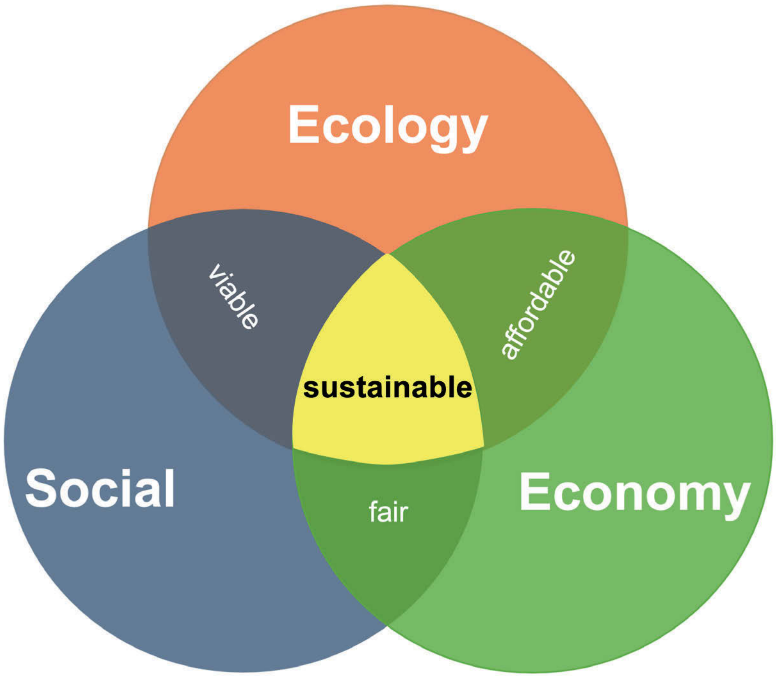

Sustainability in Underground Construction

Basics, Boundary Conditions and Objectives

DAUB-Working Group

Deutscher Ausschuss für unterirdisches Bauen e. V.
German Tunnelling Committee (ITA-AITES)

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For reasons of readability, the simultaneous use of feminine, masculine or neutral forms of language is dispensed with in the following and the generic masculine is used. All personal terms apply equally to all genders.

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Preamble

The preservation of natural resources for current and future generations has preoccupied society and politics for a long time. At the same time, there is a continuing need for living space, work, education, mobility, supply/disposal and the exchange of services and goods. These needs should continue to be met in the future, keeping in consideration the sustainability goals. For this purpose, Germany's infrastructure must be significantly upgraded and, where necessary, expanded. Underground construction makes a significant contribution to the preservation and expansion of infrastructure. At present, there are no guidelines available for the sustainable construction of underground facilities and their assessment from the point of view of sustainability. The German Tunnelling Committee (DAUB) will therefore issue recommendations for the realisation and evaluation of sustainable underground construction. These are expected to be completed by the end of 2024. This paper presents the topic, the current boundary conditions and the objectives.

1 Political Framework Conditions

1.1 UN Sustainable Development Goals

The United Nations (UN) Conference on Environment and Development in Rio de Janeiro in 1992 **[1]** laid the first foundations for an internationally agreed approach to sustainability with Agenda 21. In this context, the equal value of ecology, economy and social aspects was defined as a basic prerequisite for sustainable development (**Figure 1**). Two legally binding framework agreements on climate change **[2]** and on biodiversity **[3]** were also adopted.

In the meantime, the agreements have been further developed and provided with concrete targets. The 2015 Paris Climate Agreement **[4]**, for example, stipulated that greenhouse gas emissions should be reduced to such an extent, that global warming is limited to 1.5 °C compared to the pre-industrial era.

