Combined production of industrial and energy wood in Scots pine stands

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Abstract. Neglecting precommercial thinning can result in a too dense stand with an uneconomic removal structure for industrial wood harvesting. In these stands energy wood thinning directing all thinning removal to energy use can be a reasonable alternative. The annual biomass potential of energy wood thinnings in Finland is 4 million m³, of which 3 million m³ is stem biomass and the rest is crown biomass (incl. e.g. branches). Majority of the energy wood thinning stands are dominated by pine. Harvesting costs of energy wood thinnings are high due to the high number and small size of removed trees. Thus state subsidies play an important role in the economy of harvesting energy wood from young stands.

Possibilities to include energy wood thinning for a systematic part of forest management has been studied in Finnish Forest Research Institute with the help of Motti stand simulator. Results presented in this paper concern pine dominated stands. When energy wood thinning is a systematic part of forest management, precommercial thinning is not neglected, but a denser stand is left growing. Silvicultural recommendations of today advice to leave 2000 remaining trees after precommercial thinning. In energy wood thinning alternatives 3000 or 4000 trees per hectare were left growing after precommercial thinning.

In energy wood alternative thinning from below with whole tree harvesting was carried out at dominant height of 10 or 12 metres and 1300 trees per hectare were left growing. These alternatives were compared with the practice of today aiming only industrial wood production, in which thinning from below and leaving 1000 trees per hectare was carried out at the dominant height of 11–13 metres.

With combined production of energy and industrial wood a remarkable amount of energy wood can be produced without compromising the industrial wood production. The first industrial wood thinning is not necessarily replaced by energy wood thinning, as is mainly the case in stands where tending practices have been neglected. However, in first industrial wood thinning the harvesting conditions, highly influencing the harvesting productivity and costs, are better in the combined production alternative. This new practice gives us possibilities to produce energy wood and promote the energy and climate strategies of the state. Also other advantages like better quality of saw timber and employment possibilities can be reached.

Key words: energy wood thinning, Motti stand simulator, Scots pine, forest management

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Introduction

There are ambitious goals to increase the use of forest chips in the Finnish energy and climate strategies. The reserve of technically harvestable forest biomass excluding industrial round wood is considered to be as much as 15 million m$^3$ a$^{-1}$ (3 Mtoe) (Hakkila, 2004). However, the economies of procurement chains restrict the use and in the year 2005 the total use of forest chips was around three million m$^3$. Of this amount almost 60% was logging residues and 14% stumps from final fellings (Ylitalo, 2006). There is an increasing demand for small-wood chips, which are a preferred fuel for small heating plants. Small-wood chips are also needed to balance the fuel quality of larger plants whose primary source of chips is logging residues from final fellings. Small-wood chip production also has important local socio-economic effects, especially in small-scale operations (Ahonen, 2004).

Early treatments of young stands and first thinnings have not been carried out as much as needed in recent years. However, compared to the 1990's the situation in the young stand treatment is better today partly due to a successful campaign for young forest management 1997–2002. Subsidies (the Kemera funds, financing aid for sustainable forestry) play an important role in management of young stands (Hämäläinen & Korpilahti, 1999; Rämö & Toivonen, 2001; Rämö et al., 2001; Tanttu et al., 2004). Also the procurement of energy wood from young thinning forests is encouraged by state subsidies.

Neglecting early tending can result in a too dense stand with an uneconomic removal structure for industrial wood harvesting. In these stands directing all thinning removal to energy use can be a reasonable alternative. This kind of young stand treatment is called energy wood thinning. Energy wood thinnings of today are concentrated in young stands, where tending has been neglected. The national biomass potential of energy wood thinnings is 4 million m$^3$ a$^{-1}$, of which 3 million m$^3$ is stemwood and the rest is crown mass. Majority of the energy wood thinning stands are dominated by pine (Hakkila, 2004).

