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# Energy Wood Potential, Supply Systems and Costs in Tihvin and Boksitogorsk Districts of the Leningrad Region

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**Abstract**

Possibilities for energy wood procurement and use in the Leningrad region of Northwest Russia as a tool for reducing greenhouse gas emissions have been analysed in this report. Calculations have been made for selected area, where resources are available and also other preconditions are appropriate for their use for energy production. The study includes estimation of how much wood for energy purposes could be available in the vicinity of the selected area, what are suitable supply systems to consumers and what could be expected costs of energy wood procurement, when taking into account local technical and economical preconditions and constraints.

Former Boksitogorsky, Tihvinsky and Sugozersky leshoses in the Tihvin and Boksitogorsk administrative districts have been selected for analysis. There are possibilities for intensification of forest resources utilisation in the region, as annual allowable cut and intermediate fellings are not fully used. Actual available volume of energy wood generated by fellings in the region is 424,000 $m^3$ $yr^{-1}$. Full utilisation of annual allowable cut would increase volume of available energy wood up to 637,000 $m^3$ $yr^{-1}$ or + 50%. If also intermediate fellings are entirely utilised, available volume of energy wood could be increased up to 774,000 $m^3$ $yr^{-1}$ or + 83% to actual available volume.

Productivity and costs of cut-to-lenth, tree length, full tree and tree section harvesting methods in the 1st and 2nd commercial thinnings and in final fellings with the transport of energy wood up to 100 km were analysed. The supply systems based on manual felling in thinnings have lower costs of energy wood compared to the supply systems which utilise harvesters. Utilisation of harvesters becomes more feasible for final felling, where high productivity allows the cut-to-length method to be more efficient compared to the full tree and tree length methods with manual felling.

Costs of energy wood harvesting per energy unit are competitive with the price of electricity and light oil as primary energy sources. Wood fuels can compete with the price of heavy oil in the case of short transporting distances up to 50 km. However, wood fuels can not be competitive with the recent price of coal and natural gas if other factors, like for example high costs of building pipelines to the remote areas and reduction of greenhouse gas emissions are not taken into account.

**Keywords**

bioenergy, energy wood resources, supply systems, cost of energy wood supply

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# Contents

## List of acronyms

| | |
|---|---|
| CTL | – cut-to-length |
| FT | – full tree |
| LLR | – loose logging residues |
| $m^3$ | – cubic metre |
| NIW | – non-industrial wood |
| o. b. | – over bark |
| RL | – residue logs; compacted loose logging residues |
| TL | – tree- length |
| TS | – tree sections |

# 1 Introduction

The study was conducted as an outcome of the research project "Reduction of Greenhouse Gas Emissions in Russia – Finnish Business Opportunities" financed by Tekes, the Finnish Funding Agency for Technology and Innovation in the framework of its program ClimBus – Business Opportunities in the Mitigation of Climate Change.

The first module of the project has dealt with efficiency in energy production, distribution and use in Northwest Russia and has been conducted by Lappeenranta University of Technologies.

The second module of the project, conducted by the Finnish Forest Research Institute, Joensuu Research Unit, has been focused on possibilities for energy wood procurement and use in Northwest Russia as a tool for reducing net greenhouse gas emissions.

Availability of different energy wood resources, their technical and economical availability and procurement costs in the Leningrad region were estimated in the first task of the second module. Results of that task were published at the end of 2006 in the series Working Papers of the Finnish Forest Research Institute (Gerasimov et al., 2006) and they are available in an electronic format from: http://www.metla.fi/julkaisut/workingpapers/2006/mwp037.htm

The main outcomes of that study on availability of energy wood resources and procurement costs in the Leningrad region were following:

- The Leningrad region of the Russian Federation has abundant resources of energy wood. In 2004, the volume of energy wood from thinnings, final fellings, central processing yards and sawmill yards was estimated to be 4.1 million $m^3$. The deciduous tree species (birch, aspen) are dominant (65% of the total volume). There are large differences in the potentials within the region due to current intensity in forest use. However, this demonstrates theoretical potentials in the Leningrad region only.
- It is possible to intensify the utilisation of forest resources in Northwest Russia and thereby also to increase the use of wood in energy production. The annual supply of energy wood would be 3.5 million $m^3$ based on 2004 fellings and could be increased to 5.3 million $m^3$ or 54% higher, if the allowable cut would be utilised completely and even to 7.2 million $m^3$ or 106% higher, if thinnings could also be conducted at a full scale. There are, however, big differences within the region, as the current rate of utilisation of forest resources vary in the region. It should be noted that higher utilisation of allowable cut and thinnings would require investments in infrastructure, building of new roads and better maintenance of existing roads.
- Nearly 86% of the 4.1 million $m^3$ potential is non-industrial round wood and felling residues in cutting areas (56%) and central processing yards (30%). The rest (14%) are by-products from sawmilling. Currently, non-industrial round wood in central processing yards and residues from sawmills are usually utilised, for instance for house heating by inhabitants, indicating that all the potential would not be additional. Although intensive forest management would also provide more material for energy production, it would also mean that the major part of energy wood would be concentrated in cutting areas. It would limit energy wood resources available near residential areas where central processing yards and sawmills are located and would require development of technology for large-scale production of forest chips.

- Economic and technical availability of energy wood in the region varies over a wide range depending on sources. In current conditions, the pre-commercial thinnings cannot be considered a source of energy wood due to the very high harvesting costs and thus, economic reasons. Energy wood from commercial thinnings, final fellings, central processing yards and saw mills is economically much more attractive.

The outcomes of the first task showed that vast resources of energy wood are available for utilization in the region, accumulated mainly in the cutting areas and at the central processing yards. However, precise calculations should be carried out before any decision is made for the implementation of a project on the utilization of wood residues for energy.

Therefore, the second task of the project has been focused on detail calculations for a specific site, where energy wood resources are available and also other preconditions are appropriate for the implementation of the idea to utilize them for energy production.

This report includes estimation of how much wood for energy purposes could be available in the vicinity of the selected sites, what are suitable systems of its supply to consumers and what could be expected costs of energy wood procurement, when taking into account local technical and economical preconditions and constraints.

Based on the analysis made in the first task, and on consultations with companies involved in the steering group of the project, Tihvin and Boksitogorsk administrative districts, territorially covered by three former leshoses (forestry management unites dissolved by the new Russian forest code (Lesnoi kodeks… 2006)) – Boksitogorsky, Tihvinsky and Sugozersky – have been selected for elaboration of the study. One of the reasons for selection of the region has been the fact that several Finnish companies established their daughter companies there by acquisition of the logging companies, leased forests for harvesting and built up wood processing facilities. Utilization of harvesting residues and by-products from wood processing offers them new business opportunities and economical gains.

## 2 Forest resources and wood harvesting in the region

Leshozes are located in the Northeastern part of the Leningrad region, in Boksitogorsky and Tihvinsky districts. Forestlands cover about 84% of the Tihvin district and 88% of the Boksitogorsky district. Coniferous species – pine and spruce, represents over 50% of the forest area. The other common tree species are birch and aspen (about 30%). The rest is presented by different species of alder and willow. There are also small areas of young forest plantations of larch and Siberian pine.

There are several big logging companies, each with annual actual cut over 200,000 $m^3$, as well as several smaller companies operating in the districts. Recently fourteen companies have leased forests for harvesting in the territory covered by the study. A map in Figure 1 presents the forest areas leased by different companies.

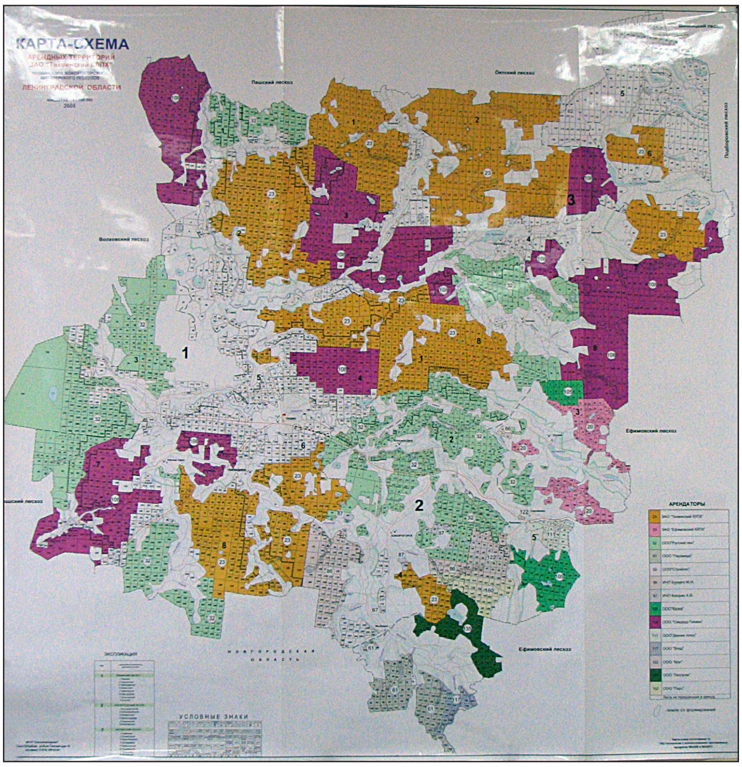


Figure 1. Forest areas leased by different companies in the case study region.
Photo: Ján Ilavský

The region has fairly developed woodworking industry. Swedwood Tihvin is the biggest sawmill with 500,000 $m^3$ of roundwood use.

Main logging methods applied in the region are cut-to-length and tree-length methods. The biggest logging companies use both methods, but share of cut-to-length method is higher as some of the companies use only that method. The tree-length method is more common for small logging companies due to lower investment requirements of machines for this method.

The tree-length method includes several technological stages (Figure 2). It requires lot of manual work. Felling and delimbing are carried out mainly by lumberjacks with chain saws. After felling, single trees are delimbed at stand or skidded bundles of trees are delimbed at skidding roads. The most widely applied skidder is Russian caterpillar tractor TDT-55 and its modifications. Tree-lengths after delimbing and topping are skidded to the roadside for loading on tree-length trucks. Hydraulic manipulators mounted on the trucks or front-end loaders are used for loading the truck. Then, the tree-lengths are transported to the end-user or to the central processing yard. Tree-lengths are cross-cut there either manually or by bucking lines.

Photo Pavel Chikulaev

Photo Ján Ilavský

Photo Vasiliy Katarov

Photo Aleksandr Seliverstov

Figure 2. Felling with a chain-saw, skidding, loading and transportation in traditional tree-length method

The cut-to-length method in Russia can include also a lot of manual work, when lumberjacks carry out felling, delimbing and bucking (Figure 3). However, some companies in the region use fully mechanised cut-to-length method. In this case, felling, delimbing, cross-cutting and piling are done by harvesters. Different assortments can be sorted and piled along strip roads for forwarding. A forwarder picks up the piles of assortments and transports them to the roadside. Assortments are then loaded on log trucks by their manipulators or by front-end loaders and transported to end-users.

