Life-cycle management in transport planning: infrastructure development and operation of high-speed rail in Norway

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Abstract We present lessons and results from recently completed life-cycle management projects for the Norwegian National Rail Administration (NNRA). Our presentation discusses issues in development of rail infrastructure in Norway, and presents use of life-cycle management at different levels: project level, transport level, and mobility level.

Our first case is based on work that has been contracted by the NNRA for investigation of high speed rail alternatives in Norway. The task was to make a life-cycle based framework for ranking of potential high speed corridors. This requires that we develop a component-based emissions inventory for high speed rail development, as well as for mobility alternatives (road, air). The results consider greenhouse gas emissions in particular, and allow separation of emissions that occur nationally as a result of railway infrastructure development and railway transport operation. In this paper we present the life-cycle framework for high speed rail planning, and how the implementation links to scenario development and long-term planning for long-distance mobility.

The second case we discuss is based on a specific railway infrastructure development project, i.e., a new corridor consisting mainly of a 20 km tunnel section to reduce travel time (named the Follo-section). The project is currently in early planning phase, allowing us to follow the project through from selection of technical solution (one tunnel with rails running in either directions, or two separate tunnel runs), via guidance for final design, directives for green procurement, environmental management during construction phase, and follow-up with regards to maintenance and waste. To achieve this we have established life-cycle inventories for technical components of the Follo-section, investigating several life-cycle impacts of railway development through the entire expected life of the section. Feedback from the NNRA is that besides being valuable to the

specific project, lessons from the Follo-section form the Railway Administration's proposal to the future common life-cycle greenhouse gas management approach, to be shared by all transport authorities.

We summarize lessons made from life-cycle management of single rail projects and national high-speed rail projects, and discuss overlaps and contrasts between the two applications. Finally, we outline a structure to link the process-specific details on project level with the consistency requirements for comparison of solutions for mobility.

1 Introduction

The life-cycle perspective is currently an integral part of European policy tools, including rules for eco-design and energy efficiency in products, directives for waste and water management, integrated pollution prevention in industries, as well as environmental management regimes for biofuels and renewables.

The increasing importance of life-cycle management (LCM) for policymakers is reflected also in transport planning. This paper concerns application of life-cycle assessment for environmental management of railway systems at different levels of the management process. We describe two cases in particular; the first is a specific 22 km railway development project currently in early planning phase, the second considers potential implementations of high-speed rail options in Norway. Both studies are conducted for the Norwegian National Rail Authority (NNRA), with brief descriptions given below.

The aim of our paper is to present results and lessons learned in use of life-cycle management for rail projects. While there are important differences between the two cases as applications of LCM in practice, there are also natural overlaps in the data and methods used. These are discussed in the final chapter of our paper, and used as basis to propose a structure to link information requirements in detailed planning of single infrastructure projects with the systems perspective of mobility used in national transport planning.

1.1 The Follo tunnel project

The development project consists of a new section connecting the Oslo main station and Ski station. The project includes a 19 km double-track tunnel and about 3 km of connecting double-track open sections. The lines connecting Oslo main station with the new tunnel is planned with extensive use of culverts, i.e., subsurface concrete box structures. The roof of these artificial tunnels will form the floor for a new recreational area.

Life-cycle management forms the grounds for selection of concept for the tunnel section, to compare one double-track tunnel with two separate single-track tunnel runs. Moreover, environmental LCM is envisaged as the guiding principle through the project life from concept selection, detailed planning, and construction phases.

The environmental assessment is the first case for comprehensive use of LCM for rail infrastructure projects in Norway. It has inspired NNRA to demand that similar life-cycle based evaluations be conducted for all projects, and forms a case study in the life-cycle greenhouse gas management principles shared by the national transport authorities.

1.2 The Norwegian high-speed rail assessment

The National Rail Authority is assessing potentials and impacts from long-distance person transport by high-speed rail, covering four main corridors and several alternative lines. End stations include Trondheim, Bergen, Stavanger, Kristiansand and Oslo.

The environmental assessment covers energy, noise, landscape and environmental interventions, and climate-related impacts. We report here for greenhouse gases from infrastructure development, rolling stock construction and operation. Following the assessment mandate, we have constructed equivalent inventories also for the relevant transport alternatives: private car, bus, and air transport. The end model is useful also for general long-term planning for long-distance mobility.

