Life-cycle assessments of rock bolts

In broad terms, the tunnelling industry is familiar with the need to improve sustainability. We would all like to "tread more lightly" in terms of our environmental footprint. Indeed some clients, such as London Underground, are even demanding that the embodied carbon dioxide is estimated and tracked as a project is developed through the design stages. Carbon dioxide is believed to be a major contributor to global warming but it is not the only or indeed the most potent greenhouse gas. Similarly, global warming is not the only way in which humans can have an impact on our world. A broader approach is needed to capture the full complexity of the environmental impact in our assessments of tunnel projects. Taking the example of rock bolts, this article seeks to demonstrate the value of the life-cycle assessment method in this broader approach.

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The life-cycle assessment (LCA) method is based on the interdependence of relationships within the environment. It is grounded in the premise that each product is linked to the environment not only by its inputs (material and energy matter), but also its outputs (substances emitted into the environment during production, consumption and disposal).

The basic principle of LCA is the collection and evaluation of the inputs and outputs and researching potential impacts of the product system on the environment throughout its life-cycle (Curran 2015, Klöpffer 2014). In LCA, the flows between the different product stages (source extraction, production, transport, storage, consumption and disposal) and the environment are mapped. The goal is to determine and quantify all potential environmental impacts of the assessed product. Typically, a LCA consists of four major phases:

1. During the definition of goal and scope, the framework of the study is developed. Amongst other things, this includes a description of the product system to be studied, the system boundaries, the functional unit and allocation procedures as well as impact categories.
2. The Life Cycle Inventory (LCI) is about collecting and analysing quantified data related to extraction of resources from nature and emissions caused by our processes (e.g. emissions to e.g. air and water, waste generation and resource consumption). The whole life cycle is included in a cradle-to-grave approach, in which all environmental burdens from the extraction of raw materials through production and use to final disposal, including recycling, reuse, and energy recovery, have been included.
3. The Life Cycle Impact Assessment (LCIA) is the estimation of potential environmental impacts in terms of climate change, summer smog, resource depletion, acidification, human health effects, etc. The environmental impacts are associated with the environmental interventions attributable to the life-cycle of a product.
4. Interpretation of the findings, providing conclusions and recommendations as well as clearly stated assumptions and limitations of the study.

In general, each product can be said to interact with the environment throughout its whole life cycle. However, the degree of influence depends on each stage of the product's life (e.g. the main impact could be in the production stages; other products may have the main potential impact during their consumption stages or the disposal stages). Product life-cycles are variable in duration (e.g. food does not usually exceed 2 weeks, but infrastructure may last tens of years).

It should be noted that one product may have several life cycles that can be compared and the LCA method can help to select the most environmental friendly option for that product. These variations may be caused by differences in production technologies, the differences in the use of the same product, differences in product disposal, etc.

LCA amongst other approaches

The LCA methodology is formally supported by EN ISO 14040. This standard helps to make it transparent. Thus the results are comparable to others; there is basic control of the used information, and comparability of potential environmental impacts.

If we compare a LCA study with a carbon footprint study, the LCA is more comprehensive because it affects more environmental categories. An LCA can study over 20 different environmental indicators at once - issues such as toxicity, ozone, water depletion, eutrophication, particular matter formation, acidification, hazardous waste, material depletion, metal depletion….and more.

In BREEAM, a LCA can score extra credits. This can help to achieve a BREEAM excellent or BREEAM outstanding ratings. These credits are available through the BREEAM section 'Mat 01 Life cycle impacts'. There are up to 9 points available, and another 6 BREEAM points can be obtained by assessing the material environmental impacts. Here the LCA may be supported by generic data (non-manufacturer specific).

LCA is also applicable to LEED certification (building lifecycle rating credits). In total, one can score 3 LCA credits in LEED. Credits can be obtained for new buildings (or parts of buildings) by completing the life cycle assessment of the structure and achieving at least a 10% reduction in environmental impact of the main building. As part of the assessment to achieve LEED certification and the LCA credits, no impact category chosen as part of the life cycle assessment can increase by more than 5% compared with the baseline building. In the case of LEED, the LCA study must comply with ISO 14044:2006 to achieve the extra credits.

CASE STUDY: LCA for rockbolts

To illustrate, we can look at a study of the environmental impacts related to a rock bolt. This comparison covered rock bolts for use in tunnels in Europe with the bolts sourced in China or Europe. We considered two typical types of permanent rock bolts: galvanized steel bolts and GFRP bolts. It was assumed that both bolts were anchored with resin cartridges.

