EFFECT OF RAW WOOD SUPPLY SYSTEM ON THE WOOD PAYING CAPABILITY OF A KRAF PULP MILL USING SCOTS PINE

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ABSTRACT: Integration of energy wood procurement into that of pulpwood is seen as a means for reducing the high procurement costs of small-diameter wood harvested from first thinnings. In the deepest mode of integration, pulp and energy fractions are separated from each other in the debarking drum of the pulp mill. In the present paper, the competitiveness of the conventional supply chain based on cut-to-length harvesting was compared to the supply systems based on the harvesting of loose whole trees and whole-tree bundling in the cases of three Scots pine -dominated first-thinning stands using wood paying capability (WPC) of a kraft pulp mill as a decisive criterion. Furthermore, the competitiveness of first thinnings as raw material sources for a pulp mill was evaluated by using intermediate thinnings as a reference.

Keywords: Wood paying capability, Thinnings, Energy wood

1 INTRODUCTION

The forest industries especially in the Nordic countries and North America are facing great challenges in their business environment. Due to severe global competition and slackening growth in the demand for paper products, integrates are closing their pulp and paper mills. In Finland, likely rising export duties on Russian roundwood are expected to impede raw wood procurement, and the forest industries are increasingly seeking for substitutive domestic roundwood, especially from first thinnings. However, increase in raw wood procurement costs resulting from impairing harvesting conditions may further deteriorate the competitiveness of the forest industry. At the same time with increasing demand for small-diameter pulpwood, the production of forest chips for energy production is predicted to dramatically increase, and the present annual forest chip production of 4.6 million m^3 (solid) [1] is planned to be increased up to 12 million m^3 by 2020 [2].

The integration of energy wood harvesting with that of pulpwood is seen as a means for reducing the procurement cost of small-diameter wood and thereby for stepping up silvicultural thinnings of young stands, which have been widely neglected during the past decades. Cutting costs can be reduced by applying whole-tree harvesting with multi-tree handling, and increase in removal in the form of branches and under-sized tops partly compensates for the high harvesting costs. On the other hand, transportation of loose whole-tree material is costly. Noticeable savings, especially in forwarding, could be achieved if whole trees were compacted into bundles [3]. The bundles of about 0.5 m^3 in solid volume can be produced using the newly-developed bundle harvester, composed of a base machine, an accumulating harvester head, and the Fixteri compaction device (e.g.[4]).

In both of the variations of whole-tree harvesting described above, pulp and energy fractions are not separated before the wood reaches the debarking drum of the pulp mill. Whole-tree material originating from young stands differs from conventional pulpwood in terms of the ratio of pulpwood (stemwood) to energy wood (stem bark, branches and foliage). There are also differences in the physical and chemical properties of pulpwood, such as basic density and fibre dimensions. The study of Jylhä and Keskinen [5] showed that un-delimbed sections of Scots pine (*Pinus sylvestris* L.) harvested from first thinnings can be processed as blends with delimbed small-diameter Scots pine pulpwood without deteriorating pulp quality. Process losses however, may be higher than in the case of conventional pulpwood harvested from young stands. The economic impact of these losses is not known.

In this study, the effects of the supply system of small-diameter Scots pine harvested from first thinnings on the wood paying capability (WPC) of a kraft pulp mill were simulated, and the results were compared to those of conventional Scots pine pulpwood harvested from intermediate thinnings.

2 MATERIAL AND METHODS

The supply systems of small-diameter Scots pine included in the comparisons were based on conventional pulpwood harvesting applying the cut-to-length (CTL) method and two variants of whole-tree harvesting, i.e. standard whole-tree (WT) harvesting and an adapted whole-tree harvesting applying whole-tree bundling (WTB). The calculations were done for three first-thinning stands located in Central Finland (Fig. 1). Furthermore, the WPCs were computed for larger-sized Scots pine pulpwood procured from a typical intermediate thinning (IMT) with a supply system based on cut-to-length (CTL) harvesting.

