Reducing the carbon footprint of municipal infrastructures

S Kytzia 1, H Brändli 2

1 University of Applied sciences Rapperswil, Switzerland
2 FPreisig AG, Zurich, Switzerland

Susanne.kytzia@ost.ch

Abstract. Developers of municipal infrastructures have focused so far mainly on the operation of infrastructure networks (e.g. roads) or facilities (e.g. district heating facilities) and their impacts on climate change. Only recently, the focus shifts to optimizing CO2 emissions embodied in building materials and caused by processes and transports related to construction, maintenance, overhaul and renewal of civil engineering works. The European standard EN 15643-5:2017 provides specific principles and requirements for the assessment of their environmental performance and a new standard for calculation methods will be published in 2022 including an assessment of embodied CO2 emissions. But, how can this information be used to systematically reduce the carbon footprint for municipal infrastructures? In an ongoing research project, we want to answer this question and develop a management cycle for optimizing the carbon footprint of municipal infrastructures. In a first step, we used expert interviews with infrastructure operators, planers and builders focusing on roads to define use cases where information on embodied CO2 emissions is needed. In a second step, we studied construction projects (completed in the past) to analyze data availability at different stages of the planning process. Based on our preliminary results, a management cycle should include the following four use cases for using information on embodied CO2 emissions for decision support. First, it should be used for monitoring of infrastructure networks (as part of scope 3 accounting for operators). Second, it supports priority setting for renewal and overhaul planning when used to analyse representative project portfolios. And, it will help developing project specific benchmarks for optimization at early design stages as well as before public tender. In the next step of our project, we will adapt existing calculation methods in collaboration with operators of municipal road networks to meet information requirements in the identified use cases.

Keywords. infrastructure management, climate change mitigation, carbon footprint, management cycle

1. Introduction
In Switzerland, around 20% of annual demand for primary building materials is used to construct, overhaul and renew infrastructures, mostly gravel and sand, asphalt and concrete (estimation based on [1]). This amounts to approximately 7% of all indirect greenhouse gas emissions (GHG emissions) caused by construction activities per year (estimation based on [1]). Up to now, most infrastructure developers ignore these embodied emissions in their project optimization. Current efforts in sustainable infrastructure development focus on minimizing GHG emissions related to operational energy demand (e.g. for operating systems and equipment [2]) or energy demand and emissions caused by users (e.g.
for vehicles on roads or rail [3]). As described in [4], “the carbon assessment should be included throughout the project development cycle and be used as a tool to rank and select options with a view to promoting low-carbon choices and options as well as the energy efficiency first principle”. For road, rail and urban public transport indirect GHG emissions are not considered a priority so far [4].

Yet, many operators of infrastructure systems already pursue promising strategies for climate change mitigation in operation and use. They often focus on changing the energy supply to renewable resources (see [5] as an example). This strategy needs time and money but will eventually reduce emissions significantly. For truly reaching climate neutrality, however, they will have to take optimization efforts one step further and include indirect GHG emissions for building materials and processes. Therefore, embodied GHG emissions in infrastructure construction will become an important issue in coming years.

There is a large body of literature on GHG emissions related to infrastructure development mostly using Life Cycle Assessment. [6] show that many studies for urban roads focus on the production of buildings materials and the construction processes. Some studies also compare alternative designs for specific types of infrastructures such as bridges (e.g. [7], [8], [9], [10] and [17]), roads (e.g. [15] and [16]), sound barriers (e.g. [14]) or slope stabilization systems (e.g. [12] and [13]).

This knowledge base will be very useful for implementing the new European standard for sustainability assessment for civil engineering works. The EN 15643-5:2017 provides specific principles and requirements for the assessment of their environmental performance and a new standard for calculation methods will be published in 2022 including an assessment of embodied GHG emissions. In this context, many experts in sustainable infrastructure development will ask, how information on embodied GHG emissions can help systematically reducing the carbon footprint of infrastructures. In an ongoing research project in applied research, we want to answer this question and develop a management cycle for optimizing the carbon footprint of municipal infrastructures.

2. Method
In a first step, we investigated how infrastructure developers can take advantage of information on embodied GHG emissions. We identified such «use cases» by
a. Identifying key tasks in project development related to resource and energy efficiency as well as climate change mitigation. We defined these tasks based on a Swiss building standard for sustainable construction of infrastructures [18].
b. Interviewing infrastructure operators, planners and builders about the relevance of these key tasks. We interviewed nine experts for operation and constructions of roads on federal, cantonal and municipal level. In these interviews we prioritized the importance of the different key tasks and specified their content.

In a second step we evaluated what data is needed to assess embodied GHG emissions in two relevant use cases. We used two road constructions projects in the city of Zurich as case studies to analyze data availability at different stages of the planning process.

We analyzed GHG emissions in these case studies with a Life Cycle Assessment, documented which data we used from the project documentation, which additional data we needed and what data sources we used to fill in data gaps. We defined the functional unit according to the clients brief for the project – in this case the civil engineering office of the city of Zurich. We limited the system boundary of our assessment to modules A1-5 according to the EN 15643-5:2017 (see figure 1). We discuss our data sources in detail in section 3.2.
Figure 1. System definition according to EN 15643-5:2017. Source: [21]

3. Results

3.1. Evaluation of use-cases
We identified different tasks in project development related to resource and energy efficiency as well as climate change mitigation according to [18], evaluated their relevance and specified their content in expert interviews. Table 1 provides an overview over the tasks we discussed in expert interviews.

All experts consider preliminary design the most relevant phase in project development. Planers define project requirements at this stage, setting the boundary conditions for optimization in design and engineering. At this stage, the road section under construction is considered as a part of a road network. They aim at finding an optimal solution for the road network / or the relevant part of it. This results in requirements for the road section under construction. This process can involve a lot of different stakeholders, including utility operators (e.g. for designing utility lines), municipal police (e.g. for defining speed limits), urban planners, operators for public transports etc. The decisions taken at this stage are very important as design options for meeting such requirements are often determined by existing building standards and guidelines, e.g. how traffic noise can be reduced by choosing a certain pavement material or how safety standards can be met by using more space. The expert interviews revealed two use cases to benefit from information on embodied GHG emissions at this stage:

(i) To evaluate the effect of existing building standards and guidelines in order to find more climate friendly solutions for meeting certain requirements. In most cases, however, project developers cannot change building standards and guidelines for a specific project. Yet, evaluating their effect can stimulate a learning process that can eventually have a broader impact in the future.

(ii) To introduce a life-cycle perspective to evaluating design options at this stage with a multi-stakeholder approach. Such a life cycle thinking would be very beneficial to better coordinate (and optimize) strategies for maintenance, overhaul and renewal of road, rail and utility networks in urban areas. Most experts that we interviewed hope that this approach would reduce construction activities in the road network.
Table 1. Selection of tasks related to resource and energy efficiency as well as climate change mitigation

| Phase                        | Tasks in project development                                      |
|------------------------------|-------------------------------------------------------------------|
| Preliminary design           | Traffic routing, road alignment, street design                    |
|                              | Choice of operating systems, e.g. for traffic control             |
|                              | Coordination between projects (e.g. construction or overhaul of utility lines) |
| Design and engineering       | Choice of building materials                                      |
|                              | Choice of equipment, e.g. for traffic control systems             |
|                              | Development of concept for site logistics, e.g. transport         |
| Procurement and construction | Definition of construction requirements for public tender         |
|                              | Evaluations of builder offers                                    |
| Operation and maintenance    | Installation of operating systems                                |
|                              | Definition of key performance indicators for monitoring           |
|                              | Documentation for maintenance, repair and overhaul                |

Most experts are convinced that civil engineers have limited options in optimizing resource and energy efficiency or climate change mitigation during design and engineering. The most important design decisions are made in the preliminary design stage and the scope in optimization is further limited by building standards and guidelines. This statement refers mostly to the choice of building materials and systems. Yet, civil engineers can still minimize the amount of material required and the amount of construction waste generated by the construction project. For this purpose, information on embodied GHG emissions could support decision making. Yet, it might already be sufficient to include an additional target for minimizing total amounts of materials and wastes instead.

For procurement and construction, most experts agreed on the benefits of including information on embodied GHG emissions in decision making. Here again, options in optimizing resource and energy efficiency or climate change mitigation are limited. But, there are numerous options for optimization ranging from choice of material suppliers, designing concepts for site logistics to on-site reuse of excavated materials. And, it is far from obvious which option is most beneficial mitigating climate change or conserving primary resources. If we want to evaluate builder offers in public tender, however, we need objective evaluation criteria. Therefore, experts identify a third use case as follows

(iii) **Evaluating builder offers in public tender based on the amount of direct and indirect (embodied) GHG emissions generated in construction.**

Finally, we discussed the benefits of information on embodied GHG emissions in operation and maintenance with our expert panel. They all agreed that there are few benefits for this information on level of a specific construction project. Operators should start collecting data on the type and amount of materials that is «stored» in infrastructure to set up resource management systems for entire infrastructure networks in future. Yet, this data base should include material data (e.g. mass or volume) rather than data on embodied emissions. But we still identified an additional use case at this stage:

(iv) **Generating data for monitoring GHG emissions for construction, overhaul and renewal of infrastructure networks as part of an overall monitoring system including operational GHG**
emissions and for setting up a system of key performance indicators or benchmarks for continuous improvement of GHG emissions in construction.

