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Forest-based biofuel production in the Nordic countries: Modelling of optimal allocation

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ABSTRACT

Biofuels have been promoted as a likely avenue for the future transportation energy mix. Hence, production of biofuels using lignocellulosic feedstocks, such as forest-based biomass, is expected to increase globally. Forest biomass abundance and experience with applying biomass conversion technologies gives the Nordic countries an advantage in catering to biofuel production capacity investment. Yet, given uncertainties in the techno-economic variables of biofuel conversion technologies, as well as differences between the Nordic countries in terms of labor costs, bioheat market prices and electricity and forest biomass costs and prices, it is unclear which of the Nordic countries are comparatively attractive for future investment in forest-based biofuel production capacity. In this paper, we quantify how techno-economic cost components of a novel forest-based biofuel production technology affect optimal allocation of biofuel production capacity in the Nordic countries at a regional level. We apply a scenario analysis approach using an endogenous biofuel capacity investment module in the Nordic Forest Sector Model (NFSM). In each scenario, we alter the techno-economic features of the technology and quantify total biofuel production allocation volume in each region and at a national level. We find that optimal capacity allocation is affected by the type of feedstock used in the technology and will affect existing industries dependent on forest feedstocks. Electricity selling or purchasing will have little effect on allocation because it comprises a small revenue or cost proportion. Bioheat may affect allocation, but this will depend on local demand. Finally, labor costs may affect allocation, but this will depend on the labor intensity, which changes with scale. The results are relevant for policy incentives to proliferate future forest-based biofuel production in the Nordic countries.

1. Introduction

The Nordic countries were once considered global forest industry leaders (Westholm et al., 2015), but they currently face the considerable challenges of declining demand for newsprint and other printing and writing paper, as well as the high cost of labor. Consequently, the Nordic countries have had varying success in maintaining their dominant position in the global forest products market. With the growing interest in bioenergy, a relatively new avenue for the Nordic forest industries has appeared in the form of biofuel production. Being one of very few alternatives to fossil fuels for transportation and aviation (Macfarlane et al., 2011), biofuels may displace fossil fuels in the future transportation energy mix. Consequently, demand for biofuels is projected to increase globally (Dornburg et al., 2008). Because of indirect land-use change risk and low climate change mitigation benefits associated with first generation feedstocks, research focus has been redirected to second generation biofuels made from lignocellulose feedstocks (Batidzirai et al., 2012; Berndes et al., 2011), such as forest biomass. In parallel, EU's Renewable Energy Directive states that at least 10% of transportation energy demand must be renewable by 2020 (European Parliament, 2009). In addition, the EU Amendment of the Fuel Quality Directive and Renewable Energy Directive has placed a cap on the use of “food” crops at 7%, leaving 3% to come from a variety of other renewable sources, including advanced biofuels, by 2020 (European Parliament, 2015). This further encourages the surge of lignocellulose-based biofuels in countries, which have ratified the Renewable Energy Directive, strengthening the case for investment in second-generation production capacity to meet mitigation targets and reduce dependence on fossil fuels.

With local access to forest and water resources for biofuel processing and expertise in applying forest biomass processing technologies, the Nordic countries may appear attractive for investment in biofuel production capacity, which would promote a proliferation of the forest industries in the Nordic countries. Conversely, it is difficult to determine whether the Nordic countries will succeed in grasping this opportunity. Within individual countries, factors such as variation in

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proximity to biomass resources, competition for biomass from the existing forest industries and the stationary bioenergy sector are paramount in determining which regions provide the best prospects for biofuel capacity investment. Factors that are different between countries, such as labor and energy costs, also aid in determining where biofuel allocation occurs. Because transportation of feedstock significantly contributes to the overall cost of biofuel production (Pettersson et al., 2015), transportation and trade between regions on a national and international level further complicate the assessment. Given the variation and magnitude of the factors, it is unclear which biofuel production cost components are most significant in determining where future biofuel capacity is allocated. Therefore, we believe an assessment of the attractiveness of biofuel investments needs to consider the regional differences in factors such as the biomass market, labor and energy costs, competition with pulp and paper industries and potential synergies with the sawmilling industry – which may supply biomass in the form of residues from sawnwood processing.

This paper quantifies how forest-based biofuel technology-specific components may affect facility allocation in the Nordic countries at a nationally disaggregate level, taking the economic aspects and market conditions into consideration. We develop and apply a Forest Sector Partial Equilibrium Model (FSPEM) with endogenous biofuel capacity investments across a range of scenarios and biofuel production levels. In each scenario, we alter technology- and cost-specific input-output parameters to determine the attractiveness of the various Nordic countries and regions as locations for biofuel capacity investment. The remainder of the paper presents the model we developed and utilize for this study, followed by the structure of the scenario analysis. We present and discuss results first on a regional level, then on a national level. Finally, we conclude by discussing how biofuel technology parameters may affect the optimal allocation of biorefinery capacity.