In the first thinning the share of stem wood waste is one fourth of the removal (Hakkila, 1991). The minimum diameter for pulpwood has an essential effect on the distribution of wood recovery between industrial and energy wood. On the stand level in the first thinning of pine, an increase of minimum diameter of pulp wood from 7 to 9 cm moves 24% of industrial wood to energy wood. If the minimum diameter of pulpwood is lowered from 7 to 5 cm, industrial wood recovery is increased by 15% (Tanttu et al., 2002). When energy wood is harvested as whole-trees and delimbing is avoided, the recovery is 15–50% higher and harvesting productivity increases 15–30%. With whole-tree harvesting it is thus possible to reduce the cost of harvesting from stumps to road side by 20–40% (Hakkila, 2003). However, whole-tree harvesting can cause nutrient loss, and the increased nutrient loss and other harmful effects of whole-tree harvesting have been of interest especially in forest soil research.

The choice between energy wood thinning and first commercial thinning has not been based on the estimates on the future stand development. When harvesting conditions have been too difficult for profitable industrial wood harvesting, the energy wood harvesting has become an attractive alternative. Heikkilä et al. (unpubl.) studied the management alternatives of 20 energy wood thinning stands mainly dominated by Scots pine. Volume growth over the rotation period, harvesting conditions and costs, silvicultural results and the income of forest owner were compared. The intensity of first thinning and recovery level of logging residues varied between alternatives. In order to attain acceptable harvesting conditions, industrial wood thinning had to be
delayed. The effect of energy wood thinning on subsequent stem wood growth was almost the same as in conventional thinning. Energy wood thinning as whole-trees proved to be profitable alternative if the stumpage price is around 3 €m\(^{-3}\), the interest rate is 3 or 5\% and the removal of pulp wood is less than 20 m\(^3\)ha\(^{-1}\). If the harvestable pulp wood yield is over 20 m\(^3\)ha\(^{-1}\), integrated harvesting of industrial and energy wood or delayed industrial wood harvesting become more profitable.

Neglecting tending leads to harvesting conditions, which are satisfactory neither for energy wood nor industrial thinning, although a lot of effort has been put on studying the procurement chains of energy wood. The increasing forest fuel procurement of power plants can not be based on forests where silvicultural treatments have been neglected. On the other hand, the possibilities of harvesting energy wood in first thinning are poor in stands, where precommercial thinning has been carried out according to recommendations (Hyvän ..., 2006). Thus there is a controversy between targets to increase use of small-sized energy wood and targets to promote good silviculture.

The aim of this paper is to study whether energy wood can be produced together with industrial round wood so that energy wood thinning follows precommercial thinning. In this combined production more stems are left growing after precommercial thinning. Effects of management alternatives on growth and yield and on the economic profitability for the forest owner during the rotation period are estimated with the help of Motti stand simulator. Harvesting conditions as well as productivity and costs of energy wood, industrial round wood and integrated thinning operations are compared. Also possible growth reductions caused by the whole tree harvesting are discussed.

Material and methods

Empirical data

The study material consisted of 15 Scots pine dominated unmanaged juvenile stands in Southern and Central Finland (Table 1). The following criteria were used in choosing the stands:

- Main tree species was Scots pine (regeneration carried out on behalf of Scots pine)
- Stand was located on mineral soil
- No precommercial thinning had been carried out
- First commercial thinning was not imminent
- Total density was over 4000 stems ha\(^{-1}\)

Study stands were either on *Vaccinium*\(^1\) or *Myrtillus*\(^2\) site types (Cajander, 1926) and temperature summation class was either 1150–1300 or 1000–1150 d.d.

Some of the stands were naturally regenerated and some were seeded or planted. All stands consisted of varying mixture of conifers and broadleaved species, because virtually no silvicultural treatments had been carried out after regeneration.

Because the data was from several origins the sample plot sizes and measured tree parameters had some variability. For each stand in the study material the total measured sample plot area was at least 154 m\(^2\) and the total number of measured trees to represent the stand was at least 121. At least following tree parameters were measured from the sample plots: number, species and breast height diameter for all living trees

\(^1\) Moderately dry site type with *Vaccinium vitis-idaea* as characteristic species in field layer
\(^2\) Moderately fresh site type with *Vaccinium myrtillus* as characteristic species in field layer
with height over 1.3 m; tree height, crown height and age for sample trees.

The extra parameters measured for sample trees were computed for all trees with KPL-software package by Finnish Forest Research Institute (Heinonen, 1994). The input data for Motti stand simulator was created from the computed tree data. This data included tree species, number, age, diameter, height, and crown ratio of trees by diameter classes. Site parameters characterizing the stands were site type, dominant tree species, regeneration method and location of the stand.

Simulations
The simulations to estimate growth and yield of the stands according to different management alternatives were made with Motti stand simulator. Motti is a stand-level simulator with distance-independent tree-level models for e.g. growth, mortality and natural regeneration. It is designed to simulate stand development under alternative management regimes and growth conditions in Finland (Hynynen et al., 2002; Salminen et al., 2005). In Motti simulator the user can define different parameters of the simulations. Management schedules, stumpage prices, harvesting costs and discount rates are for example user definable (Hynynen et al., 2002; Hynynen et al., 2005).

To estimate the effect of whole-tree harvesting on stand development Motti was customized to include a model for growth reduction due to nitrogen loss caused by whole-tree harvesting. Growth reduction was estimated with help of nitrogen concentration of different tree parts. Furthermore, the model included percentual growth loss model based on empirical experiments on the effect of whole-tree harvesting (Jacobson et al., 2000).

Five management alternatives for carrying out precommercial thinning and first thinning were compared. For each of the alternatives stand development was simulated until final felling. Alternatives were:

Alternative 1: Industrial wood production according to the current silvicultural recommendations (IWP_1)

Table 1. Stand parameters.

<table>
<thead>
<tr>
<th>Stand</th>
<th>Regeneration method</th>
<th>Age, a</th>
<th>( H_{dom} ), m</th>
<th>( H_{aver} ), m</th>
<th>( N_{pine} )</th>
<th>( N_{broadl.} )</th>
<th>( N_{spruce} )</th>
<th>( N_{tot} )</th>
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</thead>
<tbody>
<tr>
<td>Scots pine stands with broadleaf admixture</td>
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<tr>
<td>Vaccinium type</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>d.d. 1150-1300</td>
<td>1 Planting</td>
<td>14</td>
<td>4.8</td>
<td>3.7</td>
<td>2 339</td>
<td>8 445</td>
<td>0</td>
<td>10 784</td>
</tr>
<tr>
<td></td>
<td>2 Planting</td>
<td>15</td>
<td>4.4</td>
<td>3.8</td>
<td>2 209</td>
<td>12 147</td>
<td>130</td>
<td>14 486</td>
</tr>
<tr>
<td>d.d. 1000-1150</td>
<td>3 Natural</td>
<td>10</td>
<td>4.1</td>
<td>3.2</td>
<td>10 822</td>
<td>2 886</td>
<td>0</td>
<td>13 708</td>
</tr>
<tr>
<td></td>
<td>4 Natural</td>
<td>11</td>
<td>5.4</td>
<td>4.6</td>
<td>8 785</td>
<td>5 947</td>
<td>0</td>
<td>12 732</td>
</tr>
<tr>
<td>Myrillus type</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>d.d. 1150-1300</td>
<td>5 Planting</td>
<td>13</td>
<td>5.2</td>
<td>5.0</td>
<td>2 468</td>
<td>7 925</td>
<td>0</td>
<td>10 393</td>
</tr>
<tr>
<td></td>
<td>6 Planting</td>
<td>12</td>
<td>4.4</td>
<td>3.6</td>
<td>2 988</td>
<td>5 197</td>
<td>0</td>
<td>8 185</td>
</tr>
<tr>
<td>d.d. 1000-1150</td>
<td>7 Natural</td>
<td>12</td>
<td>5.5</td>
<td>4.4</td>
<td>1 443</td>
<td>4 541</td>
<td>340</td>
<td>6 324</td>
</tr>
<tr>
<td></td>
<td>8 Natural</td>
<td>11</td>
<td>5.8</td>
<td>4.7</td>
<td>5 517</td>
<td>7 496</td>
<td>42</td>
<td>10 355</td>
</tr>
</tbody>
</table>