3.2. Evaluation of data requirement
In this step, we decided focusing on (I) preliminary design and (II) procurement and construction and selected two case studies for construction projects in the city of Zurich.

The municipal administration provided project documentations for the following two projects
- «Flurstrasse»: a project to enhance drain capacity in a municipal street in Zurich Altstetten starting with a project definition in the preliminary design stage.
- «Opfikon»: a project to replace utility lines in a municipal street in Zurich Opfikon starting with documentation for public tender in procurement and construction planning.

a. Data requirement in preliminary design
At the preliminary design stage, only few data is available on the type and amount of material needed for construction. The project documentation shows the project requirements and perimeter (see Fig. 2). In our case study «Flurstrasse», the project aimed at enhancing drain capacity by replacing the existing drainage line by a larger line (with an increased diameter) and constructing a number of additional shafts.

![Figure 2. Project perimeter Flurstrasse. Source: Project documentation](image)

The project documentation only provided information on
- line length, diameter and material,
- number of shafts, their diameter and size as well as type of material for the shaft structures.

Based on this information, we had to estimate based on building standards and expert knowledge
- the type and amount of materials used in the drainage lines as well as the shaft structures.
- the type and amount of materials used and wastes generated in construction of the ditches for the drainage lines and the shafts including
  - construction waste from demolition of the existing road (including excavation),
  - gravel and concrete needed to construct and fill the ditches,
gravel and asphalt to replace the road pavement,
- types and hours of building machines used
- types and distances of transports for material supply and waste treatment.

Our estimations were entirely based on building standards for municipal roads and drainage lines/structures in Switzerland, assuming that the road and drainage system in our case study were built according to these standards. In addition, we collected information on machine use for construction and transports for material supply in interviews with building companies.

On this basis, we estimated GHG emissions with data from an official LCA data base for building materials [19], data on energy requirements of building machines [20] and data from previous studies in this field [15][16].

In spite of the rather limited data base at the preliminary design stage, we were able to carry out the environment assessment presented in Figure 3. It shows that embodied GHG emissions in this project are dominated by the concrete drainage lines. They account for almost 60% of all GHG emissions in this project. This is caused by cement used in concrete production and a reduction of the cement content (and the clinker content in the cement) would be pivotal in optimizing GHG emissions. Project developer could also consider substituting concrete drainage line with pipes using other building materials. But such substitution might be restricted by existing building standards. And it would be important to also include the service life of different types of drainage lines into consideration shifting to a life cycle perspective for the road section including all utility lines in this perimeter.

Figure 3. Results of the environmental assessment in the case study at the pre-design stage «Flurstrasse». GHG emissions are shown in the Global warming potential (GWP) as CO₂-eq. We also used two additional assessment models: cumulative energy demand for non-renewable energies (CED non renewable) and an assessment model commonly used in Switzerland, called «Ecoscarcity» (EcoPoints).
b. Data requirement in procurement and construction

At this stage in planning, there is a complete data set available of material needed for construction. The project documentation shows the amount of material required in the different parts of the construction, e.g. road covering or road base course (see Fig. 4). In our case study «Opfikon», the project aims a replacing utility lines in a municipal street in Zurich Opfikon. It required demolition and replacement of a small part of the pavement for the road as well as the sidewalk. Almost all required information was available in the project documentation. In some cases material amounts in mass units had to be estimated because they were given in other units (e.g. m², m³ or m). No data was available for GHG emissions caused by building machines or material/waste transports. These data gaps were filled in by expert interviews.

On this basis, we estimated GHG emissions with data from an official LCA data base for building materials [19], data on energy requirements of building machines [20] and data from previous studies in this field [15][16].

