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LIFE CYCLE ASSESSMENT OF NORWEGIAN STANDARD ROAD TUNNEL

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ABSTRACT

The environmental impacts of a standard Norwegian road tunnel are evaluated by the life cycle assessment combined with system dynamics. The standard Norwegian road tunnel is defined as a 3 km long 9.5m wide (67 m^2 cross-section) rock tunnel. The result shows that one meter standard tunnel has 13 tons CO_2eq emissions during its whole life. Construction stage dominates nearly all air emissions in the tunnel life. The results also indicate that the improved energy efficiency of construction machines in combination with a decreased use of imported materials will play a key role to lower the emissions from tunnel construction.

INTRODUCTION

The Norwegian Governments' long term target is to become carbon neutral by 2050 and transport is one of the major parts to realize such target. Energy used in construction, maintenance and operation of transport infrastructure is a part of indirect transport energy consumption. The knowledge concerning indirect energy use and emissions in the Norwegian transport system is rare.

The topography and landscape of Norway is challenging for infrastructure construction as they often lead to many and possibly long tunnel sections. According to Norwegian Public Road Administration (NPRA), the last 30 years there has been considerable development in the Norwegian underground activity. There are around 1,000 tunnels in Norway with a total length of over 800 km. And 20-30 km of new tunnels is built recently. Construction of tunnels is a material and energy intensive process. Such unprecedented growth construction work of tunnel in recent years is associated with significant energy use and air emissions. It is therefore important to quantify road tunnel performance in the GHGs mitigation. To explore the environmental impacts of road tunnel in Norway, the standard 9.5m wide (67 m^2 cross-section) road tunnel will be analysis here. The boundary, assumption and data sourse of life cycle assessment are briefly reviewed below. Then, the detailed results and analysis are presented. A discussion of the findings concludes the paper.

MATERIALS AND METHODS

This LCA study follows the ISO 14040/44 methodology.(ISO, 2006a, 2006b) The LCA modelling has been carried out in Simpro V7.3.3 and the ReCiPe Midpoint (E) V1.06 method has been used to estimate the environmental impacts.

Goal and scope of the study

The goal of the study is to estimate the life cycle environmental impacts of a standard rock road tunnel in the Norway. These results are then used to estimate the overall impacts from the existing road tunnel in Norway to identifying the hot spots and improvement opportunities along the supply chain.

System boundaries, assumptions and data

According geological conditions in Norway and the database of Norwegian Public Road Administration (NPRA), the standard road tunnel is defined as 9.5 wide (67 m^2 cross-section) and 3 km rock tunnel with medium blastability and drillability.

The functional unit is defined as the 'construction and operation of one m tunnel over its lifetime'. The lifetime of a tunnel is a difficult parameter to standardize because it depends on many factors. Here, following other authors (Miliutenko, Åkerman, & Björklund, 2011), the lifetime has also been assumed as 100 years in this study. Because there are little available information about road tunnel demolition (or lock up), this study comprises two main stages in the life cycle of the tunnel: construction and operation. Construction and maintenance involves extraction and manufacture of construction materials and fuels, transportation through the supply chain and on-site construction activities of the tunnels. The operation stage includes energy consumed by ventilation and lighting in tunnel.

Construction work of Norwegian standard tunnel was estimated by the cost database of Norwegian Public Road Administration (NPRA). Bills on tunnel completed during the period 2004-2011 were used to estimate the amount of different construction process work. The amount of main material is estimated by the information of tenders, related handbooks and personal communication with experts. Energy consumption for excavation is calculated by the database TunSim at NTNU. Machines used for other process were assumed to be typical machines use in Norway and energy consumption was estimated by earlier related studies in Norway and Sweden (NTNU, 1992; Stripple, 2001). The reuse of tools, temporary buildings, water consumption and production of construction machine are excluded in the study. The preparatory, control, monitoring and traffic of worker are also not taken into account here.

Transport is assumed to be done by trucks or semi-trucks that fulfill EURO IV. The distance of main material from the manufacturing gate to the construction site is assumed to be 50km. The weight of the load on the return trip is estimated 20% of material weight that was delivered to the construction site. Transportation of construction machine to construction site is excluded.

Waste disposal during the construction phase of the tunnel considered handling of blasted rock. It was assumed 100% of blasted block are reused. Based on tenders, 6% of blasting rock was reused in tunnel construction and other part was sold to the market. The waste of packaging waste was excluded here due to the accessibility of data.

Operation and maintenance of the tunnel includes electricity consumption for operation (lighting, ventilation, pumps and monitoring systems) and maintenance of the pavement. It was estimated that approximately 1280kWh / (m.year) of electricity will be used during the operation of the tunnel. The pavement during the whole life time was estimated 10 times replacement by the system dynamic model. The data for system dynamic model is based on statistical data published by Statistics Norway (SSB). Due to the difficulty of future pavement technology projection, the material and machine use for pavement replacement is assumed same to the construction stage.

The background life cycle inventory (LCI) data have been sourced from the Simpro V7.3.3 various databases. Where Norway-specific LCI data have not been available, the data used from the databases have been adapted as far as possible to reflect the Norwegian conditions, particularly with respect to the Norwegian energy mix.

