Co-operation and Integration in Wood Energy Production

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ABSTRACT

The aim of the study was to investigate the effects of co-operation and integration in large-scale wood energy production. The total procurement cost and yield of forest chips (small-sized trees and logging residues) delivered to the consumption plant were calculated for three harvesting strategies. In Alternative 1 individual stands were harvested. In Alternative 2 the harvesting of small-sized trees and logging residues was integrated within forest holdings. Alternative 3 included both co-operation between neighbouring forest holdings and the integration of harvesting. In integrated harvesting, small trees and logging residues were jointly chipped at intermediate storages.

The study material consisted of forest management planning information and forest maps, in digital form, for privately owned areas totaling 15000 ha, of which 3720 ha was forest. GIS data and costs models were used in constructing a production model for a power plant consuming 100000 m^3 of forest chips per year.

Integration raised the harvestable small energy wood yield by 30.5% (Alternative 2) and 31.5% (Alternative 3). The corresponding values for all forest chips were 12.9% and 13.3%. The average cost of forest chips was 3.4% lower in Alternative 2 and 4.9% lower in Alternative 3 than in individual stand harvesting. The cost effects on the total production cost of small tree chips were greater than on the production cost of logging residues. Co-operation and integration broaden the raw-material base for wood energy and make the supply more even.

Keywords: *wood energy, costs, logistics, integration, thinnings, state subsidies, co-operation, Finland.*

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INTRODUCTION

The goal of the Finnish energy and climate strategies is to increase the annual production of forest chips from 1.3 million m^3 (solid) in 2002 to 5 million m^3 by 2010 [23]. The theoretical annual biomass potential of wood not suitable for industrial roundwood in Finland is 50 Mm^3, of which 20-32% is technically harvestable for energy use [8]. Most of the forest chips are produced from the logging residues of final cuttings, and harvesting is integrated with conventional timber procurement [11]. For silvicultural reasons more than 6 Mm^3 of small-sized trees should be removed from first and precommercial thinnings annually. However, there is no demand for this amount of unmerchantable low-quality biomass [9]. High harvesting costs are the main obstacle to the energy use of small trees from young stands.

In Finland, the state supports young stand treatment. It is possible to obtain state subsidies for tending, energy wood harvesting and chipping of the most demanding young stands [1]. State subsidies for tending, precommercial and first thinnings are granted on an areal basis. This subsidy covers 50% of the average calculatory work costs in Southern Finland. The subsidy in precommercial thinning (BHD < 8 cm) is 124.04 US$ and in first thinning (BHD 8-16 cm) 206.37 US$ per hectare [22]. In addition to the subsidy for work costs, support is also paid for reporting the implementation of work. All these subsidies are justified on the basis of silvicultural grounds, and the recovery of energy wood is not a precondition. Up to the area-based support, a subsidy is also paid for harvesting and chipping, when small diameter energy wood is harvested from areas eligible for area-based support.

In order to be eligible for all these subsidies, the area must be more than one hectare in size and the energy wood yield must exceed 20 m^3. The stand must also meet the following silvicultural criteria [22]:

· In precommercial thinning the amount of removed trees per hectare must be over 2000 and in first thinning over 1000.
· In first thinning, the BHD must be less than 16 cm and the dominant height less than 14 metres (conifers) or 15 metres (broadleaved trees) after thinning.
· After implementation there is no immediate need for treatment.

No direct support is granted for the production of fuel chips from logging residues from late thinnings or final fellings [9].

About 54% of the forest land in Finland is privately owned, and the average area of a forest holding is 25 ha [5]. The size of an individual stand, operating unit, is typi-

cally 0.5-1.5 ha. Due to the small average stand size and removal, the possibilities for effective energy wood harvesting in individual thinning stands are often poor. Despite this, the wood procurement infrastructure is well developed. The forest road network is extensive, and most private forest owners have a forest management plan that includes harvesting and silvicultural treatment plans for the next 5- and 10- year period. In forest management plans, the proposals for treatments and estimates of removals are based on stand and tree data, measured in every individual stand. Stand and tree data are linked to digital stand maps.