2. Materials and methods

2.1. FSPEMs

The primary purpose of FSPEMs is to highlight underlying market dynamics associated with policy measures and market shocks (Latta et al., 2013). They permit the evaluation of forest sector responses to exogenously specified policy measures and shocks with varying levels of detail. Buongiorno (1996) provides a historical account of early FSPEMs, while Latta et al. (2013) provide an overview of FSPEMs and their application. In forest sector modelling, a trade-off exists between region size and associated detail and generalizability. Global models, such as EFI-GTM (Kallio et al., 2004), will be more useful for capturing competition and trade between countries, but the low regional resolution of these multi-national models will, for instance, limit their potential for domestic policy evaluation. National models with regional disaggregation, such as the Finnish Forest Sector Model (Ronnila, 1995) and the Norwegian Trade Model (NTM; Trømborg and Solberg, 1995), are more suited for national policy evaluation but apply predefined assumptions made for international markets. They are, therefore, less useful for capturing international competition. Hence, the optimal choice of model regionalization will depend on the application.

In a Nordic context, national models have, among a range of applications, been used to evaluate investment in forest-based technologies to determine the proliferation of the technologies and/or assess the implications of the technologies on the existing forest industry. NTM has been used to analyze the potential for forest-based bioheat production in Norway (Bolkesjø et al., 2006; Trømborg et al., 2007) and highlight the effects this would have on existing forest industries and on pulpwood price changes (Bolkesjø et al., 2006). Studies focusing on biofuels have addressed biofuel production integration into the existing forest industrial complex in a Swedish (Pettersson et al., 2015) and in a Finnish (Kangas et al., 2011) context. These studies highlight the merits of national models since they permit enriched regional analysis of synergies and trade-offs with existing industries on a facility scale. However, there is a profound difference between bioheat and biofuel technologies, which we believe has significant implications for the selection of model regionalization. Unlike bioheat technologies, which have quite limited distribution range, biofuels can be transported great lengths with little cost (Cazzola et al., 2013). Bioheat facilities will therefore be limited to local markets, while biofuel facilities will be able to supply international markets. Investors are therefore more freely able to select locations for biorefinery capacity investments without being dependent on local demand. Thus, countries with forest biomass can be more exposed to international competition in catering to biorefinery investment. We therefore believe national models with high spatial detail are more suited for bioheat than for biofuel investment studies, while biorefinery investment studies will benefit from multi-country model applications. However, biorefinery investment studies will still benefit from the regional analysis offered by national models due to feedstock modelling resolution. Hence, hybrid FSPEMs with national and international regionalization are better able to capture the competitiveness of individual countries, while permitting enriched regionally disaggregate national policy evaluation associated with the international competitiveness. To accommodate this, we have developed a multi-region FSPEM, with a regional focus on the Nordic countries, to be applied in this study.

2.2. Model specification

The Nordic Forest Sector Model (NFSM) is a partial equilibrium model, covering forestry, the forest industry and the bioenergy sector. It includes interregional and international products trade and endogenous investments in new biofuel production facilities. It is similar in structure to the Global Trade Model (GTM) (Kallio et al., 1987), the Global Forest Sector Model (EFI-GTM) (Kallio et al., 2004) and is based on the structure of the Norwegian Trade Model (NTMIII) (Trømborg and Sjølie, 2011), but with the addition of an investment module for biorefineries. Harvest, production, consumption, trade and capacity investments are modelled periodically; economic welfare is maximized in each period. The objective function solution provides market equilibrium prices and quantities under free competition as shown by Samuelson (1952a). Conceptually, the model contains five distinct components: (I) wood supply, (II) industrial production, (III) biofuel facility investment, (IV) product demand and (V) interregional trade. Wood supply includes supply of timber and harvest residues. The supply of timber is determined by supply elasticities, changes in growing stock and demand for timber in production industries. Harvest residue supply is determined by collection and forwarding costs. Industrial production is modelled by input-output coefficients; exogenous input prices, such as labor and energy as well as endogenous raw material prices, and final product prices determine the production quantity. Final product demand is determined by regional consumer demand, demand elasticities and endogenous prices. Finally, trade between regions for raw materials, intermediate products and final products occurs until the price difference between regions equals the transportation cost (Samuelson, 1952b). The model includes 32 regions covering Finland, Norway, Sweden, Denmark and the rest of the world. Finland, Norway and Sweden are disaggregated into 10 regions, respectively, while Denmark and the rest of the world are represented by one region each. Fig. 1 displays the regionalization of the Nordic countries.

The model contains 7 wood categories, 11 intermediate products and 13 products for end consumption. Given the comprehensiveness of the data used in the model, we cannot disclose all details here. A full description of the data used in NFSM is provided in the model report (Mustapha, 2016). The objective function is provided here: