results (Figure 3) shows advantages of up to 46 % for the heavy equipment variant, although these machines require higher fuel consumptions for construction processes due to higher engine power. However, rail-bound transports, avoiding the need of a site road, the possibility of material recycling in the excavating machine and the shortening of the route closure period cause
positive environmental effects, which compensate the additional fuel consumption for the construction processes.

4. Maintenance management systems for resilient railway transport

Constantly evolving maintenance management systems intend to guarantee resilient railway transport systems with minimized probabilities of failure for its specific components. For example, the maintenance management of the German Federal Railways (DB) induced a short-term retrofitting measure ("external reinforcement") for a railway bridge of the railway section Bamberg-Rottendorf (Germany), which avoided a closure of 1½ years and an associated detour of 50 km over the closure period [7].

An LCA study carried out for this maintenance intervention firstly compares the environmental impacts stemming from the retrofitting measure to the impacts of a total replacement of the bridge structure. Secondly the environmental impacts of the necessary detour over the closure period are determined and compared to the retrofitting and replacement results to demonstrate the influence of a failure of an essential infrastructure construction (Figure 4).

The LCA study determines that already one day of route closure causes about twice the amount of environmental impacts as the entire retrofitting measure. Considering the whole closure period shows a marginal influence of all construction related processes and underlines the environmental relevance of maintenance management systems. The results furthermore demonstrate the environmental influence of transport distance extensions and route-shortening infrastructure constructions such as bridges or tunnels and their reliability.

5. Transport scenarios on the Brenner route influenced by the Brenner Base Tunnel

The construction of the Brenner Base Tunnel (BBT) and its access routes will increase the capacity of the so-called Brenner Corridor between Munich and Verona and will enable modal shifts in the future. The BBT allows the relocation of the entire rail freight transport and parts of the rail passenger transport from the existing railway line to the new tunnel connection. In addition, the BBT is intended to alter the overall modal split of the Brenner route by shifting road transport from the Brenner motorway to rail transport on the new BBT route [8].

Figure 4. LCA results retrofitting, replacement and closure of railway bridge [7]
This study analyses environmental reduction potentials of different transport scenarios over the Brenner Pass, wherefore a Life Cycle Assessment study for fuel and electricity consumption is performed. The study focuses in particular on the benefits of the "use" of the Brenner Base Tunnel. Furthermore a comparison of the environmental reliefs caused by the modal shift and the environmental impacts from the tunnel construction is carried out [8].

The two main transport scenarios (without V1 and with BBT V2) are subdivided into five sub-scenarios [9]. For both main scenarios a basic scenario (assuming a rail-friendly transport policy) is defined (V1.3 and V2.3 – Figure 5). Starting from these basic scenarios, the modal split is changed (up to ± 30% for freight transport and up to ± 15% for passenger transport) to a high (V1.1 and V2.1) and low utilization of the rail network (V1.5 and V2.5) [8].

**Figure 5.** Modal split basic scenarios freight and passenger transport [9]

| Freight transport | Brenner motorway | Railway |
|-------------------|-----------------|--------|
|                  | [P] | [trennw. / a] | [trennw. / a] | [P] | [trennw. / a] | [trennw. / a] | [P] | [trennw. / a] | [trennw. / a] | [P] | [trennw. / a] | [trennw. / a] | [P] | [trennw. / a] | [trennw. / a] |
| 2015              | 68.2 | 31.8 | 5.497 | 31.8 | 14.9 | 71 | 0 | 0 | 0 |
| 2020              | 58.5 | 31.8 | 5.479 | 41.5 | 22.6 | 108 | 0 | 0 | 0 |
| 2025              | 48.9 | 31.0 | 5.324 | 51.1 | 32.3 | 155 | 0 | 0 | 0 |
| 2030              | 49.5 | 31.1 | 6.056 | 50.5 | 35.9 | 172 | 0 | 0 | 0 |