There is also a combination of these two methods, when wood is skidded to the roadside in the form of tree-lengths. At the roadside the tree-length stems are bucked manually or by processors. Different alternatives of those basic technological schemes are analysed in the Chapter 3 and costs of energy wood supply are calculated for them in the Chapter 4.

Energy wood has been currently used in the considered area mainly for heating of family houses, where traditional fire wood has been common fuel. There are few municipal boiler-houses using wood as fuel. Also, some big logging and wood processing companies have own boilers utilising their wood residues as fuel to produce heat energy for their own consumption.

The Leningrad region adopted a conception of the energy development in 2003 (Koncepciya razvitiya…2003). According to the conception, it is expected that the share of biofuels in energy balance of the region will increase from 3% in 2002 to 14 % by 2015. The conception considers wood fuels as one of the main sources of bioenergy. Consumption of energy wood in the region and also in the case study area will grow. It is therefore important to estimate volume of wood available for energy use in the region and to find the most feasible ways for its supply to consumers.


Figure 3. Manual (left hand side) and fully mechanised (right hand side) cut-to-length method and transportation.

# 3 Materials and methods

## 3.1 Energy wood harvesting methods and supply systems

Energy wood harvesting methods were analysed based on technologies used by companies operating in the study area. Also new technological schemes, which are suitable for the conditions in the region, were analysed.

Output of energy wood from cutting areas varies depending on the type of fellings (thinnings, final fellings) and logging methods used. In comparison with the cut-to-length and tree length methods, full tree (FT) and tree sections (TS) methods allow bigger output of energy wood from cuttings without additional inputs into collection of loose logging residues (LLR). When the tree section method is used, industrial stem wood is delimbed and rest of the tree is chipped in the stand or transported to the roadside in the form of tree sections. However, productivity of forwarding of full trees and tree sections is 10 – 20% lower in comparison to delimbed roundwood (Heikkilä et al., 2005).

It was found out in the Nordic countries that the full tree method for the pre-commercial thinning and the tree section method for the 1$^{st}$ commercial thinning are economically feasible for energy wood supply (Parikka 2005). The full tree method can be applied also for final fellings (Suhanov and Idashin 2006) with some limitations depending on specific conditions at the final felling area. Full tree and tree section methods are considered in this study for a comparison with tree length and cut-to-length logging methods. As energy wood supply from pre-commercial thinnings is not cost-effective in the Leningrad region (Gerasimov et al., 2006), the pre-commercial thinnings were excluded from the calculation of available energy wood resources and costs of their harvesting. The supply systems based on manual cutting and the cut-to-length method were not considered for final fellings. Share of these supply systems in the total volume of wood felled by the companies was low, less than 17%. The selected logging methods and the energy wood supply systems analysed in the study are presented in Table 1.

Table 1. Logging methods and supply systems analysed in the study.

| Type of fellings | Logging method | Energy wood supply systems |
|---|---|---|
| 1$^{st}$ commercial thinnings | TS | Chain-saw, forwarder, chipper, chip truck |
| | TS | Chain-saw, skidder, chipper, chip truck |
| | TS | Harvester, forwarder, chipper, chip truck |
| | CTL | Chain-saw, forwarder, log truck, end facility chipping |
| | CTL | Harvester, forwarder, log truck, end facility chipping |
| | TL | Chain-saw, skidder, tree-length truck, end facility chipping |
| 2nd commercial thinnings | CTL | Chain-saw, forwarder, chipper, chip truck |
| | CTL | Harvester, forwarder, chipper, chip truck |
| | CTL | Chain-saw, forwarder, log truck, end facility chipping |
| | CTL | Harvester, forwarder, log truck, end facility chipping |
| | TL | Chain-saw, skidder, chipper, chip truck |
| | TL | Chain-saw, skidder, tree-length truck, end facility chipping |
| Final fellings | CTL | Harvester, forwarder, chipper, chip truck |
| | CTL | Harvester, forwarder, log truck, end facility chipping |
| | FT | Chain-saw, skidder, chipper, chip truck |
| | TL | Chain-saw, skidder, tree-length truck, end facility chipping |
| | CTL+RL | Harvester, bundler, forwarder, chipper, chip truck |
| | CTL+RL | Harvester, bundler, forwarder, log truck, end facility chipping |

## 3.2 Estimation of forest energy wood resources

Estimation of available energy wood volumes requires information about:

- tree species composition,
- age structure
- growing stock
- actual volume of fellings
- allowable volume of fellings

The companies provided the data for leased forests. Three estimations of available energy wood volumes were done. The first estimation (scenario *Actual*) is based on actual volume of fellings, the second estimation (scenario *Available*) shows volume of energy wood when the entire annual allowable cut will be utilised. The third estimation (scenario *Potential*) takes into account full utilisation of the annual allowable cut and intensification of thinnings up to the level by which they used to be done in Finland. Volume of energy wood available in the district according to both scenarios was estimated on the basis of the data provided by the leshozes located in the area. In this study volume of energy wood is shown as solid $m^3$.

Volume of energy wood was estimated by the following equation:

$$EW_i = EWT_i + EWC_i + EWO_i, \quad (1)$$

*where:*
i – Scenario
$EW_i$ – volume of energy wood, $m^3\ yr^{-1}$
$EWT_i$ - volume of energy wood from thinnings, $m^3\ yr^{-1}$
$EWC_i$ - volume of energy wood from final fellings, $m^3\ yr^{-1}$
$EWO_i$ - volume of energy wood from other fellings, $m^3\ yr^{-1}$

Volume of energy wood from thinnings is:

$$EWT_i = EW_{fi} + EW_{si}, \quad (2)$$

*where:*
$EW_{fi}$ – volume of energy wood from the 1st commercial thinning, $m^3\ yr^{-1}$
$EW_{si}$ – volume of energy wood from the 2nd commercial thinning, $m^3\ yr^{-1}$

According to the selected supply systems (Table 1), energy wood from the 1st commercial thinning can include the whole above ground tree biomass, i.e. stem wood and crown wood, a part of a tree with crown or, if the cut-to-length method is used, only stem wood:

$$EW_{fi} = ESW_{fi} + ECW_{fi}, \quad (3)$$

*where:*
$ESW_{fi}$ – volume of energy stem wood, $m^3\ yr^{-1}$
$ECW_{fi}$ – volume of energy crown wood, $m^3\ yr^{-1}$

In order to minimize risk of damaging trees remaining after harvesting in the stand, only tree length and cut-to-length methods are considered for the 2nd commercial thinnings. Thereby, energy wood in this case is harvested and forwarded or skidded only in the form of stem wood. Output of energy stem wood from the 1st or the 2nd commercial thinnings is:

$ESW_{ni}=TV_{ni}*(1-IW_n)$, (4)

*where:*
$n$ – the 1st or the 2nd commercial thinnings
$ESW_{ni}$ – output of energy stem wood from commercial thinning $n$, $m^3$ $yr^{-1}$
$TV_{ni}$ – total volume of stem wood from commercial thinning $n$, $m^3$ $yr^{-1}$
$IW_n$ – rate of industrial wood for commercial thinning $n$; value 0.5

Volume of crown energy wood for the 1st commercial thinning is:

$ECW_{fi}= TV_{fi}*CR_f$, (5)

*where:*
$CR_f$ – mean crown to stem wood ratio for the 1st commercial thinning; value 0.25

According to the norms of fellings (Pravila rubok glavnogo pol'zovaniya… 1993 and Nastavlenie po rubkam uhoda… 1993), all loose logging residues at cutting areas have to be collected and piled. Therefore companies use most of loose logging residues for strip roads improvement. However, depending on bearing ability of forest soil, it can be possible to use only part of loose logging residues for strip roads improvement and the rest could be used as energy wood. Taking into account that fellings are partly done in winter time, it was assumed that about 60% of annually available loose logging residues from final fellings can be utilised for energy chips production. Logging companies in the region often use about 30 – 40% of felled aspen stem wood for road construction. Almost all felled aspen stems are non-industrial wood and its utilisation for road construction decreases total volume of energy wood available from final felling. Energy wood from the final fellings includes stem wood, collectable loose logging residues, and, if the full tree method is used, crown wood biomass also:

$EWC_i=TVC_i*(1-IWC)-TVC_i*SA*WRC+EWFT_i+CLLR_i$, (6)

*where:*
$TVC_i$ – volume of the final felling done by the CTL or TL methods, $m^3$ $yr^{-1}$
IWC – rate of industrial wood for the final fellings; value 0.78
SA – share of aspen in felled volume; value 0 - 1
WRC – share of aspen stem wood used for road construction; value 0.3-0.4
$EWFT_i$ – volume of energy wood from the final fellings done by the FT method, $m^3$ $yr^{-1}$
$CLLR_i$ – collectable volume of LLR, $m^3$ $yr^{-1}$
$_i$–scenario

Volume of energy wood supply from the final felling done by the full tree method can be estimated by the following equation:

$$EWFT_i=VFT_i*(1-IWC)+VFT_i*\ ACR_{100}, \tag{7}$$
*where:*
$VFT_i$ – volume of the final felling done by the FT method, $m^3\ yr^{-1}$
$ACR_{100}$ – average crown to stem wood ratio for final felling; value 0.14

Volume of collectable loose logging residues is:

$$CLLR_i=TVC_i*\ ACR_{100}*0.6, \tag{8}$$

The following equation was used to estimate mean crown to stem wood ratio for thinnings and final fellings. Average species composition of felled wood volume, age of stand and crown to stem wood ratios reported by Usol'tsev (2001) for tree species were taken into account:

$$ACR_a = \sum_{s=1}^{n} (CR_{sa} * S_s), \tag{9}$$
*where:*
*a* – age of felling
*s* – tree species
$ACR_a$ – average crown to stem wood ratio
$CR_{sa}$ – crown to stem wood ratio for tree species *s* at age *a*, %
$S_s$ – share of tree species *s* in species composition of felled wood volume; value 0-1

Volume of energy wood from other fellings is:

$$EWO_i=VWO_i*(1-IWO), \tag{10}$$
*where:*
i – Scenario
$VWO_i$ – volume of other fellings, $m^3\ yr^{-1}$
IWO - rate of industrial wood for other fellings, value 0.5

Table 2 provides values of industrial to stem wood ratio and crow to stem wood ratio used in the equations (1) – (9) for calculation of energy wood volume for commercial thinnings and final fellings. Only one leshoz provided data concerning industrial to stem wood ratio for intermediate fellings in 2006.