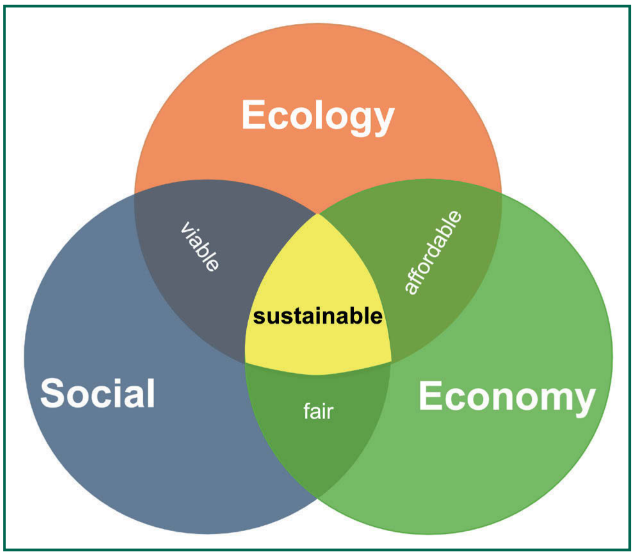


Figure 1 *Equal value of ecology, economy and social issues based on the 1992 UN Conference*

With the UN Agenda 2030 (also from the year 2015) **[5]**, a total of 17 specific Post-Sustainable Development Goals (SDGs) have been formulated (**Figure 2**). These are aimed at governments around the world, but also at the civil society, the private sector and the scientific community.

1.2 EU Requirements

Based on the superordinate international framework, the European Union (EU) has set itself the target of becoming the first climate-neutral continent. According to the targets of the EU Green Deal [6] published in 2019, no net greenhouse gas emissions are to be released from 2050 onwards and economic growth is to be decoupled from the use of the natural resources. The EU intends to promote the necessary changes in society and the economy with the Industrial Plan **[7]** published in 2023, and facilitate it through appropriate legal and improved framework conditions.

EU Taxonomy is a measure set out in the EU Sustainable Finance Action Plan, which was codified in the Taxonomy Regulation **[8]** in 2020. The aim of the action plan is to channel capital flows into environmentally sustainable activities. According to the Taxonomy Regulation, economic activities are considered sustainable if the following six environmental objectives are met:

1. Climate change mitigation
2. Climate change adaptation
3. The sustainable use and protection of water and marine resources
4. The transition to a circular economy
5. Pollution prevention and control
6. The protection and restoration of biodiversity and ecosystems

Figure 2 *The UN's 17 Sustainable Development Goals (2015)* **[2]**

Since the end of 2021, larger commercial enterprises have been required to publish an annual sustainability report on their business activities, which shows the degree of implementation of environmental goals.

1.3 Implementation in Germany

Germany supports the UN and EU targets and even aims to achieve climate neutrality as early as 2045. Since 2016, the German sustainability strategy has been oriented towards the SDGs. It was updated again in 2021 **[9]** and defines the following six transformation areas for Germany:

1. Human well-being and capabilities
2. Energy transition and climate protection
3. Circular economy
4. Sustainable building and the transformation of transportation
5. Sustainable agricultural and food systems
6. Pollutant-free environment

The goals will be achieved with the help of newly implemented legal requirements. For example, the Federal Climate Protection Act (Bundes-Klimaschutzgesetz, KSG) standardises the climate policy targets and stipulates, among other things, that public bodies must ensure compliance with the purpose of the KSG and European targets in their planning and decision-making processes.

Conclusion

- Underground construction will also make its contribution to meeting the sustainability goals under consideration of the political framework conditions.
- The DAUB recommendations on sustainability currently being developed will show in which ways this contribution can be achieved in Germany by 2045.

2 Status Quo and Current Challenges

The existing underground structures have created important pillars for a flourishing and resilient national economy: they ensure water and energy supply, they relieve inner cities of traffic thanks to underground systems and underground roads, they ensure safe transport connections over long distances and large areas, and they enable underground waste disposal systems such as sewage systems.

Underground construction generates major positive socio-economic effects, such as relieving agglomerations of noise and exhaust fumes, creating green spaces and free areas for other uses, protecting ecosystems and promoting biodiversity by creating underpasses instead of cutting up ecologically valuable areas.

Underground infrastructure is usually designed for a service life of 100 years **[5]**, but underground facilities with much longer service lives can be found all over the world. In terms of long-term use, underground structures are therefore among the most sustainable engineering structures of all.

Global population growth is currently continuing. This creates a need for additional living space, work, mobility, utilities, waste disposal, exchange of services and goods, etc. These needs are to be met in future, taking into consideration the sustainability goals. For Germany, this means that the infrastructure must be significantly expanded and upgraded. Underground construction offers a significant contribution to this process.