| Scots pine stands |
| Vaccinium type |
| d.d. 1150-1300 | 9 Planting | 12 | 5.4 | 4.8 | 4 329 | 4 839 | 159 | 9 327 |
| | 10 Planting | 12 | 4.0 | 3.3 | 4 552 | 5 284 | 32 | 9 868 |
| d.d. 1000-1150 | 11 Natural | 13 | 5.9 | 4.5 | 5 517 | 7 342 | 85 | 12 944 |
| | 12 Natural | 12 | 5.2 | 5.5 | 8 912 | 2 801 | 255 | 11 968 |
| d.d. 1150-1300 | 13 Direct sowing | 10 | 3.9 | 3.3 | 6 578 | 3 438 | 0 | 10 016 |
| | 14 Direct sowing | 13 | 4.9 | 5.5 | 8 403 | 7 979 | 2801 | 19 183 |
| d.d. 1000-1150 | 15 Natural | 12 | 4.3 | 3.2 | 5 560 | 891 | 0 | 6 451 |

Combined production of industrial and energy wood in Scots pine stands
• Density after precommercial thinning 2000 Scots pine stems ha\(^{-1}\)
• First thinning at dominant height of 11–13 m
• Density after first thinning 1000 stems ha\(^{-1}\)

Alternatives 2–5: Combined energy and industrial wood production using following management alternatives (CP_2–CP_5)
• Density after precommercial thinning 3000 or 4000 stems ha\(^{-1}\)
• Energy wood thinning at dominant height of 10 or 12 m
• Density after energy wood thinning 1300 Scots pine stems ha\(^{-1}\)

  \[
  \begin{align*}
  \text{CP}_2 &= 3000/10 \\
  \text{CP}_3 &= 3000/12 \\
  \text{CP}_4 &= 4000/10 \\
  \text{CP}_5 &= 4000/12
  \end{align*}
  \]

In the conventional industrial wood production (IWP_1) all stands were managed as pure Scots pine stands. In combined production of eight stands 2000 Scots pine stems ha\(^{-1}\) were left after precommercial thinning. Up to these Silver birch (\textit{Betula pendula}) or Downy birch (\textit{Betula pubescens}) stems were left to reach the total density of 3000 or 4000 ha\(^{-1}\). Other seven stands were managed as pure Scots pine stands and no broadleaved tree species was left growing after precommercial thinning. All existing broadleaved tree species were removed in the energy wood thinning so that during the rest of the rotation period only pine trees were growing.

The purpose of splitting the data was to assess the possibilities of growing both pine and birch stems for energy wood. As planting, which is usually used on more fertile sites, is the most expensive regeneration method in Finland it seems uneconomic to harvest planted trees for relatively low-value energy wood. However, if we could harvest for energy naturally regenerated broadleaved tree species which regularly occur in planted Scots pine stands, we can apply energy wood harvesting also on fertile sites such as \textit{Myrtillus} type.

Strip roads were opened in energy wood/first thinning operation. The strip roads covered 20% of the stand area. After the first thinning stands were managed after recommendations (Hyvän…, 2001).