As it can be seen from the Table 2, the leshoz and companies provided different data concerning output of industrial wood from final fellings. The value provided by the companies was used for estimation of energy wood volumes available from the forests leased. The companies do not perform thinnings and have no practical data on assortments structure of middle age and maturing stands. Data provided by the leshoz related to output of industrial wood from intermediate fellings seems to be too high. The reason probably is that the leshozes perform such intermediate fellings mainly as selective cuttings, because the reported average diameter of harvested trees was 20 cm.

Table 2 Values of industrial to stem wood ratio and crown to stem wood ratio.

| Felling | Industrial to stem wood ratio | | | Crown to stem wood ratio |
|---|---|---|---|---|
| | leshozes | companies | used for the calculations | |
| 1st commercial thinning | - | - | 0.50* | 0.25 |
| 2nd commercial thinning | - | - | 0.50* | 0.22 |
| Intermediate fellings | 0.70 | - | - | - |
| Final felling | 0.78 | 0.67 | 0.67 | 0.14 |

*- Anan'ev (2006)

## 3.3 Productivity of energy wood supply systems

Costs of energy wood procurement depend on many factors such as supply system applied, productivity of the machinery, volumes and spatial distribution of energy wood, average distance of transportation and others. Average stem volume is the main factor, which determines productivity of logging operations.

The companies provided data on productivity as volume of wood processed per 8 hours machine shift. Data on time distribution for different operations during shifts was not available. Therefore, productivity for cost calculations is shown as volume of wood processed per an hour of total working time if nothing else mentioned.

The productivity of manual felling, cutting by harvesters, forwarding and skidding for final felling was obtained from the companies. Different data concerning productivity of harvesters was provided, because some of the companies have own harvester operators and some have contractors with operators from Finland. Generally, Russian operators have lower productivity due to less experience. It is expected that the productivity of the Russian operators will grow in the future.

The reported values of productivity show the upper limit of productivity for thinnings. The companies do not perform thinnings and could not provide any data on productivity of cutting and forwarding or skidding for these fellings. Productivity of harvesting and forwarding was calculated by a cost calculator (Laitila 2005) taking into account average stem volume and the productivity difference between forwarding after a harvester and after a lumberjack (Laitila et al. 2007). However, this calculation was done according to Finnish methodology and it is based on Finnish studies of productivity of logging operations. It has to be mentioned that in conditions of the companies working in the region, productivity of logging operations will be lower than the calculated one due to poorer skills of the machines operators, less dense road network, its lower quality and other factors. For this reason, a reduction coefficient was used to estimate presumptive productivity of harvesting and forwarding for thinnings, which can be reached by the companies. The coefficient reflects a difference between average productivity of harvesting and forwarding in Finland and the productivity reported by the companies. The coefficient was calculated as:

K=PC/PF, (11)
*where:*
K – reduction coefficient of productivity, value 0-1
PC – the productivity reported by the companies for final fellings, $m^3$ $h^{-1}$
PF – average productivity in Finland for final fellings, $m^3$ $h^{-1}$

The reduction coefficient gives possibility to estimate presumptive productivity of thinnings for the companies using the calculated productivity for thinnings in Finnish conditions:

TP=CP*K, (12)
*where:*
TP – productivity of thinnings for the companies, $m^3$ $h^{-1}$
CP – calculated productivity for thinnings in Finnish conditions (Laitila 2006), $m^3$ $h^{-1}$

Significant volume of loose logging residues is generated during final felling. Low bulk density of loose logging residues makes expensive their utilization for production of wood chips. Bundling method was designed to reduce costs of forwarding and transportation of loose logging residues. A bundler forms so called residue logs from loose logging residues (Figure 4).

A residue log contains about 0.7 solid $m^3$ and can be easily handled by machines designed for the cut-to-length method (Figure 5). Productivity of bundling at unprepared final felling areas is about 17 $m^3$ $h^{-1}$ (Slash bundler JD 1490D). The reduction coefficient calculated for harvester can be also used to estimate bundler's productivity in Russia, because work stages of these machines are relatively similar. Forwarding productivity of logging residue logs in Finnish conditions varies from 20 $m^3$ $h^{-1}$ up to 30 $m^3$ $h^{-1}$ (Kärhä et al. 2005).

There are several types of machines disigned for chipping of wood, depending on material to be chipped, its ammount, place of chipping and other factors. Mobile chippers are used for production of wood chips at stands and at roadside (upper landings) (Figure 6). Stationar crushers usually are more powerfull and have higher production abilities compared to mobile ones. Stationnary crushers are used at terminals and powerplants, where uncomminuted wood is transported from logging areas. Stationary crushers are more expencive but less sensetive to different impurities like stones and metals, therefore they can be used for crushing of stumps.

Figure 4. Bundling of spruce loose logging residues by a slash bundler. Photo Ján Ilavský

Figure 5. Forwarding residue logs by a conventional forwarder. Photo Ján Ilavský

Productivity of a chipper was provided by the manufacturer and for the chosen model it is up to 56.7 solid $m^3$ of wood chips for effective hour (Drum chipper… 2007). Productivity of chipping can vary depending on conditions. For the cost calculations the chippers' productivity was as much as 29 solid $m^3$ of wood chips per effective working hour. Cost of wood chipping strongly depends on utilisation degree of the chipper used. Mobile chippers utilization degree varies from 50 to 80% of the total working time (Asikainen and Pulkkinen 1998). For the Tihvin and Boksitogorsk districts 60% utilization rate was used, taking into account longer average distance between cutting areas and lower quality of forest roads

Figure 6. A chipper powered by a farm tractor. Photo Lauri Sikanen

Wood chips can be transported with conventional trucks. However, transportation of wood chips by trucks with small load capacity is expensive due to low bulk density of wood chips. Specially designed chip trucks with enlarged body and an additional trailer are used to transport wood chips with acceptable costs (Figure 7). One truck with a trailer can transport about 46 – 50 solid $m^3$ of wood chips at once.

Table 3 provides productivity reported by the companies for final fellings, mean productivity of harvesting and forwarding in Finland (Nurminen et al. 2006) and the calculated reduction coefficient.

Table 4 provides calculated productivity of felling operations, forwarding and skidding for the 1st and 2nd commercial thinnings taking into account average stem volume and the reduction coefficient. Productivity of manual felling, delimbing and skidding for thinnings was obtained from Mejotraslevie normi virabotki…(1995). These norms give felling productivity for a range of stem volumes. For example, felling productivity is 0.8 $m^3$ $h^{-1}$ for the stem volume range from 0.06 to 0.12 $m^3$ and 1.4 $m^3$ $h^{-1}$ for the stem volume range 0.13 – 0.22 $m^3$. Using the same productivity for quite a wide range of stem volumes decreases the accuracy of the cost calculations.

Figure 7. Chips truck of 130 $m^3$ load space. Photo Ján Ilavský

Table 5 provides calculated productivity of felling operations, forwarding and skidding for the final felling taking into account average stem volume and the reduction coefficient.

Table 3. Productivity of harvesting and forwarding in final felling, $m^3 h^{-1}$ and the reduction coefficient.
Table 4. Average volumes of tree stems (Groshev et al. 1980) and productivity of operations in thinnings.
Table 5. Average volumes of tree stems (Groshev et al. 1980) and productivity of operations in final felling.

Table 3.

| Felling | Average stem volume | Volume, $m^3 ha^{-1}$ | Productivity* | | Productivity** | | Reduction coefficient | |
|---|---|---|---|---|---|---|---|---|
| | | | harvester | forwarder | harvester | forwarder | harvesting | forwarding |
| Final felling | 0.45 | 272 | 13 | 10 | 20 | 13.3 | 0.7 | 0.8 |

* - average data from the companies
** - Nurminen et al. (2006)

Table 4.

| Thinning | Average for trees felled | | | Productivity, $m^3 h^{-1}$ | | | | |
|---|---|---|---|---|---|---|---|---|
| | height, m | diameter, cm | stem volume, $m^3$ o. b. | harvester* | chain-saw** | forwarding after* | | skidding** |
| | | | | | | harvester | lumberjack | |
| 1st commercial | 14 | 12 | 0.08 | 5.0 | 0.8 | 9.0 | 7.8 | 1.6 |
| 2nd commercial | 17 | 16 | 0.16 | 9.0 | 1.4 | 9.0 | 7.8 | 2.0 |

* - calculated, using data of Laitila (2006) and the reduction coefficient
** - Mejotraslevie normi virabotki … (1994)

Table 5.

| Felling | Average | | | Productivity, $m^3 h^{-1}$ | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | height, m | diameter, cm | stem volume, $m^3$ o. b. | harvester* | felling, delimbing, skidding* | bundler** | forwarder | | |
| | | | | | | | stem wood* | LLR** | residue logs** |
| Final felling | 21 | 23 | 0.45 | 13 | 4 | 9 | 10 | 5 | 14 |

* - average data from the companies
** - calculated using data of Laitila (2006), Kärhä et al. (2004), JD 1490D Slush bundler (2007) and the reduction coefficient

## 3.4 Cost calculations

The companies use cut-to-length method with fully mechanized felling and tree-length method with manual felling. Costs of energy wood supply were calculated for both methods to make a cost comparison of the logging methods. Costs of energy wood supply were estimated for the 1st and 2nd commercial thinnings and final felling. As it was mentioned earlier, the pre-commercial thinning is not considered due to obviously highest costs of energy wood procurement (Gerasimov et al. 2006).

Total cost of wood chips supply was calculated as a sum of cost of wood resource (stumpage for thinning and forest rent for final fellings), costs of production of 1 $m^3$ of energy wood at each production stage and additional expenses such as: inputs to road construction, silvicultural works, marketing, administration and etc. The total cost was calculated by:

$$TC_y = CWR_y + \sum_{y,p=1}^{n} C_{yi} + \sum_{y,k=1}^{n} AE_{yk}, \quad (13)$$

*where:*

*y* – type of felling
*p* – production stage
*k* – kind of additional expense
$TC_y$ – the total cost of wood chips, € $m^{-3}$
$CWR_y$ – cost of wood resource, € $m^{-3}$
$C_{yi}$ – cost of energy wood at production stage *i*, € $m^{-3}$
$AE_{yk}$ – value of additional expenses *k* for felling *y*, € $m^{-3}$

The total cost of wood chips supply from final felling and commercial thinnings includes different payments for wood resources. In case of final felling it is forest rent. According to the Russian forest code (Lesnoi kodeks… 2006), a logging company does not pay forest rent for wood from thinnings if the company uses own funds to perform thinnings. However, in this case, the company is obliged to pay stumpage stipulated by the state authority for the region. Values of the minimal stumpage depend on tree species, merchantability of wood and transportation distance (O minimal'nih stavkah… 2003). Table 6 provides average value of forest rent provided by the companies and the value of stumpage in 2005 (O stavkah lesnih podatei… 2005) which were used for the cost calculations.

