Bulletin of the *Transilvania* University of Braşov
Series II: Forestry • Wood Industry • Agricultural Food Engineering • Vol. 6 (55) No.1 - 2013

IMPROVING THE PRIMARY FOREST FUEL SUPPLY CHAIN

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Abstract: *The paper comprises various topics covering the primary forest fuel supply chain, provides an overview of actual research and outlines future research issues. Starting with estimating the potential supply volumes of primary forest fuel, which proved to be a really crucial task for the whole supply system, the supply network is then described. Further development of forest fuel supply chain engineering is shown and proven to be a valuable measure in improving supply chain performance. The paper concludes with critical reflections on some shortcomings of developed forest fuel supply models and ends by illustrating future research options.*

Key words: *primary forest fuel, bioenergy, transportation, logistics.*

1. Introduction

The paper comprises various topics covering the primary forest fuel (PFF) supply chain, provides an overview of actual research and outlines future research issues. Therefore, it does not intend to present a comprehensive literature review on each issue, since supply chain research is a broad field, even if one focuses mainly on the PFF supply chain.

A supply chain is defined as a system consisting of material suppliers, production facilities, distribution services and customers, who are all linked together via the downstream feed-forward of materials (deliveries) and the upstream feedback of information (orders) [1]. Accordingly, the wood supply chain spans everything from the forest to the forest-based industry, including the bioenergy generation, as well as the procurement of wood products for further processing steps, e.g., deals for solid structure timber production.

Measures for improving the supply chain differ in terms of their time horizon and aggregation of information and processes. Strategic supply chain decisions have a planning horizon of several years and are thus long-term decisions, such as supply chain design, which includes decisions on transportation modes or facility location decisions (e.g., power plant location or terminal location). Additionally, wood procurement planning decisions are often interconnected, e.g. a decision for a specific plant location can restrict transportation modes, which can furthermore restrict potential suppliers or supply regions. Tactical supply chain decisions take into consideration a medium-term planning horizon of up to several months. Typical tactical planning tasks are transportation planning, including harvest area and plant allocation or capacity planning, production planning and materials requirement planning. Operational supply chain decisions are

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short-term decisions made from day to day or a planning horizon of a few weeks. Detailed schedules for machines and harvest sites, or transportation decisions, such as vehicle routing for forest fuel transport, are typical operational tasks [2]. The level of planning detail increases from the strategic to the operational level. Contrary, research dealing with strategic and tactical supply chain decisions strongly relies on input data gathered in operational studies (e.g., including chipping operations in a model depends on chipping costs for different chipping devices obtained in field trails).

2. Estimating Potential Supply Volumes

In Europe, recent regulations have stimulated sustainable and CO_2-neutral energy sources, since fossil fuels have been recognized as an uncertain and climate-threatening energy source. Biomass presents enormous opportunities for global energy production in the coming decades [3], and various studies indicate that forests can become a major source of bioenergy, even without negative side effects, such as further deforestation [4]. Accordingly, wood fuel[i] is seen as one of the most promising options for the future among the other renewable energy sources [5]. Therefore, the ambitious national and EU bioenergy targets (e.g., 20 20 20 by 2020 target) demand further increasing the proportion of wood-based bioenergy systems. Therefore, the demand for wood fuel and particularly for PFF[ii], has skyrocketed [7]. Fuel supply planning has been based on studies that evaluated the potential supply volume (e.g. [8], [9], [10]) based on the yearly increment and wood reserves accumulated as a result of under-utilization in the past and took technical and economic limitations into consideration. However, even though it was not explicitly declared, the authors assumed that every forest owner would be utilizing timber within a couple of years, if it could be done in a profitable way. In contrast, most of the calculated potential comes from small-scale forests, where an increasing number of owners value their forests as a place to spend their leisure time and, in fact, they do not want to harvest timber at all [11],[12]. Furthermore, small-scale forest owners tend to set the harvest time according to their own investment needs. Ignoring these restrictions resulted in excessively high supply potentials for wood fuel [13]. Therefore, as a robust basis for the design of a regional supply chain, a stepwise heuristic approach was introduced that integrates seasonality of supply and demand based on calculation of the available market potential [14]. In subsequent applied projects for the bioenergy industry, it could be proven that the available forest fuel potential is a good indicator for estimating whether planned plants can be supplied with feedstock, as well as making a first estimation of expected average transport distance and related transportation cost.

