Applied Energy 154 (2015) 62–73

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Sustainable biomass supply chains from salvage logging of fire-killed stands: A case study for wood pellet production in eastern Canada

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HIGHLIGHTS

- Eastern Canada has large wood supply from natural disturbances that is under-utilized by sawmills.
- Despite high variability, biomass from fire-killed trees can contribute to a profitable pellet supply chain.
- Ecological and operational constraints have little impact on biomass supply.
- Uncertainties due to the variability of natural disturbances need to be accounted for.

ARTICLE INFO

Article history:
Received 10 February 2015
Received in revised form 10 April 2015
Accepted 12 April 2015
Available online 14 May 2015

Keywords:
Bioenergy
Costs
Ecological constraints
Natural disturbance
Optimization

ABSTRACT

While western Canada is an international leader in the growing pellet market, eastern Canada remains a minor player despite its abundance of wood residues from natural disturbances. This study investigates the potential amount of biomass from salvage logging of fire-killed stands along with harvesting residues from clearcut to supply pellet plants in eastern Canada between. We built and optimized supply scenarios in two forest management units to fulfill different pellet plant capacities under various operational, ecological, and economics constraints. Despite the high spatial and temporal variability of burned area, this study confirms the large quantities of biomass from fire-killed stands available as ecologically sustainable feedstock for bioenergy, which, combined with the comparatively smaller and more stable quantities from clearcut harvesting residues could supply theoretical pellet plants. Our results show that under current market conditions, biomass both from harvest residues and fire-killed stands could fulfill on average between 5% and 66% of a 50 000 ODT y^{-1} plant needs at a price of $90 ODT^{-1} of wood chips for the decade considered. With a wood chip price at $120 ODT^{-1}, 100% of the production capacity of a 50 000 ODT y^{-1} plant or even of a 100 000 ODT y^{-1} plant could be met. Ecological constraints related to the need to protect sensitive sites and prevent recovery operations on them, and operational constraints related to the capacity of the machinery to recover biomass from a given site, have little impact on the supply of biomass from fire-killed stands. However, important regional variations exist in terms of potentials and constraints, which would need to be taken into account when designing bioenergy industrial networks.

1. Introduction

According to the International Energy Agency (IEA), energy from biomass needs to provide close to 146 EJ by 2050 in order to limit greenhouse gas (GHG) emissions to the atmosphere, with a large share of biomass being used for power generation [1]. Functional international biomass markets have become an essential part of bioenergy systems [2] and will play a crucial role for reaching the IEA target [3]. Notably, the imports of wood pellets to the European Union (EU) are expected to reach 15–30 Tg by 2020, with the United States and Canada as two of the main exporter countries [4] and [5]. To make the most of the opportunity in biomass international trade flows and global bioenergy systems, Canada's forest sector is looking at strategies for increasing the mobilization of its forest biomass supply chains, which requires detailed knowledge on biomass availability, costs and logistics [3].

The three main feedstocks currently used in Canada for pellet production are (i) industrial residues from wood processing activities in sawmills and, to a lesser extent, (ii) forest harvesting

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http://dx.doi.org/10.1016/j.apenergy.2015.04.048

residues (comprised of tree tops and branches as well as bucking and trimming material that are by-products of stemwood harvesting operations) and (iii) standing dead trees resulting from natural disturbances such as fire, insects and disease [6–8]. Forest harvesting residues are collected from (often clearcut) harvested sites using either a grapple mounted on a forwarder, or a bundler that compacts loose slash into bundles [9]. For their part, standing dead trees are harvested in an operation called salvage harvesting, using similar equipment as regular roundwood. Harvesting residues and dead wood from natural disturbances are crucial to the further mobilization of biomass supply chains for international trade for at least three reasons. First, mill processing residues are almost fully employed already and other sources of feedstock should be rapidly considered to feed the growing pellet market. On the other hand, forest harvesting residues are not utilized by sawmills and pulpmills. Dead wood resulting from natural disturbances are also unappreciated by those industries, because they have a short shelflife for processing into traditional products. Past this shelflife, which varies between disturbances, tree species, and site conditions [7], the degraded dead wood fibre causes hurdles at the mill and affects the profitability of the operations [6]. Conversely, harvesting residues and standing dead trees have been shown to be an adequate source of biomass feedstock for bioenergy [9,10], that would not compete with other forest industry activities. Second, recent studies have shown that both sources represent a large potential across Canada to ensure the growth of the bioenergy sector, with the availability of dead wood from natural disturbances being significantly higher than that of harvesting residues [11–13]. For instance, the large areas of dead trees created by the recent mountain pine beetle epidemic in British Columbia have supplied stands of lower quality, mainly directed towards the wood pellet industry [14,15]. This source of biomass has been recognized as a special case of under-utilized forest growth that should contribute to the global increase in biomass output [16]. Third, climate change is predicted to increase the occurrence of natural disturbances in the boreal forest biomes, and strategies are needed to cope with the disturbed forest areas and the wood they contain [17,18]. Salvage harvesting of naturally disturbed stands and adapting forest product value chains to the large amount of wood generated by these disturbances is an integral part of a larger framework of forest management adaptation to climate change [13,16,19].