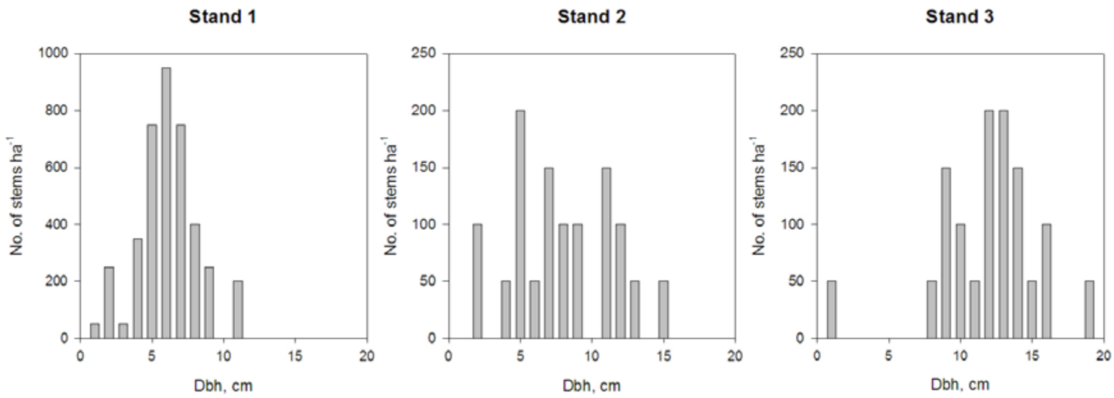

Figure 1. Breast height diameter distribution of the removal in the example stands. Mean breast height diameters of the removals in Stands 1-3 were 6, 8, and 12 cm, respectively.

The wood paying capabilities were calculated as presented by Diesen [6], with the exception of capital costs, i.e. capital allowances, imputed interests and taxes, that were ignored in the calculations. In the cases of the first-thinning stands, the raw material characteristics affecting wood paying capability (Table 1) were derived from the stand data as described by Jylhä et al. [7]. For the intermediate thinning, the pulpwood density reported by Hakkila [8] was used, and the bark proportion was obtained from the study of Saikku and Rikkonen [9]. The essential parameters of pulp mill processes are listed in Table 2, and the procedure applied when computing raw material balance of wood handling is described by Jylhä et al. [7]. The values of the cost variables and the prices of end-products used in the calculations are summarised in Table 3.

Table 1. Physical properties of the raw material processed at the pulp mill by raw material source and supply system.

Parameter	**Supply system**	**Raw material source**			
		IMT	**Stand 1**	**Stand 2**	**Stand 3**
Stemwood density, kg/m^3	CTL	417	418	406	403
	WT & WTB	-	416	404	401
Stem bark density, kg/m^3	CTL, WT & WTB	300	267	267	267
Bark proportion, % of stem volume	CTL	10.8	15.8	15.9	12.4
	WT & WTB	-	16.0	16.1	12.5
Branch proportion, % of intake	CTL	0	0	0	0
	WT & WTB	-	16.3	19.6	9.4
Density of branches, kg/m^3	WT & WTB	-	380	380	380

Table 2. The essential process parameters by raw material source and supply system.

Parameter	**Supply system**	**Raw material source**			
		IMT	**Stand 1**	**Stand 2**	**Stand 3**
Wood loss in debarking, %	CTL	1.3	2.5	2.3	1.9
	WT	-	13.3	6.5	3.5
	WTB	-	13.3	6.4	3.4
Debarking efficiency, %	CTL	95.5	95.1	95.3	93.7
	WT	-	92.9	92.6	89.8
	WTB	-	92.9	92.6	89.9
Dry solids of the debarking residue, %	All	45.0	45.0	45.0	45.0
The total energy from the debarking residue, GJ/ADt*	CTL	2.82	4.12	4.19	3.15
	WT	-	15.36	14.23	7.03
	WTB	-	15.36	14.19	7.00
The total yield of fiber line, %	All****	43.5	43.4	43.4	43.4
The yield of by-products, %	All	3.01	3.01	3.01	3.01
Alkali charge in cooking, %**	All	18.5	18.6	18.6	18.6
The total dry solids of black liquor (BL), t DS/ADt	All	1.73	1.73	1.73	1.73
- inorganics in BL, t DS/ADt	All	0.65	0.65	0.65	0.65
The total energy production from BL, GJ/ADt***	All	14.5	14.5	14.5	14.5
Energy from additional fuel, GJ/ADt	All	0.3	0.3	0.3	0.3
Heat consumption in the mill, GJ/ADt	All	13.38	13.38	13.38	13.38
Electricity consumption in the mill, GJ/ADt	All	2.68	2.69	2.69	2.69

* A bark boiler efficiency of 85%; steam production 70%, electricity production 30%; ADt = Air Dry ton of pulp (solid content 90%)
** The amount of effective alkali 110 kg/m^3, the recovery rate of cooking chemicals 95%.
*** A recovery boiler efficiency of 75%; steam production 80%, electricity production 20%.
**** The same value for all supply systems

Table 3. The basic values of the cost variables and the prices of the end-products used in the calculations with their ranges applied in the sensitivity analyses.