3. The Wood Supply Network

Terminals balance the seasonal fluctuation of the plant's demand and the respective variability of supply from the forests [15] and serve as transshipment

[i] Woodfuels (or wood fuel): “All types of biofuel originating directly or indirectly from woody biomass.” [6]: p.42.

[ii] Primary forest fuel or forest fuels: “Wood fuel produced where the raw material has not previously had another use. Forest fuel is produced directly from forest wood by a mechanical process.” [6]: p.35. It comprises traditional fuel wood, sub-standard industrial roundwood, and logging residues, and is supplied either directly from the forest to the energy plant or via terminals. Sometimes it is also called primary forest fuel in order to separate it from other wood fuels, such as the industrial by-products saw chips or black liquor.

points, where chipping is carried out. Therefore, terminals are used to ensure a reliable supply, even under extraordinary conditions (e.g., when wood fuel piles in the forest cannot be accessed after a period of rain or heavy snowfall; [16]). Furthermore, terminals are sometimes needed to store energy wood and chips because of low storage capabilities at the plant location. Allocating a terminal with chipping operations needs to take vicinity to settlements into account because of noise and dust produced during chipping.

Setting up a terminal results in a tradeoff between additional costs (e.g., investment and material handling) and decreasing chipping and transportation costs due to scale effects [17]. Therefore, the cost-cutting potential of a terminal depends on the entire PFF supply chain [18].

Seasonality of both the fuel supply from the forest and the fuel demand, leading to a maximum volume of forest fuels stored at a given time of the year, should determine the storage capacity of the regional terminal [14].

Terminals as large buffer storage areas are also prerequisites for ship and rail transport, because high volumes have to be unloaded and stored within a short time period [16]. Usually, a stationary chipper at a plant operates more cost effectively (economy of scale) than chipping at roadside landings, for example [19]. Terminals may differ in terms of location, storage capacity and chipping technology.

Industrial terminals are located at a forest-based industrial plant, where a stationary chipper is mainly used for chipping wood for pulp or panel production, but its capacity also allows handling forest fuels [16]. Furthermore, an industrial terminal using a stationary chipper can be located directly at an energy conversion plant. According to forest fuel supply chain cost analyses, terminals at energy conversion plants required a large storage area, a high annual processing volume and a stationary chipper to be competitive [17]. Industrial terminals mainly use existing infrastructures and profit from scale effects in acceptance of wood or chipping and thus provide low costs [19]. Accordingly, for a national PFF supply chain it was proved that industrial terminals offer considerable saving potentials [18]. Consequently, a forest-based industrial partner as terminal provider can offer important cost cuttings.

Simple terminals in or near the forest only provide storage areas for several thousand cubic meters of wood fuel, as well as year-round access for trucks and mobile chippers. Often entrepreneurs with mobile chippers are engaged, since chipped volumes are low. Compared with the annual demand of a CHP, the storage capacity of a regional terminal is relatively low, and the same applies to scale effects on chipping and transportation [18]. Agricultural infrastructures providing a calibrated weighbridge and asphalted storage surface, such as terminals built for processing sugar beets, are also used as forest fuels terminals [16]. The actual implemented forest fuel supply chains in Central Europe rely on the transportation modes, such as truck, rail and inland waterways, with the truck as the most commonly used mode (Figure 1).

In supply chains, shortages are usually buffered by means of stored material, leading to so-called hidden inventory costs due to material deterioration. Contrarily, storing woody biomass properly for several months increases the net calorific value due to drying, however biodegradation leads to dry matter losses.

