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Environmental impacts of roundwood supply chain options in Michigan: life-cycle assessment of harvest and transport stages

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ABSTRACT

Here, we analyze greenhouse gas emissions and fossil energy demand for roundwood supply chain activities (harvesting and transport) within the state of Michigan. A life-cycle assessment was completed, relying on a combination of peer-reviewed literature, national databases, and primary data collected from Michigan loggers and truckers. Several equipment configurations and operating scenarios for roundwood harvesting have been considered. Results indicated that a full processor/forwarder is the best combination of harvesting equipment, with greenhouse gas emissions of 9.9–14.7 kg CO_{2eq}/green tonne, due to relatively low inputs and high reported productivity, although environmental impacts of harvesting depend strongly on the intensity of harvest being conducted. Bimodal truck + rail transport has environmental burdens roughly one third to half that of typical log truck transport at longer transport distances, directly related to the increased fuel efficiency of rail transport. Aggregated results for roundwood supply within Michigan are comparable to similar studies in other regions, although the mechanization of the harvesting industry and large size of Michigan log trucks are factors in the smaller environmental burden. A sensitivity analysis indicated that a variety of factors related to truck transport (distance, fuel economy, load factor, truck capacity) are the most influential for overall environmental impacts of the forest biomass supply chain. Environmental impacts associated with roundwood supply are quite low in comparison to the carbon content and embodied energy of delivered wood, implying that roundwood supply activities do not preclude beneficial use of this feedstock in biofuels or bioenergy applications.

1. Introduction

Emissions of greenhouse gases from transportation are a major contributor to human-caused climate impacts on a global scale. Recent studies have predicted serious consequences from a “business as usual” approach to energy production and use, including increasing global temperatures, sea level rise, displacements of human populations from submerged lands, changing weather patterns, and increase in incidence of certain diseases (Intergovernmental Panel on Climate Change, 2007a,b). Biofuels made from renewable feedstocks are among the largest expected contributors to the transportation industry’s planned emission reductions over the foreseeable future (Hoekman, 2009). Additionally, in recent years the U.S. has roughly half of its oil needs from foreign sources (U.S. Energy Information Administration, 2012). Such a high dependence increases U.S. strategic vulnerability, and a domestic biofuels industry is increasingly seen as a way to combat this trend while increasing employment in rural areas of the country (Perez-Verdin et al., 2008).

Biomass from forest resources will be an important feedstock source in forested regions of the U.S., and are a significant contributor to the available biomass inventory nationwide (Department of Energy, 2011). According to statewide U.S. Forest Service data, the state of Michigan has the seventh largest timberland area in the United States, and current annual growth

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exceeds removals and mortality in most forest types (Van Deusen and Roesch, 2008). Decline of traditional roundwood-utilizing industries in the region over recent years (pulp and lumber) have opened up a portion of forest biomass to alternate uses (Leefers et al., 2010), while alternative markets for this timber would stabilize prices and maintain forest products industry infrastructure in the region [e.g., (Dwivedi and Alavalapati, 2009). Additionally, several thousand acres of abandoned or unproductive agricultural lands in Michigan could be converted to short-rotation forest (SRF) crops of fast-growing willow or poplar, suitable to the growing conditions in Michigan [e.g., (Froese and Abbott, 2012).

To be a sustainable and environmentally beneficial industry, alternative fuels should be produced in a responsible manner that achieves measurable and significant gains in environmental performance over 'business as usual' use of fossil fuels. For biofuels, this typically translates to reductions in greenhouse gas emissions and fossil energy demand over the cradle-to-grave life cycle of the alternative fuel, compared to conventional gasoline or diesel. Many industry sectors are addressing sustainability issues by reducing the emission of greenhouse gases across the entire production chain. Previous life cycle assessments (LCAs) of biofuels produced from a variety of feedstocks have highlighted the importance of feedstock production and supply in the overall life cycle of a given fuel product (Fan et al., 2011; Handler et al., 2012; Shonnard et al., 2010). Commercial biofuel operations will rely on inputs of feedstock grown over a large area, with potentially variable supply over the course of a year. Assessing supply chain options for this type of emerging industry will be critical for continued success.

