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An integrated wood pellet supply chain development: Selecting among feedstock sources and a range of operating scales

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HIGHLIGHTS

- A wood pellet SC is developed by using spatially explicit optimization.
- Wood pellet SC is integrated with traditional forest products SCs.
- Selection among feedstock sources and a range of operating scales.
- Supply cost sharing mechanisms and governmental subsidies are explored.
- Conditions under which government subsidies are efficient are determined.

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ABSTRACT

An approach to developing a wood pellet supply chain (SC) which selects among several sources of biomass feedstock is proposed. The approach is based on a downstream to upstream analysis of the SC and includes five phases: (1) Identifying potential markets and projected demands. (2) Determining feedstock types, locations, and available quantities. (3) Evaluation of raw material and final product transportation options, potential plant location, and logistics components that can be integrated with existing forest products SCs. (4) Cost estimation of raw material supply, production, and final product delivery. (5) Utilizing a spatially explicit optimization and generic model to determine the optimal operational conditions under which the wood pellet SC is profitable while taking into account economies of scale. The model selects the best feedstock locations and determines the optimal quantities to supply as well as the optimal production capacity. The associated ROI is calculated to assess economic feasibility. To show the value of the approach, we applied it to a real case study proposed by a regional development agency interested in developing the wood pellet sector in Eastern Canada. The results show that implementing a 100,000-tonne plant using biomass harvested in the forest as the sole feedstock is profitable. However, harvesting costs must be shared among the pellet mill and other forest companies and the government must provide financial support. The use of sawmill residues in the mix of feedstock allows implementing a highly profitable 50,000-tonne plant without any government support or harvesting cost sharing mechanism. Under a high wood pellet selling price, harvesting cost sharing and government support, the production capacity can reach 150,000 tonnes/year. An important finding is that government support is not necessary for ensuring profitability in all cases. Government support has a significant impact on profitability in the case where sawmill residues are not available as a feedstock for manufacturing pellets or the selling price is high enough to allow operating a profitable plant of large size.

1. Introduction

Bioenergy products offer an alternative to fossil fuels in reducing greenhouse gas (GHG) emissions. Currently fossil fuels dominate the world's primary energy supply, representing 80% of global energy demand [1]. However, governments worldwide are

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taking steps toward reducing fossil fuel consumption and GHG emissions. For instance, in an effort to reduce GHG emissions, the European Union has decided to produce 20% of its energy from renewable sources such as wood pellets by 2020. In this regard, wood pellets are considered to be a good energy alternative since they can be transported over long distances at low costs due to their relatively high energy density. Wood pellets are one of the largest internationally traded solid biomass commodities [2]. In terms of traded volume, they can be compared to biodiesel or bioethanol [3]. 28 M tonnes of wood pellets were produced in 2015, of which 15 M tonnes for heating usage and 13 M tonnes for industrial usage [4]. The major producers of wood pellets are Europe, the U.S., and Canada [5]. Long-term market prospects are very positive, with growth expected in both industrial and heating demand [4]. In 2025, the world pellet market is estimated at 54 million tonnes, 38 million tonnes of which is expected to be consumed in Europe [5]. North American and Asian markets are also expected to significantly grow as a result of legislative supports and GHG reduction policies [6,7]. Industrial wood pellet CIF (cost, insurance and freight) prices[1]have increased from around €115 per tonne in July 2007 to €140 per tonne (around $165 CAD and $225 CAD, respectively) at the beginning of 2009. The history of industrial wood pellet prices indicates that the market is relatively stable and will remain below the price of fossil fuels. Lastly, the prices decreased mainly due to the low prices of fossil fuel [8]. However, fossil fuel prices are expected to increase in the future. Non-industrial pellets (used for domestic heating) are generally more expensive than industrial pellets [2].

To benefit from wood pellet market opportunities, the forest industry is increasing its investments in wood pellet production. However, sawmill residue (e.g., sawdust and shavings) from which wood pellets are usually produced is becoming scarce as it is an attractive feedstock for a wide range of products. Consequently, manufacturers have been forced to procure fiber directly from the forest. For instance in Canada, usually up to 25% of the raw material can come from harvest residues (branches, tops, etc.) [9]. Over the last few years, whole trees infested with mountain pine beetle, deemed unfit for traditional wood products (timber, paper, etc.) have been used for manufacturing wood pellets and other bioenergy products in Western Canada [10–12]. Species or tree sections with low value deemed unsuitable for traditional forest products are also being used as raw material [13]. However, despite the abundance and the variety of woody biomass sources available in the forest, bioenergy products manufacturers make limited use of it. The relatively high supply cost is the main hurdle. It is hypothesized that if bioenergy products logistics can be appropriately integrated with traditional wood supply chains (SCs), various economic, environmental and social benefits could be generated for the industry, governments, and local communities; for instance, in terms of access to additional fiber, lower timber harvesting costs, and employment opportunities.

