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Life-cycle greenhouse gas emissions associated with a highway reconstruction: a New Jersey case study

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ABSTRACT

A comprehensive greenhouse gas (GHG) life-cycle assessment was conducted for a large highway reconstruction project in New Jersey. The GASCAP model was used to determine the total life-cycle GHG emissions associated with the materials used, construction equipment, mobilization of resources for the project, traffic disruption during construction, and materials used for life-cycle maintenance. The focus of the case study was to determine the relative share of these various components, as well as the importance of accounting for non-CO_2 GHG emissions. Results suggest that non-CO_2 emissions are substantial enough that they should be included and that various smaller material components, not just those associated with materials in the pavement should also be included. For this specific case-study, traffic disruption was a minor component of total emissions, though this result will differ depending on project and road network details. GHG emissions associated with this reconstruction project account for about 20% of the total emissions expected to be generated from traffic using the highway over a 50 year lifetime.

1. Introduction

New Jersey's Global Warming Response Plan (GWRP) seeks to significantly reduce carbon emissions by 2050. Within New Jersey, transportation associated emissions account for over 40% of total greenhouse gas (GHG) emissions. One of the specific action items listed within the plan is to “establish a carbon footprint standard for transportation projects” (NJ Dept. of Environmental Protection, 2009). This requires the assessment of the life-cycle GHG emissions associated with the construction and maintenance of transportation projects.

The Greenhouse Gas Assessment Spreadsheet for Transportation Capital Projects (or GASCAP) model[1] was developed with this in mind (Noland and Hanson, 2011; 2014a). The model permits an analysis of project life-cycle greenhouse gas (GHG) emissions, including direct and upstream estimates for CO_2, CH_4, N_2O, HFC, and SF_6, as well as providing estimates of the combined global warming potential. One objective is to allow engineering staff to design and stage project construction to minimize life-cycle GHG emissions. This paper summarizes the analysis of a major road reconstruction project, reconstruction of a four lane arterial (two lanes in each direction) state highway, located on a barrier Island in Ocean County, NJ, that was extensively damaged by Hurricane Sandy.

2. Methods

The GASCAP model includes components to estimate the upstream and direct emissions from each phase of the construction and maintenance of highway projects. These include the emissions associated with construction materials, construction equipment, project mobilization, traffic disruption during construction, and life-cycle maintenance activities. Upstream life-cycle emissions for all components are derived primarily from the GREET model, which is frequently updated, is freely available, and provides an easy to use resource for government agencies (Argonne National Laboratory, 2009; Argonne National Laboratory, 2011).

The primary materials used in construction projects are asphalt, concrete, and steel. Emissions from asphalt are sensitive to the heating input and the energy and emissions are derived from a heating model (Hanson et al., 2012). Smaller construction components, such as materials for drainage, culverts, pipes, and other minor items are contained in project bid-sheets which define the detailed inputs for projects. A procedure to input this information is an integral part of the GASCAP model.

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[1] The model is available for download at www.gascap.org.

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Construction equipment emissions are derived from EPA's NONROAD model (US Environmental Protection Agency, 2014b) and assumptions on project-specific equipment activity are drawn from activity logs based on California data (Kable, 2006).

GASCAP also includes a module for estimating emissions from project mobilization. This provides estimates for moving materials, equipment, and labor to a jobsite, as well as lighting for night work, if needed. How the project is staged is also a potential source of emissions; if the road must be closed to traffic, then diversions will likely generate additional emissions from the vehicles that use the road, compared to when the road is fully open. The model includes methods to evaluate the emissions associated with delayed and diverted traffic, based on traffic flow assumptions derived from the *Highway Capacity Manual* (Transportation Research Board, 2010) and emissions for on-road vehicles estimated using EPA's MOVES model (US Environmental Protection Agency, 2014a). Staging is one way that a state transportation agency might have substantial control over the emissions that are generated from construction and maintenance activities.

An additional issue is the maintenance of a road over its lifetime. In theory, transportation agencies should implement an optimal maintenance strategy that minimizes costs and keeps a road surface in a state of good repair. This involves a set schedule of crack sealing, pothole filling, and milling and repaving the surface, typically over about a 50 year lifetime. As an example, Pennsylvania provides published guidance on life-cycle maintenance procedures (Pennsylvania Department of Transportation, 2010). The GASCAP model uses similar procedures developed for New Jersey (Noland and Hanson, 2014a), and accounts for the emissions associated with the materials used and the equipment used during maintenance activities over a 50 year schedule of activities. Retirement and deconstruction of the road is assumed not to occur, although at the 50 year mark, it is assumed that major reconstruction would occur, but this is not accounted for in the analysis.

