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Research paper

Seeing the forest for the trees: How much woody biomass can the Midwest United States sustainably produce?

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ABSTRACT

Widespread interest in advancing goals of energy independence, climate change mitigation, and rural economic development has led to unprecedented growth of the global bioeconomy. Continued development of this burgeoning industry relies upon the long-term availability of plentiful, sustainable sources of biomass. In the Midwest United States, efforts to secure such supplies have focused on herbaceous plants, either from the seeds or residues of annual crops or from perennial lignocellulosic species. Here, we explore the potential for this region to provide woody biomass from forests and short rotation woody crops (SRWC). We compare estimates of current and future availability—as defined by biophysical, technical, or economic potential—from four United States governmental entities. We find that estimates vary widely due to key parameter choices and assumptions, from current annual potential of 19.9–47.6 Mg (Mg, or metric ton) and future (year 2030) potential of 8.1–210.5 Mg. For the largest future estimate, the economic woody biomass potential from SRWC is triple that of forests. To complement these detailed assessments of flows, we introduce a comparison with biomass stocks to assess the long term sustainability of biomass extraction. We find that the average biomass growth rate of Midwestern forests (3.4%) is lower than estimated extraction rates when prices are high (3.7%) and even less sustainable for specific states, such as Minnesota (2.4% growth compared to 8.6% extraction). We recommend that future studies of biomass potential should (1) estimate stocks and flows all three categories (biophysical, technical, and economic) side-by-side, (2) improve the transparency of parameter assumptions, and (3) make models and methods available to the public so that readjustments of parameters can be tested and harmonized. The potential quantities and spatial distribution of the biomass potentials shown here can provide the basis both for planning of regional bioenergy production and for future work that explores the ecosystem services provided by agroforestry ecosystems.

1. Introduction

Woody biomass is the largest source of renewable energy globally [1], and growing interest in reducing fossil fuel use and greenhouse gas emissions may expand its use even further. Already, renewable energy goals in the United States and elsewhere in the world have increased demand for woody biomass for bioenergy, including liquid biofuels [2] and electricity and heat generation [3,4]. For these industries to expand in a sustainable way, however, investors and policy makers need estimates of current and future woody biomass availability as constrained by environmental concerns and competing demands. In other words, how much woody biomass is available for meeting bioenergy goals while maintaining the productivity and ecosystem functioning of harvested lands and while meeting demand from markets for other woody biomass products such as roundwood and pulpwood?

Numerous studies have sought to clarify just how much woody biomass might be available under different sustainability criteria and economic conditions. To do so, they commonly distinguish among different categories of potential biomass availability, including biophysical, theoretical, geographical, technical, economic, realistic, implementable, and environmental or ecological potential [5–7]. In general, the biophysical or theoretical potential is the maximum possible production on any given land unit constrained solely by physical limitations of sunlight, climate, soil type, and grade. Other categories of biomass potential are a subset of this biophysical or theoretical potential bound by additional

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constraints. For instance, technical potential may restrict land availability or may limit yield potential due to lack of technological access. Ecological potential may exclude land that is protected for the purpose of mitigating negative environmental impacts. Similar terms used by different studies may be interchangeable (for example, ecological and environmental), and categories need not be distinct. For instance, a common assumption is to prevent land that is currently used for the production of non-bioenergy products, such as lumber or food, from switching to producing woody biomass for bioenergy. This assumption constrains woody biomass potential for both economic reasons (ensuring adequate production) and environmental reasons (preventing unsustainable land expansion and forest clearing) [8,9].

Even after correcting for such semantic differences, studies on woody biomass availability, are often, for a variety of reasons, not readily compared with one other or arrive at vastly different conclusions. For instance, biophysical potential is commonly estimated by modeling either net primary productivity [1,8,10–14] or potential biomass crop yields using process-based models [15–17]. For those studies that estimate technical or economic potential, some focus on current potential while others focus on future potential for a given year. Furthermore, potential is often estimated as a flow for a given year (*i.e.*, annual availability), but such estimates are rarely compared with the resource stock upon which this annual flow depends.

Another reason for differences is the scale and scope of analysis. Many studies that explicitly distinguish among different types of woody biomass potential have done so at a global scope with relatively low resolution, typically reporting results in summary tables or maps with raw data unavailable in the public domain [11,13–16]. Other studies use high-resolution GIS and process-based modeling to estimate local potential for SRWCs or forests, but data are limited to a local scope [18–23]. Furthermore, at both ends of the spectrum (global, low-resolution or local, high-resolution) only a few studies consider both forests and SRWCs simultaneously, and difference in scale, scope, and typology make comprehensive synthesis difficult [1,11,14,21,22,24].

