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Profitability of short-rotation biomass production on downy birch stands on cut-away peatlands in northern Finland

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ABSTRACT

The economic feasibility of short-rotation energy biomass production was evaluated from measurements on six naturally afforested 15–26-year-old downy birch-dominated (*Betula pubescens* Ehr.) stands in a former peat-production area in northern Finland. In the financial analysis, afforestation by natural or broadcast seeding was assumed, and the stands were regenerated by coppicing after the first, second, and third rotations. With respect to the first rotation, the sales revenues from whole-tree fuel chips covered their production costs in five cases out of six when a 21 EUR MWh^{-1} price for energy on delivery was assumed. The bare land value (BLV) was positive even with a five per cent discount rate in five cases, reaching a maximum of 995 EUR ha^{-1}. With an interest rate of three per cent, for example, the break-even stumpage price for energy wood (assessed as the net present value of the first generation equal to 0) fluctuated between approx. 1 and 7 EUR per cubic metre, implying an economic surplus to be reached without subsidies in these cases. The unit price of energy (when bare land value equals 0) for the majority of the stands was well below the assumed price level, indicating noteworthy long-term financial incentives associated with the production.

1. Introduction

Fuel peat accounts for 6–7% of the total energy consumption in Finland. Peat is used also as bedding material in animal husbandry, a culture medium in horticulture, and absorbent material in environmental protection, for example. The total peat-production area is approx. 60,000 ha. About 2500 ha of peat-harvesting area is released from production each year, and currently these areas amount to 40,000 ha [1]. Erosion and subsequent leaching of nutrients into watercourses may continue for many years after the cessation of peat production [2]. Furthermore, cut-away peatlands can be a significant source of atmospheric carbon [3]. Therefore, their rapid reuse is recommended [4]. The production of bioenergy can be continued via growing of energy crops (e.g., reed canary grass) or establishment of an energy biomass plantation with woody

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species. After afforestation, these sites also sequester atmospheric carbon [5,6]. Earlier studies have shown, however, that growing of various energy crops is unprofitable for the farmer without subsidies [7–13].

The reduction of greenhouse gas (GHG) emissions by 2020 by 20% relative to emissions in 1990 is among the headline targets of the climate policy of the European Union [14]. During the subsequent decennium, GHG emissions would need to be further reduced by 40% relative to 1990 figures. This reduction would be on track for reaching a GHG reduction of 80–95% by 2050 [15]. The proportion of renewable energy in Finland is to be increased to 38% of total energy consumption by 2020 [14]. This goal is to be reached in particular via greater use of forest chips in energy generation. Their annual consumption is to be increased to 13.5 M m^3 (25 TWh) by 2020 [16]. In 2013, 8.7 M m^3 of forest chips were consumed in Finland [17].

The greatest potential for increased use of forest chips lies in young stands, which are also potential sources of pulpwood [18]. However, the competitiveness of small-diameter wood harvested from thinnings is poor, mainly because of the high harvesting cost resulting from low removal per hectare and small stem size. In particular, the cutting cost for small-diameter downy birch is high [19]. The thinning response of downy birch grown in peatland forests is poor, and early clear-cutting of dense birch stands for energy biomass can be more profitable than production of industrial roundwood by means of thinnings [20]. Furthermore, the quality of downy birch grown in peatland forests seldom meets the requirements of sawlogs and veneer logs [21]. Downy birch is an early successional tree species thriving on peatlands and in mineral soils with poor drainage. Dense downy birch stands can be established on cut-away peatlands by planting, seeding, or natural afforestation [2,22–26]. On account of the low concentrations of potassium and phosphorus in residual peat, however, improvement of soil nutrient status is usually a prerequisite for successful afforestation [2,23,25–27].

Earlier studies of the economy of wood biomass production focused on short-rotation species, such as willow and poplar. These plantations require considerable investments in biomass production (stand establishment, fertilisation, and weed control) [9–11,28], and actual biomass yields have been lower than reached in intensively managed experiments [29]. In the present case study, we assess the profitability of low-cost downy birch biomass production on cut-away peatlands, based on natural or broadcast seeding and coppice regeneration. We calculated the bare land value (soil expectation value) with alternative discount rates for an infinite number of rotations. Further, the minimum break-even price for energy (EUR MWh^{-1}) resulting in a net present value of 0 for the first generation was calculated. In the sensitivity analysis, the stumpage prices for energy biomass were determined for the first generation.

2. Material and methods

2.1. Stand properties

The six stands included in the case study had been established naturally in a cut-away peat-production area in northern Finland (64°48′ N, 25°24′ E), either in fertilised areas or on sites with a shallow layer of residual peat. The stands were inventoried in autumn 2010. On each stand, 3–8 circular sample plots of 50 or 100 m^2, depending on stand density, were established. Diameter at breast height (DBH) was measured for all trees greater than 20 or 30 mm. Height was measured for every fifth to every tenth tree. The estimates of stand ages were based on the mean biological age of two dominant trees on the main sample plots. Their ages were determined from increment cores taken from the base and adding of two years to the number of annual rings.

The number of trees (DBH<20 mm or 30 mm) taller than 1.3 m and their mean height was determined by species from sub-sample plots of 20–50 m^2 situated in the middle of the main sample plots. The mean breast height diameters for the undergrowth species for the biomass calculations were obtained with regression models based on the data measured from the main sample plots. The degrees of determination (R^2) of these models were 90%, 92%, and 87% for birch, willow, and pine, respectively.

The energy biomass was assumed to be harvested in the form of whole trees. Dead branches were excluded from the biomass-recovery estimates, since they are likely to shed significantly during harvesting. Because of winter harvesting, also foliage of the broadleaf species was excluded. The biomass of birch, Scots pine (*Pinus sylvestris* L.), and Norway spruce (*Picea abies* L.) was calculated using the models of Repola [30,31]. In light of the lack of applicable species-specific models for willow (*Salix* sp.) and aspen (*Populus tremula*), the model for alder (*Alnus* sp.) [22] was used. The biomass values were converted into volumes in accordance with the basic densities of small-diameter whole trees [32]. For aspen and willow, however, the basic density of alder was applied.

The energy content of wood harvested from the case stands was determined on the basis of the heating values reported by Nurmi [33] and Tahvanainen [34]. The biomass produced on the case stands was assumed to be delivered to a heating and power plant in the form of forest chips with a moisture content of 40% [35]. Heating value on delivery was calculated in the manner described by Hakkila [36]. The procedure described above resulted in a mean heating value on delivery of 2.3–2.4 MWh m^{-3} (solid).

Downy birches dominated the stands (Table 1). Their proportion was 57–94% of the tree number and 77–99% of the biomass (Fig. 1). On the two oldest stands, less than 10% of the biomass removal was accumulated from the two smallest diameter classes (DBH<5 cm) while on the youngest stand trees below 5 cm DBH accounted for almost two thirds of the biomass recovery.

2.2. Stand management

We assumed soil amelioration in the stand establishment phase with wood-ash fertilisation (5000 kg ha^{-1}) or by mounding, which raises the mineral soil available to the seedlings. Stand establishment was assumed to have occurred through natural seeding (Base) or broadcast seeding (Seed). Soil preparation or ash fertilisation was expected to take place in the first spring following the last peat-production season, which typically ends by early September. Therefore,