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Research paper

Planning land use for biogas energy crop production: The potential of cutaway peat production lands

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ABSTRACT

Each year, thousands of hectares of peatland that had been harvested are being released in Finland, which can offer an opportunity to increase energy crops and attain the bioenergy targets for non-agriculture lands. In this study, the Geographic Information System (GIS) method was used to improve the assessment of decentralized renewable energy resources. The amount of peat production lands and future cutaway areas for energy crop production was calculated as a case study by using ArcGIS and the Finnish Topographic database. There are almost 1000 km^2 of peat production lands in Finland, and theoretically, approximately 300 km^2 of cutaway peatlands could be used for energy crops after 30 years. The dry biomass yield of reed canary grass (*Phalaris arundinacea*) or timothy-fescue grass (mix of *Phleum pratense* and *Festuca pratensis*) could be higher than 100 Gg a^{-1} in these lands indicating methane potential of approximately 300 GWh. The exhausted peat production areas in the western region of Finland have significant potential for use for energy crops; North and South Ostrobothnia account for almost 45% of the total peat production land. A future goal could be to use the cutaway peat production lands more efficiently for bioenergy to mitigate climate change. Since the use of wastelands (including peatlands) are being considered in Europe as a way to avoid competition with food production, the GIS method used in the study to identify suitable peat lands could be applicable to biomass resource studies being conducted in many countries.

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1. Introduction

Many agro biomass plants, traditionally grown on agricultural land, are suitable for producing bioenergy, through combustion, gasification, pyrolysis [1], and biogas technology [2]. However, the first-generation energy plants are competing with food production [3]. One solution for avoiding the competition is to grow energy plants on non-agriculture areas such as cutaway peat production lands. Versatile wastelands have been studied in India to promote *Jatropha curcas* for biodiesel [4]. Additionally, in Sweden, energy willow has been studied in landfill areas, and in Latvia, abandoned farmland has been estimated for bioenergy production [5,6].

1.1. Peatland utilization and cutaway dynamics

Peatlands are areas that have a naturally accumulated peat layer at the surface soil. Peat consists of partially decomposed organic material, originating mostly from plants, which has accumulated under oxygen deficiency, waterlogging, acidity, and nutrient deficiency conditions. Worldwide, peatlands cover almost 4,000,000 km^2 and most of peatlands are in pristine condition. Approximately 500,000 km^2 of peatland have been used in agriculture, forestry, and peat extraction. In 2008, the total amount of peat consumed as fuel worldwide was 17.3 Mt [7]. Finland is the most densely mired country and the biggest peat producer in the world. The total peatland is about 90,000 km^2, and about 0.8% (700 km^2) of the total peatland is under production in Finland [7–9]. Peat is used for energy generation or environmental peat products (e.g., horticulture, bedding material, and compost ingredient). Most is used as energy in combustion plants [7,10]. In 2013, peat energy accounted for about 4% of the total energy consumption in Finland when the total energy consumption was 1.34 EJ [11].

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The preparation phase, including permission and water drying, lasts from 11 to 15 years in Finland, while the peat production phase itself can last from 15 to 30 years (Fig. 1). The most popular peat form, milled peat, is based on a process in which the surface layer to a depth of 10–40 mm is collected with tractors after the turning and drying process. Another form, sod peat, is produced by pressing the peat into cylindrical sods. The peat in peat production areas is on average 2 m thick, but the thickness depends on the topography. There are usually 40 to 50 peat harvesting days annually in Finland [12] during which an approximate 10 cm thick layer is removed every year (with 20–30 production years). Peat production has negative environmental impacts, such as positive global warming effect (slowly renewable energy source) and loss of nature habitat and water quality. Production is regulated by several laws and is implemented as environmentally friendly as possible in Finland [7,12].

Each year, 2000–5000 ha are released from production since the production phase usually lasts for only a few decades [12,13]. It is estimated that about 44,000 ha of peatland will be reclaimed by 2020 [14]. After-use of peat production lands may include forestry, agriculture, nature conservation, wetland, and tourism (Fig. 1). The most common after-use method in Finland is forestation. Another choice for cutaway peatlands is growing energy crops and producing energy. However, several factors affect the choice of after-use methods, e.g., the need to pump water, soil type, land owners' interests, and possible transportation distance between the cutaway land and the final use of the biomass.

Different sections of the peat production area are not released from production at the same time, which should be taken under further consideration before any decision is made about their after-use [12]. Furthermore, acid sulfate soils as well as topography and groundwater levels are essential factors to consider. Acid sulfate soils can cause acidification if land use methods such as ditch digging oxidize otherwise anoxic soil. When sulfide is oxidized, it can start a reaction that leads to the formation of sulfuric acid. Acidification can be prevented by liming the soil and carefully planning land use [15]. After-use forms of cutaway lands are not limited by law [12,13]. The minimum analysis suggested for mineral subsoils are pH, sulfur content, and fine material (<0.06 mm) percentage [16]. According to Salo and Savolainen [12], especially during the 1990s much of the peat production area moved to the after-use phase when the oldest peat production lands were exhausted in Finland.