Table 6. Values of stumpage for thinnings and forest rent for final felling in 2005.

| Payment | Value, € $m^{-3}$ | | | |
|---|---|---|---|---|
| | Transportation distance, km | | | |
| | 0 | 20 | 60 | 100 |
| Stumpage | 0.31 | 0.27 | 0.23 | 0.18 |
| Forest rent | 1.84 | | | |

When TS or FT logging methods are used, stumpage and forest rent can be allocated to the whole volume of harvested biomass.

Table 7 shows average values of the additional expenses provided by the companies for final fellings. Values of the additional expenses for thinnigs were assumed equal to the ones for final fellings as these costs are irrespective to the total volume of fellings.

Table 7. Values of additional expenses (k).

| Additional expenses | Value, € $m^{-3}$ |
|---|---|
| Repairing of machines | 0.86 |
| Reforestation | 0.06 |
| Road construction and maintenance | 0.89 |
| Loading-unloading works | 0.45 |
| Service of mechanisms | 0.02 |
| Overhead costs | 2.08 |
| General costs | 0.11 |
| Marketing costs | 3.46 |
| Total | 7.93 |

The companies provided data on costs of wood supply and hourly productivity of logging operations for final felling by production stages. Only those expenses, values of which were provided by the companies, are included into the cost calculations. It was possible to use this data to calculate hourly costs of machinery exploitation for commercial thinnings, as it was assumed that the same machinery could be used for both thinnings and final fellings. Hourly costs of machinery exploitation were calculated by the following equation:

$$HC_p = HP_{cp} * C_{cp}, \qquad (14)$$

*where:*
$HC_p$ – hourly cost of machinery utilisation, € $h^{-1}$
$HP_{cp}$ – hourly productivity of final felling at production stage, $p$ $m^3$ $h^{-1}$
$C_{cp}$ – cost of wood of final felling at production stage, $p$ € $m^{-3}$

In case of final felling, costs of uncomminuted energy wood at each production stage were assumed equal to the wood costs provided by the companies. Hourly costs of machinery utilisation for production systems which are not applied by the companies (manual felling, bundling, forwarding of bundles, chipping of wood and transportation of chips) were calculated according to the methodology by Mäkelä (1986) and modified for Russian conditions by Gerasimov et al. (2006). Values of average salary and working regime of the companies were taken into account. Costs of energy wood at each production stage for thinnings were calculated as:

$$C_{tp} = HC_p / HP_{tp}, \qquad (15)$$

*where:*
$C_{tp}$ – cost of wood from thinnings at production stage $p$, € $m^{-3}$
$HP_{tp}$ – hourly productivity from thinnings at production stage $p$, $m^3$ $h^{-1}$

Cost of chipping was calculated for mobile and stationary chippers. The mobile chipper consisted of Kesla C4560 drum chipper with own engine and manipulator F700 mounted on Kamaz 65117-1029 truck. Such a system is cheaper in comparison with case when the drum crusher has own chassis and powered by a tractor or a truck. The stationary chipper consists of the same drum crusher and the manipulator.

Costs of energy wood transportation were calculated for 20, 60 and 100 km distances. The companies provided only average costs of transportation of 1 $m^3$ for average transportation distance. That was not enough to estimate costs for the selected transportation distances. Therefore, a calculation model by Salo and Uusitalo (2001) was used to estimate the transportation costs of energy wood. The model was modified for Russian conditions (Gerasimov et al. 2006). Such parameters of the model as cost of the trucks, fuel and oils were selected according to the current prices in the Leningrad region. The models of trucks, average value of salaries and working regime were set according to the data reported by the companies. None of the companies in the region had a chip truck in the use and for the cost calculation a chip truck based on Scania R 580 (Scania R 580. 2006) was selected due to its high productivity. It has to be mentioned that permission from the local authorities would be needed to use this truck in Russia as full weight of the truck can be up to 60 tonnes.

The model was checked by using data provided by the companies. The difference, between transportation cost reported by the companies and the calculated value for the same distance, was only +0.02 € $m^{-3}$. This means that the model provided valid data for the selected transportation distances.

Transportation costs strongly depend on the staking factor of the transported energy wood. A staking factor is a ratio of the solid volume to the loose volume of transported wood. Table 8 shows stacking factors for different kinds of energy wood.

Table 8. Stacking factors for different kinds of energy wood (Bit & Vavilov 2005).

| Type of wood | Industrial wood | Non-industrial delimbed wood | Tree section* | LLR | Residue logs | Wood chips** |
|---|---|---|---|---|---|---|
| Stacking factor | 0.60 | 0.47 | 0.37 | 0.1 | 0.47 | 0.34 |

* - Richardson, J. et al. (2002)
** - Instrukciya po proektirovaniu … (1982)

Non-industrial wood has smaller stacking factor than industrial wood due to big variation of diameters and irregular stem shapes. Therefore, productivity of non-industrial wood transportation is lower compared to transportation of saw logs or pulpwood. Loose logging residues have the smallest staking factor and transportation of them is the most expensive. Long distance transportation costs can be decrease by compressing loose logging residues into residue logs or by chipping them at the road side.

## 3.5 Characteristics of average cutting areas

Average species composition of the forests leased by the companies is: spruce 28%, pine 19%, birch 29%, aspen 25% of the growing stock volume. Growing stock and available energy wood volumes were estimated according to average species composition. Cutting intensity for thinnings was determined according to Anan'ev et al. (2002). Characteristics of cutting areas, felling intensity, volume of felled wood and volume of energy wood available are presented in Table 9.

Table 9. Average characteristics of cutting areas, felling intensity, volume of felled wood o. b. and volume of energy wood available for supply.

| Felling | Age of stand | Average growing stock $m^3/ha$ | Cutting intensity | | Industrial wood | | Volume of aspen wood for road construction, $m^3\ ha^{-1}$ | Energy wood, $m^3\ ha^{-1}$ | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | % | $m^3/ha$ | % | $m^3\ ha^{-1}$ | | Stem wood | Crown biomass | Collectable LLR | Total |
| 1st commercial | 50 | 138 | 35 | 48 | 50 | 24 | - | 24 | 6 | - | 30 |
| 2nd commercial | 70 | 198 | 35 | 69 | 50 | 35 | - | 34 | - | - | 34 |
| Final felling | 100 | 272* | 100 | 275 | 67 | 182 | 24 | 66 | 38 | 23 | 104**/89*** |

* - including over maturing stands
** - FT method
*** - CTL or TL method

# 4 Results

## 4.1 Available energy wood resources

An estimation of energy wood volumes was done on the basis of data about actual and allowable volume of fellings in three leshozes of the considered area. Table 10 provides actual volume of final fellings, thinnings and other fellings done and annual allowable cut in 2004 (Ministerstvo prirodnih resursov… 2006).

Table 10 shows that all leshozes have not utilized annual allowable cut, which is defined for final fellings only. Therefore, there are possibilities to increase volumes of cuttings and output of energy wood. Three different scenarios were calculated in order to estimate volume of energy wood available in the considered area (Table 11). The estimation consists of the following scenarios – *Actual, Available,* and *Potential*. Scenario *Actual* is volume of energy wood available in the region according to actual volume of wood felled in 2004. Scenario *Available* gives an estimation of energy wood availability if all annual allowable cut is utilised. The third scenario *Potential* additionally takes into account possible increase of wood supply if thinnigs are used as intensively as it is currently in Finland, where thinnings give 30% of the annual actual cut (Kariniemi 2006). It means that in the third scenario, volume of thinnings was increased up to 30% of annual allowable cut. Volume of other fellings is the same as in the previous scenarios. Volume of crown wood biomass was calculated only for final fellings.

The results of the calculations presented in Tables 10 and 11 do not include volume of bark that is 10 – 12% of the stem volume.

Table 11 shows that utilisation of all annual allowable cut will increase energy wood volume available for supply by 50% (Scenario *Available*). Thinnings can also make a significant contribution to increasing volume of harvested wood. Full utilisation of annual allowable cut and thinnings could increases volume of available energy wood by 83% (Scenario *Potential*). The biggest potential to increase the available volume of energy wood is in Shugozersky leshoz, where over 336,000 $m^3$ of energy wood is available for supply in scenario *Potential* in comparison to 125,000 $m^3$ in scenario *Actual*. Currently, there are about 0.4 million $m^3$ of wood available in the region for energy use. However, the potential is much higher if the whole annual allowable cut is used, reaching 0.6 million $m^3$. The potential for energy use is almost 0.8 million $m^3$ if biomass from thinning is also utilized.

Table 10. Actual volume of final fellings, thinnings and other fellings and annual allowable cut for 2004, thousand $m^3$ under bark.

| Leshoz | Actual volume of fellings | | | | Annual allowable cut |
|---|---|---|---|---|---|
| | Final fellings | | Thinnings | Other | |
| | Total volume | Industrial wood | | | |
| Boksitogorsky | 197 | 132 | 35 | 96 | 366 |
| Shugozersky | 269 | 180 | 10 | 17 | 580 |
| Tikhvinsky | 244 | 163 | 51 | 49 | 280 |
| Total | 710 | 475 | 96 | 162 | 1226 |

Table 11. Volumes of energy wood available in the leshozes according to the scenarios and increase to scenario *Actual* (%), thousands m$^3$ under bark.

| Leshozes | Scenario | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Actual | | | Available | | | Potential | | |
| | Stem wood | Collectable LLR | Total | Stem wood | Collectable LLR | Total | Stem wood | Collectable LLR | Total |
| Boksitogorsky | 131 | 17 | 148 | 186 | 31 | 217 (47%) | 224 | 31 | 255 (72%) |
| Shugozersky | 102 | 23 | 125 | 205 | 49 | 254 (103%) | 287 | 49 | 336 (169%) |
| Tikhvinsky | 131 | 20 | 151 | 142 | 24 | 166 (10%) | 159 | 24 | 183 (21%) |
| Total | 364 | 60 | 424 | 533 | 104 | 637 (50%) | 670 | 104 | 774 (83%) |

## 4.2 Costs of energy wood supply

Costs of energy wood supply systems were calculated and compared according to the supply systems presented in Chapter 3.1. In case of thinnings costs of felling and forwarding (skidding) were allocated to the total volume of wood felled, both industrial and non-industrial. Six different supply systems for each, the 1$^{st}$ commercial thinning, the 2$^{nd}$ commercial thinning and for final fellings, respectively, were analysed in numeric and in graphic forms.

### 1$^{st}$commercial thinning

Table 12 provides costs of wood chips from the 1$^{st}$ commercial thinning. When transportation distance is 60 km, share of manual felling is approximately 17 – 27% of the total cost. If a harvester is applied for the 1$^{st}$ commercial thinning, share of felling in the total cost is higher, approximately 33%. Forwarding is approximately 18% of the total cost for manual felling and for felling by a harvester it is less, about 13%. Skidding constitutes the biggest part of the total cost for the supply systems which use the tree section method, 29 % of the total cost. Mobile chipping is approximately 7% of the total cost and end facility chipping is only 4% of the total cost. Transportation of chips due to higher productivity looks more cost efficient than transportation of logs or tree sections and it is about 16%, 21% and 26% of the total costs accordingly. The other significant expenses are overhead costs and marketing costs which are approximately 8% and 13% correspondingly. The supply systems based on manual felling provide lower costs of energy wood supply in the studied conditions.

Table 12. The costs of wood chips from the 1st commercial thinning

| Inputs | Distance from the stand to the end user, km | | | |
|---|---|---|---|---|
| | 0 | 20 | 60 | 100 |
| | Cost, € $m^{-3}$ | | | |
| | **Chain-saw, forwarder, chipper, chip truck (TS)** | | | |
| Stumpage | 0.31 | 0.27 | 0.23 | 0.18 |
| Felling and cross-cutting | 4.92 | 4.92 | 4.92 | 4.92 |
| Forwarding | 4.49 | 4.49 | 4.49 | 4.49 |
| Chipping | 1.93 | 1.93 | 1.93 | 1.93 |
| Transportation | | 2.10 | 4.30 | 6.30 |
| Additional expenses | 7.93 | 7.93 | 7.93 | 7.93 |
| **Total** | **19.58** | **21.64** | **23.80** | **25.75** |
| | **Chain-saw, forwarder, log truck, end facility chipping (TS)** | | | |
| Stumpage | 0.31 | 0.27 | 0.23 | 0.18 |
| Felling and cross-cutting | 4.92 | 4.92 | 4.92 | 4.92 |
| Forwarding | 4.49 | 4.49 | 4.49 | 4.49 |
| Transportation of tree sections | | 3.27 | 6.72 | 9.99 |
| End facility chipping | 1.23 | 1.23 | 1.23 | 1.23 |
| Additional expenses | 7.93 | 7.93 | 7.93 | 7.93 |
| **Total** | **18.88** | **22.11** | **25.52** | **28.74** |
| | **Chain-saw, forwarder, log truck, end facility chipping (CTL)** | | | |
| Stumpage | 0.31 | 0.27 | 0.23 | 0.18 |
| Felling, delimbing and cross-cutting | 6.96 | 6.96 | 6.96 | 6.96 |
| Forwarding | 3.93 | 3.93 | 3.93 | 3.93 |
| Transportation of uncomminuted wood | | 2.57 | 5.3 | 7.87 |
| End facility chipping | 1.23 | 1.23 | 1.23 | 1.23 |
| Additional expenses | 7.93 | 7.93 | 7.93 | 7.93 |
| **Total** | **20.36** | **22.89** | **25.58** | **28.10** |
| | **Chain-saw, skidder, chipper, chip truck (TS)** | | | |
| Stumpage | 0.31 | 0.27 | 0.23 | 0.18 |
| Felling and cross-cutting | 4.92 | 4.92 | 4.92 | 4.92 |
| Skidding | 8.05 | 8.05 | 8.05 | 8.05 |
| Chipping | 1.93 | 1.93 | 1.93 | 1.93 |
| Transportation | | 2.10 | 4.30 | 6.30 |
| Additional expenses | 7.93 | 7.93 | 7.93 | 7.93 |
| **Total** | **23.14** | **25.20** | **27.36** | **29.31** |
| | **Chain-saw, skidder, tree-length truck, end facility chipping (TS)** | | | |
| Stumpage | 0.31 | 0.27 | 0.23 | 0.18 |
| Felling and cross-cutting | 4.92 | 4.92 | 4.92 | 4.92 |
| Skidding | 8.05 | 8.05 | 8.05 | 8.05 |
| Transportation of uncomminuted wood | | 3.05 | 6.4 | 9.72 |
| End facility chipping | 1.23 | 1.23 | 1.23 | 1.23 |
| Additional expenses | 7.93 | 7.93 | 7.93 | 7.93 |
| **Total** | **22.44** | **25.45** | **28.76** | **32.03** |
| | **Harvester, forwarder, chipper, chip truck (CTL)** | | | |
| Stumpage | 0.31 | 0.27 | 0.23 | 0.18 |
| Harvesting | 8.62 | 8.62 | 8.62 | 8.62 |
| Forwarding | 3.49 | 3.49 | 3.49 | 3.49 |
| Chipping | 1.93 | 1.93 | 1.93 | 1.93 |
| Transportation | | 2.10 | 4.30 | 6.30 |
| Additional expenses | 7.93 | 7.93 | 7.93 | 7.93 |
| **Total** | **22.28** | **24.34** | **26.5** | **28.45** |
| | **Harvester, forwarder, log truck, end facility chipping (CTL)** | | | |
| Stumpage | 0.31 | 0.27 | 0.23 | 0.18 |
| Harvesting | 8.62 | 8.62 | 8.62 | 8.62 |
| Forwarding | 3.49 | 3.49 | 3.49 | 3.49 |
| Transportation of uncomminuted wood | | 2.57 | 5.30 | 7.87 |
| End facility chipping | 1.23 | 1.23 | 1.23 | 1.23 |
| Additional expenses | 7.93 | 7.93 | 7.93 | 7.93 |
| **Total** | **21.58** | **24.11** | **26.8** | **29.32** |

Figure 8 shows structure of energy wood supply costs for the 1st commercial thinning and 60 km transportation distance. In the case of the 1st commercial thinning, manual felling is more competitive than felling by a harvester. Usage of harvesters provides the highest cost of felling among the considered supply chains. Therefore, despite of higher productivity of harvesting, application of fully mechanised supply chains for the 1st commercial thinning is not economically reasonable. The reason is in high capital costs of such supply chains. However, supply chains with manual felling are cost-effective only if forwarders are used. Due to low productivity, skidding of wood after manual felling is more expensive than forwarding and thus results to higher supply costs. The log trucks used by the companies have lower productivity compared to the chip trucks. It explains why transportation of uncomminuted wood is more expensive than transportation of wood chips.

Figure 9 shows variation of wood chips costs depending on transportation distance and production system for the 1st commercial thinning.

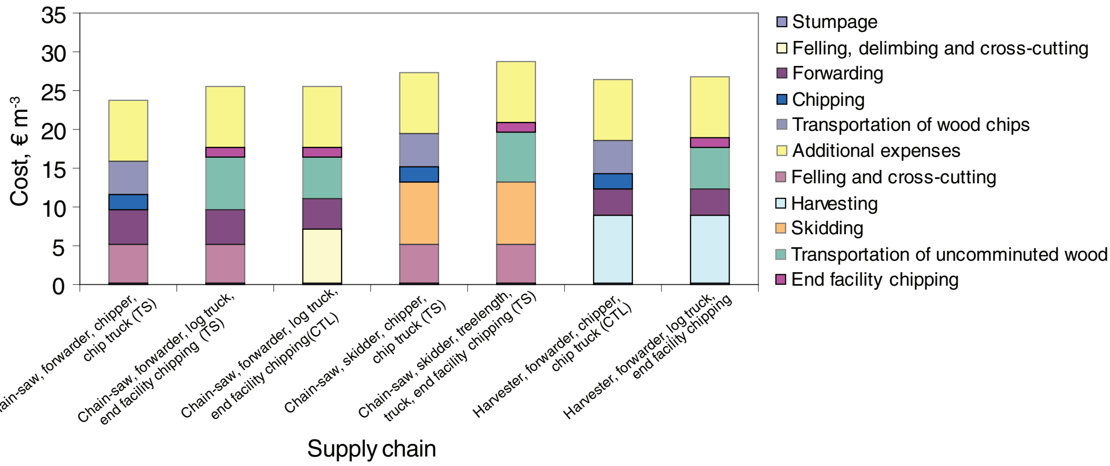


Figure 8. A structure of energy wood supply costs for the 1st commercial thinning and 60 km transportation distance.

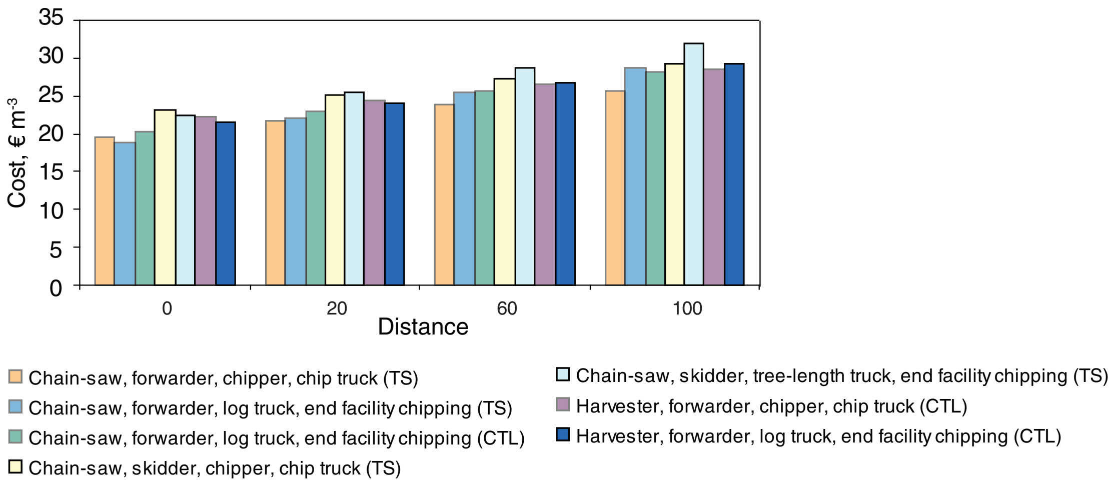


Figure 9. Costs of wood chips from the 1st commercial thinning for different supply systems and transportation distance.

Figure 9 shows that at the road side, i.e. without transport, there is no big difference in costs of energy wood for the tree section and cut-to-length logging methods for the supply systems based on manual felling, forwarding and end facility chipping. However, the tree section method provides the lowest costs of energy wood at the roadside. The reason is that in the case of the tree section method, cost of felling can be allocated to the total volume of wood chipped, i.e. stem wood and crown wood biomass. Also, such production stage as delimbing is excluded partly or completely from the felling operations. Transportation of tree sections is more expensive than transportation of wood chips or logs. The tree-section logging method and the supply system based on manual felling, forwarding, chipping of tree sections at the roadside and transportation of chips provides the lowest supply costs. The supply systems which include skidding are not cost-efficient due to low productivity of that operation. Utilisation of harvesters for supply of energy wood from the 1$^{st}$ commercial thinning seems to be economically inefficient.