The aim of the study was to investigate the effects of co-operation and integration in large-scale wood energy production. The total procurement cost and yield of forest chips (small-sized trees and logging residues) delivered to the consumption plant were calculated for three alternative harvesting strategies. In Alternative 1 (later A1) individual stands were harvested separately. In Alternative 2 (A2) the harvesting of small-sized trees and logging residues was integrated within forest holding. Alternative 3 (A3) included both co-operation between neighbouring forest holdings and the integration of harvesting. In integrated harvesting, small trees and logging residues were jointly chipped at intermediate storages.

MATERIAL AND METHODS

Study Area

The study area was located at Orimattila in Southern Finland (60°51'N, 24°40'E). The study material consisted of forest management planning information (stand and map data) and forest road maps, in digital form, for a total of 15000 hectares of privately owned land, of which 3720 hectares was forest (Figure 1). A total of 101 forest holdings with an average forest area of 36.8 hectares were included in the study. The proportion of forest holdings less than 50 hectares was 76 %. Only 2 % of the holdings were more than 100 hectares in size. The average size of the operating unit, i.e. the forest stand, was 1.4 hectares. Forest management planning information for the next 5-year period was used. Industrial roundwood harvesting or precommercial thinning for 1331 stands totalling 2109.9 hectares was proposed for this period (Table 1).

Of the proposed final fellings, 80% were dominated by Norway spruce (*Picea abies*), 18% by Scots pine (*Pinus sylvestris*) and 2% by broadleaved trees, mainly birches (*Betula pubescens*, *Betula pendula*). Of the first thinnings, 63% were dominated by pine, 15% by spruce and 22% by broadleaved trees.

Table 1. The treatments proposed for the next 5-year period.

Treatment	ha^{-1}	stands, n
Final cuttings	436.3	302
Shelterwood removals	380.8	270
Later thinnings	597.5	405
First thinnings	410.7	257
Precommercial thinnings	284.6	97
Total	2109.9	1331

The three different alternatives (A1 - A3) were applied to the map material. In Alternative 3, which included both co-operation and integration, the forest holdings were compartmentalized visually into 20 associating areas on the basis of the map material.
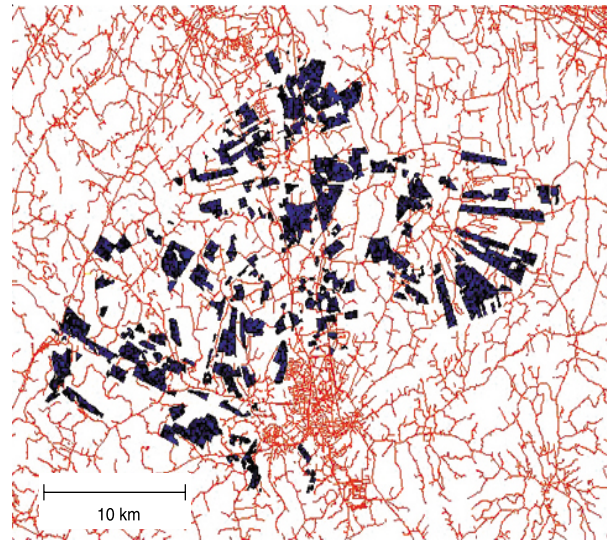

Figure 1. The forest management planning maps and roadmaps of the study area.

Energy Wood Yield

The stands suitable for energy wood harvesting during the next 5-year period were determined on the basis of the forest management plans. The young stands (first and precommercial thinnings) were divided into those eligible and those ineligible for state subsidies. The subsidy criteria [22] (breast height diameter, height of dominant trees and the number of removed trees) were estimated from the forest management planning data. In the case of precommercial thinnings, only stands eligible for subsidies were regarded as harvestable.