2 Environmental life-cycle assessment of rail transport

2.1 Literature review

As a basis for discussion and to aid in the interpretation of results from the two cases, we present a brief review of available literature on life-cycle assessment of rail. We may add a few characteristics of specific relevance for Norway; wide use of domestic air transport, small total transport market, and sparse population along main long-distance corridors. Put briefly, the market for domestic mobility in Norway can be summarized as few people living far apart.

There are several examples of relevant life-cycle assessments and equivalent environmental studies in the literature, both for conventional rail [1-3] and high-speed rail [4-10]. Given a Norwegian setting, main lessons from literature are summarized below.

- A study for just evaluation and comparison of rail as a transport system must apply a life-cycle perspective, and cover infrastructure, rolling stock and operational inputs in a consistent manner. However, many of the studies identified in this review do not explicitly refer to LCA methodology.
- Construction and maintenance of infrastructure is the dominant contributor to most impact categories in the Scandinavian countries, for two reasons in particular
    - A large portion of renewables in the electricity grid
    - Few passengers, i.e., high infrastructure load per passenger
- Tunnels and bridges require more input of materials per km and carry therefore relatively more impact in construction and maintenance. An inventory for railway line construction and maintenance must therefore separate between the type of line, and single/double track lines.
- Steel and cement are important materials for the environmental impact from rail infrastructure (global warming, eutrophication, material-related energy use). Results for other impacts are less conclusive, where large contributions are found from insulation material XPS (ozone degradation) and the blasting process (acidification and photochemical oxidant formation).
- Seat and infrastructure load are important controllers for the environmental impact per passenger km.
- Development of rail infrastructure will lead to a shift in market and passenger volumes depending on the preexisting and future domestic transport system in Norway. It follows that a study to investigate environmental benefits from rail must model market effects and model equivalently the environmental properties of relevant alternative transport scenarios.

Following the review, there clearly are several uncertain and scenario-specific assumptions in an LCA for rail. Seen together with a high general interest and stakeholder investment in possible railway development in Norway, this underlines the importance in modelling environmental impacts in a transparent and flexible manner. An assessment of the life-cycle performance of rail systems must accomodate properly ways to communicate and discuss controlling assumptions with stakeholders.

2.2 Life-cycle assessment of a railway project (Follo tunnel)

The life-cycle assessment covers impacts according to the PCR for rail infrastructure, i.e., global warming, acidification, eutrophication, photo-chemical oxidant formation and ozone degradation. We replace the PCR recommended CML baseline method with the equivalent impact categories in the recent and updated ReCiPe (H) method.

Our life-cycle inventory draws on the material and process information used for cost estimation for the project. Through the assessment project we have established a generalized inventory model, which links the output from costing to inventory data in ecoinvent. New inventories are made for technical components of the railway system, particularly for signalling, electronics, etc. More details may be found in the full report [11].

Results indicate that material inputs are main factors with respect to the life-cycle impact of rail infrastructure. As indicated in the literature review, these are cement, steel, XPS used for insulation, and blasting of the tunnel. A view into the pattern for greenhouse gas emissions is shown in figure 1 below.

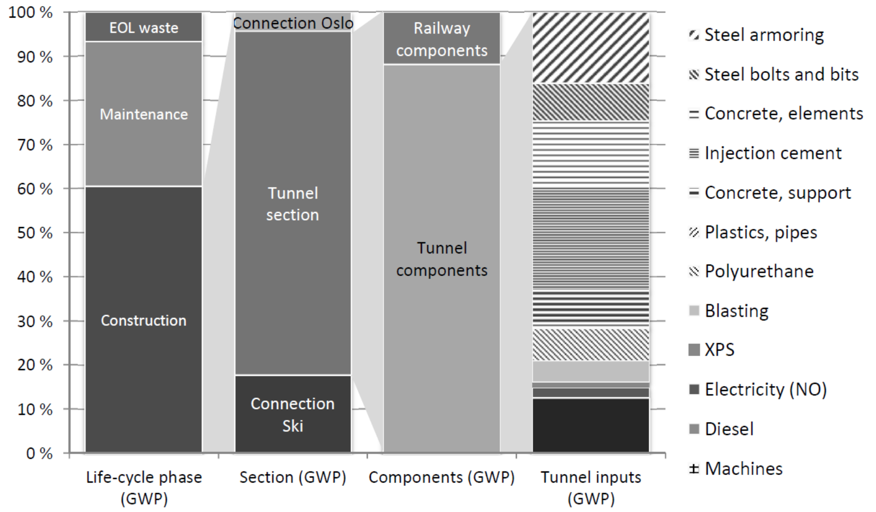

Fig.1: **Distribution of life-cycle greenhouse gas emissions (CO2e) from the Follo infrastructure project**

We see that the construction phase stands for 60 % of total CO2e, with large inputs also from maintenance and waste. It follows that *lifetime consideration and good maintenance programs are important measures* to better the performance of railways. The Follo project is mainly a tunnel development, and it is therefore not surprising that the tunnel is the main cause for GHGs. However, the connection to Oslo actually has a higher carbon footprint per km of section, due to the large use of cement culverts. The culvert section represents almost 20 % of the total CO2e even if it is only 13 % the total distance. To compare, the intensity of CO2e per km is about a factor 2.5 lower for the connnection to Ski station.

Put crudely, a track section consist of a base, railway ties and rails, and electric and technical components. We find that for the tunnel section, track-specific components stand for slightly over 20 % of emissions from the construction phase, whith the remainder originating from components and processes in tunnel construction. Hence, *lifetime considerations must include more than railway systems, they must also cover processes and structures for the construction of the base and tunnels*. It is probably more important to monitor and maintain concrete elements put into the tunnnel than to optimize in detail the railway specific components of the tunnel.

At the most detailed level, the results indicate that *there are several origins for the carbon footprint of tunnel construction*. Steel and concrete/cement are main inputs, but they are installed as part of several different systems. For cement, it may be used injected to the tunnel walls at site, used in ready-made support concrete, or in concrete elements that are installed. Other inputs of importance include plastics, pipes, insulation materials, transport and blasting. *Available improvement measures differ depending on the application*, due to material and quality requirements, preexisting contracts, and flexibility and control in supply chain management.

A brief investigation of improvement potentials for steel and concrete shows that greenhouse gas emissions from the infrastructure may be reduced by 10-20 % just by enforcing stricter procurement requirements, i.e., use of recycled steel materials and cement containing secondary material (fly ash).

2.3 Life-cycle assessment of high-speed rail in Norway

The results from our model for high-speed rail and alternative transports will not be complete untill January 2012. However, in Figure 2 we show results from a literature search, compared with results from our draft model when set-up equivalent to the case in literature. Methodology and sources for the draft model are given in reference [12].

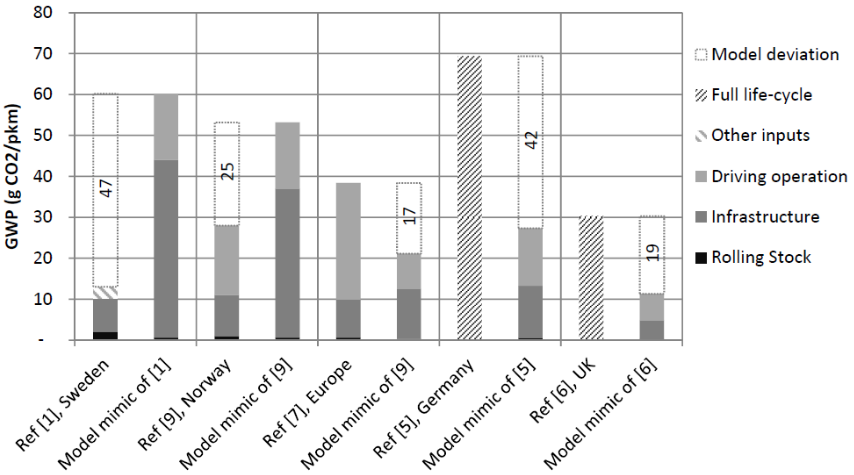

Fig.2: Distribution of greenhouse gas emissions (kg CO2e) from high-speed rail; original data and equivalent results using an intermediate model for HSR concepts in Norway.

It seems our current model gives results above those reported by previous Nordic studies, while below reports for several European HSR concepts. The "model" calculations are Norwegian mimic set-ups by use of our intermediate model for Norwegian HSR with infrastructure composition and market data as in the original study.

The results show the importance of infrastructure, in most cases representing half or more of total GHG emissions. Since infrastructure is such a dominant factor, *utilization becomes an important issue for LCM*. In a holistic perspective, utilization may improve the performance of HSR in two ways:

- Passenger volume and seat occupancy, which directly controls the contribution from operational energy and the rolling stock life-cycle, as well as the the infrastructure load
- Infrastructure load, which directly controls the contribution from construction and maintenance of the railway

The importance for infrastructure is very diffferent for rail compared to alternative transport systems, such as private car or air transport, both for greenhouse gas emissions and life-cycle energy use [2-4]. The consequence is that the *environmental performance of HSR is set at the concept stage*, since this controls both the environmental performance of the infrastructure, and that market allocation follows from important design decisions. Market potential follows from travel time compared to air transport, and intermediate travel market is given by alignment and scheduling designs. Operational efficiency may be improved by better management, but only within the bounds given by the initial infrastructure investment.

Our HSR assessment model covers also the alternative transport modes, adapted to include scenarios for expected future transport markets.

An added feature in the model is a split in life-cycle emissions, between emissions occurring nationally and in the global context. This increases the model value as it explicitly links national transport policy with carbon policy. Emission splits are based on assumed sourcing of materials for the infrastructure, by process-LCA and keys from input-output modelling. One may argue that the split is irrelevant, since greenhouse gas emissions are a global challenge. It does, however, add to the interpretation of the trade-off between shrt-term infrastructure investment and the long-term expected savings in operation.

3 A structure for life-cycle management

The case studies described above build on a common structure, i.e., a unit process inventory model for rail transport. An overview of the model is presented in Figure 3, which also indicates a framework for LCM in rail planning, from project to mobility. What is not shown in the figure is that an identical framework is applicable to alternative ways of transport, e.g., use of private car, or air transport.

The term life-cycle management (LCM) carries different meanings. We focus here on environmental management and interpret LCM as integration of life-cycle environmental performance in the management of business strategy, culture and operations. Following Linnanen et al [13] and Svensson [3], we separate the following applications of LCM:

- Company management, life-cycle as an integral part of business strategy
- Product management, better products from a life-cycle perspective
- Organizational management, a culture for life-cycle thinking

Svensson discusses LCM based on energy analysis for rail in Sweden, and discusses particularly implementation of LCM in strategy and operative thinking. Separating between stretgic and operative decisison, we find the following main issues for LCM:

- Operative: a greener materials supply chain; better use of material inputs (maintenance, recycling, and reuse of materials and components); design solutions with low-emission material types and qualities
- Strategic: insights into upstream environmental challenges with risks and potential top-sides; early indication for environmental performance leaves more room for improvement on costs, energy and environment