Attempts to address the scope and scale issue have been made by mid-range studies that combine a local scale with a regional or country level scope to capture both the accurate spatial representation of heterogeneous landscapes and production systems with a scope that shows broader trends relevant to markets and national policies. However, it is not yet common practice at this scale to distinguish among different types of potential as clearly as global studies typically do, nor it is common to present biophysical, technical, and economic woody biomass potential side-by-side with biomass stocks and transparent parameter assumption comparisons. At this mid-range scale and scope, four U.S. governmental institutions —the U.S. Forest Service (USFS), the U.S. Department of Energy (DOE), the U.S. Environmental Protection Agency (EPA), and the National Renewable Energy Laboratory (NREL)—have estimated woody biomass potential from forests or SRWCs for the entire Midwest U.S, which is the focus of this paper. None of these studies, however, addresses the long-term sustainability of their estimates by comparing annual extraction capacity with the stock of biomass upon which it depends.

This paper has three objectives. The first is to compare estimates of annual biophysical, technical, and economic woody biomass potential in the Midwest U.S., both in the present and for possible futures. The second is to highlight the key parameter choices that have the largest effect on these estimates. The third is to assess the long-term sustainability of these estimates of biomass flows by comparing them with data on biomass stocks. This comparison and analysis comes from synthesizing and comparing estimates of potential woody biomass from both forest biomass stocks and SRWC farming systems from the four mid-range studies at the county level for the 12 Midwestern states (Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin). This regional scope allows focus on a distinct region that has historically been an important center of high productivity agricultural land and forestland.

The rest of this paper is organized as follows. In Section 2, we describe the data from each of the four sources we compare and discuss our method for comparison. In Section 3, we present a comparison of existing estimates of biomass stocks and annual production (in megagrams (Mg), equal to 1.10231 short tons) by source and spatial distribution in the Midwest, both for current production and future potential. The results highlight the differences in estimates and the parameter assumptions that create the most variability in future estimates. We also present an analysis of the biomass stocks and flows to assess the sustainability of these annual extraction estimates. In Section 4, we discuss some of the implications of the data comparison, highlight the key parameters that create the variability, and consider the sustainability of these ranges. In Section 5, we conclude with suggestions for improving the transparency and compatibility of potential biomass estimates and continuing research.

2. Methodologies and data

This study synthesizes existing woody biomass data from four sources that provide county-scale data for the entire U.S. Midwest on either forest or SRWC biomass potential: the Forest Inventory and Analysis (FIA) from the U.S. Forest Service (USFS) [25], the National Renewable Energy Laboratory (NREL) [26], the U.S. Environmental Protection Agency (EPA) [27], and the U.S. Department of Energy (DOE) Billion-Ton Update study [28]. For comparison, we aggregate the various annual feedstocks into five categories used by these studies: commercial roundwood, annual forest residues (logging residues, thinning residues, other removals), annual primary and secondary mill residues, annual urban wood residues (municipal solid wastes, construction and demolition wastes), and short rotation woody crops. Table 1 shows the categories included by each study, discussed in further detail in Section 2.1.

The biomass potential of these feedstocks is their annual extraction potential, which is a function of estimates of either current or future biomass stocks. We therefore also compare annual extractions from forestland with the total forest biomass stock and growth estimates from the USFS [25], the only one of the four sources that provides this information.

We distinguish three types of potential: biophysical, technical,

Table 1
Types of annual woody biomass potential considered for the production of bioenergy, biofuels, and bioproducts by different sources.

Woody biomass type	USFS [25]	NREL [26]	EPA [27]	DOE [28]
Commercial roundwood	+	−	−	+
Forest residues				
Logging residues	+	+	+	+
Forest thinnings	−	+	+	+
Other removals	−	+	+	+
Mill residues				
Primary mill residues	+	+	+	+
Secondary mill residues	−	+	−	+
Urban wood residues				
Municipal solid wastes	−	+	+	+
Construction and demolition wastes	−	+	+	+
Short rotation woody crops (SRWC)	−	−	−	+

Note: + indicates consideration of biomass type; - indicates biomass type was not considered.