Variable	**Basic value / range**
Pulp mill production, ADt/year	400 000 / 200 000 – 600 000
Pulp price, €/Adt	475 / 350 - 600
The total chemical costs, €/Adt	48.0 / fixed
The other variable costs (excl. wood costs), €/ADt	21.0 / fixed
Fixed costs, €/a	60 000 000
Steam price, €/MWh	10 / 6 - 14
Electricity price, €/MWh	50 / 30 - 70

3 RESULTS

3.1 Effect of pulp mill capacity on wood paying capability

As seen from Table 4, WPC increases with increase in production, but not in a linear manner. The highest WPC with a production of 400 000 – 600 000 ADt/a is attained when using conventional pulpwood harvested from intermediate thinnings. With the lowest production of 200 000 ADt/a, the whole-tree options (WT and WTB) give higher WPCs than conventional pulpwood (CTL) harvested from the first thinning stands. There are only minor differences in the raw material balances of wood handling between the whole-tree options, and the differences in their WPCs at mill are at maximum only 0.03 €/m^3.

Table 4. Effect of pulp production on wood paying capability (WPC) by raw material source and supply system.

Supply system	**Production***	**Raw material source**			
		IMT	**Stand 1**	**Stand 2**	**Stand 3**
	ADt/a	€/m^3			
CTL	200 000	21.88	21.81	21.26	21.01
CTL	400 000	54.19	52.03	50.64	51.51
CTL	600 000	64.96	62.10	60.43	61.67
WT	200 000	-	24.89	24.17	22.39
WT	400 000	-	47.47	46.88	49.64
WT	600 000	-	55.00	54.45	58.72
WTB	200 000	-	24.89	24.16	22.38
WTB	400 000	-	47.47	46.90	49.66
WTB	600 000	-	55.00	54.47	58.75

* Pulp price 475 €/ADt, electricity price 50 €/MWh and steam price 10 €/MWh (see Table 3).

3.2 Effect of pulp price on wood paying capability

WPC increases linearly with an increase in pulp price in the cases of all raw material sources and supply systems (Table 5). In the case of cut-to-length system, conventional pulpwood harvested from intermediate thinnings gives higher WPC than the pulpwood harvested from the first-thinning Stands 1-3 with the cut-to-length system. In the cases of the first thinning stands, cut-to-length system gives higher WPCs than the whole-tree alternatives with pulp price more than 475 €/ADt.

Table 5. Effect of pulp price on the wood paying capability.

Supply system	**Pulp price***	**Raw material source**			
		IMT	**Stand 1**	**Stand 2**	**Stand 3**
	€/ADt	€/m³			
CTL	350	31.94	31.21	30.41	30.50
CTL	475	54.19	52.03	50.64	51.51
CTL	600	76.45	72.84	70.88	72.52
WT	350	-	31.91	31.23	30.86
WT	475	-	47.47	46.88	49.64
WT	600	-	63.03	62.53	68.41
WTB	350	-	31.91	31.23	30.86
WTB	475	-	47.47	46.90	49.66
WTB	600	-	63.03	62.56	68.45

* Production 400 000 ADt/a, electricity price 50 €/MWh and steam price 10 €/MWh (see Table 3).

3.3 Effect of energy price on wood paying capability

The WPCs also increase linearly with increase in electricity and steam prices (Tables 6-7). When comparing the three alternative supply systems in the first-thinning stands, CTL system gives always the highest WPCs, and the WPCs are equal in the cases of the whole-tree systems (WT and WTB).

Table 6. Effect of electricity price on the wood paying capability by raw material source and supply system.

