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Research paper

Wood biomass potentials for energy in northern Europe: Forest or plantations?

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ABSTRACT

Wood biomass for energy can be largely produced in northern Europe from forest land resulting from silvicultural practices and from agricultural land in the form of fast-growing plantations. The present paper estimates and compares the current regional potentials for wood biomass production attending to these sources. The data are based on spatialized estimates from previous models, largely based on empirical records concerning forest and plantation's productivity. The results show that 8.5 Mm^3 of wood biomass can be produced annually from plantations when using 5% of the total available agricultural land, and 58.5 Mm^3 from forest lands using current estimates of forest production. However, the results also show that a strategy for wood biomass resource management should be local rather than general: wood biomass potential from fast-growing plantations was larger in 19 regions than from forest resources (10 in Denmark, 6 in Norway and 3 in Lithuania) out of the 91 regions in the area included to this study. When considered together, northern Europe presents significant potential for wood biomass production for energy uses, and each country - and even region - should develop independent policy strategies of biomass generation in order to most efficiently realize their own potential for wood-based bioenergy.

1. Introduction

Where lays the largest potential of wood biomass for energy in northern Europe? Wood biomass for energy can be largely produced from forests, resulting from silvicultural and management practices, as well as from agricultural lands in the form of fast-growing plantations.

In the case of forest biomass, it consists mainly of by-products of forest management. In other words, products that are felled during commercial and non-commercial operations but are not utilized for conventional forest industries such timber and pulp. Available biomass fractions for energy uses include small diameter stems, branches, tops, needles and even stumps and roots [1] and have been the focus of several studies aiming at estimating forest based potentials for wood biomass for energy, revealing large amounts of unused biomass resources (e.g. Refs. [1–4]).

Concerning fast-growing plantations, they consist of fast-growing tree species established on former agricultural land. In northern Europe, the tree species belong to genera *Salix* and *Populus*, in management regimes called *short rotation forestry*. These plantations are intensively managed, often including fertilization practices and harvests every 3–6 years [5] with a lifespan of 20–25 years and expected high annual yields.

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Currently, the use of wood biomass in northern Europe varies among countries, as there are differences concerning the location and availability of forest resources, feasible sourcing distance, technology availability, power plants, national laws and other issues that affect the development of the bioenergy sector [1]. For example, Finland accounts for 25% of its total energy consumption from biomass (93 TWh) [6] and Sweden accounts for 23% of its total energy supply from biomass (129 TWh), and 49% of this figure is based directly on wood-derived fuels [7] (the rest being: black liquor, biodiesel, and other biomass-based products). In both cases, the wood originates mostly from forest resources, although Sweden moreover presents a well-established scheme for fast-growing plantations since the 1980s [8]. The combined harvest potential of forest fuels in the Nordic and Baltic countries have been recently estimated in 236–416 TWh [9]. Currently, the primary production of biomass and waste in the area is 313.8 TWh [10].

However, future trends in biomass utilization for energy pose a challenge to the existing resources, as well as other competing uses of these resources in biocomposites or chemicals manufacture [11–13]. In fact, it is expected that the wood demand will double in the following years, exceeding the material availability between 2015 and 2020 [14] and getting even broader by 2030 [15], resulting in a significant wood deficit if the current mobilization of wood biomass remains at the same levels. However, the gap between supply and demand of wood biomass can, to a certain extent, be compensated increasing the current mobilization of forest wood biomass in combination with the establishment of fast-growing plantations [14].

The combination of wood biomass resources from forest and plantations will certainly play an important role in the development of energy alternatives. However, regions may present individual profiles concerning the wood potentials available, which determines the efforts to develop them. The present study estimates and compares regional estimates of biomass potential for bioenergy in northern Europe from both forest and plantations on agricultural land and contributes to reflect on regional strategies to translate this potential into practice.

2. Material and methods

2.1. Data parameters

The area of study entailed northern Europe including Denmark, Estonia, Finland, Latvia, Lithuania, Norway and Sweden. Two alternate sources of wood biomass for energy were considered: forest biomass and fast-growing plantations on agricultural land.

The estimates of local wood production from forest land were based on Verkerk et al. (2015) [16]. The dataset consisted on estimates obtained at 1 × 1 km resolution, and were based on surrogate variables used for top-down disaggregation of public statistics related to growth conditions, growing stock forest cover and net annual increments, among others [17]. This resulted in a collection of 10 maps based on the annual estimates for wood production for the years 2000–2010. In addition, country based estimates of forest wood for energy were collected for different biomass fractions (Table 1).

The estimates for fast-growing plantations of agricultural land were based on [18]. The data were calculated at 1 × 1 km resolution, using empirical records from 1790 plantations using climatic variables and management assumptions as extrapolation proxies. This resulted in three scenarios of plantation performance (low, medium and high).

The disaggregation methods used in both studies (forest and plantation productivity) were based on boosted regression trees, which combines statistical and machine learning techniques. These aim at the improvement of the performance of a single model by recursively partitioning the explained variance into many individual consecutive models and combining them for prediction [21].

2.2. Methods to regionalize potential

Data concerning production potentials were harmonised to match the same units and spatial extent. The regional unit considered was the NUTS-3 level (Nomenclature of Territorial Units for Statistics) as defined by the European Commission [22] and the equivalent county level in the case of Norway. The spatial distribution of the data was visually examined, and metrics concerning their frequency distribution, mean and median were retrieved at country and regional levels. Calculations were based on the average of the 2000–2010 period covered in the original study [16], as the forest production is variable along time. Concerning plantation productivity, the calculations were based on the most productive of the three scenarios available.

In order to calculate the wood biomass available for energy from the data retrieved, two different parameters had to be estimated: 1) what fraction of forest biomass can be used for energy, and 2) what share of agricultural land can be considered for plantations.

In the case of forest biomass for energy use, there are expansion factors that consider additional biomass fractions other than the conventionally extracted biomass. These fractions include stumps, roots, needles, and branches, in addition to small diameter trees not fit for other industrial uses. At the same time, assumptions must be made to differentiate the theoretical potential (all biomass that can be used for energy) from the available potential (using availability reduction factors to estimate the total technical potential of harvestable biomass). Thus, in this study the available potential at country level for each of these fractions was extracted from previous studies and the final relationships were based on the estimated available potential for energy, considering felling residues and below-ground biomass based on Karjalainen et al. (2004) [1], Asikainen et al. (2008) [2] and Anttila et al. (2009) [3]. The retrieved estimates were based on assumptions that, in general lines, can be summarised in: grouping the forest species in main categories (spruce, pine and broadleaves), use of simple equations for the expansion factors, application of general restrictions for the use of wood available (e.g. assuming 75% of clear cut areas and 45% of

Table 1
Main sources of wood production estimates included in the analysis.

Variables	Sources
Fast-growing plantations (1 × 1 km) 3 maps	Mola-Yudego et al., 2016 [18]
Forest wood productivity (1 × 1 km) 10 maps	Verkerk et al., 2015 [16]
Forest available wood potential for energy	Karjalainen et al., 2004 [1]Asikainen et al., 2008 [2]Anttila et al., 2009 [3]
Agricultural and forest land (250 × 250 m)	Corine land uses maps for Denmark, Estonia, Finland, Latvia, Lithuania, Sweden (2000) [19]
	Land use maps for Norway [20]