The unmerchantable part of the removal in final cuttings and young stands was estimated at the stand level on the basis of the forest management planning data. In final

cuttings, the potential energy wood comprised the crown (without needles and dead branches) and unmerchantable stem parts of merchantable trees [6, 11]. The potential energy wood yield in final cuttings was estimated using the following model:

$$V_R = (V_p 0.168 + V_S 0.32 + V_L 163) + 0.04(V_p + V_S + V_L) \quad [1]$$

where

V_R = Energy wood potential, m^3
V_P = Industrial wood removal of pine, m^3
V_S = Industrial wood removal of spruce, m^3
V_L = Industrial wood removal of broadleaved trees, m^3

In first and precommercial thinnings the potential energy wood yield was estimated using the following logarithmical regression model [31]:

$$\text{In } y = -11.1023 + 0.090127 D_{BA} + 0.936714 \sqrt{H_{BA}} + 3.262682 \log(N) + 0.317485 S \quad [2]$$

where

y	=	Energy wood potential, m^3 (loose)/ha
D_{BA}	=	Breast height diameter, cm
H_{BA}	=	Average height, m
N	=	Number of trees, n, ha^{-1}
S	=	Dummy-variable = 1, if dominant tree is spruce, otherwise 0.

All of the crown biomass is not removed from the stand in any of the energy wood harvesting techniques used in Finland. The proportion of unharvested biomass was removed from the energy wood potential in final cuttings using a coefficient of 0.35, and in young stands a coefficient of 0.20 [7, 10]. The stands not suitable for energy wood harvesting owing to silvicultural or ecological reasons (sites of lower fertility than the Vaccininium site type, spruce dominated first thinnings) were excluded from the data. The stands not suitable for energy wood harvesting owing to their low yield (final cuttings under 35 m^3 and young stands under 20 m^3 per hectare or all stands under 40 m^3 per site) were also excluded from the data.

Transport Distances

Forest haulage distances were calculated from rasterbased (25*25 m) stand and road maps using ArcInfo software. The distance raster, in which the value of each pixel is the distance to the nearest road, was calculated from the road network raster. The average distance of each stand to the nearest road was calculated on the basis of the distance and stand map rasters [27]. The calculated distance was multiplied by the forest haulage coefficient of 1.4 [39].

The road transport distances were estimated for a heating and power plant with an annual consumption of 100000 m^3 of forest chips. The size of the circular delivery area was based on energy wood yields (m^{3}km^{-2}a^{-1}). The average distance to the plant in the middle of the circle was used, and the energy wood yield was assumed to be evenly distributed over the delivery area. The calculatory transport distances were multiplied by 1.3 in order to obtain the actual road transport distances [3].

Costs Calculations

In the first and precommercial thinnings eligible for subsidies the cutting costs were calculated for manual felling and bunching. The costs of manual felling and bunching were calculated according to the agreements on piece wages [20, 21]. Indirect employee costs were added to the cutting piece wages using a coefficient of 1.72 [29, 40]. The average costs for manual worker per man-day including the additional costs, were 97.18 US$. The costs of felling and bunching in precommercial thinning with a typical tree size of 15 dm^3 were 18.01 US$/m^3 for Scots pine, 20.42 US$/m^3 for Norway spruce and 16.02 US$/m^3 for birch. In first thinning with a 25 dm^3 tree size, the costs were 15.93 US$/m^3 for pine, 18.06 US$/m^3 for spruce, and 14.17 US$/m^3 for birch. A currency conversion rate of 1US$ = 1.02 €was used in the costs calculations.

The costs in first thinnings ineligible for subsidies and in final cuttings were calculated for the integrated mechanized felling of energy and industrial wood. The tops of the stems, branches and unmerchantable small-sized trees were piled close to the industrial roundwood. In final cutting this extra piling of energy wood reduces the productivity of a one grip-harvester by 2-4 % [37, 38]. However, large differences have been reported concerning the influence of extra piling between operators, working techniques and stands [4, 25]. An additional cost item of 0.33 US$/m^3 [3] for extra piling in final cutting was used in the costs calculations.