Supply system	**Electricity price***	**Raw material source**			
		IMT	**Stand 1**	**Stand 2**	**Stand 3**
	€/MWh	€/m³			
CTL	30	52.30	49.88	48.54	49.62
CTL	50	54.19	52.03	50.64	51.51
CTL	70	56.09	54.17	52.74	53.40
WT	30	-	43.53	43.15	46.97
WT	50	-	47.47	46.88	49.64
WT	70	-	51.41	50.61	52.31
WTB	30	-	43.53	43.17	46.99
WTB	50	-	47.47	46.90	49.66
WTB	70	-	51.41	50.62	52.32

* Production 400 000 ADt/a, pulp price 475 €/ADt and steam price 10 €/MWh (see Table 3).

Table 7. Effect of steam price on the wood paying capability by raw material source and supply system.

Supply system	**Steam price***	**Raw material source**			
		IMT	**Stand 1**	**Stand 2**	**Stand 3**
	€/MWh	€/m³			
CTL	6	53.45	51.16	49.79	50.76
CTL	10	54.19	52.03	50.64	51.51
CTL	14	54.93	52.89	51.49	52.25
WT	6	-	45.73	45.24	48.51
WT	10	-	47.47	46.88	49.64
WT	14	-	49.21	48.52	50.76
WTB	6	-	45.73	45.26	48.53
WTB	10	-	47.47	46.90	49.66
WTB	14	-	49.21	48.53	50.78

* Production 400 000 ADt/a, pulp price 475 €/ADt and electricity price 50 €/MWh (see Table 3).

3.4 The importance of the examined variables on the wood paying capability

Figure 2 indicates that pulp price (350 - 600 €/Adt) is the most significant parameter affecting the wood paying capability. Pulp production (200 000 - 600 000 ADt/a) has also a very strong effect on WPC, but the relationship is non-linear. Electricity (30 - 70 €/MWh) and steam prices (6 - 14 €/MWh) have only negligible effect on WPC. For practical reasons, the sensitivity analysis is presented only for conventional pulpwood harvested from intermediate thinnings (IMT) with the cut-to-length system. The other supply systems behave in a similar manner in all first-thinning stands included in the comparison.

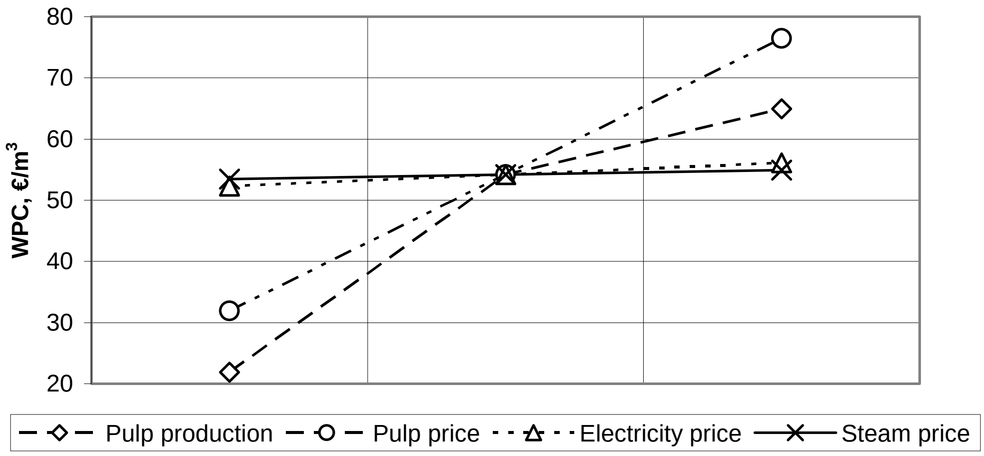

Figure 2. Effect of examined parameters on the wood paying capability at mill in the case of conventional pulpwood harvested from intermediate thinnings by the CTL system. Ranges of the examined variables: pulp production 200 000 – 400 000 ADt/a, pulp price 350 – 600 €/ADt, electricity price 30 – 50 €/MWh, and steam price 6 – 14 €/MWh. In each sensitivity analysis, the other variables were set constant as follows: pulp production 400 000 ADt/a, pulp price 475 €/ADt, electricity price 50 €/MWh, steam price 10 €/MWh .

4 DISCUSSION

The wood paying capability (WPC) is a residual value that a mill can afford to pay for wood after all expenses, including capital costs, have been subtracted from the revenues [10]. Originally the concept of WPC was created for situations in which there was scarcity of wood. Calculating the WPC was a useful complement to profitability. If the scarcity reached a level where existing mills or machines had to be shut down, the WPC was often the decisive criterion used by the companies [6]. The WPC has also been used when selecting the products to be produced and their manufacturing processes. The WPC has been adopted also when estimating the allocation of small-diameter wood between forest and energy industries [10]. Recently the WPC has been applied when comparing the profitability of biorefineries to those of conventional pulp and paper mills [11].