RESULTS AND DISCUSSION

Construction stage of emits 6.5 tons CO_2eq (Figure 1A) per 1m tunnel. Production of materials used for the tunnel construction dominates all kinds of impacts in the construction stage. Energy use on construction site is responsible to 9 % global warming potential (GWP) and transportation of materials to and from the construction site account 15% of total GWP. A more detailed analysis of the GWP of onsite construction indicated that the concrete is biggest contribution (42%) and the diesel use for construction machine is the second one (8%). And explosives respond to 4.8% GWP in the construction stage.

Construction stage also occupies 50% of total CO2eq emissions in the whole life span of tunnel (Figure 1B). The contribution to GWP is from the operation stage and maintenance is 35% and 15% respectively. Construction stage also dominates main air emissions such as CO_2, CFC, NMVOC, PM10 and SO_2 during the whole life span of tunnel. Therefore, reduction of air emissions during life time of tunnel relies on the policies and regulations to the tunnel construction. Operation stage has highest share of HTP, IRP, FEP and three main eco-toxicity potential (TETP, FETP and METP). Impacts of tunnel operation came from the electricity production. Thus the control of toxicity during tunnel life span depends on the efficiency of ventilation and lighting system and production of electricity.

When the whole tunnel sector in Norway is taken into account, it is found that at least 0.9 million tons CO_2 was embodied in the new tunnel construction during the period 2004-2011.

Moreover, 53 kilotons CO_2 will emit annually due to the tunnel operation and maintenance when it is supposed no new tunnel will be built. Norwegian population passed 5 million in 2012 and will have another one million growths at the end of next decade. This will result more road and tunnel construction in these two decades. It can be estimated that around annual 180 kilotons CO_2 emit to atmosphere due the construction, maintenance and operation of road tunnel when it assumed new 20 km tunnel will be built annually. Material, diesel use for construction machine, electricity and transportation of materials contributes 57%, 16%, 16% and 11% to such emissions. Moreover 20% of building materials used in Norway is imported. And 50% of energy use in Norwegian manufacture sector is hydropower which has considerably lower output level of CO_2. Therefore domestic materials are recommend to be used due to their lower CO2 intensities when were compared with imported one.

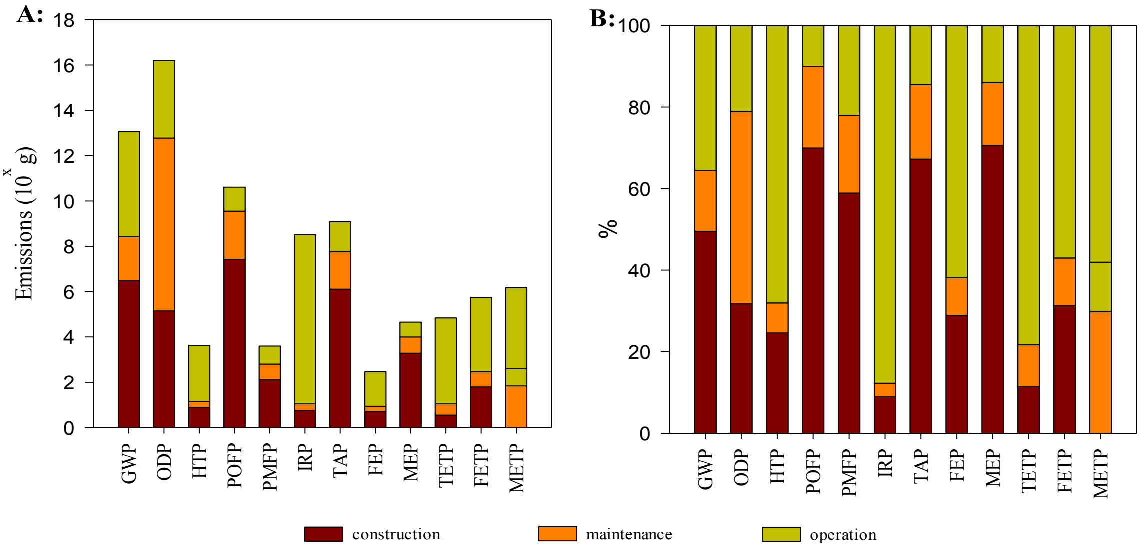

Figure1 A: Impacts of one meter tunnel during its life cycle (left); B: Distribution of impacts of one meter tunnel during its life cycle (right)

(Note: Climate change (GWP): 10^6g CO_2 eq; Ozone depletion (ODP): 10^{-1}g CFC-11 eq; Human toxicity (HTP): 10^6g 1,4-DB eq; Photochemical oxidant formation (POFP): 10^4g NMVOC; Particulate matter formation (PMFP): 10^4g PM10 eq; Ionising radiation (IRP): 10^6g U235 eq; Terrestrial acidification (TAP): 10^4g SO2 eq; Freshwater eutrophication (FEP): 10^3g P eq; Marine eutrophication (MEP): 10^3g N eq; Terrestrial ecotoxicity (TETP): 10^3g 1,4-DB eq; Freshwater ecotoxicity (FETP): 10^4g 1,4-DB eq; Marine ecotoxicity (METP): 10^4g 1,4-DB eq)

CONCLUSIONS

By life cycle assessment of the Norwegian standard road tunnel, this paper reveals that:

The total GWP over the lifetime of 100 years for one meter Norwegian standard road tunnel is 13 tons CO2 eq. The construction stage is the main contributor to all air emissions. The operation stage dominates the main toxicity impacts which are mainly related to energy use. There is a significant pontetial of reducing the environmetal impact from Norwegian tunnels with increasing the share of domestic materials, improving energy efficiency of construction machine, and ventilation lighting system in the tunnel.

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