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Life cycle assessment of large scale timber bridges: A case study from the world's longest timber bridge design in Norway

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ABSTRACT

This paper seeks to use life cycle assessment to investigate the comparative environmental impacts of two proposed bridge designs for the new Mjøsa Bridge over Lake Mjøsa in Norway. The Norwegian Public Roads Administration has designed one timber and one concrete alternative for the 1650 m 4-lane highway bridge. If the timber bridge design is chosen, it will be the longest timber bridge in the world once constructed.

The main motivation for building the timber bridge is to utilize local industry and to reduce environmental impacts in road infrastructure. This study aims to determine the expected emissions from both construction designs by using life cycle assessment. Life cycle assessment studies on smaller timber bridges have been carried out in the past with favorable results towards timber designs, but no bridge of this scale has been built and therefore a more comprehensive study is required to confirm if a timber bridge of this size is a sustainable choice for transport infrastructure.

The results of the study show that the timber bridge has significantly lower emissions than the concrete bridge across all impact categories included in the scope of this study. Additional environmental gains can be made from end-of-life treatment of materials. This study shows that large scale timber bridge designs should be considered for future road projects.

1. Background

The average concentration of global CO_2 emissions has passed 400 ppm, an increase of over 44% from historical pre-industrial era measurements, due to anthropogenic activity and causing global temperature increases through climate change (Le Quéré et al., 2016). The effects of climate change have pushed governments into climate agreements which prioritize sustainable development to reduce global greenhouse emissions (United Nations Framework Convention on Climate Change, 2016). The emissions from infrastructure, largely due to steel and concrete production, are declining but still significant contributors to global CO_2-emissions (Olivier et al., 2016). Cement production is estimated to be between 5–8% of global CO_2-emissions (Chen et al., 2010), (International Energy Agency, 2015), (Olivier et al., 2015) signifying large emissions for new built infrastructure globally. In Norway, the forthcoming National Transport Plan, set to be implemented by 2018, has an explicit goal to reduce emissions from transport infrastructure by 40% below 2005 levels by the year 2030 (Avinor et al., 2016a).

The National Transport Plan is also concerned with constructing or expanding capacity of major roads in Norway, most notably major construction projects on European highways E6 and the E39. Road traffic in Norway has increased by 12.5% (in total kilometers driven) in the last decade, which has been used to support the road construction policies set forth in the National Transport Plan (Statistics Norway, 2016; Statens vegvesen, 2015). Innovations in construction materials, techniques and structural designs will

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be required in order to meet emissions targets and future transport.

Determining the impacts of road infrastructure is better understood by broadening the scope of the study to include all life cycle processes using a methodology such as life cycle assessment (LCA). LCA studies have been successfully completed in the past on *road construction* (Stripple, 2001; Huang et al., 2012; Barandica et al., 2013; Jullien et al., 2014; Wang et al., 2014; Miliutenko et al., 2014; Fernández-Sánchez et al., 2015), *pavements and asphalt* (Santero et al., 2011; Yu and Lu, 2012; Celauro et al., 2015), *road maintenance* (Huang et al., 2009; Jullien et al., 2014; Yu et al., 2015; Keijzer et al., 2015), *bridges and tunnels* (Bouhaya et al., 2009; Huang et al., 2015; O'Born et al., 2016), *materials and end of life treatment* (Birgisdóttir et al., 2006; Huang et al., 2007; Sandin et al., 2014), and total transport systems (Treloar et al., 2004; Chester and Horvath, 2009; Singh and Strømman, 2013; Pérez-Martínez and Miranda, 2014; Chester and Cano, 2016) to varying degrees of detail. While these studies have separate scopes that may not make them directly comparable, a common pattern that emerges with each is the environmental impact from materials used. Emissions from material production are found to contribute upwards of 90% of total road infrastructure CO_2-emissions (Cass and Mukherjee, 2011) and up to 80% in heavier infrastructure such as tunnels and bridges (Wang et al., 2014) while material production is no less than 60% of total energy demand (Muench, 2010). Reducing the impact of materials and material production in infrastructure is critical to the overall sustainability of road infrastructure projects. It is reasonable to assume that future material production emissions for conventional road building materials, namely concrete and steel, can be reduced by future innovations. It is important, however, to alter building techniques to implement materials that are already less emissions intensive. Timber is a material that is gaining more attention in sustainable infrastructure planning despite being one of the oldest building materials in the world.