The modules, assumptions, and data sources for GASCAP are summarized in Table 1. Direct emissions are based on those activities that occur on site. For example, the heating of asphalt when it is laid is counted as a direct emission, as is the fuel consumption from construction equipment activity on site. Indirect or upstream emissions are based on activities that occur at other locations, such as the production of materials and process emissions from fuel production. The analysis separates these to provide an accounting of whether direct or upstream emissions are the main source in construction projects.

We have attempted to provide estimates for all GHG emissions, but due to some data limitations cannot include all in each module. For upstream emissions we account for CO_2, CH_4, N_2O, and SF_6. For direct emissions we only account for CO_2, CH_4, and N_2O. HFC from air conditioning leakage is accounted for in our mobilization module, but due to the method used to estimate construction equipment activity we cannot estimate the time that equipment is dedicated to the project (leakage rates are based on average leakage rates, independent of vehicle activity). Black carbon is estimated for direct and upstream equipment emissions (but not for equipment used for mobilization and maintenance activities). Global warming potentials (GWP) as reported in (IPCC, 2007b) are used to estimate carbon-equivalent emissions; for black carbon the GWP is reported in (Fuglestvedt et al., 2010).

As mentioned above, our primary data sources are the GREET, NONROAD, and MOVES models. Supplemental data for asphalt and concrete are from (Choate, 2003; Zapata and Gambatese, 2005) respectively. Minor emission factors for some materials were derived from EPA AP-42 reports (EPA, 2010).

The GASCAP model provides a template for analysis that is substantially more sophisticated that earlier work in this area. The PaLATE model, developed in California, was one of the first attempts to estimate life-cycle emissions associated with road construction (Horvath et al., 2007). The model estimated CO_2 emissions associated with the main materials used in roads, primarily concrete and asphalt pavement, base, and the fill components for sub-base. It also included methods to account for disposal and recycling of materials and their use as fill materials. PaLATE is somewhat limited in that its scope does not include other GHGs and does not include many of the other components of road construction.

Defining the boundary of any life-cycle assessment determines both its broad applicability and the scope of the assessment. In any road construction project there are both minor components and much larger factors that typically generate the bulk of the emissions associated with the project. A framework for defining system

Table 1
Boundary assumptions, data sources, and emissions calculated for each module.

	Materials	Construction equipment	Mobilization	Traffic disruption	Future maintenance activities
Direct emissions	Asphalt heating on site	Fuel consumption from equipment activity	Fuel consumption from vehicle activity, air conditioning leakage	Fuel consumption from vehicle activity	Asphalt heating on site
Estimated pollutants	CO_2, CH_4, N_2O	CO_2, CH_4, N_2O, Black Carbon	CO_2, CH_4, N_2O, HFC	CO_2, CH_4, N_2O	CO_2, CH_4, N_2O
Data sources	GREET model, AP-42, heating calculations, Choate (2003); Zapata and Gambatese (2005)	NONROAD model	MOVES model, HFC leakage estimates from literature	Highway Capacity Manual, MOVES model	NJDOT schedule of maintenance activities, NONROAD, GREET model, same as Material sources
Indirect or upstream emissions	Production of materials including process fuel inputs	Process emissions from fuel production	Process emissions from fuel production	Process emissions from fuel production	Production of materials including process fuel inputs
Estimated pollutants	CO_2, CH_4, N_2O, SF_6	CO_2, CH_4, N_2O, Black carbon, $SF_{6.}$	CO_2, CH_4, N_2O, SF_6	CO_2, CH_4, N_2O, SF_6	CO_2, CH_4, N_2O, SF_6
Data sources	GREET model	GREET model	GREET model	GREET model	GREET model
Components not included	Some minor material components, end-of-life disposal of materials	Manufacturing of construction equipment, HFC emissions	Manufacturing of vehicles and mobilization equipment	HFC emissions	Vehicle emissions from road deterioration and future traffic disruptions, emissions associated with end-of-life disposal,