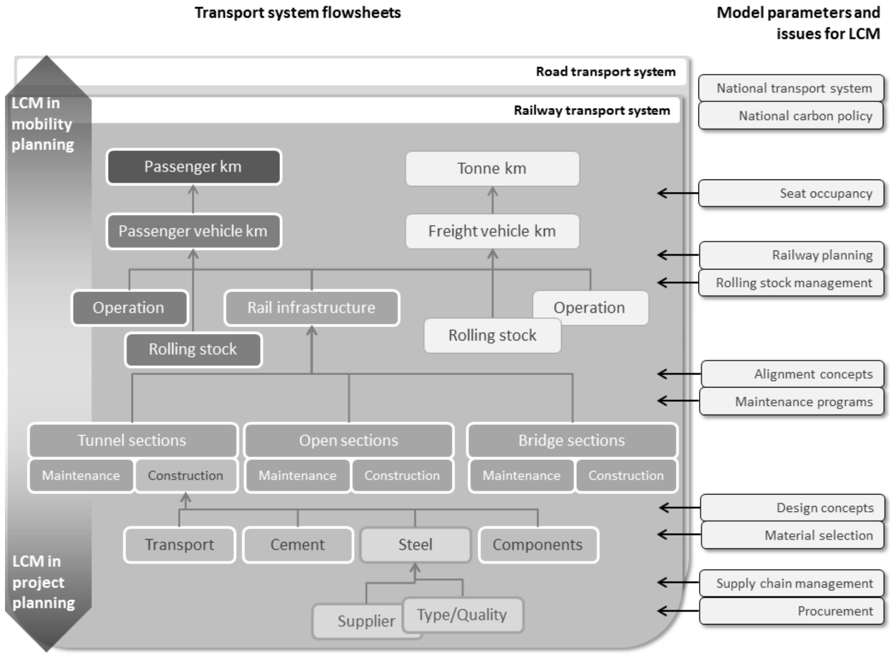

Fig.3: **Framework for life-cycle management in transport planning, with example for the railway transport system**

We may separate the issues for LCM for rail along the classification of Svensson, using Figure 3. The issues in the top of the right column in Figure 3 fall within long-term planning, while the lower belong to short- and near-term planning - i.e., product management and day-to-day project planning. Important issues for railways on the level of mobility is infrastructure utilization and rolling stock management. Our results have indicated that infrastructure controls the life-cycle performance of the rail transport system. Use of rail for freight, schedule optimization with respect to market development and market share, become strategically important issues. Life-cycle management for transport planning therefore must cover not just infrastructure but the whole transport system from realization to utilization.

The environmental performance of person transport by rail is controlled by seat and infrastructure utilization rates, as well as the environmental propertes of the infrastructure itself. Issues for LCM for rail therefore includes:

- Route and schedule planning, to optimize infrastructure utilization versus emissions from fleet operation
- Market conditions, through alignment and station placement that increases the total passenger volume
- Co-utilization of infrastructure for freight

The life-cycle perspective should be integral in planning of both single and large-scale projects, in all procurement decisions, as well as form the basis for maintenance programming.

4 Way forward

Insights from the environmental life-cycle assessment for the Follo tunnel will be used to preevaluate and compare in an early phase proposed concepts and design solutions. The early availability of environmental information, as offered in the planning process the Follo tunnel and envisaged expanded through more generalized planning tools, is a great aid for systematic use of life-cycle information in decision processes.

The results of the LCA has helped intensify the Rail Authorities focus on procurement, especially for large steel and concrete inputs. It has also generated interest in programs to manage better maintenance and service life of foundation, track and other components.

The assessment for high-speed rail in Norway has overlapped in time with the Follo assessment. The view offered by the HSR study into the life-cycle impacts from rail as a means for mobility, has broadened significantly the perspectives used by the Rail Authority, from a process-oriented focus on infrastructure to a systems perspective of infrastructure, rolling stock and operations. The assessment therefore moved from a strict infrastructure analysis to a transport evaluation, which has brought to the attention the importance of infrastructure utilization. In total, Follo assessment has generated significant interest in life-cycle management tools and practices:

- It has served as input to the common national method for environmental accounting for infrastructure projects, an approach shared by all national transport authorities. The methodology will be developed into 2012.
- Conclusions from the infrastructure assessment form the basis for a specific guideline, to be used in calls for project planning. This means

that all rail infrastructure design proposals must specify use of input factors for a selection of predefined materials, energy and fuel.
- The LCA results are used as basis to direct and design procurement guidelines, i.e., what materials and components to include and the format of requirements.

Already we have experienced that the content and structure of the LCA model for high-speed rail in Norway has generated significant interest for life-cycle thinking in transport planning. These perspectives have been largely left out of national transport planning so far mainly due to lack of data. Initiatives to include the life-cycle of infrastructure are seen in both road and rail planning, where environmental management historically has been dominated by operational issues and single-issue environmental initiatives.

In our work for the Norwegian Rail Authority, we make the same conclusions as Svensson [3], that information is the starting point for LCM. Insights from the Follo tunnel assessment has generated a momentum where also organizational culture in the Rail Authority and in the supply chain for rail is forced to change. Environmental life-cycle performance is becoming a required part of the planning process, exemplified by environment listed as a separate issue in the recent call for planning of a specific passing loop section (the Aas passing loop). Early identification of environmental challenges leaves more room for improvement, and lets environmental performance be a decision criteria through the entire planning and design process.

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