## 2$^{nd}$ commercial thinning

Table 13 provides the costs of wood chips from the 2$^{nd}$ commercial thinning. The structure of supply costs of energy wood from the 2$^{nd}$ commercial thinning has changed compared to the cost structure from the 1$^{st}$ commercial thinning. When transportation distance is 60 km, the share of harvesting in the total cost decrease to 21% from 33% for the 1$^{st}$ commercial thinning. Manual felling has smaller share than in the 1$^{st}$ commercial thinning and it is between 14 and 19% of the total cost. Share of forwarding costs changed slightly in all supply systems. Shares of transportation, chipping, marketing and overhead costs have not changed significantly. The supply systems based on manual felling provide slightly lower total costs of wood chips than use of a harvester.

Figure 10 shows structure of energy wood supply costs for the 2$^{nd}$ commercial thinning and 60 km transportation distance. Manual felling is still more cost-efficient than felling by harvesters, but the difference is not as big as in the case of the 1$^{st}$ commercial thinning. Costs of forwarding are lower for fully mechanized supply systems, because productivity of forwarders is higher after harvesters than after lumberjacks. The lower forwarding costs equalize energy wood supply costs of the fully mechanized systems and the systems where manual felling is used. The TL logging method has lower cost of manual felling than CTL method because bucking is excluded from the TL method. However, low productivity of subsequent skidding significantly increases the production costs to such extent that this method is the most expensive.

Table 13. The costs of wood chips from the 2nd commercial thinning.

| Inputs | Distance from the stand to the end user, km | | | |
|---|---|---|---|---|
| | 0 | 20 | 60 | 100 |
| | Cost, € $m^{-3}$ | | | |
| | Chain-saw, forwarder, chipper, chip truck (CTL) | | | |
| Stumpage | 0.31 | 0.27 | 0.23 | 0.18 |
| Felling, delimbing and cross-cutting | 4.31 | 4.31 | 4.31 | 4.31 |
| Forwarding | 3.93 | 3.93 | 3.93 | 3.93 |
| Chipping | 1.93 | 1.93 | 1.93 | 1.93 |
| Transportation | | 2.10 | 4.30 | 6.30 |
| Additional expenses | 7.93 | 7.93 | 7.93 | 7.93 |
| **Total** | **18.41** | **20.47** | **22.63** | **24.58** |
| | Chain-saw, forwarder, log truck, end facility chipping (CTL) | | | |
| Stumpage | 0.31 | 0.27 | 0.23 | 0.18 |
| Felling, delimbing and cross-cutting | 4.31 | 4.31 | 4.31 | 4.31 |
| Forwarding | 3.93 | 3.93 | 3.93 | 3.93 |
| Transportation of uncomminuted wood | | 2.57 | 5.30 | 7.87 |
| End facility chipping | 1.23 | 1.23 | 1.23 | 1.23 |
| Additional expenses | 7.93 | 7.93 | 7.93 | 7.93 |
| **Total** | **17.71** | **20.24** | **22.93** | **25.45** |
| | Chain-saw, skidder, chipper, chip truck (TL) | | | |
| Stumpage | 0.31 | 0.27 | 0.23 | 0.18 |
| Felling and delimbing | 3.51 | 3.51 | 3.51 | 3.51 |
| Skidding | 8.05 | 8.05 | 8.05 | 8.05 |
| Chipping | 1.93 | 1.93 | 1.93 | 1.93 |
| Transportation | | 2.10 | 4.30 | 6.30 |
| Additional expenses | 7.93 | 7.93 | 7.93 | 7.93 |
| **Total** | **21.73** | **23.79** | **25.95** | **27.90** |
| | Chain-saw, skidder, tree-length truck, end facility chipping (TL) | | | |
| Stumpage | 0.31 | 0.27 | 0.23 | 0.18 |
| Felling and delimbing | 3.51 | 3.51 | 3.51 | 3.51 |
| Skidding | 8.05 | 8.05 | 8.05 | 8.05 |
| Transportation of uncomminuted wood | | 2.40 | 5.04 | 7.66 |
| End facility chipping | 1.23 | 1.23 | 1.23 | 1.23 |
| Additional expenses | 7.93 | 7.93 | 7.93 | 7.93 |
| **Total** | **21.03** | **23.39** | **25.99** | **28.56** |
| | Harvester, forwarder, chipper, chip truck (CTL) | | | |
| Stumpage | 0.31 | 0.27 | 0.23 | 0.18 |
| Harvesting | 4.79 | 4.79 | 4.79 | 4.79 |
| Forwarding | 3.49 | 3.49 | 3.49 | 3.49 |
| Chipping | 1.93 | 1.93 | 1.93 | 1.93 |
| Transportation | | 2.10 | 4.30 | 6.30 |
| Additional expenses | 7.93 | 7.93 | 7.93 | 7.93 |
| **Total** | **18.45** | **20.51** | **22.67** | **24.62** |
| | Harvester, forwarder, log truck, end facility chipping (CTL) | | | |
| Stumpage | 0.31 | 0.27 | 0.23 | 0.18 |
| Harvesting | 4.79 | 4.79 | 4.79 | 4.79 |
| Forwarding | 3.49 | 3.49 | 3.49 | 3.49 |
| Transportation of uncomminuted wood | | 2.57 | 5.3 | 7.87 |
| End facility chipping | 1.23 | 1.23 | 1.23 | 1.23 |
| Additional expenses | 7.93 | 7.93 | 7.93 | 7.93 |
| **Total** | **17.75** | **20.28** | **22.97** | **25.49** |

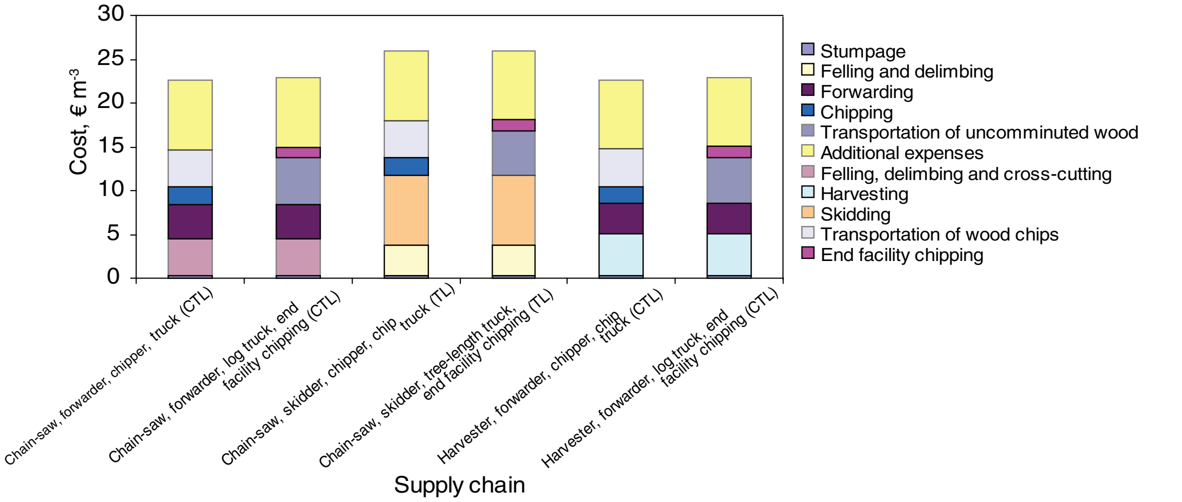


Figure 10. Structure of energy wood supply costs for the 2nd commercial thinning and 60 km transportation distance.

Figure 11 shows variation of wood chips costs depending on transportation distance and supply system for the 2nd commercial thinning.

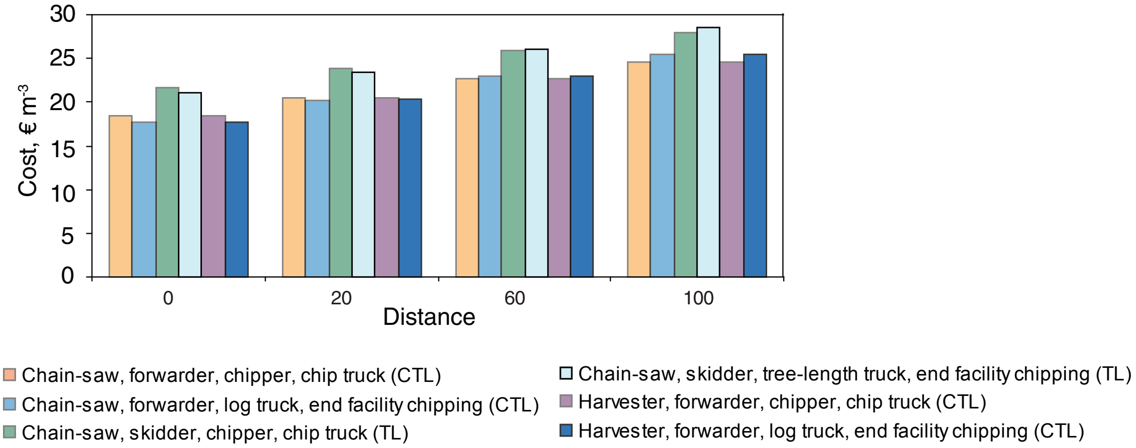


Figure 11. The costs of wood chips from the 2nd commercial thinning for different supply systems and transportation distance.

For the 2nd commercial thinning the cut-to-length and tree-length logging methods were considered and compared. There is almost no difference in energy wood costs for the supply systems using the cut-to-length method and based on manual or fully mechanized felling. The cut-to-length method and end facility chipping provide the lowest costs of energy wood if transportation distance does not exceed 20 km. Then transportation of wood chips becomes more efficient than transportation of uncomminuted stem wood. This is caused by the higher payload when using imported high capacity chips trucks in comparison to the traditional Russian trucks for assortments of roundwood transport. The supply system based on chipping at the road side and transportation of wood chips provides the lowest supply costs. Costs of energy wood for the supply systems based on tree-length method are the highest.

## Final fellings

Table 14 provides the costs of wood chips from the final felling. When transportation distance is 60 km, the share of felling and skidding together is about 40% of the total supply cost. Shares of harvesting and forwarding represent 21 and 15% of the total cost correspondingly. Cost of bundling represents about 16% of the total supply cost. Costs of transportation of wood chips contribute to the total costs about 17 - 20% and transportation of logs about 20 - 23%. Shares of mobile and end facility chipping have not changed compared to thinnings. The other significant expenses, overhead and marketing costs, contribute to the total cost independently from the logging method applied, 9 and 15% respectively.