1.2. Energy crops and increased bioenergy production on cutaway peatlands

Cutaway peat production areas can be used to grow energy crops if the natural water level can be kept low enough with gravity drainage. If the water level has been adjusted with pumps, the hydrological conditions are usually too wet for agriculture. In that case, a suitable after-use method is wetland or mire regeneration [12]. About 26–42% of cutaway peat production lands are suitable for agriculture or energy crop production depending on the boulder-poor areas [16]. The biggest peat producer in Finland, Vapo, used approximately 30% of the cutaway lands in practice for agriculture or energy crops in 2010 [17]. Nevertheless, the use of fertilizer is necessary in many cases to ensure the normal growth of the plants, biomass production, and proper soil fertility [12].

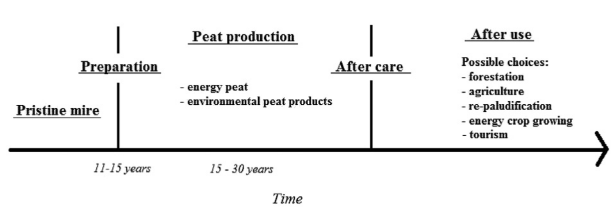

Fig. 1. Peat production land dynamics from pristine mire to the after-use phase in Finland (modified from Salo and Savolainen [12]).

If agricultural use will be possible, reed canary grass (RCG, *Phalaris arundinacea*) can be grown on cutaway peatlands [18,19] as well as timothy grass (*Phleum pretense*). RCG is the most high-yielding grass species in peatlands [20] with dry biomass yields of 5 to ca 12 Mg ha^{-1} a^{-1} when fertilization and liming are optimal [20,21]. However, in practice, the dry biomass yield is usually closer to 5 Mg ha^{-1} a^{-1} because of e.g. frost damage and temporary flooding [22]. In addition, the need of ditches decreases the biomass yield because of the intensive drainage process. There are usually 500 m of ditches per hectare of peat production land [23]. According to Järveoja et al. [24], reed canary grass is the best after-use alternative if GHG (greenhouse gas) emissions, related to soil use and biomass combustion, are considered. Similar results were calculated by Kirkinen et al. [25].

In 2009, there were about 20,000 ha of RCG cultivation on cutaway lands and agricultural fields in Finland. RCG was a promising plant species when renewable energy was the focus; however, because technical difficulties (the need to separate the feeding line into the combustion chamber) appeared in combustion plants, RCG farming has decreased significantly since 2010 [26]. Instead of combustion, RCG have methane potential ranging from 246 to 430 dm^3 kg^{-1} volatile solids (VS), and can be used in biogas plants [3,27,28]. Cutaway peat production areas could offer opportunities for neighboring farmers to make farm-scale biogas plant investments more profitable when local available feedstock resources increase. Peat production areas are usually large units (from tens to even hundreds of hectares) and logistically easily accessible [12]. In addition, farmers have harvesting equipment for energy crops. Co-digestion of crops with cow manure can stabilize the process and increase the amount of biogas and even decrease farming-associated greenhouse gases [29]. For instance, 50 ha of cutaway peatland for energy crops would theoretically offer an 815 MWh gross energy yield for a farm-scale biogas plant (dry biomass yield of 5 Mg ha^{-1} a^{-1} with a methane yield of 326 dm^3 kg^{-1} total solids (TS) [28]). Consequently, it is essential to recognize cutaway peat production lands as part of potential wasteland for energy crop production to increase decentralized renewable energy production.

The energy crop resources of cutaway peatlands can be estimated by using Geographic Information Systems (GISs). GIS-based methods have been used to calculate regional biogas potential [6,30–34]. Spatial distribution of biomass resources and the most effective utilization location for energy production can be investigated by combining location optimization methods and GIS. Optimization methods have been used to calculate the best supply chains of biofuels [35]. When GIS and location optimization methods are combined, there are many advantages such as better visualization in solving problems [36].

The objective of this study was to apply GIS-based methods to calculate the area of peat production land in Finland. Based on the area, the future after-use potential of cutaway peatlands for energy crop production can be assumed by using previous studies and knowledge of biomass yields in peatlands. This type of research has not been conducted in such wide context before, and the results of this study can offer knowledge for policymakers and energy businesses stakeholders to develop bioenergy-based commercial activity in rural areas. The GIS method used in the study can be applied in other countries, if biomass resources must be allocated. This study did not include greenhouse gases or energy inputs related to energy crop production (harvesting, transportation, etc.).

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