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Carbon footprint comparison of innovative techniques in the construction and maintenance of road infrastructure in The Netherlands

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ABSTRACT

The ambition of European countries to reduce their national greenhouse gas emissions, has been translated in the Netherlands in green procurement policy of the national road administration. An increasing amount of innovative techniques and approaches in road infrastructure construction and maintenance are available, but their contribution to achieving the national goals is often unknown. The aim of this research was to develop insight for policy makers and researchers on the potential impact of existing and nearly operative innovative techniques in road infrastructure. The emissions during the whole life cycle of Dutch road infrastructure forms the baseline of this study. The total greenhouse emissions from Dutch road infrastructure are estimated at 2 Mt CO_2-equivalents per year, which are mainly resulting from production and construction of asphalt road, bricks, concrete elements and electricity for lighting. Subsequently, ten currently and nearly operative innovations are inventoried and assessed on their reduction potential for greenhouse gas emissions. Large reductions can be achieved by switching the energy source of lighting installations towards renewable sources. For asphalt roads, low energy asphalt and the application of rejuvenators had the highest carbon reduction potentials. Reducing the amount of new made bricks by using concrete elements instead leads to almost 30% CO_2 reduction for the emissions of brick roads. For concrete element roads, the highest reduction potential is in further applying the construction recycling concept called "Kringbouw". The cumulative greenhouse gas reduction potential is 37% for both the main road network and the asphalt roads in the secondary road network, 28% for both bricks and concrete element roads, and 84% for maintenance and control of the total road infrastructure. This study shows that the reduction potential for carbon emissions in infrastructure is substantial: a cumulative reduction of one third of the Dutch road infrastructure emissions could be achieved. This study as well as similar follow-up studies can serve as a guide for policy makers in early development stages and decision making.

1. Introduction

Europe wants to shift towards a resource-efficient, low-carbon economy to achieve sustainable growth (European Commission, 2011a). The white paper on a resource efficient transport system (European Commission, 2011b) shows that the focus of this transformation is on alternative fuels, fuel efficiency and increasing the efficiency of transport and infrastructure. The transport sector has to achieve a greenhouse gas reduction of at least 60% by 2050 with respect to 1990. These European targets are translated to goals and policies on national, regional and local levels. In the Netherlands for example, where the majority of the road infrastructure is controlled by the authorities, policy makers and road developers have to consider both the European greenhouse gas reduction targets as well as the government's target of a 100% green procurement procedure.

Miliutenko et al. (2014) showed that there is not yet a formalised procedure for integration of greenhouse gas reduction or green procurement in road infrastructure projects in all European countries. The Netherlands are relatively advanced in

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the implementation of green procurement in a quantitative and objective manner, which is supported by two main tools. The environmental impact over the whole life cycle of a project, which must be included in the tender, can be uniformly calculated by a life cycle assessment tool called "DuboCalc", which was developed by the national road authority "Rijkswaterstaat" for this specific goal. In the same period, the maintainer of the Dutch rail system "ProRail" developed the "CO_2 Performance Ladder", which is a certification scheme that helps companies to gain insight in the CO_2 emissions of their company and tries to stimulate them to reduce their carbon footprint (SKAO, 2012).

The basis of the calculations in DuboCalc lies on an extensive, synchronized database. This database contains environmental profiles of infrastructural products, based on the "National Environmental Database" (van Ewijk, 2011). However, as the database consists of products, calculations can only be made on the basis of existing materials, and the impact of innovative techniques or products cannot be calculated. The problem exists also, though in a smaller extent, for the CO_2 Performance Ladder: although carbon footprinting of general infrastructural processes is relatively common practice, analysing innovative and deviating processes is not and there is a notable lack of quantitative assessment tools for innovative techniques.

Currently nor policy makers and neither product developers have the tools to assess the impacts of different innovations in road infrastructure construction, maintenance or management techniques. The aim of this paper is to generate insight in the effects of a range of existing and near operative innovative techniques, in order to support decision making and development. To gain this insight, it is necessary to assess the current available information on the environmental impact of road infrastructure, to inventory the available range of innovative techniques, and to assess the impact that they could have on the total footprint of Dutch road infrastructure.