In thinnings the cost of cutting and piling of energy wood in connection of industrial roundwood harvesting was 6.06 US$/m^3 in the year 1995 [28]. The change in thinning productivity and costs between 1995 and 2001 was included with the coefficient of 1.14, [26, 41], and in costs calculations the cost 6.91 US$/m^3 for mechanized energy wood cutting in thinnings was used.

Off-road transport was carried out in all the methods with a medium-sized forwarder. In the forest haulage of energy wood, the productivity per effective hours (E$_0$ hours) [24] with a medium-sized forwarder was calculated as a function of the haulage distance [3]. This productiv-

ity was converted to productivity per operating hours (E_{15} hours) [24] using a coefficient of 0.75 derived from follow-up studies [16]. In the forest haulage of logging residues a load size of 8 m³ and a strip road distance of 15 metres were used in calculating the density of logging residues per 100 metre of strip road. With small sized-trees the corresponding figures in the density calculations were 5 m³ and 20 metres. The operating cost of 49.63 US$/ E_{15} hours was used for the forwarder. With a forest haulage distance of 250 metres, the cost of forwarding per m³ was 5.30 US$ in final cuttings, 6.44 US$ in first thinnings ineligible for subsidies, and 6.53 US$ in first thinnings eligible for subsidies and in precommercial thinnings. The costs of forwarder transfers between sites, 62.86 US$ per site, were added to the forest haulage costs [3].

The costs of comminution were calculated for road side chipping with a truck-based drum chipper. The chipping cost for the logging residues of final cuttings was 4.47 US$/ m³ [3]. The productivity in the chipping of small trees was estimated to be 11 % higher than that for logging residues [17], and a chipping cost of 4.02 US$/ m³ was used in calculations. The costs of chipper transfers, 46.32 US$ per site, were added to the chipping costs [3].

The cost of truck transport was calculated for a 3-axle, semi-trailer truck with a total weight of 48 tonnes and a load capacity of 75 m³. The costs calculations of truck transport were based on time consumption in driving empty, driving loaded, loading and unloading. A loading time of 1.6 h and unloading time of 0.5 h per load and hourly costs of 52.94 US$ for loading and unloading, and 75.27 US$ for driving, were used in the calculations. Time consumption for loaded and for empty driving were calculated using the following driving speed functions [3]:

$$v_k = -0.44591 + 31.695 \log(l) \qquad [3]$$
and
$$v_t = -5.7917 + 30.630 \log(l) \qquad [4]$$

where
v_k = driving speed loaded, km/h
v_t = driving speed empty, km/h
l = driving distance, km

Organizational costs in energy wood harvesting are 0.74-1.02 US$/MWh [3]. In Alternative 1 an organizational cost of 0.85 US$/MWh was used. With integration and co-operation, the size of the harvesting area increases and the organizatory costs can be reduced. Organizatory costs (US$/MWh) in A 2 and A3 were calculated by dividing the total organizatory costs of A1 by the energy wood yields of A2 and A3.

The state subsidies for bunching, off-road transport,

chipping and reporting of implementation were subtracted from the production costs of stands eligible for subsidies [22]. The subsidies are shown in Table 2.

Table 2. The state subsidies for bunching, off-road transport, chipping and reporting of implementation.

Energy tree bunching	3.44 US$/m³
Off-road transport	3.44 US$/m³
Reporting of implementation (harvesting)	4.14 US$/ha⁻¹
Chipping	1.67 US$/ m³ (loose)
Reporting of implementation (chipping)	0.09 US$/m³ (loose)

All costs per volume unit (US$/m³) were converted to costs per energy unit (US$/MWh) by tree species [10]. The cost of fuel at the power plant was calculated for final cuttings, young stands eligible for subsidies, young stands ineligible for subsidies, and for all forest chips in A1-3 as:

$$T = \frac{L + F + C + T + O - S}{Y} \qquad [5]$$

where
T = Total cost of fuel at power plant, US$/MWh
L = Cutting costs, US$
F = Off-road transport costs, including forwarder transfers, US$
C = Chipping costs, including chipper transfers, US$
T = Road transport costs, US$
O = Organizational costs, US$
S = State subsidies, US$
Y = Energy wood yield, MWh

RESULTS

Energy Wood Yield

All the criteria set in the study for harvestable stand (minimum yield, silvicultural and ecological criteria) were fulfilled in a total of 277 stands in Alternative 1. The relative proportions of the harvestable stands of the stands proposed for treatments are presented in Table 3. The number of harvestable stands in Alternative 2 was 328 and 335 in Alternative 3. The number of storages for chipping in A1 was 277, 89 in A2 and 20 in A3.