Forest biomass is generally scattered in low density over large areas; the logistics of collection and transportation from forest sites to processing facilities therefore represent a challenge and need to be carefully planned to ensure the profitability of the supply chain [20–22]. These challenges might be exacerbated in the case of dead wood from natural disturbances, since events such as wildfires are often controlled by climate and are therefore stochastic in nature. Given that the periodicity, location, spatial extent and quantities of forest biomass available after disturbances vary wildly, salvage logging of naturally disturbed stands therefore necessitate careful valuation that encompasses this uncertainty [23,24].

Moreover, forest biomass procurement for bioenergy production still raises questions about the ecological sustainability of this practice at an industrial scale because of the pressure the increased removal of organic material may cause on ecosystem functions [25,26]. In the case of salvage logging in particular, the removal of dead trees reduces the stock of coarse woody debris at the stand and landscape levels, with possible impacts on biodiversity and soil fertility [27–29]. Besides, recent discussions about development of sustainability criteria for solid biomass in a number of EU Member States have concluded that the best way of demonstrating that woody biomass meets the criteria is by demonstrating sustainability at forest site-level [30]. This requires detailed knowledge about ecological features and constraints of the forest sites. As suggested by Sikkema et al. [31], forest biomass supply can be assessed based on its theoretical potential, i.e. the maximum biomass potential from forests, to which we overlay economical, operational and ecological constraints to obtain the actual potential that can serve as sustainable feedstock. Since there are large variations in ecological, operational and economical conditions across the boreal forest of Canada, this framework should be applied at the regional level [32].

Currently, more than 75% of Canadian wood pellets exported to Europe are produced in western Canada (mostly shipped from Vancouver on a 16 000 km long route via the Panama Canal); conversely, eastern Canada has a very low share of the wood pellet production. Meanwhile, this region offers a large potential of becoming a hub pellet exporter to Europe because its large amounts of biomass, notably from wildfires, are under-exploited by the timber and pulp industries, and also because open ports on the Atlantic offer shorter transportation distances to Europe (6000 km) [4]. Eastern Canada therefore represents an interesting case study for identifying roadblocks and opportunities for the mobilization of international and sustainable forest biomass supply chains based on dead wood from natural disturbances.

With the aim of bridging some of the gaps between theory, development and implementation of forest biomass supply chains feeding international trade and bioenergy systems, this study investigates the potential utilization of dead wood from fire-killed stands along with harvest residues from clearcuts of mature stands as feedstock for wood pellet production in eastern Canada. Two forest management units (FMUs) with contrasting characteristics in terms of harvesting level, soils and fire risk are used as case studies. The objectives of the study are (1) to quantify potentially available biomass from salvage logging of stems from wildfire-affected stands as well as those from harvest residues (tree tops and branches) for two forest management units (FMU) between 2002 and 2011; (2) to assess the spatial and temporal variability of these amounts under various levels of economical, ecological and operational constraints related to biomass procurement; and (3) to use a decision support system to compare biomass supply scenarios for various pellet plant capacities under constraints identified in previous steps.

2. Material and methods

2.1. Study area

The study area is located in northeastern Quebec, which is mostly covered by the boreal forest. In this part of Canada, the forest industry is primarily oriented towards the production of paper and lumber. However, it got strongly affected by the downturn of the forest product sector over the past decade and has seen many plant closures. As a result, more than 6000 jobs have been lost over the last 5 years. This decrease in activity has left a significant volume of wood unexploited that has been recognized as an interesting opportunity for the development of bioenergy sector in the region [33].

The analysis focuses on FMU_2503 and FMU_9301 in the province of Quebec (Fig. 1), which are similar in size (~10 000 km^2) but characterized by contrasting historical levels of harvesting and fire risk. FMU_2503 is characterized by a high risk of fire, with a recent burn rate of 0.5% y^{-1} (burn rate being expressed as the average annual percent area affected by wildfire) [34], while FMU_9301 has a burn rate that is five times lower, at around 0.1% y^{-1} [35,36]. In both FMUs, the fire risk is driven by natural factors mostly associated with climate [36] and the dominant species are *Picea mariana* (63%) and *Abies balsamea* (14%), with a small share of *Pinus banksiana* (7%) and *Betula papyfera* (6%) [37]. For