Indeed, a higher net calorific value of fuel reduces both the quantity of ashes produced and the ash disposal costs [20].

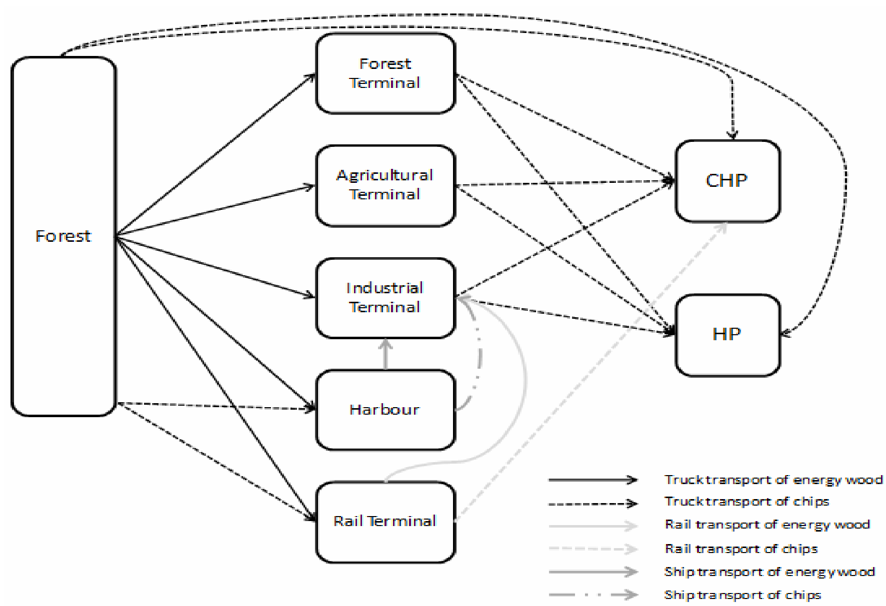

Fig.1. *PFF supply network for Austrian energy conversion plants (CHP: combined heating plant; HP: heating plant)*

4. Forest fuel supply chain engineering

Innovation potential on an operational level is nowadays small compared with that on a tactical or strategic level. Furthermore, with the expeditiously growing forest fuel demand, the strategic problem of how to design a cost-efficient distribution network has evolved. Studies addressing tactical or strategic decisions in the forest fuel supply network focus on terminal location, transportation mode, or supply and demand allocation. The task is to design a forest fuel supply network where the procurement areas, different terminal types and plants are all connected in a cost effective manner via various kinds of fuel supply chains.

A forest fuel supply network with several supply regions, one central terminal as a processing site, and a single energy plant was described and solved for a multi-period horizon with Linear Programming, by which it was shown that the transportation costs constituted the most essential part of the total forest fuel supply cost [21]. A geographic information system (GIS)-based model was developed for estimating the total purchase and transportation costs for supplying woody fuel from the forest directly to coal-fired power plants. The results stressed the importance of a plant-based approach for assessing both biomass resources and procurement costs in order to determine the profitability of co-firing woody fuels [22].

A recently developed model combines the GIS-based fuel potential and cost estimates with a Linear Programming model to allocate forest fuels from regeneration cuttings to CHPs, but no terminals are considered in the potential supply chains [23]. A Mixed Integer Linear Programming model supported supply chain planning for heating plants firing both forest and sawmill residues. Decisions to be taken included the kind of fuels (e.g., forest residues, sawmill byproducts and decay-damaged wood), harvest area and sawmills to be contracted, as well as transportation modes [15]. A heuristic solution was developed in order to more quickly solve the problem with a planning horizon of one year, considering monthly periods. At a regional level, a Linear Programming Model located and sized CHPs by considering the fuel harvest and transportation costs, as well as regulatory and social restrictions [24]. An evaluation method of a forest fuels supply network design that comprised inventory management policies to buffer seasonal fluctuations in fuel demand and supply shows that the supply chain outperforming all regional terminals located within a radius of 100 km was using a central, forest industry-based terminal [14]. In addition, a more recently developed operational forest fuel logistics model includes daily variations in moisture content of delivered woodchips, as well as weather conditions that slow down the logging operations [25].