The harvestable energy wood yield in Alternative 1 was 40.6 m³km⁻²a⁻¹, of which 19.7 % was small trees (Figure 2). The integration of energy tree harvesting within forest holdings (A2) increased the yield by 12.9 %. The gain for logging residues was 8.5 % and for small trees 30.5 %. Joint integration and co-operation between forest hold-

ings increased the yield by 13.3 % compared to Alternative 1. The gain for residues was 8.8 % and for small trees 31.5 %.

Table 3. Relative proportion of harvestable stands.

Treatment	A1	A2	A3
	Proportion of harvestable stands, %		
Final cuttings	59	65	66
First thinnings ineligible for subsidies	12	23	24
First thinnings eligible for subsidies	34	44	45
Precommercial thinnings	37	41	43
All	42	50	51

Table 4. The average energy wood yields per hectare.

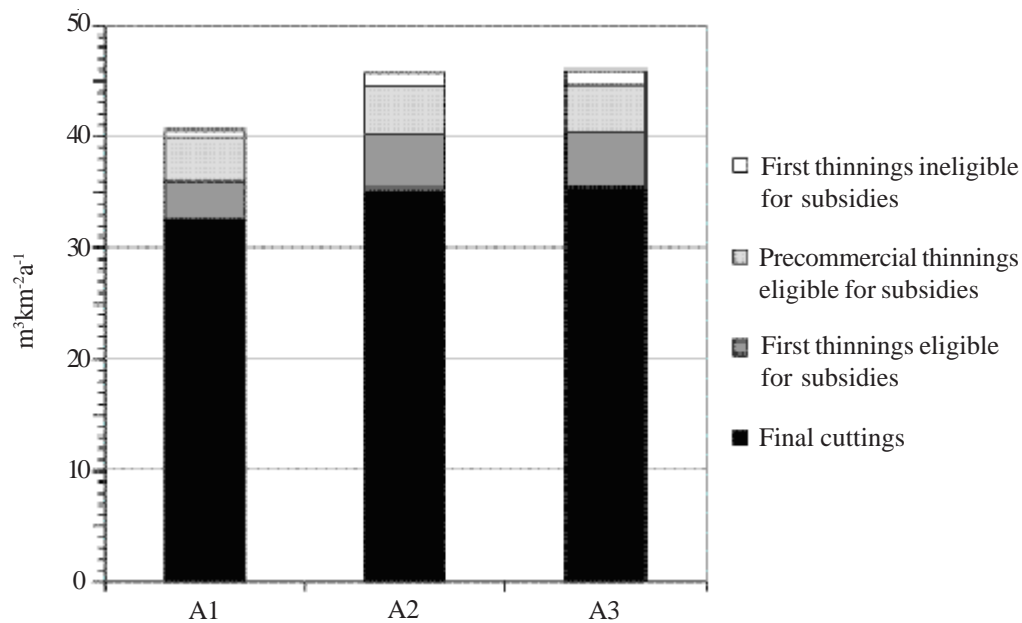| Treatment	A1	A2	A3
	Energy wood yield, m^3/ha^{-1}		
Final cuttings	72.3	70.9	71.1
First thinnings ineligible for subsidies	28.1	26.7	25.7
First thinnings eligible for subsidies	31.0	33.7	33.1
Precommercial thinnings	27.5	26.9	27.4
All	55.8	53.9	53.8

Figure 2. Harvestable energy wood yield in the different alternatives (A1-A3).