However, the construction and operation of buildings and structures are responsible for 38 % of CO_2 emissions worldwide (**Figure 3**) **[10]**. The main source of greenhouse gas emissions in the construction industry is the cement contained in concrete. In addition, there are emissions from other materials, especially steel, and the use of the required construction equipment. The goal is to reduce these emissions as much as possible and, where this is not possible for chemical and physical reasons, to compensate for them with suitable measures.

Since all excavated material must currently be designated as waste due to legal requirements, the construction industry also plays a key role with regard to the issue of waste. According to evaluations by the Federal Statistical Office **[11]**, the construction industry in Germany contributed 55 % (= 229 million tonnes) of the total tonnage of gross waste (= 414 million tonnes) in 2020 (**Figure 4**).

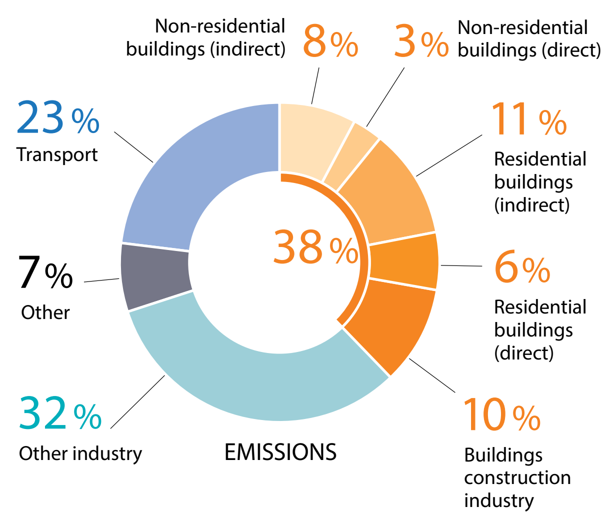
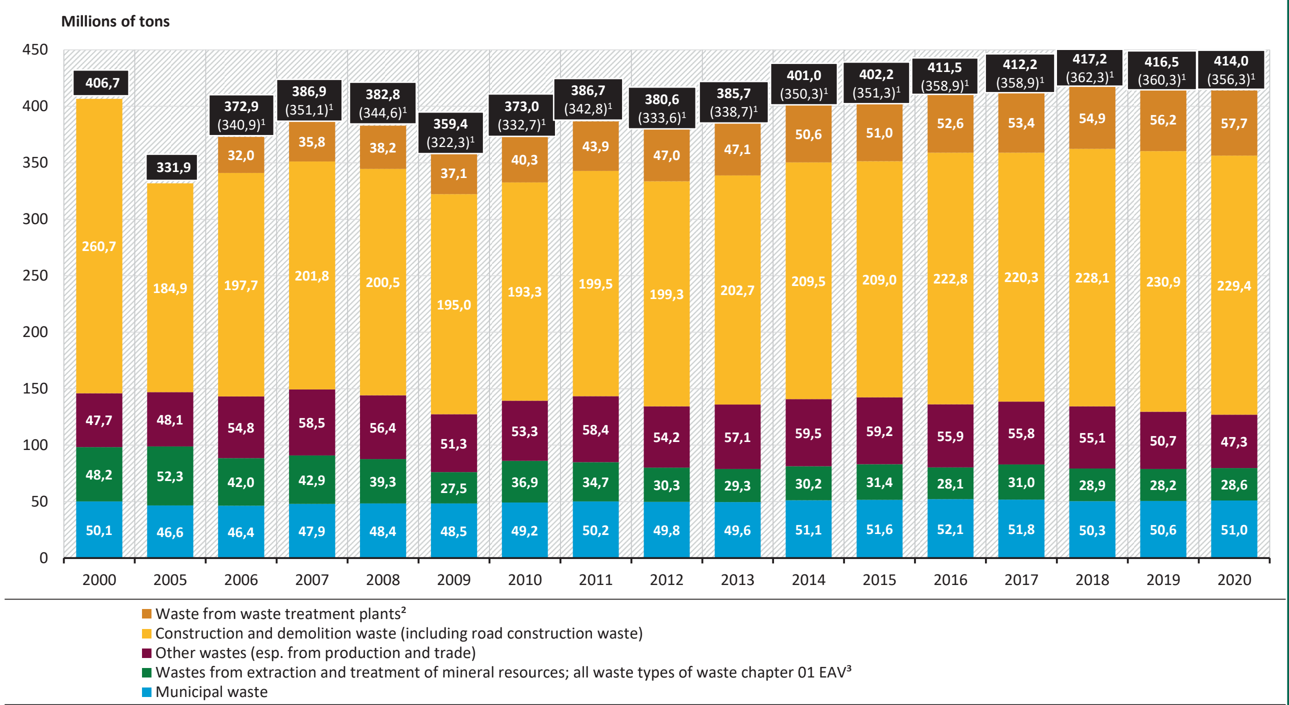