Figure 12 shows that full tree and tree-length logging methods are more expensive compared to the cut-to-length method due to lower productivity of manual felling and skidding. Utilisation of loose logging residues requires additional production stage – bundling and significantly increases supply costs of energy wood despite of bigger output of biomass compared to supply systems where loose logging residues are not collected for energy purposes. The supply systems which include bundling are the most expensive. On the contrary, fully mechanised cut-to-length supply systems are the most cost-effective among considered supply chains.

Supply systems utilising only stem wood are more cost-efficient despite of lower output of biomass from cutting areas compared to systems which use stem wood and loose logging residues. The reason is in high cost of bundling of loose logging residues. If loose logging residues are collected for energy purposes, cost of harvesting for such supply systems is lower than for the supply systems where only energy stem wood is utilised. However, bundling of loose logging residues adds more than 4 € $m^{-3}$ to the total cost of energy wood and the lower harvesting cost does not decrease the total cost. The supply system consisting of harvesting, forwarding, transportation of logs and end facility chipping provides the lowest costs of energy wood at the roadside and can be used for supply of energy wood if transportation distance does not exceed 60 km. For longer distance, the supply system based on harvesting, forwarding, chipping at the roadside and transportation of chips is the most cost-efficient due to lower costs of transportation.

Figure 12 shows a structure of energy wood supply costs for the final felling and 60 km transportation distance.

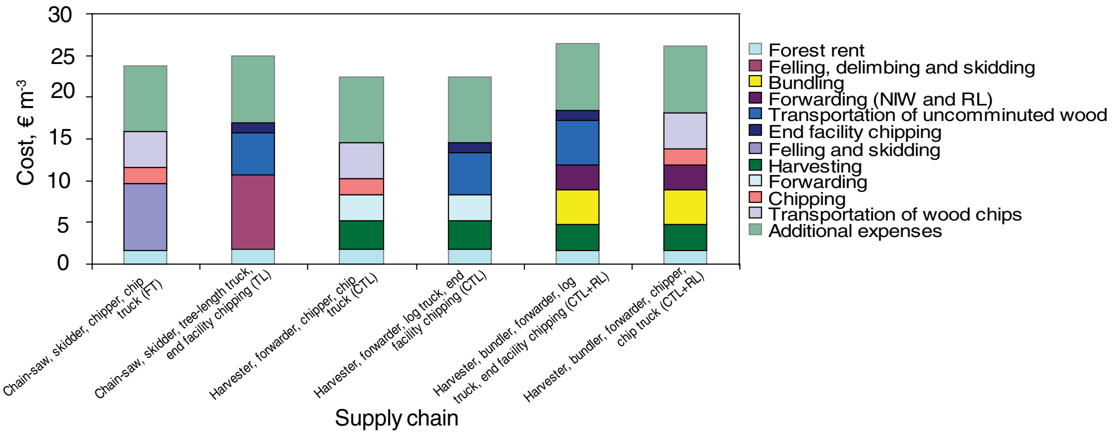


Figure 12. Structure of energy wood supply costs in final felling and 60 km transportation distance.

Table 14. The costs of wood chips from the final felling.

| Inputs | Distance from the stand to the end user, km | | | |
|---|---|---|---|---|
| | 0 | 20 | **60** | **100** |
| | Cost, € $m^{-3}$ | | | |
| | Chain-saw, skidder, chipper, chip truck (FT) | | | |
| Forest rent | 1.61 | 1.61 | 1.61 | 1.61 |
| Felling and skidding | 8.01 | 8.01 | 8.01 | 8.01 |
| Chipping | 1.93 | 1.93 | 1.93 | 1.93 |
| Transportation | | 2.10 | 4.30 | 6.30 |
| Additional expenses | 7.93 | 7.93 | 7.93 | 7.93 |
| **Total** | **19.48** | **21.58** | **23.78** | **25.78** |
| Without cost of felling and skidding | 11.47 | 13.57 | 15.77 | 17.77 |
| | Chain-saw, skidder, tree-length truck, end facility chipping (TL) | | | |
| Forest rent | 1.84 | 1.84 | 1.84 | 1.84 |
| Felling, delimbing and skidding | 8.89 | 8.89 | 8.89 | 8.89 |
| Transportation of uncomminuted wood | | 2.40 | 5.04 | 7.66 |
| End facility chipping | 1.23 | 1.23 | 1.23 | 1.23 |
| Additional expenses | 7.93 | 7.93 | 7.93 | 7.93 |
| **Total** | **19.89** | **22.29** | **24.93** | **27.55** |
| Without cost of felling, skidding and delimbing | 11.00 | 13.40 | 16.04 | 18.66 |
| | Harvester, forwarder, chipper, chip truck (CTL) | | | |
| Forest rent | 1.84 | 1.84 | 1.84 | 1.84 |
| Harvesting | 3.31 | 3.31 | 3.31 | 3.31 |
| Forwarding | 3.14 | 3.14 | 3.14 | 3.14 |
| Chipping | 1.93 | 1.93 | 1.93 | 1.93 |
| Transportation | | 2.10 | 4.30 | 6.30 |
| Additional expenses | 7.93 | 7.93 | 7.93 | 7.93 |
| **Total** | **18.15** | **20.25** | **22.45** | **24.45** |
| Without costs of felling | 11.70 | 13.80 | 16.00 | 18.00 |
| | Harvester, forwarder, log truck, end facility chipping (CTL) | | | |
| Forest rent | 1.84 | 1.84 | 1.84 | 1.84 |
| Harvesting | 3.31 | 3.31 | 3.31 | 3.31 |
| Forwarding | 3.14 | 3.14 | 3.14 | 3.14 |
| Transportation | | 2.40 | 5.04 | 7.66 |
| End facility chipping | 1.23 | 1.23 | 1.23 | 1.23 |
| Additional expenses | 7.93 | 7.93 | 7.93 | 7.93 |
| **Total** | **17.45** | **19.85** | **22.49** | **25.11** |
| Without costs of felling and forwarding | 11.00 | 13.40 | 16.04 | 18.66 |
| | Harvester, bundler, forwarder, log truck, end facility chipping (CTL+RL) | | | |
| Forest rent | 1.69 | 1.69 | 1.69 | 1.69 |
| Harvesting | 3.05 | 3.05 | 3.05 | 3.05 |
| Bundling | 4.14 | 4.14 | 4.14 | 4.14 |
| Forwarding (NIW and bales) | 3.07 | 3.07 | 3.07 | 3.07 |
| Transportation (NIW and bales) | | 2.57 | 5.30 | 7.87 |
| End facility chipping | 1.23 | 1.23 | 1.23 | 1.23 |
| Additional expenses | 7.93 | 7.93 | 7.93 | 7.93 |
| **Total** | **21.11** | **23.68** | **26.41** | **28.98** |
| Without costs of felling | 18.06 | 20.63 | 23.36 | 25.93 |
| | Harvester, bundler, forwarder, chipper, chip truck (CTL+RL) | | | |
| | 1.69 | 1.69 | 1.69 | 1.69 |
| Harvesting | 3.05 | 3.05 | 3.05 | 3.05 |
| Bundling | 4.14 | 4.14 | 4.14 | 4.14 |
| Forwarding (NIW and bales) | 3.07 | 3.07 | 3.07 | 3.07 |
| Chipping | 1.93 | 1.93 | 1.93 | 1.93 |
| Transportation | | 2.10 | 4.30 | 6.30 |
| Additional expenses | 7.93 | 7.93 | 7.93 | 7.93 |
| **Total** | **21.81** | **23.91** | **26.11** | **28.11** |
| Without costs of felling | 18.76 | 20.86 | 23.06 | 25.06 |

Figure 13 shows variation of energy wood costs depending on transportation distance and supply system for the final felling.

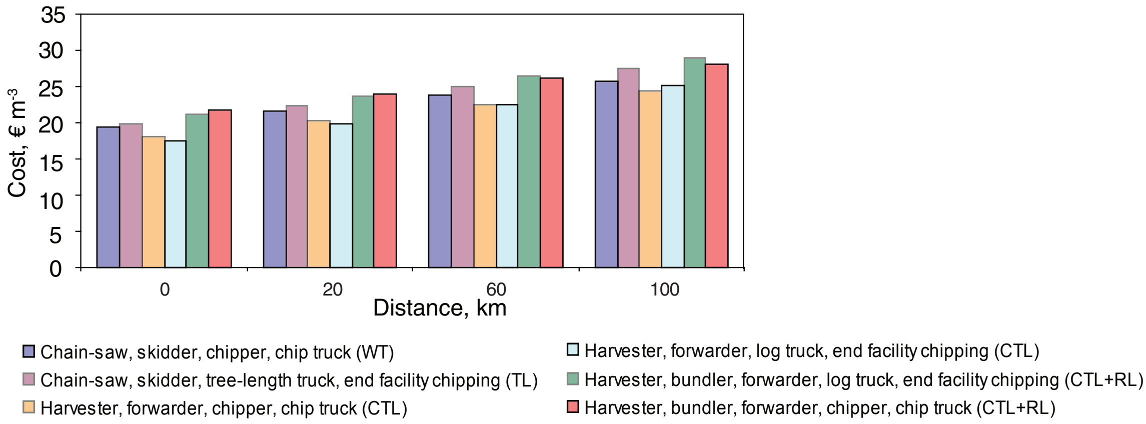


Figure 13. The costs of wood chips from the final felling for different supply systems and transportation distance.

## 4.3 The most cost-efficient energy wood supply systems

Supply costs vary depending on the type of felling, the supply system applied and transportation distances. Figure 14 shows a comparison of the most cost-effective energy wood supply systems for the 1st and 2nd commercial thinnings and final fellings.