The robustness of the forest fuel supply network design was tested by means of changes in the transportation cost and domestic forest timber utilization rate. It was possible to demonstrate that industrial terminals offer considerable saving potentials. Therefore, the cooperation of CHP operators with a forest-based industrial partner as a terminal provider is one of main management implications of the study results [18].

The concept of using scenario analyses in order to test the sensitivity of a forest fuel supply model was further implemented for evaluating the impacts of rising energy costs on procurement sources, transport mix and procurement costs on a national scale (Austria). Furthermore, the influence of truck route optimization on procurement costs and modal split was evaluated. [16].

In conclusion, it can be said that various optimization models have been developed for a number of forest fuel supply decisions. In addition, models became more and more detailed and spatially explicit, but examples for the estimation of the surplus of optimized supply networks compared to concrete actual supply situation are still rare. An example for cooperative wood procurement by two Swedish pulp producers, who optimize the allocation of sawmill chips to pulpmills in order to minimize transportation cost is provided by [26]. They state that this cooperation reduces transportation cost, but give no exact figures on the saving potential.

One attempt to close aforementioned gap has be made by [27], who simulated actual forest fuel procurement costs for Austria with heuristics and found that they are at least 20% higher than procurement costs based on a MILP model. Cooperation between all Austrian CHP plants lowers forest fuel transportation costs by 23% on average and reduces average transportation distances by 26%. This corresponds with the results of [28], who noted a 20% reduction in truck transport costs by inter-enterprise cooperation in the roundwood procurement of three large timber industries.

Nevertheless, cooperation amongst all 91 CHPs throughout Austria would seem to be rather unrealistic. Therefore the next logical research step was to explore the effects of concrete cooperation and possible cost cutting. Accordingly, the above-described methodology was adapted to calculate the economic benefits of cooperative fuel procurement as a result of the fictional cooperation of seven of the largest Austrian CHPs [29]. Savings through cooperation were calculated as the difference between the sum of total transportation costs of all partners with or without cooperation. Average savings span from 14% to 24% of the transportation costs, but differ amongst the cooperating partners.

Establishing partnerships and working alliances for forest fuel procurement thus has important management implications for achieving efficiency in forest fuel supplies and strengthening the competitiveness of wood fuel-based energy production. Despite the benefits of cooperation, several critical issues still exist. One important issue is that cooperation benefits may not be distributed equally between cooperating partners. Such is the case, if one partner receives a larger share of cost-cutting effects than the other(s). Accordingly, recent developments consider cost-saving sharing as a key issue of inter-enterprise cooperation in transportation and are discussing new cost allocation methods according to the example of a forest-based industry [30].

5. Shortcomings of Developed Forest Fuel Supply Models

Many of the developed optimization models (which are mainly MILP models) minimize specific costs under the implicit assumption of perfect cooperation and coordination among all involved business entities. Due to competition, on the contrary, calculated costs are certainly lower than in reality, as was proven by [27], who found that real costs were at least 20% higher. To simulate a competitive situation, they applied three different models to figure out the practical behavior of managers supplying a single CHP.

Further frequent shortcomings of many of the presented network models are the exclusion of the long-distance transportation modes of rail and ship, the assumption of too small procurement areas disregarding the supply and demand of adjacent regions, or competing material uses (e.g., panel production), and disregarding import options.

Furthermore, even though several models support strategic decisions with a long-term planning horizon, basic economic assumptions are market stability, in terms of supply and demand volumes, prices or supply costs. Accordingly, like most forest planning models, many forest fuel supply models are also based on the assumption that all information is deterministic [31].