Figure 3** Global share of construction in CO_2 emissions, 2019* ***[10]



[1] Net waste generation, excluding waste from waste treatment plants; surveyed as part of waste generation for the first time in 2006.

[2] Excluding wastes from wastewater treatment plants (SAB 1908), wastes from the preparation of water for human consumption or industrial process water (SAB 1909), wastes from soil and groundwater remediation (SAB 1913) and secondary wastes leaving the disposal process as raw materials/products.

[3] Wastes from extraction of mineral resources.

Source: Federal Statistical Office, Waste Balance Sheet, Wiesbaden, various years

Figure 4** Waste generation in Germany 2000 to 2020* ***[11]

In 2020, for example, the category "soil, stones and dredged material", which is produced to a large extent in underground construction, accounted for about 132 million tonnes. In this category, up to 85 % of the material is already processed or reused today **[11]**. Nevertheless, from a legal point of view, the total quantity counts as waste. Despite the already relatively high recycling rate for excavated material, waste avoidance and the re-introduction of construction waste into the circular economy are important imperatives for the entire construction industry and underground mining in particular.

Conclusion

- Underground construction per se fulfils many of the sustainability goals listed above, since, for example, infrastructure relocations create surfaces for other uses and avoid impairments to people and nature.
- The currently excessive greenhouse gas emissions must be reduced, and the circular economy must also be strengthened in underground construction.

3 Ways to Sustainable Underground Construction

3.1 Sustainable Planning

In underground construction, overall project-specific planning is decisive. Holistic considerations must be made, especially in the early planning phases. For example, potential on the (construction) material side could be identified and its use optimised, or the processes that build on each other, such as excavation methods and (excavation) material management, could be carried out sustainably.

This applies, among other things, to life cycle considerations of the structures and their potential extension. In particular, the integral mapping of the execution and operation phases allows processes to be optimised and socio-economic aspects to be integrated. The use of BIM methods can accelerate integrated planning and also facilitate the implementation of long-term digital operating models, with the help of which maintenance intervals and maintenance processes can be optimised. The networking of spatial construction models with sensor data from production and maintenance can improve economic efficiency (needs-based maintenance) and safety (failure notification).

Ultimately, planning, which takes sustainability aspects into account, has a positive influence on the socio-ecological effects of underground structures, so their advantages for society can be communicated accordingly and acceptance can be increased as a result.

3.2 Circular Economy

In underground construction, the excavated material is the largest quantity to be handled in the entire production process. The excavated material is declared as waste by the legislator as long as no proof of recycling is provided. This fact is one of the greatest challenges in the realisation of underground construction projects. The geological properties, the boundary conditions of the project and the legal framework play an important role in the recycling of excavated tunnel material.

The most important goal is to recycle the excavated material as close to the construction site as possible. For optimal material management, early and integral planning of supply and disposal in connection with process engineering is of great importance, since the excavation method has a great influence on the properties of the resulting material and its subsequent recycling. A coordinated concept must be drawn up at an early stage to determine where and when the material is to be excavated and, if necessary, how it is to be processed, including the space required and its subsequent recyclability. The continuity of the sometimes very complex concepts, which synthesise with each other, from the beginning of the planning phase to the final construction phase, is a decisive factor in the success of sustainable tunnel construction projects and can have a considerable influence on them.

In 2024, DAUB will publish a corresponding recommendation on possible processing methods and the subsequent possibility of recycling (recommendation on the recycling of excavated tunnel material).