In the present article, the WPC was used when comparing alternative raw material sources and supply systems with each other. Therefore, omitting capital costs in the calculations does not affect reciprocal competitiveness of the supply systems. One should note, however, that the WPCs obtained in this study are higher than in reality. According to Suomi [11], the WPC in softwood pulping in Finland is about 32 €/m^3 at mill. Adding the mean stumpage price of 16.3 €/m^3 of pine pulpwood [12] to the average procurement (including cutting, forwarding, truck transportation and overheads) costs of 24.7 €/m^3 of pulpwood harvested from thinnings in 2008 [13] results an estimate of 41 €/m^3 for an average wood cost of a Finnish pulp mill using domestic softwood. It exceeds the WPC presented by Suomi [11] by 28%. Our calculations, however, show that the WPC is very sensitive to the assumptions used in the calculations. There is a lot of variation in the WPC between mills and production processes, and it does not directly reflect profitability of operation.

The present study shows that increase in production improves the wood paying capability of the pulp mill. This can be explained by the fact that the fixed costs are allocated to a larger amount of end-products. A large and a small pulp mill would have equal WPCs, if the fixed costs were equal per a unit of produced pulp. The larger-sized wood harvested from intermediate thinnings with the CTL-system gave higher wood paying capabilities than the wood originating from first thinnings. With the lowest production level of 200 000 ADt, however, the virtual pulp mill had higher WPC with whole-tree material of the first thinning stands than with the wood harvested from intermediate thinnings with the CTL-system. As expected, pulp price was the most important factor affecting the WPC – the higher pulp price, the higher WPC. The effect of energy price was similar, but the response was remarkably weaker than in the case of pulp price.

The differences in the WPCs at mill between the example stands resulted from the differences in dry-based raw material balances of wood handling. The higher the wood density is, the more pulp can be produced from one cubic meter of wood. Increase in stem bark and branch proportion, and debarking loss of stemwood increased energy generation of the bark boiler. Analogously, the amount of pulp decreased. For this reason the WPCs behaved evenly. In the case of cut-to-length harvesting, the differences between the three first-thinning stands in the WPC can be explained by the variation in wood density. If the examination of the production process would include wood procurement from stump to the mill, the situation would probably be adverse regarding competitiveness of the example stands as raw material sources in terms of the WPC. Due to poor harvesting conditions with low removal and small stem size, the residual value at stump will probably be lowest in the case of Stand 1 with the highest wood density. After subtracting procurement costs from the WPCs at mill, the residual values at stump at least in the cases of Stands 1 and 2 fall likely below zero with current pulp and energy prices (cf. Fig. 3). In the beginning of 1990's, the wood paying capability at stump of a pulp mill using Scots pine was negative when breast height diameter of the wood harvested was less than 12 cm [14].