Additionally, most presented models are not sensitive to stochastic supply delays caused by natural hazards or technical breakdowns. However, the resulting delays of terminals or direct supplies have a considerable impact on economic performance of the supply chain and should be considered in the supply network design (e.g., whether additional terminals are needed for fuel buffer stocks; [18], [20]).

Similar to other supply decision-making models, many of the presented approaches focus on a single parameter and are exposed to produce suboptimal solutions to the sourcing problem [32], because multiple criteria (e.g., supply security, product quality, risk splitting) are usually important in sourcing decisions.

6. Future Research Options

Optimization of supply chains, as well as operational studies on new logging and wood transportation techniques and machines, will still offer a vast research field and contribute to the further development of wood supply chains. Innovative technologies (e.g., torrifaction and pelletization of wood chips) will expand the scope of usable raw materials from agricultural, forestry and industrial residues, and provide new opportunities. Furthermore, in addition to economic sustainability, environmental, social and cultural dimensions of sustainability of wood procurement also have to been taken into consideration and integrated in an adaptive collaborative management [33].

Including sustainability issues will further enrich the complexity of wood supply chain research, and it represents an ongoing daunting challenge for innovative scientists working in this field.

Acknowledgements

The author would like to thank the “South East Europe Transnational Cooperation Programme” an EU program for financially supporting this research within the project “FOROPA - Sustainable Networks for the Energetic Use of Lignocellulosic Biomass in South East Europe”.

References

1. Disney S.M., Towill D.R., 2003. The effect of vendor managed inventory (VMI) dynamics on the Bullwhip Effect in supply chains. International Journal of Production Economics 85: 199–215.
2. D'Amours S., Rönnqvist M., Weintraub A., 2008. Using Operational Research for Supply Chain Planning in the Forest Products Industry. Infor 46:265–281.
3. Heinimö J., Pakarinen V., Ojanen V., Kässi T., 2007. International Bioenergy Trade - Scenario study on international biomass market in 2020. Lappeenranta University of Technology, Department of Industrial Engineering and Management. Research Report 181. 42.
4. Smeets E.M.W., Faaij A.P.C., 2007. Bioenergy potentials from forestry in 2050. An assessment of the drivers that determine the potentials. Climatic Change, 81: 353–390.
5. Goldemberg J., 2000. World energy assessment. UN Development Program, New York, 558.
6. FAO, 2004. Unified Bioenergy Terminology UBET. FAO Forestry Department. Wood Energy Programme.50.
7. Fischer K., 2005. Das Kreuz mit dem Ökostrom [Problems with bioenergy]. Umweltschutz, 5, 18-20. (In German.)
8. Jonas A., 2000. Potenzial-Studie Forst und Grundlagen der Forst- und Holzwirtschaft. Forest potential study and basic data of forest based industries. Nachhaltige Bioenergiestrategie für Österreich, Vol. 1. (In German.)
9. Jonas A., Haneder H., 2001. Energie aus Holz [Wood based energy] 8. Aufl. St Pölten: NÖ LWK. (In German.)
10. Streißelberger J., Jonas A., Kirtz M., Neubauer J., Hlavka M., Haberhauer O., 2003. Potenzialabschätzung Waldhackgut [Estimating the forest fuel potential]. St Pölten: AgrarPlus. (In German)
11. Hogl K., Pregernig M., Weiß G., 2005. What is new about new forest owners? A typology of private forest ownership in Austria. Small-Scale Forest Economics, Management and Policy, 4, 325-342.
12. Bohlin F., Roos A., 2002. Wood fuel supply as a function of forest owner preferences and management styles. Biomass and Bioenergy, 22: 237-249.
13. Wenzelides M., Hagemann H., 2007. Determination of the sustainable mobilizable dendromass potential in North Rhine-Westphalia on the basis of the federal and state forest inventories. Forstarchiv, 78, 73-81.
14. Gronalt M., Rauch P., 2007. Designing a regional forest fuel network. Biomass & Bioenergy, 31(6): 393-402.
15. Gunnarsson H., Rönnquist M., Lundgren J., 2004. Supply chain modelling of forest fuel. European Journal of Operations Research. 158 (1): 101-123.
16. Rauch P., Gronalt M., 2011. Effects of rising energy costs and transportation mode mix on forest fuel procurement costs. Biomass and Bioenergy, 35:690-699.
17. Asikainen A., Ranta T., Laitila J., 2001. Large –Scale Forest Fuel Procurement. In: Pelkonen P., Hakkila P., Karjalainen T. and Schlamadinger B. (eds.): Woody Biomass as an Energy Source. EFI Proceedings 39:73-78.