**Economic analysis**

The profitability of different forest management alternatives during the whole rotation period for the forest owner was determined by discounting the income of cuttings to the period of precommercial thinning. In first thinning the profitability of whole-tree harvesting and integrated harvesting of industrial and energy wood in combined production were compared with industrial wood production. The average stumpage prices of the year 2005 (Metinfo, 2005) were used in later thinnings and final cutting. In first thinning the stumpage prices tend to be lower because of the high harvesting costs and reduced prices were used. In first thinnings the sawlog prices were 40 €m\(^{-3}\) for pine, 41 for spruce and 35 for birch and for pine pulpwood 10, spruce pulpwood 17 and birch pulpwood 10 €m\(^{-3}\). The stumpage price of energy wood was 2 or 4 €m\(^{-3}\).

No minimum diameter for energy wood was used and 100% biomass recovery was a default. The minimum sawlog top diameter was 15 cm for pine, 16 cm for spruce and 18 cm for birch. The minimum pulpwood top diameter was 6 cm for pine, 7 cm for spruce and 6 cm for birch.

**Harvesting productivity and costs in first thinnings**

Effects of management alternative on harvesting were studied in first thinnings. Harvesting productivity of mechanized cutting and forest haulage of industrial
wood was calculated by results of Kuitto et al. (1994). For energy wood harvesting productivity functions for whole-tree harvesting with feller-buncher and forwarder were used (Laitila et al., 2004). An operating cost of 70 € per E$_{15}$ hours was used for the medium-sized harvester, 65 € per E$_{15}$ hours for feller-buncher and 50 € per E$_{15}$ hours for the forwarder. Forest haulage distance of 250 metres was used in calculations. Load sizes for industrial round wood depended on timber assortment and varied between 9.3–12.8 m$^3$. For energy wood 7.0 m$^3$ load size was used.

Results

Growth and yield

The removals from different harvests, natural mortality, total yield and rotation time are presented in Table 2. The maturity for final felling was determined by average diameter of stems and the rotation times of stands varied considerably under different management chains.

Combined production did not decrease possibilities to produce industrial wood. E.g. on Myrtillus type industrial wood production of combined production is larger than in conventional management. There are not large differences in mean annual increment of management alternatives. Conventional management led to a few years shorter rotation period than combined management on Myrtillus type. However, on Vaccinium type the rotation period with combined management was shorter than with conventional management, if energy wood thinning was carried out at the dominant height of 10 metres. In combined production the rotation time was more affected by the timing of energy wood harvesting than the number of trees after precommercial

<table>
<thead>
<tr>
<th>Table 2.</th>
<th>Removals from different harvests, natural mortality, total yield (m$^3$ha$^{-1}$) and rotation time of different management chains. (MAI=mean annual increment, m$^3$ha$^{-1}$a$^{-1}$).</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Vaccinium type</strong></td>
<td></td>
</tr>
<tr>
<td>D.D. class</td>
<td>Management alternative</td>
</tr>
<tr>
<td>1150-1300</td>
<td>IWP_1</td>
</tr>
<tr>
<td>n=4</td>
<td>CP_2</td>
</tr>
<tr>
<td></td>
<td>CP_3</td>
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<tr>
<td></td>
<td>CP_4</td>
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<td>CP_5</td>
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<td>1000-1150</td>
<td>IWP_1</td>
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<td>n=4</td>
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<td>CP_3</td>
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<td></td>
<td>CP_4</td>
</tr>
<tr>
<td></td>
<td>CP_5</td>
</tr>
</tbody>
</table>

Combined production of industrial and energy wood in Scots pine stands
thinning. In combined production the rotation period of mixed stands with broad-leaved trees was a little bit longer than in pure Scots pine stands.

Energy wood thinning at the dominant height of 12 metres was carried out mainly at the same time as first industrial wood thinning of conventional management alternative. When carried out at the dominant height of 10 metres, energy wood thinning took place 5–10 years before the time of first thinning of conventional management alternative. On *Vaccinium* type conventional management included one more thinning after first thinning. Combined production included two industrial wood thinnings after energy wood thinning. On *Myrtillus* type conventional management included a total of three thinnings combined production still having two industrial wood thinnings up to energy wood thinning.