3.3 Use of New Materials and Construction Methods

Ecologically sustainable construction is only possible through the use of CO_2-reduced concrete. In order to achieve this goal, significantly reduced cement (clinker) contents in concrete, new types of special binders, additives adapted to these and automated control concepts are required. New types of concrete lead to altered setting behaviour and strength properties.

There are also possibilities for making steel production more sustainable (e.g. by using hydrogen). In addition, classic steel bar reinforcements can be replaced by steel fibre reinforcements, thereby reducing CO_2 emissions.

In order to be able to use these materials and construction methods, approval procedures for permits and, if necessary, adapted standards are just as necessary as timely use in projects in order to gain experience at an early stage. Previous approval paths must be significantly accelerated and optimised. Swift joint action by the competent authorities with the relevant clients and contractors will become essential.

Sustainable production, especially in underground construction, will increasingly result in the use of automation solutions, linking with robotics and end-to-end digitalisation. The industry is already working at full speed on solutions in many areas, which are either available now or in the near future.

3.4 Greenhouse Gas Balancing

An essential component for the identification of sustainable tunnelling variants is the balancing of greenhouse gases in the construction and operation phases. In addition to the consideration of carbon dioxide, this includes all other greenhouse gas emissions defined by the Intergovernmental Panel on Climate Change **[12]**. The greenhouse potential (Global Warming Potential, GWP) of all gases is expressed in CO_2-equivalents.

In addition, further aspects of sustainability and resource conservation should be identified in underground construction. For example, if one not only aims to save materials with high CO_2 emissions, but also includes measures that have a positive influence on the climate. It would be conceivable, for example, to generate geothermal energy in underground structures by means of heat exchangers in the tunnel lining or to use the same for the operation of a structure, e.g. in railway stations.

Underground structures are mainly built for infrastructure (road, rail, pipelines, etc.). The resulting shift of transport services underground is positive per se, even if materials with high CO_2 emissions are currently still being used.

3.5 Renewal and Conversion of Underground Structures

Underground structures in Germany are designed for a long technical service life. Currently, the goal is a standard value of 100 years **[5]**. Existing structures in all modes of transport already achieve significantly longer lifetimes (**Figure 5**). Renewals and upgrades ensure that they meet the current traffic, normative and regulatory requirements after their initial service life and that they can continue to serve efficiently for decades to come.

Comparable figures can also be found for other modes of transport – e.g. in the metro networks of major cities. For example, shortly after the beginning of the 20th century, 80 % of Berlin's underground network was already in use. This means that it has already substantially exceeded the service life aimed for in accordance with the valid regulations. The advantage of underground infrastructure is, that it is relatively weatherproof and thus largely only exposed to the effects of the surrounding soil or rock and those of its use.

Where further use as a mode of transport is no longer indicated, conversion is possible, but in extreme cases also the filling of the cavity. In Germany,