18. Ranta T., Rinne S., 2006. The profitability of transporting uncomminuted raw materials in Finland. Biomass and Bioenergy, 30: 231-237.
19. Rauch P., Gronalt M., 2010. The terminal location problem in a cooperative forest fuel supply network. International Journal of Forest Engineering 21 (2): 32-40.
20. Rauch P., 2010. Stochastic Simulation of Supply Chain Risks in Forest Fuel Procurement. Scandinavian Journal of Forest Research (25): 574-584.
21. Erikson L., Björheden R., 1989. Optimal storing, transport and processing for a forest-fuel supplier. European Journal of Operations Research. 43, 1, 26-33.
22. Noon C., Daly M., 1996. GIS-based biomass resource assessment with BRAVO. Biomass and Bioenergy, 10, 101-109.
23. Ranta T., 2002. Logging residues from regeneration fellings for biofuel production - A GIS-based availibility and supply cost analysis. Dissertation, Lappeenranta University of Technology, 180.
24. Mahmoudi M., Sowlati T., Sokhansanj S., 2009. Logistics of supplying biomass from a mountain pine beetle-infested forest to a power plant in British Columbia. Scandinavian Journal of Forest Research, 24, 76-86.
25. Carlsson D., Rönnqvist M., 2005. Supply chain management in forestry. Case studies at Södra Cell AB. European Journal of Operational Research, 163, 589-616.
26. Rauch P., Gronalt M., Hirsch P., 2010. Cooperative forest fuel procurement strategy and its saving effects on overall transportation costs. Scandinavian Journal of Forest Research, 25 (3):251-261.
27. Palander T, Vääatäinen J., 2005. Impacts of interenterprise collaboration and backhauling on wood procurement in Finland. Scand J For Res; 20 : 177-183.
28. Rauch P., 2010. Bestimmung des Einsparungspotentials einer kooperativen Holzbiomassebeschaffung für Kraftwärmekopplungsanlagen anhand konkreter Beispielskooperationen. Allg. Forst- und Jagdzeitung 181 (7/8): 156-160.
29. Audy J-F., D'Amours S., Rousseau L-M., 2011. Cost allocation in the establishment of a collaborative transportation agreement—an application in the furniture industry. Journal of the Operational Research Society 62: 960-970.
30. Kangas A.S., Kangas J., 1999. Optimization bias in forest management planning solutions due to errors in forest variables. Silva Fennica 33: 303-315.
31. Galloway G., Katila P., Krug J., 2010. The need for new strategies and approaches. In: Mery G., Katila P., Galloway G., Alfaro R.I., Kanninen M., Lobovikov M., Varjo J. (eds.): Forests and Society - Responding to Global Drivers of Change. IUFRO World Series 25: 489-499.
32. Wu D., Olson D., 2008. Supply chain risk, simulation, and vendor selection. International Journal of Production Economics, 114, 646-655.
33. Galloway G., Katila P., Krug J., 2010. The need for new strategies and approaches. In: Mery G., Katila P., Galloway G., Alfaro R.I., Kanninen M., Lobovikov M., Varjo J. (eds.): Forests and Society - Responding to Global Drivers of Change. IUFRO World Series 25: 489-499.