LCA is different to other approaches of environmental assessment since it is a relative approach based on a functional unit and specific to the system boundaries. The functional unit is a description of the quantified performance of a product system. It is used as a reference unit, meaning that all environmental impacts are related and broken down to this functional unit. In our case, the functional unit used is:

*1m of rock bolt, 100 years life-time [environmental impacts per (1m*100a)]*

This functional unit was chosen in order to allow comparability with other studies.

All life cycle stages shown in Figure 1 have been considered in the study, with particular focus on production and installation processes, where original data has been used. Foreground and background processes, in particular transport processes, have been modelled with help of generic data based on the Ecoinvent database (version 2.2). If no process data have been available, we estimated with expert judgements or used process data from equivalent processes or products.

We assessed the environmental impact using the CML (Centrum voor Milieuwetenschappen Leiden) methodology. This methodology uses the midpoint impact categories, meaning that the degree of environmental impact is expressed in different impact categories (toxicity, ozone, water depletion, etc.). However, no damage on areas of protection such as natural ecosystems, human health or resources is modelled. The indicator results in each impact category are expressed relative to the reference substance causing the same degree of environmental impact, i.e. the global warming potential of methane is described relative to carbon dioxide in CO_2-equivalents. The study presents results as impact category indicators and the normalised results.

Results of the study

When we compared the product systems based on the functional units of "one metre rock bolt with a lifetime of 100 years", we estimated the impact as shown in the following graph (for the cases of steel bolts produced in Europe and China). While it has been assumed that the galvanized steel bolts have a lifetime of 100 years, this is a highly questionable assumption since the protective coating can be damaged during transport and installation. For steel bolts to have a life-time of 100 years, they are often required to have multiple layers of corrosion protection.

Results of the characterisation underline that composite GFRP shows less than 65% of environmental impacts compared to steel. Regarding the "material miles", it is clear from the graph that the biggest difference in terms of negative impacts occurs within the categories of acidification and eutrophication. In the case of these two categories, the impact of road transport by truck within Europe is 50% lower than in the case of shipping from China. The tunnel project was located in Scandinavia. Furthermore, we can observe the differences within the Mineral Discharge category (Abiotic Depletion), Global Warming, and Photochemical Oxidants. In the case of these three categories, the distinction between different product systems differentiated by the different modes of transport is significant (the effect of transporting bolts by road transport over moderate distances is 7-15% more environmentally friendly than by long distance shipping). The lower impact of road transport is mainly due to its 10 times smaller distance than in the case of shipping in the example. Obviously, the exact location of each project and the potential suppliers would affect this calculation. However, the importance of this factor is clear.

The concept of "food miles" was first coined by Prof Tim Lang in the 1990s and it is now well-established in consciousness. Similarly in the construction industry, we may need to start thinking about "materials miles" as an important aspect in enhancing project sustainability. In this study, we applied a transport model based on Ecoinvent 2 data. The shipping distance was calculated only from the port and to the port, because the marginal distance from the port to the place of installation was negligible (less than 1% of the total impact) and therefore the cut off rule was applied. Average distances for shipping 20,000km and 2,000km for trucks were assumed. This difference in the overall impact is also visible in the following chart, where individual impact category was normalised[1] for easier interpretation:

LCA analysis can give us an insight into the individual life cycle stages (production, transport and maintenance) as shown in Figure 4.

The figures show that the dominant influence on the environment is the production of the product (rock bolt). When the product is transported by ship, the transport of product has a significant influence on the environment. However, when the product is transported by lorry, then, from the point of view of the environmental impact, the installation phase is more dominant than the transportation.

The original study had a wider scope and also compared rock bolt and GFRP bolt. It is known that there is a high risk of damage during transport and installation in the case of rock bolts. In contrast, GFRP exhibits very good long-term durability. Therefore, in practice, if GFRP has a longer lifetime, it will have even lower environmental impact.

Figure 1: The life-cycle stages of a rock bolt considered in this study

Figure 2: The characterisation of a rock bolt - shipped from China and Europe (midpoint category, CML method)

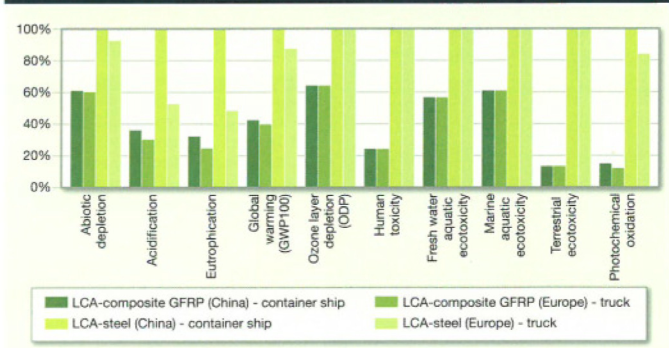
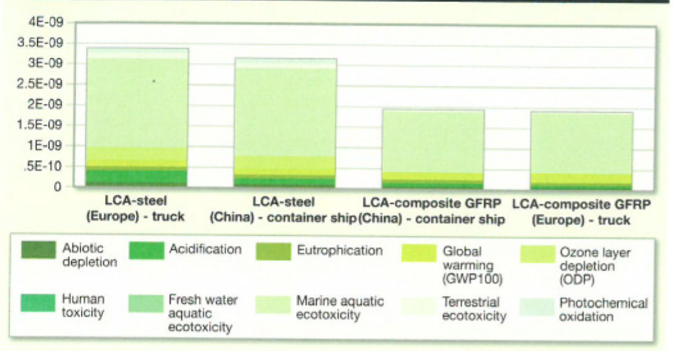