Natural mortality varied between management alternatives. Delaying the energy wood thinning increased the natural mortality. The mean annual growth over rotation period varied only slightly between management alternatives. Keeping the growing stock at high level by delaying energy wood thinning increased the annual growth.

**Forest owner’s profitability**

Discounted harvesting incomes of the rotation period are presented in Figure 1. In energy wood thinning all the removal is allocated to energy wood, and stumpage prices of 2 and 4 € m\(^{-3}\) for energy wood are compared. The effects of discount rate and energy wood stumpage prices on relative profitability of combined production (CP_2) with conventional industrial wood production (IWP_1=100%) during rotation are presented in Figure 2.
Combined production was not profitable for the forest owner with the stumpage price of 2 or 4 €m$^{-3}$ for energy wood and discount rate of 0–5%. There were no large differences between profitability of different combined production alternatives. Relative profitability of alternatives is affected by discount rate and stumpage prices. Relatively high first thinning removals of IWT_1 also including sawlogs and the large difference between industrial and energy wood stumpage prices press the profitability of combined production. However, with the energy wood price of 4 €m$^{-3}$ and discount rate of 3% combined production gave only a little bit lower profitability for the forest owner than conventional management. Of the studied combined production alternatives CP_2 gave the best economic result for the forest owner during the rotation period.

Profitability of management alternatives for the forest owner was also calculated separately for the first thinning. In combined production it is possible to use whole-tree harvesting or integrated harvesting of pulpwood and energy wood. In integrated harvesting pulpwood and energy wood are harvested simultaneously, but tops of industrial-sized trees and trees under pulpwood minimum diameter are sorted to separate piles in cutting (Heikkilä & Tanttu, 2004). In whole-tree harvesting all removal is allocated to energy wood.
Figure 3 presents the influence of harvesting method, energy wood price and discount rate on the relative profitability (net income of forest owner discounted to the time of precommercial thinning) of combined production compared with industrial wood production (zero level).

From a forest owner’s point of view integrated harvesting of energy and industrial wood is a profitable alternative with a price of 2 €/m$^3$ and when the operation is carried out with the dominant height of 12 metres. At the dominant height of 10 metres integrated harvesting and combined production are not profitable due to the low amount of industrial wood removal. On Myrtillus type the relative competitiveness of integrated harvesting and combined production is worse than on Vaccinium type. Whole-tree harvesting of energy wood in combined production is not profitable for the forest owner with the presented price and discount rate alternatives.

**Comparison of first thinning harvesting conditions and costs**

Harvesting conditions, especially average stem size (dm$^3$) and removal (m$^3$ha$^{-1}$) as well as harvesting method have large influence on productivity and costs of harvesting. There are several harvesting alternatives in young stands. E.g. energy wood thinning can be carried out with whole-tree harvesting method using feller-buncher or by harvesting delimbed energy wood with multi-tree handling technique. It is also possible to integrate energy wood and industrial round wood harvesting. All these alternatives have different removal structures, productivity and costs as well as effects on nutrient losses.
In the following first thinning harvesting productivity and costs of management alternatives are compared. Removals and average stem sizes in first thinnings are presented in Figure 4. Figure 5 presents productivity and costs of cutting and forwarding in management alternatives. Productivity and costs for alternative IWP_1 are calculated for industrial round wood harvesting. For combined production productivity and costs for whole-tree harvesting are used.

Figure 4. Removals and average stems size (in IWP_1 industrial wood size, in CP size of whole trees) in first thinning/energy wood thinning.

Figure 5. Productivity and costs of mechanized cutting and forwarding in first thinning/energy wood thinning of different management alternatives.
In the study stands precommercial thinning operations were carried out giving reasonable harvesting conditions for first thinnings. In industrial round wood alternative the average stem size was 71 dm³ and removal was on Myrtillus type 65 m³ha⁻¹ and Vaccinium type 56 m³ha⁻¹. In these conditions productivity and costs of round wood harvesting are acceptable. In energy wood thinnings of combined production harvesting costs are lower than in industrial round wood harvesting. The difference comes from cutting, where whole-tree harvesting with feller-buncher gives lower costs than those of one-grip harvester.