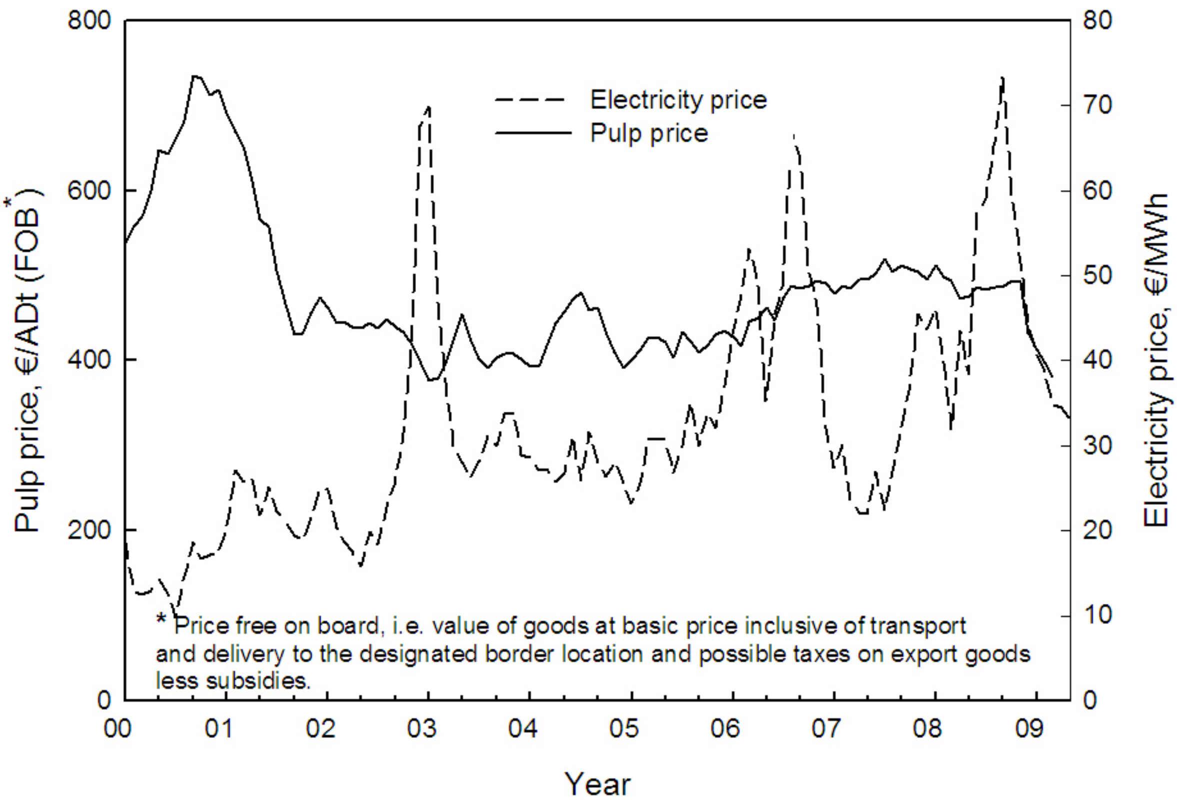

Figure 3. Monthly price development of softwood kraft pulp exported from Finland [15] and monthly Nord Pool electricity prices in 2000 – 2009 [16].

Decline in pulp price improves the competitiveness of whole-tree systems (WT and WTB) in terms of the WPC at mill, even tough their WPCs are slightly lower than in the case of the cut-to-length (CTL) system. However, the WPCs of the whole-tree systems cannot be directly compared with those of the cut-to-length (CTL) systems. Besides raw material composition, there are differences also in the procurement costs and stumpage prices. Weighing the stumpage prices of energy wood and merchantable pulpwood harvested from first thinnings in 2005 – 2008 [17] by their volumetric proportions in the whole-tree removals of the three example stands [7] gives 11 – 49% (1.5 – 6.9 €/m^3) lower stumpage prices than in the case of merchantable pulpwood harvested by the CTL system. The reduction in this hypothetical stumpage price is dependent on the increment of removal in the form of branches, under-sized stems, and top sections of the pulpwood-dimensioned stems. Furthermore, cutting costs could be reduced by about 40% in the example stands when applying whole-tree (WT) harvesting instead of CTL-harvesting. Forest haulage costs could be reduced by whole-tree bundling (WTB) at maximum by 55% when compared to the CTL system and even by 58% when compared to the WT system. However, truck transportation costs of whole-tree bundles would be 7 – 17% higher than in the case of conventional pulpwood harvested by the CTL-system. WTB system would enable savings of more than 40% in truck transportation when compared to the WT system [7].

5 CONCLUSIONS

The results of the present study indicate that the highest WPCs per m^3 of wood at mill can be achieved by using the traditional supply system based on cut-to-length harvesting (CTL) when the production capacity of the pulp mill is more than 400 000 ADt/a. However, whole-tree harvesting enables significant savings in procurement costs when applied in appropriate conditions. In stands with poor harvesting conditions (e.g. Stand 1 of the present study), even with standard whole-tree harvesting can lower wood cost per produced ton of pulp be achieved than in the case of the conventional CTL system. The higher the production and pulp or energy price are, the higher is the WPC at mill in the cases of all examined supply systems, and increase in energy price improves the competitiveness of the whole-tree options.

From the pulp mill's point of view, using whole-tree material harvested close to the mill might be a more profitable raw material than conventional pulpwood with higher WPC, transported from further away. Competitiveness of the WTB system depends on the cost of cutting and compaction, which are not yet known. However, it might be possible to extend the procurement area of whole-tree material by the combination of whole-tree bundling and trail transportation sequence.

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