The average energy wood yield per jointly transported and chipped harvesting area in A1 was 109.9 m^3, 386.1 m^3 in A2 and 1725.1 m^3 in A3. The average energy wood yield per hectare of all harvestable stands in A1 was 55.8 m^3, 53.9 m^3 in A2, and 53.8 m^3 in A3 (Table 4).

Cost of Fuel at the Power Plant

In Alternative 1 the average cost of fuel at the power plant was 8.82 US$/MWh, which was 3.4 % higher than in Alternative 2 and 4.9 % higher than in Alternative 3 (Table 5). The cost of residues was correspondingly 4.6 % (Alternative 2) and 5.4 % lower (Alternative 3), and the cost of all small tree chips was 3.6-4.6 % lower (Alternative 2) and 7.2-6.1 % lower (Alternative 3) than in Alternative 1.

Table 5. The cost breakdown of fuel at the power plant (US$/MWh).

	Final cuttings			Young stands						Altogether		
				Ineligible for subsidies			Eligible for subsidies					
	A1	A2	A3	A1	A2	A3	A1	A2	A3	A1	A2	A3
	Costs, US$/MWh											
Cutting	0.15	0.15	0.15	3.57	3.57	3.57	7.87	7.82	7.87	1.56	1.74	1.74
Forest haulage	2.77	2,61	2.56	3.87	3.85	3.57	3.48	3.34	3.20	2.91	2.78	2.71
Chipping	2.26	2.15	2.11	2.32	2.30	2.10	2.16	2.05	1.95	2.25	2.13	2.08
Road transport	2.17	2.15	2.15	2.39	2.36	2.36	2.25	2.22	2.22	2.19	2.17	2.16
Organizing	0.85	0.78	0.78	0.85	0.47	0.47	0.85	0.68	0.68	0.85	0.75	0.75
Subsidies	-	-	-	-	-	-	-5.37	-5.38	-5.38	0.94	-1.05	.05
Total cost	8.21	7.85	7.77	13.00	12.54	12.07	11.23	10.74	10.54	8.82	8.52	8.39

State Subsidies

Altogether 59.0 % of the number of first thinning stands met the subsidy criteria, and 33.7 % of them also fulfilled the criteria for a harvestable stand set in the study (minimum yield, silvicultural and ecological criteria). Altogether 80.0 % of the precommercial thinning stands met the subsidy criteria, and 45.8 % of them also fulfilled the criteria set for a harvestable stand.

The subsidies decreased the average cost of all forest chips (logging residues and small-sized trees) 9.6 % in A1, 11.0 % in A2 and 11.1 % in A3. In stands eligible for subsidies the average costs reduction was 32.3 % in A1, 33.4 % in A2 and 33.8 % in A3. In stands eligible for subsidies harvesting support covered 41.2 % of the harvesting costs and support for chipping 91.3 % of the chipping costs.

DISCUSSION

The study area was typical for Southern Finland. The proportion of forest holdings smaller than 50 hectares was 77% in the study area. The corresponding proportion in Southern Finland was 86% in 2000 [5]. Of the proposed harvesting area in the forest management plans, 23 % were first thinnings and 24% final cuttings. In all private forests in Finland the proportion of first thinnings in 2000 was 27 % and that of final cuttings 34% of the total harvesting [5]. Final cuttings were dominated by spruce and first thinnings by pine, which meant that the area was suitable for energy wood harvesting.

Industrial roundwood has a better depreciation value than energy wood [14]. In this study the energy wood included the nonmerchantable removal of cuttings and silvicultural treatments. The estimates for energy wood removals were calculated using energy tree models from forest management plans. Forest management plans for the next 5-year period only were used, even though the plans also include treatment proposals for the 10-year period. However, by defining the material to the next 5-year period, a more precise estimate of the energy wood yield of young stands was achieved due to the rapid growth of young stands.