When alternatives of combined production are compared, alternative leaving less stems after precommercial thinning gives about 15 dm³ larger stem size in energy wood thinning, if the operation is carried out at the same dominant height. In dominant height of 10 metres the harvesting costs are 2 €m⁻³ higher than in height of 12 metres. Mixed stands with broadleaved trees have a little bit higher harvesting costs than pure Scots pine stands, difference being higher on Vaccinium type.

Discussion

The simulations were made with Motti stand simulator. Reliability of growth predictions of Motti simulator have been studied earlier (Matala et al., 2003; Ahtikoski et al., 2004; Huuskonen & Ahtikoski, 2005). Growth models of the simulator have been adjusted to cover also mixed stands (Hynynen et al., 2002a). Possible systematic errors on growth predictions exist in all of the treatment alternatives allowing reliable comparing of the alternatives. Growth decline model due to nitrogen loss was formulated from rather limited data (Jacobson et al., 2000). However, as additional data of this kind do not exist, the model can be considered as best available. The presented results do not always represent optimal forest management, as after first thinning always same thinning strategies and criteria for final felling were used. Growth losses caused by whole-tree harvesting are estimated solely by nitrogen loss, even many more nutrients having possible effects are taken away.

Combined production did not decrease possibilities to produce industrial wood. If energy wood thinning is carried out at the dominant height of 10 metres, loss in industrial wood production is 18 m³ on Vaccinium type. There were no large differences in mean annual increments or in rotation times between management alternatives.

Mielikäinen (1980) studied development of mixed pine-birch stands. Results showed that heavy birch admixture causes problems for pine. The growth of pine is disturbed especially when the proportion of birch is more than 20% of volume. Downy birch was not as harmful as silver birch in this connection. However, in combined production birch admixture was cut in energy wood thinning.

It could also be possible to carry out energy wood thinning of combined production earlier (e.g. at the dominant height of 8 metres) or later (e.g. at the dominant height of 14 metres). In this earlier alternative the removal would include much less industrial-sized trees, the average size of removed trees being only 30 dm³. Later energy wood thinning would significantly increase removal, which would also include remarkable amounts of industrial wood. If all the removal is allocated to energy wood, the profitability of operation is poor due to the large price differences between energy and industrial wood prices. Growing of dense stand up to the dominant height of 14 metres would also cause a risk for tree damages. In pine dominated stands a basal area increase of 1 m² means 10% larger risk for competition damage. Also large proportion of broadleaved trees increases damage risk in conifer stands (Yli-Kojola, 2005).

Energy wood harvesting with whole-tree method causes growth losses. These
losses are included in the growth and yield results gained by Motti stand simulator and the losses are based on the amount of nitrogen taken out of forest with branches and tops. The increase in nitrogen loss caused by whole-tree harvesting was 57–89 kilos per hectare. Possible nutrient loss also affects the economical result of forest growing but the knowledge concerning effects of whole-tree harvesting is still insufficient (e.g. Nurmi & Kokko, 2001). The influences of nutrient losses of whole-tree harvesting depend on stand development stage, soil type, tree species and amount of nutrient loss (Hynynen & Ahtikoski, 2004). It is also possible to harvest delimbed energy wood. Delimbing reduces nutrient loss, but the recovery of fuel is also reduced and the harvesting costs are higher compared to whole-tree harvesting (Heikkilä et al., 2005).

Results of presented economic analysis are based on given prices. In combined production first industrial wood thinning takes place later than in conventional management, and there is still a large difference between energy wood and pulpwood stumpage prices. These differences in timing and prices weaken the profitability of combined production, especially when the energy wood thinning is carried out at the dominant height of 12 metres.