Studies in the literature report on attempts to integrate wood pellet production with traditional forest products manufacturing (sawmills, pulp mills, etc.), by using for example sawmill residues as raw materials [14,22,10,15]. Excess heat from sawmill operations has been considered as an energy source for the drying phase in the wood pellet production process [16,22,17,18]. However, integration mechanisms proposed in the literature are limited to the production phase and other integration opportunities along the SC remain largely unexplored. These traditional integration mechanisms may not be sufficient to significantly reduce the operations costs and ensure economic feasibility when feedstock is totally or partially harvested in the forest. In fact, studies analyzing the entire SC, from the forest up to the end costumer are scarce [12,19,20]. Therefore, most studies ignore logistics and market aspects such as raw material availability, transportation infrastructures, and final product requirements in the market. According to Mobini et al. [12], this limits the credibility of obtained results. Most studies tend to focus on the production phase of wood pellets and the economic feasibility of implementing a plant that uses mill residues as the main feedstock [14,15,21,22]. Other studies have analyzed the economic feasibility of implementing a pellet mill that uses alternative feedstock sources such as insect killed trees, green standing timber, and harvest residues, as raw materials [10,11,23]. These studies rarely explicitly consider all processes of the SC. Moreover, Hughes et al. [24] reported that most studies examine wood pellet SCs from an upstream to downstream perspective, i.e., the product is created based on capacity and then pushed out into the marketplace. Finally, when optimization-based model approaches are adopted, economies of scale are seldom considered. The models developed by Sultana and Kumar [25], Mobini et al. [12,20] are among the rare models that explicitly consider all processes of the SC. Mobini et al. [12,20] developed simulation-based models to facilitate regular and torrefied wood pellet SC design studies. The cost of delivering pellets to various customers, the amount of energy consumed along the SC, and associated carbon emissions can all be estimated. Sultana and Kumar [25] developed an optimization-based methodology to determine the suitable locations, optimal sizes and number of biomass-based plants for a particular region.

This article develops a generic approach for selecting the best raw material sourcing locations, determining the optimal quantities and mix of feedstocks to supply (alternative biomass sources harvested in the forest and mill residues), and designing a profitable wood pellet SC while considering economies of scale. To demonstrate the value of the approach, we applied it to a real case study proposed by a regional development agency in Eastern Canada interested in supporting its fragile forest industry by adding opportunities for underutilized fiber sources. The remainder of the article is organized as follows: the next section presents the proposed approach. Section 3 introduces the case study and presents the implementation phases of the approach. The results are presented in Section 4. Finally, the main conclusions and research perspectives are presented in Section 5.

2. Proposed approach

The developed approach allows for examining wood pellet SCs from both logistical and economic feasibility perspectives. All logistics processes are considered: raw material procurement, inbound logistics of raw materials, processing of raw materials into wood pellets, and outbound logistics to the end customer. As shown in Fig. 1, the approach is based on a downstream to upstream analysis. That is, market analysis (market location, demand estimation, wood pellet types and prices) is performed prior to SC development. The approach is comprised of five phases: (1) market analysis, (2) raw material analysis, (3) SC design, (4) cost estimation, and (5) SC optimization and profitability analysis. Each phase is aimed at achieving specific goals, and all five phases are coherently integrated, i.e., the results of former phases are inputs for next phases. The main results of all five phases are shown in Fig. 1.

- **Phase 1: market analysis**

This phase consists in identifying potential markets (e.g., domestic and foreign), the type of wood pellets sold in these

[1] In 2008, the Industrial Wood Pellets price index was launched at Rotterdam's energy trading platform APX-Endex, which deals with industrial wood pellets traded in the ports of Amsterdam, Rotterdam and Antwerp (ARA). The index lists prices as CIF, meaning cost, insurance, and freight. CIF ARA has become the measuring stick for global trading of industrial pellets.