Harvesters were obviously not competitive to manual felling in the 1st commercial thinninng. The supply systems based on manual felling provided lower total cost of energy wood supply in case of the 1st commercial thinning. For the 2nd commercial thinning, there is almost no difference in energy wood costs for the supply systems using the cut-to-length method and based on manual or fully mechanized felling. Only in final fellings, utilisation of harvesters provided the supply of energy wood with lower costs than in the case of manual final felling done by the tree length

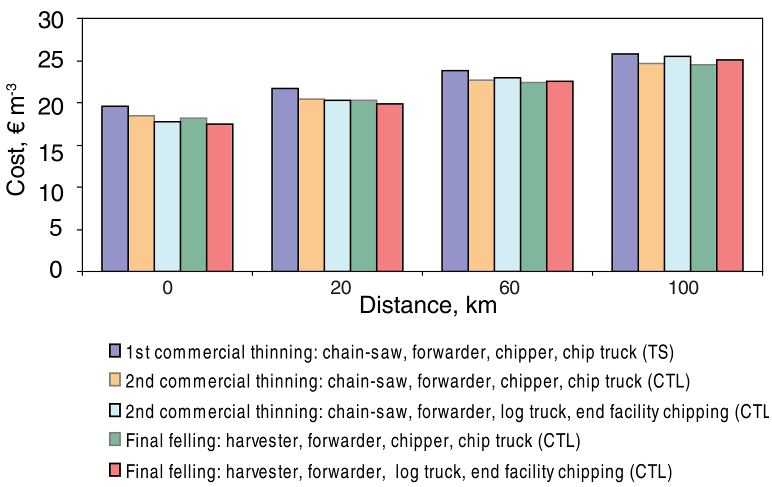


Figure 14. The most cost-effective energy wood supply systems for the 1st and 2nd commercial thinnings and final fellings.

or full tree method. The 1st commercial thinning was the most expensive source of energy wood among considered ones in this study. Small average stem volume of felled trees caused low felling productivity. Bigger average stem volume in the 2nd commercial thinning increased productivity of logging operations. As a result, supply costs of energy wood, in average, was 1.0 € $m^{-3}$ lower in comparison with the 1st commercial thinning. In final felling, the supply systems using harvesters had almost the same supply costs as the supply systems utilising manual felling for the 2nd commercial thinning.

One of the reasons of such small difference between the costs of energy wood from the 2nd thinning and from the final felling is in higher cost of wood resources (forest rent) in the case of final fellings (1.84 € $m^{-3}$) compared to stumpage for thinnings (0.18 – 0.31 € $m^{-3}$). Other reasons are in low productivity of harvesters and low costs of manual felling as a result of cheaper manual work in Russian conditions. The difference between the costs would be bigger if the productivity of harvesters in the studied area corresponded to average productivity of harvesters in Finland. The data provided by the companies showed that productivity of their harvesters was 35% lower compared to the productivity of harvesters in Finland in final fellings of forests with the same average stem volume. This means that there is a possibility to decrease energy wood supply costs by further training of harvester operators and by taking appropriate organizational measures.

The most cost-effective supply system for the 1st commercial thinning is based on the tree section method which consists of manual felling, forwarding, chipping at the road side and transportation of wood chips. There are two cost-effective energy wood supply systems for the second commercial thinning and final felling. When transportation distance is smaller than 60 km, the supply system with transportation of energy wood in the form of logs is the most cost-effective. If transportation distance is more than 60 km, then supply system based on transportation of wood chips becomes more cost-efficient. The key cost-factor here is the form in which energy wood is transported. Due to the bigger payload of the chips truck it has higher productivity in comparison with the log trucks used by the companies and with growing distance transportation of wood chips becomes cheaper than transportation of energy wood in the form of logs.

## 4.4 Comparison of costs of different energy sources

One of the most important factors influencing feasibility of utilization of wood for energy is actual market situation with other energy sources in the particular region. The costs of wood chips supply calculated in the study were compared with average prices of traditional energy sources used in Northwest Russia. Table 15 presents average costs of different energy sources in Russia as of June 2006 (O tekushei situacii… 2006) and the lowest and highest costs of wood chips produced by analysed supply systems. To make the figures comparable all costs were recalculated to the same unit of the energy content for the respective fuel.

The costs of the energy unit of wood chips supplied by the most costly supply system, which is cut-to-length method in the 1st commercial thinning, and the cheapest supply system cut-to-length method in final fellings for different transporting distances were calculated in the Table 16.

Table 15. Average costs of different energy sources in Russia (June 2006) and the calculated costs of wood chips.

| Fuel | Unit | | | |
|---|---|---|---|---|
| | GJ $t^{-1}$ | MWh $t^{-1}$ | Price, € $t^{-1}$ | Price, € $MWh^{-1}$ |
| Heavy oil* | 40 | 11.1 | 132.00 | 12 |
| Light oil* | 41 | 11.4 | 322.00 | 28 |
| Natural gas** | 49 | 13.6 | 57.14 | 4.2 |
| Electricity* | - | - | - | 30 |
| Coal*** | 20 | 5.6 | 16 | 3 |
| Wood chips**** | 10 | 2.8 | 24.92 – 42.00 | 8.9 – 15.0 |

* Värri et al. (2007)
** Natural gas – 34.25 MJ $m^{-3}$; $1m^3$ = 0.7 kg; 1000 $m^3$ = 40 € (www.spp.sk)
*** - GOSKOMSTAT (2007)
**** Wood chips – moisture 55%; 1 $m^3$ = 0.7 t; supply costs

Table 16. Cost of energy unit obtained from energy wood harvested by the cut-to-length supply system

| Type of felling | Transporting distances, km | | | |
|---|---|---|---|---|
| | 0 | 20 | 60 | 100 |
| | Costs, € $MWh^{-1}$ | | | |
| 1st thinning - CTL | 11.0 | 12.3 | 13.7 | 15.0 |
| Final felling - CTL | 8.9 | 10.1 | 11.5 | 12.5 |

Comparison of the price level of different fuels per energy unit is shown in Figure 15.

It can be seen, that the cheapest fuels in the region are natural gas and coal. Wood fuel can not compete with it because even the cheapest source is 2 – 3 times more expensive depending on the transporting distance. However, energy wood from the final felling harvested by the cut-to-length method is cheaper up to 60 km transporting distance than heavy oil. Energy wood from thinning is more expensive fuel than heavy oil. It can be expected, that energy wood harvested by the most of the analysed supply systems is at the same costs level with heavy oil up to the transporting distance of some 50 km. Supply costs of energy wood harvested by all analysed supply systems with its transport for more than 100 km are much lower than light oil and electricity.

Figures can not be linked with the overall costs of energy production from different fuels. There are different needs for capital, operating and indirect costs for different fuels. It means that the total costs of energy production should be calculated taking into account all those factors.

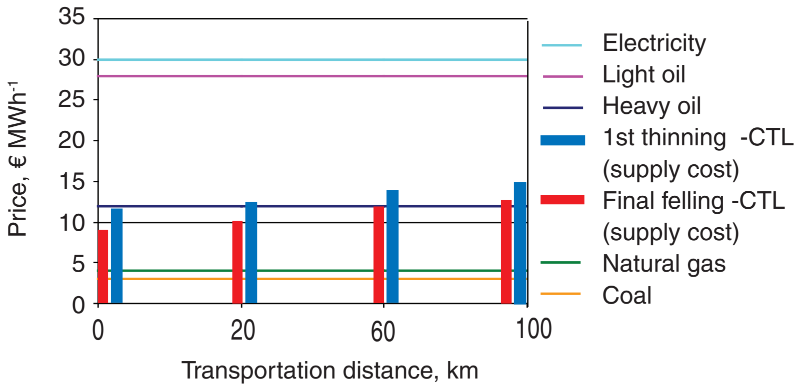


Figure 15. Comparison of price level of different fuels with cost of wood chips per energy unit.

# 5 Conclusion

The considered area has good potential for energy wood supply. Forest resources of three leshozes Boksitogorsky, Shugozersky and Tihvinsky would also allow significantly increase energy wood supply. There are possibilities for intensification of forest recourses utilisation as annual allowable cut and intermediate fellings are not used completely. Actual available volume of energy wood, generated by fellings in the region, is 424,000 $m^3$ $yr^{-1}$. Full utilisation of annual allowable cut would increase volume of energy wood available for supply up to 637,000 $m^3$ $yr^{-1}$ or + 50%. If also intermediate fellings will be entirely utilised, available volume of energy wood could be increased up to 774,000 $m^3$ $yr^{-1}$ or + 83% to actual available volume.

Logging companies operating in the region mainly use two logging methods: cut-to-length and tree-length methods. These methods were compared with the full tree method and the tree section method which can be also applied for energy wood supply. Costs of energy wood supply were estimated for the 1$^{st}$ and 2$^{nd}$ commercial thinnings and final felling.

It was found out that for the 1$^{st}$ commercial thinning supply systems using the cut-to-length and tree section method and based on manual felling and forwarding provides lower costs of energy wood at roadside in comparison with other supply systems. The other supply systems have higher costs of energy wood at the roadside independent of the logging method applied. The cut-to-length method has lower costs of energy wood at the road side comparing to other methods for the 2$^{nd}$ commercial thinning and final felling.

In thinnings, the supply systems based on manual felling has lower costs of energy wood compared to the supply systems which utilise harvesters. Utilisation of harvesters becomes more feasible for final felling. In spite of higher hourly cost of harvesters, high felling productivity allows the cut-to-length method to be more efficient compared to the full tree and tree length methods with manual felling.

The 1$^{st}$ commercial thinning was the most expensive source of energy wood among analysed. Small average stem volume of felled trees affected productivity of logging operations resulting to the highest supply costs. In case of the 1$^{st}$ commercial thinning, the most cost-effective supply systems, depending on transportation distance, provided supply costs between 18.8 and 25.8 € $m^{-3}$. The 2$^{nd}$ commercial thinning had lower costs of energy wood supply compared to the 1$^{st}$ commercial thinning. The most cost-efficient supply systems have costs between 17.8 and 24.6 € $m^{-3}$. Final felling was the cheapest source of energy wood. The most feasible supply systems provided costs between 17.4 and 24.4 € $m^{-3}$.

According to the Russian forest legislation (Lesnoi kodeks… 2006) cutting areas must be cleaned after logging. All wood felled has to be hauled to the road side and logging residues have to be collected and pilled. Therefore, cost of felling and forwarding of energy wood can be allocated to costs of industrial wood, especially in case of final felling, where output of industrial wood is high. This would decrease supply costs of energy wood from final felling to 11.0 – 17.8 € $m^{-3}$, depending on transportation distance.

The analysis of transportation costs showed that for the 1$^{st}$ commercial thinning transportation of wood chips was the most cost-efficient. In case of the second commercial thinning and final felling, transportation of energy wood in the form of logs was cost-efficient for distance shorter than 60 km. It was more efficient to transport energy wood for longer distances in the form of wood chips by special large capacity lorries.

The supply systems which additionally to stem wood utilise loose logging residues had higher costs of energy wood supply despite of higher output of energy wood from cutting areas. The reason was in bigger number of supply stages.

Costs of energy wood harvesting per energy unit are competitive with the price of electricity and light oil as primary energy sources. Wood fuels can compete with the price of heavy oil in the case of short transporting distances up to 50 km. However, wood fuels can not be competitive with the recent price of coal and natural gas if other factors, like for example high costs of pipelines building to the remote areas and reduction of greenhouse gas emissions are not taken into account. In that light there is high potential for utilization of energy wood in the analysed region.

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