Of the compared combined production alternatives CP_2 gave the best profitability to forest owner. This alternative gives on Vaccinium type a better profitability for the forest owner with the energy wood stumpage price of 6 €m⁻³ and 3% discount rate. On Myrtillus type 8 €m⁻³ energy wood price is needed for profitability. Integrated harvesting would increase the profitability of combined production. E.g. on Vaccinium type stumpage price of 2 €m⁻³ for energy wood at the discount rate of 2% would be profitable for the forest owner.

However, the economic results of different management alternatives are quite near to each other. State subsidies were not included in economic comparisons. Small-wood chip production of today highly depends on state subsidies, and even so the ability to pay stumpage price for energy wood is low (Tanttu et al., 2004). It is also most probable, that stumpage prices of energy wood will arise with increasing demand. Ability to pay stumpage price for energy wood can be also affected by the emission trading.

Different forest management alternatives give different harvesting conditions. Harvesting conditions have large influence on harvesting productivity, costs, silvicultural harvesting result and even on stumpage price. Harvesting methods (e.g. whole-tree harvesting and round wood harvesting) are affected in a different way by harvesting conditions. In this study precommercial thinning was carried out in all compared alternatives. This gave reasonable harvesting conditions for both energy wood thinning and first industrial wood thinning. In mechanized energy wood thinning the minimum removal of 30 m³ha⁻¹ (Salo, 2004) and the average stem size of 20–30 dm³ are needed for profitable harvesting (Fredriksson, 2004; Salo, 2004). In combined production the lowest average stem size was 39 dm³ and removal over 70 m³ha⁻¹.

In combined production the first industrial wood thinning after energy wood thinning could be carried out in good conditions. The average stem size was 23–43 dm³ larger on Vaccinium type and 52–67 dm³ larger on Myrtillus type than stem size in first thinning of conventional management. In harvesting removals the differences were not as large as in stem sizes. However, these changes in conditions mean differences especially in productivity and costs of cutting.

Today the procurement of small-wood chips is mainly based on the stands with neglected young stand treatment, where energy wood harvesting in whole-trees is a way to decrease costs and increase thinning areas. Young stand treatments as well as
energy wood harvesting are promoted by state subsidies. Tanttu et al. (2004) compared different harvesting alternatives and their profitability for the forest owner in delivery sale. In stands where precommercial thinning has been neglected the harvesting conditions even with whole-tree harvesting are difficult due to the high number of small diameter trees and there is also a high risk for harvesting damage (Äijälä et al., 2004). In those conditions large scale users of energy wood have poor ability to pay any stumpage price for small-sized energy wood if there were no state subsidies The calculatory price of small-tree chips at plant was around 36 € m⁻³ and the subsidized cost around 25 € m⁻³ (Tanttu et al., 2004). Even the subsidized cost of small-tree chips is higher than the average price of all types of forest chips at plant, which in 2004 was 19.0 € m⁻³ and 22.4 € m⁻³ in 2005 (Ylitalo, 2005; Ylitalo, 2006). If we want to increase the use of small-wood chips, the stands with neglected precommercial thinning can not be the basis for fuel procurement of plants.

Denser spacing of young stands in combined production can also have positive effects on timber quality. With denser spacing branch thickness is reduced and stem form is improved (Kärkkäinen & Uusvaara, 1982; Vuokila, 1982). Mäkelä et al. (2000) found, that most favorable combination for reaching high quality and productivity in Scots pine stands is achieved using a slightly less intensive thinning regime than currently recommended in practical forestry. Varmola & Arola (2001) stated, that the recommendations of today (Hyvän..., 2001) compromise with yield and quality. Timber quality, in the butt log in particular, is largely determined by the early growth rate. It is most probable, that in the future the stumpage price of Scots pine logs is more than today affected by the quality. Thus timber quality effects can be seen as one more advantage of combined production alternative

References
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