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# Assessing Biomass Removal and Woody Debris in Whole-Tree Harvesting System: Are the Recommended Levels of Residues Ensured?

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**Abstract:** Forest biomass is a sustainable source of renewable energy and a valuable alternative to finite fossil fuels. However, its overharvesting may lead to soil nutrient depletion and threaten future stand productivity, as well as affect the habitat for biodiversity. This paper provides quantitative data on biomass removal, fine woody debris [ $d \leq 7$  cm], and coarse woody debris [ $d > 7$  cm] left on the forest floor in whole tree harvesting systems. Using tree allometric equations and inventory field methods for woody debris estimation, we assessed biomass removal on nine fuelwood harvesting sites in Central France, as well as fine and coarse woody debris left on the sites. The aboveground biomass estimates showed a high variability between the studied sites, it varied between 118 and 519 Mg ha<sup>-1</sup>. However, less variability was found among sites managed as coppice-with-standards 174 ± 56 Mg ha<sup>-1</sup>. Exported biomass was 107 ± 42 Mg ha<sup>-1</sup> on average, including 35 ± 9% of fine wood. The amounts of both fine and coarse woody debris left on sites were generally less than 10% of the total harvested biomass in 2/3 of the studied sites. These amounts are lower than the minimum retention levels recommended by the sustainable forest biomass harvesting guidelines. Therefore, more technical effort and additional management measures should be taken to ensure more woody debris, especially in poor forest soils and thus, to guarantee a sustainable biomass harvesting.

**Keywords:** whole-tree harvesting; biomass; fuelwood; fine woody debris; coarse woody debris; coppice-with-standards



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## 1. Introduction

The European Union is resolved to reduce greenhouse gas emissions and promoting the development of new energy policies to reverse the trend of global warming associated with climate change [1,2]. These policies aim to develop new and sustainable energy sources and contribute to a reduction in the growing dependency of EU countries on fossil fuels. Amongst renewable resources, paramount importance has been given to the bioenergy because it has low negative environmental impacts. Biomass was one of humanity's earliest sources of energy, and it remains an important resource today and for the future to enhance security energy. Today, biomass accounts more than half of all the EU's renewable energy production and 10% of all energy sources [3]. This figure is likely to rise in the future because it is considered a promising alternative to fossil energy in order to shift towards sustainability. Woody biomass accounts for more than 60% of all EU domestic biomass [4]. Indeed, fuelwood seems to be a promising option in temperate forests and developed countries [5] by providing a local supply of renewable energy and by allowing forest owners to diversify their sources of income [6]. In most European countries, woody biomass demand is rising fast with many bioenergy strategies [7,8], which have led to the adoption of new logging practices [9–11]. Different biomass harvesting methods are used in Europe; their selection depends on site conditions, silvicultural treatments,