There is a range of environmental studies on road infrastructure available; Santero et al. (2011) provide an overview of them. In general, many studies focus on asphalt roads and pay little attention to other road types (e.g. the Ecoinvent report of Spielmann et al., 2007). In addition, there is large amount of environmental or carbon footprint studies on road infrastructure that discuss the scores of concrete versus asphalt roads (for example: Athena Institute, 2006), which are not seldom commissioned by either of the two market parties without an external and independent review. Moreover, a part of the studies are case specific and limited in their local, geographical and situational characteristics (e.g. Häkkinen and Mäkelä, 1996, or Loijos et al., 2013, or Sianipar and Dowaki, 2014). The other, non-specific, studies often present only general environmental footprints of roads and do not show the impact of individual elements like materials, processes and/or life cycle stages. An example of such a study is Spielmann et al. (2007) who do extensively describe four road types and their total material and energy requirements over the whole lifecycle. Another example is Zhang et al. (2008), who describe the greenhouse gas emissions for different life cycle stages of three road types, but do not go into detail about processes. A last characteristic of the existing studies is that the focus is usually only on the current situation and proven technologies (e.g. Habert and Roussel, 2009 or Jullien et al., 2014) or on technologies that are in an advanced stage of development, such as recycling (e.g. Biswas, 2014 or Blankendaal et al., 2014). An exception to these conservative approaches is Santero et al. (2013), but though they do include many innovations, they focus on concrete roads only.

The described studies are unable to solve the data gap for quantitative innovation assessment tools for several reasons. First, studies that focus only on one kind of road material type (asphalt) are unsuitable for the assessment of the whole infrastructural system. Second, many studies are too specific and therefore unable to be used for generalized calculations. In addition, most studies analyse only the current situation and do not investigate innovative alternatives. Moreover, there are few studies available that focus on the carbon footprint of Dutch infrastructure, which differs from other countries by the large-scale application of blast furnace cement in concrete roads, the high recycling rates in asphalt (Molenaar et al., 2011) and choices for large scale application of asphalt types with high noise reduction. Summarizing, the existing studies are often too specific and therefore not useful for general calculations on the effect of measures or adaptations in road infrastructure projects. The less-specific studies are however not suitable for our research question either, because they often do not provide insight in the impact of individual elements which makes it impossible to vary certain elements in order to experiment with effects of innovations.

There is thus a large knowledge gap in both the carbon footprint of (components of) the Dutch infrastructure and the potential impact of innovations. In this study, a pragmatic approach is applied in order to draw the overview picture of the impact of innovations on the total impact of road infrastructure.

2. Materials & methods

2.1. Methodology

In order to investigate the potential impacts of infrastructural products, the Life Cycle Assessment (LCA) approach is followed, as described by ISO 14040-44. This stepwise approach involves subsequently goal and scope definition, inventory analysis and impact assessment.

The goal of this study is to analyse the potential impact of innovations on the carbon footprint of Dutch road infrastructure. Because there are large variations in the length, width and presence of different road types, an assessment of the whole infrastructural system will not provide insights in the impact differences of innovations. Therefore the functional unit of this study is not the complete road network, but "1 m^2 of a certain road type on a typical Dutch road for one average year".

The baseline of this study is the situation at present in The Netherlands. Since infrastructure characteristics can differ much between countries on fundamental aspects – for example the share of concrete or asphalt roads – the results cannot be extrapolated to other countries. The temporal scope focuses on the present and near future situation, meaning all innovations that are expected to be operative or at least expected to be operative within the coming decade. Long-term scenarios and their impacts, for example an increase in the total road surface or depletion of fossil resources like bitumen and required measures, are not taken into account. This means that the results are useful for short-term (near decade) policies for innovation strategies, but do not reflect expected impacts on the long term (one century or more).

The impact of the innovations expresses all impacts during the life cycle of the road, meaning all stages from cradle (winning of materials) to grave (end of life, recycling) are taken into account. Since the aim of this study is to analyse average roads and not detailed variations, the study was preceded with a quick scan on the contribution of different components. Components with an impact of less than 10% of the total were excluded from further analysis. This is the case for infrastructural elements like bridges and tunnels. In this earlier research it also became clear that lighting is an influential factor on the carbon footprint and therefore it is included. Road traffic is excluded from all calculations, since the focus of this research lies on the life cycle of road infrastructure itself.

The end of life treatment is modelled by a substitution approach, because most of the foundations and asphalt roads in