The use of timber in long lived products such as road infrastructure, is in effect creating a temporal carbon storage and thus a carbon sink for atmospheric CO_2 (Røyne et al., 2016). This perception of sustainability is driving increased interest towards the use of timber and glue laminated timber as a building material for modern, large-infrastructure (Sandin et al., 2014; Mallo and Espinoza, 2014). The sustainability benefits of timber in Norway are supported by comprehensive studies that look at the overall life cycle impacts of Norwegian timber production (Timmermann and Dibdiakova, 2014; Røyne et al., 2016). Newly planned and completed projects showcasing the viability and versatility of timber, from medium-rise apartment buildings (Felton et al., 2014) (Malo et al., 2016), to airports (Petersen and Solberg, 2002) to simple roadways (Dias et al., 2016), are gaining widespread attention for their ingenuity and elegant design. Although most successful applications of modern timber designs have focused on buildings, research is pushing the boundaries for how timber can be utilized in other large structures, including in road bridges (Norwegian Wood Technology Institute, 2007; Bouhaya et al., 2009; Rodrigues et al., 2013; Dias et al., 2016).

In Norway, over 200 timber bridges have been constructed in the last 25 years, including world's strongest (Kjøllsæter Bridge) and world's longest timber roadway bridges (Tynset Bridge – 125 m) respectively (Statens Vegvesen, 2015; Bjertnæs et al., 2015). Despite the increase in use of timber in roadway bridges, most projects are relatively small and have not been conceived as large projects, such as extended multiple lane highway bridges. A small collection of timber bridge LCA studies have shown that timber bridges have the potential for lower environmental impacts compared to concrete bridges (Bouhaya et al., 2009; Hammervold, 2010; Brattebø, 2012; Hammervold, 2014; Rodrigues et al., 2016) but it is unknown how timber used in a large-scale highway bridge will compare. The purpose of this study is to determine whether large bridges made from timber can be a sustainable alternative to bridges built using more conventional techniques and materials.

2. Case study description

The current Mjøsa Bridge is located on the European Highway 6 (E6) approximately 140 km north of Oslo and crosses Norway's largest lake, Mjøsa, between the communities of Biri and Moelv. The E6 is one of the main national highways and is a vital overland link that connects southern and northern Norway. The existing 1420-m Mjøsa Bridge was opened in 1985 and has a daily average traffic (AADT) of 13,000 vehicles. The existing Mjøsa Bridge was built with a 50-year lifetime and theoretically can stand until 2035. However, continuing operation of the current Mjøsa Bridge would incur heavy maintenance costs to control deformations and would require upgrading to current Norwegian road standards to meet expected future traffic demands (Statens Vegvesen, 2015). Due to these issues, the existing bridge is slated to be demolished and replaced by a new structure before the year 2021 (see Fig. 1).

One of the proposed designs for the new Mjøsa Bridge has incorporated a glue laminated (glulam) timber superstructure. The timber design of the Mjøsa Bridge has been investigated by the Norwegian Public Roads Administration (NPRA/Statens vegvesen) as a viable alternative to a concrete bridge solution and if constructed, this timber bridge would be more than 1000 metres longer than any other timber bridge in the world. A timber bridge of this scale is meant to showcase the viability of timber materials in large-scale transport infrastructure and promote local industry (Jakobsen et al., 2013). The research costs for developing this timber bridge are

Fig. 1. Concrete bridge (left) and timber bridge (right) designs for the new Mjøsa Bridge (Statens Vegvesen, 2015).