| Railway          | Brenner pass | BBT |
|------------------|--------------|-----|
|                  | [P] | [trennw. / a] | [trennw. / a] | [P] | [trennw. / a] | [trennw. / a] | [P] | [trennw. / a] | [trennw. / a] |
| 2015              | 68.2 | 31.8 | 5.497 | 31.8 | 14.9 | 71 | 0 | 0 | 0 |
| 2020              | 58.5 | 31.8 | 5.479 | 41.5 | 22.6 | 108 | 0 | 0 | 0 |
| 2025              | 48.9 | 31.0 | 5.324 | 51.1 | 32.3 | 155 | 0 | 0 | 0 |
| 2030              | 49.5 | 31.1 | 6.056 | 50.5 | 35.9 | 172 | 0 | 0 | 0 |

| Passenger transport | Cargoside | Cst/Driver | Railway |
|---------------------|-----------|------------|---------|
|                     | [P] | [trennw. / a] | [trennw. / a] | [P] | [trennw. / a] | [trennw. / a] | [P] | [trennw. / a] | [trennw. / a] | [P] | [trennw. / a] | [trennw. / a] | [P] | [trennw. / a] | [trennw. / a] |
| 2015                | 90.0 | 10.9 | 10.983 | 26.1 | 9.0 | 6.996 | 19.4 | 6.0 | 64 | 0 | 0 | 0 |
| 2020                | 90.0 | 10.9 | 10.983 | 26.1 | 9.0 | 6.996 | 19.4 | 6.0 | 64 | 0 | 0 | 0 |
| 2025                | 51.2 | 10.9 | 16.259 | 27.7 | 9.0 | 8.706 | 19.3 | 6.4 | 78 | 0 | 0 | 0 |
| 2030                | 51.5 | 10.7 | 16.021 | 27.7 | 9.0 | 8.706 | 19.3 | 7.2 | 78 | 0 | 0 | 0 |
| 2015                | 51.2 | 10.5 | 10.980 | 26.5 | 10.9 | 10.980 | 26.5 | 9.2 | 78 | 0 | 0 | 0 |
| 2020                | 51.2 | 10.5 | 10.980 | 26.5 | 10.9 | 10.980 | 26.5 | 9.2 | 78 | 0 | 0 | 0 |
| 2025                | 51.2 | 10.5 | 16.259 | 27.7 | 9.0 | 8.706 | 19.3 | 6.4 | 78 | 0 | 0 | 0 |
| 2030                | 51.5 | 10.3 | 16.021 | 27.7 | 9.0 | 8.706 | 19.3 | 7.2 | 78 | 0 | 0 | 0 |

**Figure 6** shows the comparison of V1.1 vs. V2.1 with maximum shift to the railway for the year 2035. V1.1 corresponds with V1.3 due to the capacity of the existing railway line. The shift of 86.5% of the overall freight transport in 2035 to the BBT route results in a great reduction of up to 54% of the yearly environmental impacts (Figure 6). The r-CED indicator has increased by about 40% due to the shift to the energy efficient railway, which utilizes an electricity mix with a high content of renewable energy sources [8].
A comparison of the positive environmental effects of the utilization of the BBT (V1.3 vs. V2.3) and the construction processes for the tunnel [10] demonstrates the short time environmental break-even point of the new construction of the tunnel (e.g. Global warming Potential 13 years – Figure 7). Hereby it is necessary to admit that the maximum transport capacity of the route Munich – Verona analyzed in this study requires the completion of the access routes in the north and the south of the BBT including terminals in order to achieve a logistic chain.

Figure 6. LCA results optimized scenarios V1.1 vs. V2.1 for the year 2035 [8]

Figure 7. Comparison of GWP results of BBT new construction processes and transport shift [8]
6. Conclusions
The demonstrated studies and results underline the key role of railway transports systems within a sustainable built environment. Optimized construction materials and processes as well as resilient high-speed and high-capacity railway transport systems can be seen as “environmental investment” in a future-proof transport solution in the sense of the UN SDGs and the European Green Deal. As an example for this kind of investment the Trans-European Transport Network (TEN-T) can be named, with which the European Union aims to offer an attractive, comprehensive and sustainable transport infrastructure with railway transport playing the leading role. The high-capacity trans-alpine railway section Munich-Verona with the Brenner Base Tunnel (BBT) as its core component is part of the Scan-Med-Corridor of TEN-T.

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