The supply chain environmental assessment presented here focuses on forest biomass grown within the state of Michigan. Our objective was to develop environmental metrics for greenhouse gas emissions and fossil energy demand for forest-based biomass harvesting and transport within Michigan. Improved estimates of woody biomass sustainability require a more detailed description of the full supply chain for these materials, to fully assess costs and environmental impacts (Department of Energy, 2011), which were achieved in this study through collection of data from a large sample of workers in Michigan's forest products industry. Furthermore, the intent is that the study results could be utilized both to understand the impacts associated with a particular forest biomass supply scenario and to be generally applicable to the current forest product industry as it exists in aggregate. To this end, we have developed a limited-scope life-cycle assessment (LCA) procedure for several forest biomass harvesting and transportation scenarios, using a well-detailed process assumptions and inventory data. The intended audience of results from this study is other LCA professionals, forest industry companies, environmental managers, government regulators, and biofuel developers. Results and methods from this study may be later used at different levels of data aggregation when considering specific biofuels or bioenergy projects within the state of Michigan, and may be applicable to forest-based biomass supply within the broader Great Lakes region.

2. Research methods

2.1. Goal and scope

The goal of our LCA is to determine greenhouse gas (GHG) emissions and fossil energy demand associated with harvesting and transport of forest-based biomass within the state of Michigan. For the purposes of this study, harvesting includes cutting trees from the stump, processing into typical pulpwood length (100 inches), and moving the logs to a forest landing. Transport refers to movements of wood from the forest landing to a processing facility. The scope is limited in the sense that our focus is only on those stages in the forest-based biomass supply chain that occur prior to biomass conversion into biofuels, bioproducts, or bioenergy at a processing facility (Fig. 1). Material and energy inputs used directly during feedstock supply chain activities, i.e. wood harvesting and transport, will be considered. Of these inputs, fuel is the most important, but other inputs are also included, including major equipment used to harvest and transport wood (harvesters, forwarders, log trucks, etc.) and estimates of lubricants and inputs used to maintain equipment.

We also do not include inputs from any activities that would occur 'upstream' of the wood harvesting process, such as forest replanting or carbon stock changes on the landscape resulting from direct or indirect land-use change. The vast majority of wood currently harvested in Michigan is from forest stands which were initiated by natural processes, with no external inputs. These stands have been cultured by foresters under the guidance of forest management plans that dictate the intensity of harvest operations and intended outcomes for future forest regeneration and growth. Michigan's forested land base has been increasing in size and volume of wood fiber for many decades, and we do not expect new uses of forest biomass to contribute to losses of forestland within the state. A growing body of research on impacts of different harvesting regimes on soil carbon storage reveals a range of potential outcomes that are likely dependent on specific site characteristics, although the average result seems to be little or no change in soil carbon stocks over time [e.g., (Johnson and Curtis, 2001)]. Potential environmental impacts of increased harvest activity on landscape carbon stocks, through shorter rotation ages on actively managed lands or an increased willingness of landowners to actively manage their forestlands for timber production, is an important issue that should be addressed in further research.

2.2. Functional unit

The functional unit for this study was one green (50% moisture content) (Argonne National Laboratory, 2013) metric tonne of forest biomass, defined here as roundwood pulpwood that can be harvested and collected with forestry equipment commonly used in Michigan. Forest products industry workers in Michigan were most comfortable with English units as our data collection efforts were devised and tested on sample respondents, but they have been converted here. Harvesting activities are normalized to this functional unit, while transportation activities have been normalized on the basis of a tonne-mile, due to the dependence of transport burdens on the particular distance moved. No specific origin-destination pairs of feedstock location and processing facilities were utilized in this study, so the transportation data can be utilized by parties interested in specific case studies by multiplying environmental burdens per tonne-mile by the mileage of the specific transport step, as is done in a few examples presented below. For the purposes of comparison to other studies, results are also presented in English units (lb CO_{2eq} per U.S. short ton) and on a dry weight basis.

2.3. Life cycle input data

The data and assumptions required for this study came from a variety of sources. An important component of our life cycle inventory was the use of primary input data from loggers within the state of Michigan. A comprehensive logging and transportation survey was mailed to loggers within the State of Michigan from 2009 to 2010. Information was collected on current equipment and operations using in harvesting and transportation supply stages. The combined results of over 220 unique survey respondents represent the most current and accurate picture of forest products

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