Figure 3: Normalised results rock bolt - shipping from China and Europe (midpoint category, CML method)



General application of LCA

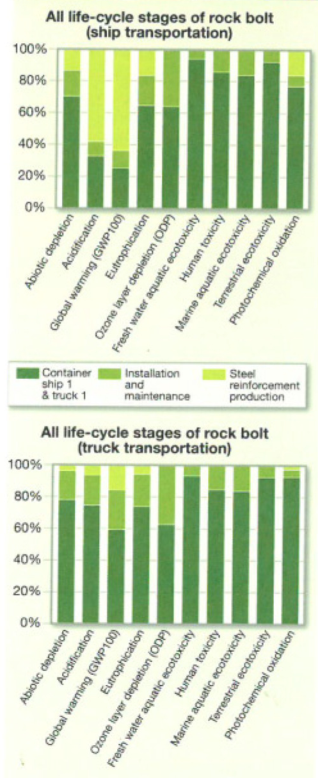
The LCA method is currently considered to be one of the most promising tools to facilitate putting the principles of sustainable development into practice. However, the adoption of this method varies from country to country.

As an example of best practice, in the European countries, the LCA method is usually used in environmental labelling (mostly for environmental labelling of EN ISO Types I and III). Label Type I is in accordance with EN ISO 14024 – Environmental labelling and declarations (ISO 14024, 2000) and with the National environmental labelling programme of individual countries. The National environmental labelling programme establishes two kinds of the environmental labelling Type I – an environmentally friendly product (at a national level) and EU Ecolabel known as European flower (at an European level). In the case of Type I labels, LCA is usually used in the creation of product's directive (standard). The producers need not create a specific LCA for their product; they just have to demonstrate compliance with the relevant product directive.

Type III labels comply with EN ISO 14025 – Environmental labelling and declarations (EPD) – The environmental product declaration (ISO 14025, 2006). If a producer wants to obtain this type of label, they have a complex LCA study made for their product, and based on this study, materials for EPD are prepared. Therefore, in this case an LCA study is the key instrument, and must be created and verified for each individual product. In the Czech Republic, 27 valid EPD labels on the national level are currently certified (9 of them are certified on the European level) and another 12 EPD labels are at the stage of precertification at present. The majority of the registered and pre-certified products are simple products, such as basic chemical substances, furniture and construction materials.

In general, construction/building materials are experiencing a boom in EPD labelling in accordance with EN 15 804 – Building sustainability – Environmental product declaration (EN 15804, 2012).

Figure 4: The share of the individual life-cycle phases in the overall impact (midpoint category, CLM method)



Conclusions

In conclusion, the LCA method offers an excellent way to assess the broad environmental impact of a construction material, covering the whole or part of its life-cycle, as required. This gives a much more comprehensive picture of the impact than, for example, an assessment of just the embodied carbon dioxide. However, this requires more effort and there is a need for manufacturers to provide more data to databases such as Ecoinvent. While manufacturers can assist in the period up to transport to site, users need to provide their own assessment of transport, application and disposal, since these are project specific conditions.

LCA is also a dynamic method that penetrates other tools/methods that can be used in the tunnelling industry such as BREEAM, LEED, carbon footprint, sustainable buildings or different types of environmental labelling of products. The method can be applied to any product used in any type of tunnel. In the example shown, various rock bolts sourced from various locations were assessed. This LCA highlighted the strong negative impact of the transport distance – i.e. in general high "materials miles" have a negative impact on environmental impact. In this particular case, GFRP bolts were found to be the most sustainable option, all aspects considered.

Hopefully, in the future, the tunnelling industry will increase the sophistication of its analysis of environmental impacts by using tools like LCA and driving down the environmental impact will be seen as equally important as reducing financial costs as projects are developed.

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[1] The essence of the normalisation is relating the indicators of the impact category to the set reference values. The impact category indicators are divided according to the set reference values which are set with regard to European countries. (Budavari, 2011)