The density of young stands is not precisely measured in forest management plans [31]. For this reason, energy wood estimates of young stands are not as accurate as those of final cuttings, where the volume of logging residues was estimated on the basis of industrial wood removal by using crown mass coefficients. In Southern Finland the proportion of whole crown mass in pine trees in final cuttings is 21.4 %. The corresponding figure for spruce is 54.2 % and for leafless birch 15.9 % [9].

Current forest management plans do not give the best possible estimates of the energy wood yield of young stands [31]. Operative planning can only be done properly, if the forest management planning is developed in such a way, that the potential stands for wood energy harvesting are identified and located. Stand characteristics should be measured so that the energy wood can be handled in the same way as other timber assortments [19].

In the study the energy wood supply included all those stands, for which treatments were proposed in forest management plans. In 2001 the technically available biomass reserve was estimated to be 10-16 Mm^3 or 22-35 % of the theoretical potential, but the production of forest chips was only 1.3 Mm^3 [8]. There are also large local differences in the supply and demand of energy wood.

GIS data has been used in several studies for estimating the transport distances [2, 27, 30]. The raster-based distance is not the same as the real forest haulage distance but when information about the location of landings is not available, raster-based calculation is the most reliable

way to estimate the forest haulage distances [27]. GIS data was also used in this study for estimating the distances.

The costs calculations were based on earlier results concerning the productivity and costs in forest chip production. However, there is rapid development going on in both production methods and machines. Due to the changes in productivity as well as in the cost level, there may be some ambivalence in cost models. The methods used in the production of forest chips, especially in young stands, are not yet very customary. No stumpage price was included in the calculations; there is no stumpage price for forest chips in Finland [8].

The critical cost point in the production of small-tree chips is cutting, especially debranching. This has led to whole-tree harvesting. Manual cutting and bunching is still cost competitive compared to mechanized felling and bunching in small diameter stands [18]. Thus, both manual and mechanized methods were included in the study.

There is no stumpage price for energy wood in Finland. In final cuttings, logging residue extraction has clear silvicultural benefits in forest regeneration [9]. The importance of subsidies in energy wood harvesting has been reported in several studies [32, 33]. The subsidies can be justified on the basis of young stand management. The criteria for stands eligible for subsidies and the targeting of subsidies play an essential role in the energy wood harvesting of young stands [34, 35, 36]. State subsidies should be developed in such a way that they promote fuel recovery.

Integration of small trees and logging residues within forest holdings increased the harvestable energy wood yield by 12.9 % and decreased the price of forest chips by 3.4 %. The size of harvesting units after the integration of operations within forest holdings was so large, that co-operation between neighbouring holdings neither significantly increased the number of harvestable stands nor the scale advantages in costs. In young stands, the advantages of co-operation in energy wood harvesting were larger than in final cuttings. However, the increase in the relative proportion of small trees in the forest chips yield reduced the cost savings achieved through integration due to the high costs of small-tree chips. The cost effects of integration could be even greater if the effects of machine waiting time would be taken into account. Only the scale effects of machine transfers and organizing costs were studied here. On small sites, a hot production schedule is often a problem, and waiting times for the machinery can be high [12].

The advantages of integration and co-operation in en-

ergy wood harvesting are clear. There is also willingness for co-operation between forest owners. The attitudes of forest owners towards co-operation are being studied in an ongoing project [34]. According to the preliminary results, there is relatively high willingness to co-operate. Some earlier studies have also been carried out on the willingness of forest owners to co-operate [13, 15]. The forest management associations (FMA), to which private forest owners pay compulsory fees, play an important role in co-ordinating the co-operation. The FMA´s role is important in the large-scale procurement of fuel wood from young stands. In order to realize the advantages of integration, the co-operation of timber procurement organisations is also needed

The development of machinery and mechanized harvesting methods is a precondition for costs reduction in small-tree chip production. There are several reasons to increase the use of small-sized trees as a raw material for forest chips. Integrated harvesting broadens the raw-material base for energy, and makes the chip supply more even. Small-tree chips also improve the quality of forest chips. However, the competitiveness of small-tree chips is dependent on the cost effectiveness of the harvesting techniques and on the integration of forest chip production.

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