![Cross profile Opfikon. Source: Project documentation](image)

**Figure 4.** Cross profile Opfikon. Source: Project documentation

With this data base, it was easy to carry out the environment assessment presented in Figure 3. It shows that embodied GHG emissions in this project are dominated by concrete mostly used for utility lines and ditches. They account for over 60% of all GHG emissions in this project. Similar to the project «Flurstrasse» cement used in concrete production is pivotal in optimizing GHG emissions. Construction companies could consider using concrete with a lower cement content. They could also suggest optimizing concrete in ditch construction or replacing it with other materials, e.g. liquid soil. Here again, it would be very important to consider the entire project life-cycle in optimization, including the pavement and all utility lines in this perimeter.
**Figure 5/Figure 6.** Results of the environmental assessment in the case study at the procurement and construction stage «Opfikon». GHG emissions are shown in the Global warming potential (GWP) as CO₂-eq. We also used two additional assessment models: cumulative energy demand for non-renewable energies (CED non renewable) and an assessment model commonly used in Switzerland, called «Ecoscarcity» (EcoPoints).

These case studies showed that it is feasible to estimate GHG emissions at both stages of planning.

- At the preliminary design stage, we have to make a lot of additional assumptions, e.g. based on buildings standards. It requires a lot of expert knowledge and has a significant margin of effort. Yet, it yield meaningful results for project optimization.
- At the procurement and construction stage, we have a lot of information on amount and type of materials. A planner will have to make additional assumption for the use of building machines (types and hours) and material transports (types and distances). Yet, a builder can provide this additional information in his offer.
- At both stages, it would be useful to provide additional information on the life cycle of the project. When considering replacing materials or changing building designs, it is important to consider all implication such choice have during the entire service life and at the end of life. Yet, this information was not available in either design stage in our case studies.

4. **Management Cycle for Climate Change Mitigation**

Based on our results, we developed a management cycle for optimizing the carbon footprint of municipal infrastructures (Fig. 7). It includes all use cases we identified in the expert interviews (see 3.1).

This management cycle starts with setting priorities for climate change mitigation in infrastructure development by the owner and/or the operator. Such priorities could refer to using certain building materials (e.g. use as little concrete as possible), design principles (e.g. always use road coverings with recycled asphalt for temporary pavements), or strategies in maintenance and overhaul (e.g. maximize service life of utility lines with increased maintenance). Such priorities are pivotal for optimizing infrastructure management. They should be based on an assessment of GHG emissions for alternatives in preliminary design for large variety of projects. These priorities set the stage for defining requirements in client briefs for specific construction projects.

These requirements set targets as well as boundaries for the preliminary design stage in the development of a specific project. At this stage, an assessment of GHG emissions should include the
entire life cycle of the section of the infrastructure network under construction including all infrastructure networks involved (e.g. roads, rails, utilities). This may sound challenging, but it will in many cases promote the reduction of GHG emissions as well as life cycle costs. As result of this assessment we will get a rough estimate of GHG emissions for the construction project that can be used as bench mark in project optimization.

In project development, engineering will aim at optimizing GHG emissions using the first benchmark from preliminary design as starting point. The infrastructure owners or operators might even include such benchmarking into an incentive scheme to motive engineers and planners to develop new and innovative alternatives. At the end of this planning phase, GHG emissions are estimated again and the result can be used as bench mark for construction.

In public tender, this «bench mark for construction» can be used to evaluate builder offers. Builders could be asked to assess GHG emissions for the entire construction process and include the results in their offer. A comparison between these assessments with the bench mark could be used to identify the best offer.

After construction is completed, the builder should be required to provide information in GHG emissions caused in construction including embodied GHG emissions. This information could be used for bench-marking or monitoring of the entire infrastructure network.

**Figure 7.** Management cycle for optimizing the carbon footprint of municipal infrastructures.

In follow-up projects, we are currently developing this management cycle in close collaboration with builders as well as infrastructure operators and owners. Our focus is on (i) setting up a monitoring system for infrastructure operator (project commissioned by the city of Zurich) and (ii) developing an assessment tool for public tender (project commissioned by a Swiss business association of builder (InfraSuisse). First results will be available by September 2022.

5. Conclusions

Optimization of embodied GHG emissions of municipal infrastructures involves a number of stakeholders at different stages of asset management and construction planning/execution including the municipal government, road and utility operators, urban and traffic planners, operators for public...
transports, construction planers and building companies. They can maximize their impact on embodied GHG emissions by starting at an early design stage (e.g. defining the clients brief) and consistently pursuing this goals in all decision taken in the following process.

