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The effect of increased extraction of forest harvest residues on soil organic carbon accumulation in Sweden

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ABSTRACT

The demand and potential for increasing the use of bioenergy from harvest residues in Sweden are large. However, harvest residue (branches and tops) and stump extraction negatively affect soil organic carbon (SOC) accumulation. The main objective of this study was to assess the effects of increased harvest residue extraction on soil organic carbon (SOC) accumulation at national level. Further, the reduction in CO2 by substituting coal with biofuel from harvest residues and stumps was assessed. Several scenarios with increased harvest residue extraction were simulated with the forest management system HUGIN and the SOC decomposition model Q and the effects on SOC accumulation in Swedish coniferous forest soils were assessed. All scenarios resulted in decreased SOC accumulation. The decrease in SOC accumulation was largest for stump extraction, with 0.15 Mg C ha^{-1} y^{-1} loss on average over a 100-year simulation period. In all scenarios, the short-term effects on SOC accumulation were greater than the long-term effects. The effect of substituting coal with bioenergy was an immediate reduction of net CO_2 emissions. An increase in the use of forest residues leads to CO_2 mitigation in the atmosphere, even when SOC losses are accounted for.

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1. Introduction

There is global interest in mitigating climate change. The European Union (EU) has set an emission target for reducing greenhouse gas emissions (excluding land use, land use change, and forestry (LULUCF)) by 80–95% by 2050, compared to 1990 levels [1]. The target is in line with ambitions for limiting global temperature increase to 2 °C above pre-industrial temperature. In the 2009 climate bill, the Swedish government expressed a vision of a sustainable and resource efficient energy production and zero net emissions of greenhouse gases into the atmosphere by 2050 [2]. To meet these targets, it is likely the demand for bioenergy will increase, thus, putting pressure on the forestry sector to increase extraction of harvest residues and stumps.

Bioenergy from harvest residues comprises the majority of renewable fuels in Sweden, and current bioenergy use is

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around 112 TWh y^{-1}, which is equivalent to around 20% of the national energy consumption. Although approximately 45% of harvested Swedish forest biomass is used for energy [3], about 80% of harvest residues (branches and tops) from commercial thinning are left in the forests, and stump extraction is applied at trial stage only [3]. Therefore, there is potential for increasing the use of harvest residues and stump extraction in order to achieve the national energy goals stated by the Swedish government. The long-term forecasts of the Swedish Forest Agency estimate the demand of harvest residues and stumps will be 15 TWh y^{-1} (heating energy) in 2020. The Swedish Forest Agency further estimates the potential for Sweden to increase harvest residue extraction for bioenergy production to 25 TWh y^{-1} [4]. These increased extractions are equal to a 7 and 17 TWh increase, based on that the current amount of energy (8 TWh) from harvest residues. The potential stated by the Swedish Forest Agency of 25 TWh is equivalent to the annual amount of energy needed for heating 185 000 average small houses in Sweden during one year [5,6]. However, more intensive use of harvest residues for bioenergy will cause land use or management changes that might indirectly cause CO_2 emissions into the atmosphere [7,8]. Increased harvest residue extraction affects the forest ecosystem negatively through decreasing the soil carbon pool, acidifying the soil by removal of base cations, and disturbing biodiversity by removing the habitats of many insects and mosses or lichens [9]. Changes in forest management that increase the extraction of harvest residues negatively affect soil C accumulation, which leads to increased C emissions to the atmosphere [7,10–14]. At stand level scale, the change in soil carbon is relatively small when extracting harvest residues [15,16], and the use of harvest residues for bioenergy reduces net greenhouse gas emissions when coal is substituted with bioenergy from harvest residues [17,18]. The potential substitution of coal (compared to the real substitution: how much coal can be substituted) is suitable for running a scenario where energy consumption is expected to increase and the energy source is not yet defined. In addition, if spruce branches and stumps are substituted for coal, the estimated reduction of CO_2 emissions from harvest residues as bioenergy is temporarily delayed by five years for spruce branches and 15 years for spruce stumps, because the decomposition of the residues, if left in the forest, also emit CO_2 to the atmosphere [11].

The main objective of this study was to assess the effects of increased harvest residue extraction on soil organic carbon (SOC) accumulation at national level. In addition, CO_2 emission reduction was assessed by substituting bioenergy from harvest residues for coal. Several scenarios with increased harvest residue extraction were simulated with the forest management system HUGIN and the SOC decomposition model Q. The effects of the increased extraction of harvest residues on biodiversity and nutrient depletion were not considered in this study.

2. Materials and methods

2.1. *Overview*

The study was conducted with the forest simulation system HUGIN [19] and the decomposition model Q [20] (Fig. 1) to assess the effect of increased harvest residues and stumps on soil organic carbon. Biomass estimates from the HUGIN system produced for the Swedish Forest Agency in their national forest impact analysis [4] were used to generate scenarios with increased levels of harvest residues or stump extraction, compared to a reference scenario. The amount of extracted harvest residues or stumps corresponded to an annual energy use of 15 (harvest residues) or 25 TWh (harvest residues and stumps separately). Both economic and ecological restrictions were taken into consideration. Stands less than 1 ha were not included in the extraction due to economic reasons. Within each stand, 40% of the harvest residues and the stumps were left in the forest. No residues were extracted from wet or moist soils with low productivity, soils with uneven surface terrain or with large blocks, and sites with a slope larger than 20° [4]. The change in CO_2 emission for the substitution of coal by

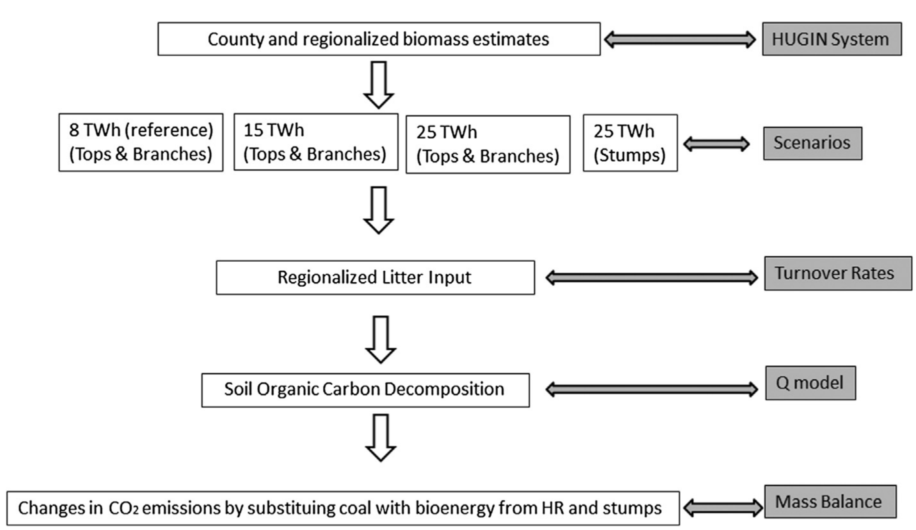

Fig. 1 – Schematic flow of the scenarios, illustrated as energy production in TWh for Sweden and by which method (grey boxes) the different steps in the calculation flow (white boxes) are interlinked.

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