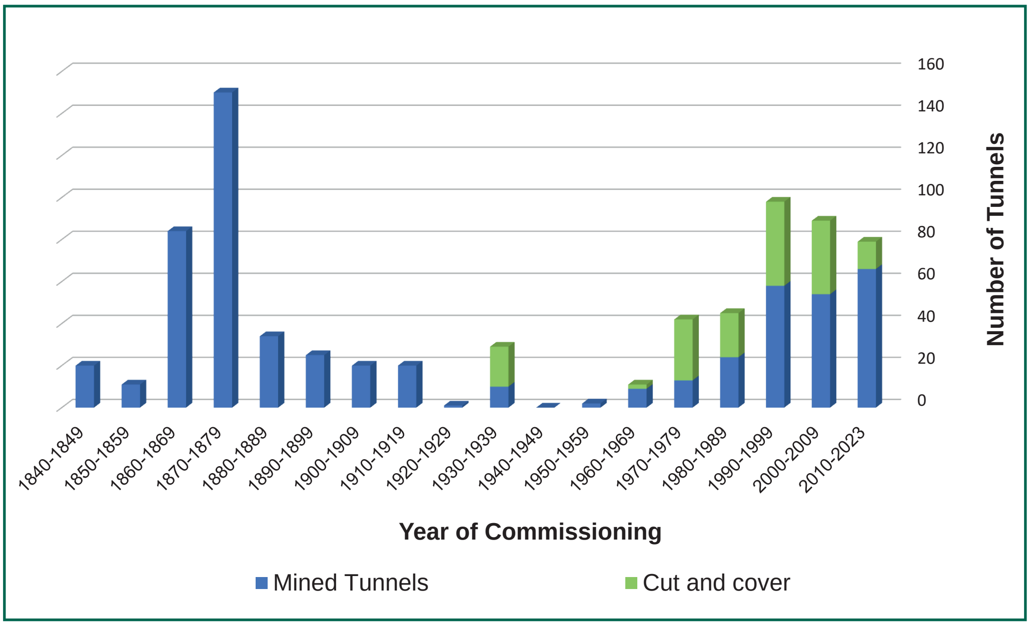


Figure 5 *Age structure of DB's railway tunnels, as of December 2022* ***[13]***

for example, former railway freight lines are being revived and put to new use (e.g. as cycle paths) together with the tunnel structures connected to them.

Conclusion

- The foundations for sustainable underground construction (including ecology, economy and social aspects) are laid in the planning phase.
- A refined circular economy, the use of new materials and possible integration of energy generation into the structure, as well as the use of environmentally friendly equipment during construction, contribute to the achievement of the goal.

4 Project Assessment

Consensus exists internationally that sustainability is generally a matter of the three areas of ecology, economy and social issues (**Figure 1**). This involves assessing the potential impacts of a product, process or activity on the three areas mentioned above over the entire life cycle. This mainly involves aspects that were briefly described in **chapter 3** of this publication.

With regard to the economic criteria, all monetary aspects of the life cycle are considered (compare DAUB recommendations for the determination of life cycle costs for underground structures). In addition to the construction phase, the focus is essentially on the operating phase of a tunnel structure.

Social and functional aspects of sustainability can mainly be identified as soft factors and can therefore only be quantified to a limited extent. In addition to the functionality of the structure, questions of aesthetics and design as well as aspects of health protection and comfort come to the fore. On the one hand, underground infrastructure objects generate values with regard to the quality of life of the users in the vicinity of the structures, for example by relocating noisy and polluted traffic routes underground (e.g. lowering of the ground level Rheinuferstraße in Düsseldorf, **Figure 6**). On the other hand, entire regions can be strengthened in a structured manner by connecting them to the interregional transport network, thereby improving their living conditions (e.g. DB high-speed lines Cologne–Frankfurt, Wendlingen–Ulm, Berlin–Munich, **Figure 7**).

In order to be able to carry out the evaluation of a specific object in a structured and reproducible manner, different national and international evaluation procedures and methods are used. The basic structure of such approaches is always the same: Based on a defined object of assessment, criteria are developed which characterise this object and at the same time represent the protection goals in terms of sustainability. Various indicators can then be assigned to each criterion to define and describe the respective criterion in its characteristics. Considering the weighting of the criteria, these individual assessments can then be aggregated into an overall assessment. A central requirement of such a target system is that it must include all relevant criteria and indicators. At the same time, impacts must not be recorded twice, from which the selectivity of the target system can be derived as a further requirement.

In many cases, assessment tools have been developed for the real estate sector. An application of such proprietary systems to underground construction is not possible without complications, given its particular constraints and the long lifetimes mentioned above.

Particularly in the case of underground structures, the difficulty lies in the fact that the assessment of sustainability aspects represents a heterogeneous and multi-criteria assessment situation.

Figure 6 *Düsseldorf Rheinuferstraße in the past and today (Photos: City of Düsseldorf/City Archive (left) and alamy (right))*

Figure 7 *Connecting regions to the supra-regional transport network and replacing air traffic (Transport Project Unit VDE 8, Berlin–Munich line (Photo: Deutsche Bahn/ Frank Barteld)*

Clearly defined indicators – i.e. those that can be quantified unambiguously (e.g. investment costs of a measure) – have to be set in relation to fuzzy indicators that can only be assessed qualitatively (e.g. increase in the quality of life of the users or the environment).

Conclusion

- An assessment of sustainability aspects of underground structures includes clearly quantifiable as well as only qualitatively ascertainable factors.
- DAUB has set itself the goal of formulating a recommendation for carrying out sustainability assessments for underground structures.

5 Literature

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