BIOMASS AND BIOENERGY 75 (2015) 213–226

Available online at www.sciencedirect.com

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Supply assessment of forest biomass – A bottom-up approach for Sweden

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ARTICLE INFO

Article history:
Received 22 April 2014
Received in revised form
17 February 2015
Accepted 20 February 2015
Available online 13 March 2015

Keywords:
Woody biomass
Harvesting cost
Supply curves
Bioenergy

ABSTRACT

As there is increasing interest in the use of biomass for energy in Sweden, the potential availability and harvesting costs of forest roundwood, harvesting residues and stumps were estimated up to the year 2069 in 10-year intervals, using a high spatial resolution GIS. In each individual forest area, an average harvesting cost per forest assortment was estimated, based on the geographic and other properties of the area. Using cost structure and resource availability, marginal cost curves were constructed to allow analyses of the effects of changing market conditions and different policy frameworks. Based on geographically explicit data, the results indicated that the average harvesting costs would be 21–24 € m^{-3} for roundwood, depending on the type of harvesting and extraction operation. The corresponding cost estimate for harvesting residues was 23–25 € m^{-3} and 35 € m^{-3} for stumps. The harvesting cost estimates lie on the steeper part of the marginal cost curve, suggesting that increases in the supply of woody biomass can only occur at significantly higher harvesting costs. From a policy perspective, this suggests that subsidies aimed at reducing the harvesting costs will only have limited success in increasing the harvested volumes, given current technology. Therefore, for future development in the supply of forest assortments for energy generation, it is important to consider not only the supply potential, but also the integration of improvements in harvesting and transportation systems.

1. Introduction

Growing concerns over greenhouse gas emissions and resource depletion have created considerable interest in the use of renewable biomass for energy generation and as a source of biomaterials and biochemicals. In 2012, the European Commission adopted a strategy and action plan for a sustainable bioeconomy in Europe [1]. The plan focuses on process and technology development, development of

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http://dx.doi.org/10.1016/j.biombioe.2015.02.022

markets and competitiveness in bioeconomy sectors and encouragement of policymakers and stakeholders to work more closely together. These actions are also integral to Horizon 2020, the EU framework programme for research and innovation, where issues related to biomass and bioeconomy are embedded throughout the programme [2].

The main biomass sources include agricultural crops, forest resources and waste. Sweden is well forested, making forest-based biomass the most likely source for any substantial increase in utilisation. Forest-based biomass has a wide variety of uses, including traditional industrial uses for pulp and paper production and sawn wood products, as well as use in the energy sector, where it is utilised as fuel for combined heat and power generation, residential heating and heat for industrial processes. Further, forest-based biomass is of considerable interest for the future development of large-scale production of advanced liquid and gaseous biofuels. Thus, forest biomass represents a key component of available national, regional and local supply of renewable raw materials. In quantitative terms, the net forest fellings in Sweden in 2011 amounted to approximately 72 hm^3 (solid excluding bark) of roundwood, which corresponds to around or 138 TWh. In addition, roughly 40 TWh of wood fuels were supplied [3].

Geographical Information Systems (GIS) are useful tools for understanding the spatial context of a wide range of issues pertinent to bioenergy, not least demand and supply. Geographically explicit analyses also face a number of challenges, the foremost of which is a common lack of spatial data [4,5]. Further, spatial analyses are scale-dependent. It is therefore important to use the appropriate spatial scale for the problem under investigation. GIS-based approaches to investigate forest biomass availability and/or procurement costs have been reported in a number of studies. Nord-Larsen and Talbot [6] assessed forest fuel resource availability in Denmark, but limited the estimation of the procurement costs to using standard average values. A similar approach was used by Ranta [7] and Natarajan et al. [8] for Finland. Stasko et al. [9] applied a more comprehensive methodology to estimate forest bioenergy procurement costs for the southeastern USA, including logging and transportation costs, while Yoshioka et al. [10] reported a similar approach for a mountainous region in Japan.

The present study adds to previously reported work by providing a long-term perspective on the spatial distribution of both woody biomass availability and procurement costs, for various forest biomass assortments. The study had three objectives. The first was to assess the potential spatial availability of forest products over a timeframe in which estimates were provided in 10-year intervals up until the year 2069. The second objective was to calculate spatially explicit harvesting costs of forest products, in order to construct supply curves (marginal cost curves). In each individual spatial location, the average harvesting and extraction cost per forest biomass product was estimated, based on the specific factors operating in the area. The supply curves were thus based on both the spatial availability of forest products and the spatially explicit harvesting costs, using GIS and a high spatial resolution. The third objective was to relate the constructed supply curves to changing market conditions and different policy frameworks. Understanding these scenarios may contribute to reducing the dependency on foreign energy resources, to expanding the share of renewable energy and to substituting fossil with renewable fuels in the transportation sector.

2. Material and methods

The analysis used here builds upon and expands previous models, e.g., [4,11–14]. To estimate the spatial availability of forest resources and the associated variation in harvesting costs, current land use and harvesting technologies, harvesting statistics and forest product price information were used. The harvesting cost estimation was based on a bottom-up approach, relying on productivity functions for forest machinery, such as harvesters and forwarders. The harvesting cost estimates were then combined with the availability data of each forest assortment per spatial area, in order to create supply curves. Finally, the supply curves formed the foundation for the analyses of changing market conditions and policy frameworks.

2.1. *Estimation of availability*

Roundwood is the main product of harvesting operations, while branches, needles and tops (hereafter referred to as harvesting residues) and stumps with attached root system (hereafter referred to as stumps) are regarded as by-products. In the first step, the potentially available volumes and spatial distributions of roundwood, harvesting residues and stumps for the period 2010–2069 in Sweden are estimated. The estimations are based on the Swedish Forest Inventory (SFI) for the period 2002–2006 and take into account all productive forests in Sweden, including areas within formally protected areas (e.g., national parks, nature reserves, etc.). The SFI has then been used by the Swedish Forest Agency [15] to make long-run forecasts regarding growth and potential harvesting volumes, under different scenarios. In this study, two scenarios from Refs. [15], the production scenario and the environmental scenario [15], were used as starting points for the availability estimation. Both scenarios assume that: (*i*) Swedish silvicultural practices will not change, (*ii*) annual fellings will still be at a level that is regarded as sustainable, (*iii*) environmental legislation will not change and (*iv*) climate change will be moderate. In addition, the environmental scenario assumes that the protected forested areas in Sweden will increase, more buffer zones along forest streams and lakes will be created (compared with the production scenario), and that more environmental consideration will be given to final felling operations. The production scenario is based on measures to increase the production of the forest areas, for example more contorta pine will be planted (an increase from 500 000 ha today to 900 000 ha by 2030).

The method generated a list of approximately 52 000 plots for the production scenario and 49 000 plots for the environmental scenario; both selected sets are subject to either thinning or final harvesting during the period 2010–2069. The dataset comprises information for each plot: the county location, the harvesting operation that will take place