Based on our results, we suggest a consistent approach to support this optimization process. We focus on developing bench marks as interfaces between the different stages of planning and construction rather than suggesting a comprehensive assessment tool for the entire planning process. We suggest to prioritize benchmarks for early design to involve stakeholders in government, urban and traffic planning, infrastructure operators as well as standardization organizations. As the current discussion in Switzerland, however, focusses on different stages in planning (mostly public procurement of planning and construction services), we propose a management cycle for optimizing the carbon footprint of municipal infrastructures. An individual infrastructure owner/operator can start developing a management cycle most suitable for his/her specific context. Yet, we strongly encourage to aim for the entire cycle to ensure a maximum effect for climate mitigation.

References
[1] Gauch, M., Matasci, C., Hincapié, I., Hörler, R. and H. Böni (2016), Material- und Energiereessourcen sowie Umweltauswirkungen der baulichen Infrastruktur der Schweiz. Studie der EMPA im Auftrag des BAFU.
[2] Peeling, J., Wayman, M., Mocanu, I., Nitsche, P., Rands, J. and J. Potter (2016), Energy Efficient Tunnel Solutions, Transportation Research Procedia, Volume 14, 2016, Pages 1472-1481, https://doi.org/10.1016/j.trpro.2016.05.221.
[3] Milan, J. (2006), Sustainable Transport in the European Union: A Review of the Past Research and Future Ideas, Transport Reviews, 26:1, 81-104, DOI:10.1080/0144164050178908.
[4] European Commission (2021), Technical guidance on the climate proofing of infrastructure in the period 2021-2027. Brussels, 29.7.2021. C(2021) 5430 final
[5] www.hochbahn.de/en/responsibility/environment-and-climate
[6] Hoxha, E., Vignisdottir, R.R., Passer, A., Kreiner, H., Wu, S., Li, J. and R.A. Bohne (2020), Life cycle assessment (LCA) to evaluate the environmental impacts of urban roads: a literature review. IOP Conference Series Earth and Environmental Science 588. DOI:10.1088/1755-1315/588/3/032032.
[7] Yishu Niu & Gerhard Fink (2019) Life Cycle Assessment on modern timber bridges, Wood Material Science & Engineering, 14:4, 212-225, DOI: 10.1080/17480272.2018.1501421
[8] J. Hammervold et al. Environmental life-cycle assessment of bridges. Journal of Bridge Engineering, 2011.
[9] L. Bouhaya, L. Le Roy, and A. Feraaille-Fresnet. Simplified environmental study on innovative bridge structure. Environ. Sci. Technol., pages 2066–2071, 2009.
[10] Horvath et al. Steel versus steel-reinforced concrete bridges: Environmental assessment. Journal of Infrastructure Systems, September 1998. ASCE.
[11] Final Report of Innosuisse project «Carbon Footprint für Infrastrukturbauten» (2021, unpublished).
[12] Kytzia S., Roduner A. und R. Bucher, CO2-Footprint of slope stabilization methods - TECCO system (mesh) vs. Shotcrete. 2009 SSEE International Conference 23./24.11.2009.
[13] Flum D., Kytzia S., Roduner A., CO2-Footprint von Böschungssabilisierungsmethoden- Vergleich von Lösungen mit flexibler Geflechtabdeckung zu Spritzbeton. Technischen Akademie Esslingen, 8. Kolloquium „Bauen in Boden und Fels“, Januar 2012.
[14] Güntert R., Mosimann C. und S. Kytzia, Kosten und Umweltbelastungen im Lebensweg von Lärmschutzwänden. In: Strassenverkehr Schweiz 2014, S. 87-89.
[15] Pohl T. und S. Kytzia, Ökobilanz der Herstellung von Asphaltbelegen. In: Straße und Autobahn 10.201, S. 829-835.
[16] , Ökobilanz der Herstellung von Asphaltbelägen. In: Strasse und Autobahn 8/2021. Themenheft Asphaltrecycling. S. 641-652.
[17] Final Report «LCA of a wildlife bridge in the Kanton of Zurich» (2021, unpublished).
[18] SN 530 112/2 (2016), Nachhaltiges Bauen – Tiefbau und Infrastrukturen.
[19] https://www.kbob.admin.ch/kbob/de/home/themen-leistungen/nachhaltiges-bauen/oekobilanzdaten_baubereich.htm
[20] https://www.liebherr.com/de/che/specials/spritsparrechner/sprit-sparen.html
[21] EN 15643-5:2017. Sustainability of construction works - Sustainability assessment of buildings and civil engineering works - Part 5: Framework on specific principles and requirement for civil engineering works