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Global forest energy resources, sustainable biomass supply and markets for bioenergy technology - GLOENER

The pre-feasibility study of biomass plant in Kostomuksha

FINAL REPORT

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Summary

This pre-feasibility study of a biomass plant in Kostomuksha is part of the project 'Global Forest Energy Resources, Sustainable Biomass Supply and Markets for Bioenergy Technology (GLOENER)'.

The aim of this pre-feasibility study is to analyze the feasibility of the biomass plant construction in Kostomuksha town. The study will cover the assessment of forest energy resource potential (1) in the surroundings of the plant Kostomuksha, the study of harvesting technology of energy wood for the plant (2) and biomass plant assessment (3).

In Kostomuksha the energy system consists of the boiler installation situated near the iron pellet mill owned by JSC Karelskij Okatysh (KO) and the heat transmission and distribution systems for the iron pellet mill and for the town of Kostomuksha. All heat is produced in the boiler house.

The techno-economic potentials of energy wood from the actual annual cut in the Kostomukshsky, Kalevalsky, Yushkozersky and Muyezersky forest districts is 179 100 m^3 (358 GWh/a) and from the annual allowable cut 280 000 m^3 (560 GWh/a). The wood fuel potential is assumed to come totally from final fellings. The peat resources in Kalevalsky, Muezersky and Kostomukshsky are remarkable. The total peat resources suitable for peat production are 326 TWh.

The roadside chipping method is slightly the most economic forest chip production method. The average road transporting distance for the use of all available energy wood in the area is 118 km. The weighted average procurement cost of the logging residue chips delivered at plant is 12.6 €/MWh. One euro is 41.6 rubles.

A CHP-plant producing heat (40 MW), steam (25 MW) and electricity (40 MW) was assessed in the research. The share of energy wood would be about 40 % of the total fuel need in the power plant. In the study the rest 60 % of the fuel would be either coal or peat. The energy production costs of the biomass/coal fired boiler (37 €/MWh) are higher than those of an oil fired boiler (27 €/MWh). The new boiler plant would be economical if the price of Mazut oil (15 €/MWh) would be doubled.

If peat is used instead of coal the average energy costs would increase by 1.4 €/MWh. However, the use of peat instead of coal has some benefits. E.g. peat is a local fuel and it gives work opportunities for the local people.

Confidentiality	Public

Jyväskylä 26.9.2008

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Preface

This pre-feasibility study of a biomass plant in Kostomukshsky is a part of the project '*Global Forest Energy Resources, Sustainable Biomass Supply and Markets for Bioenergy Technology (GLOENER)*'. The project is carried out under the CLIMBUS technology programme, funded by the Finnish Funding Agency for Technology and Innovation, TEKES. In addition to TEKES, six Finnish companies (John Deere Oy, Metso Power Oy, Neste Oil Oyj, Pentin Paja Oy, Stora Enso Oyj and Vapo Oy) are participating in the funding and the executive group of the project.

The ClimBus programme aims to enhance the business possibilities of renewable energy production. This GLOENER-project, implemented under ClimBus programme, focuses on finding new markets for the Finnish bioenergy technology and expertise in rapidly growing global markets.

Pre-feasibility studies are the most important and largest part of the research project. Three feasibility studies will be made on fuel and energy production chains of wood biomass. Wood biomass consists of logging residues from final fellings, small wood from thinnings or forest industry wood-processing residues. Pre-feasibility studies include also biomass-based power and heat production in different countries in East-Europe and in North and South-America. This pre-feasibility study in Kostomukshsky continues the previous pre-feasibility studies made in the previous ClimBus programme's project '*EU's wood fuel resources, energy technology market and international bioenergy trade mechanism*', in which the pre-feasibility studies were carried out in Bialystok (Poland in 2005), in Zabreb (Czech Republic in 2007) and in Chaumont (France in 2008).

The pre-feasibility study is coordinated by VTT Technical Research Centre of Finland (VTT). The Finnish Forest Research Institute (Metla) has collected and provided data on forest use and forest fuel resources used in the pre-feasibility study. Forest fuel procurement technology and wood chips production cost analysis was made by VTT. Also the power plant assessment including the energy production cost analysis was made by VTT.

This study was carried out at VTT in Jyväskylä and at Metla in Joensuu during the years 2007 and 2008.

Authors

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1 Introduction

Bioenergy could supply a significant part of the heat energy in many communities and industries in Russia. Biomass is not very widely used in municipal or industrial energy production, but it is a quite common energy source for households. All in all, activities in the Russian bioenergy sector have increased in the last years and are expected to increase substantially in the near future.

At present, biomass is used to a lesser degree, even though the biomass resources in Russia are vast. The consumption of biomass is very low in Russia. From the total energy consumption the share of biomass is only about 3 % of the total primary energy consumption. The total biomass power capacity in Russia is about 3 000 MWth. But there are some regions, especially in the North West Russia, where the share of biomass of the total energy consumption can be 10 – 20 %. In Kostomuksksky, Muezersky and Kalevalsky districts the firewood consumption is 23 % of energy consumption. The other energy sources are gas (26 %), coal (17 %), oil and diesel (34 %) and peat (0.1 %).

The main users of biomass are the forest industry companies using bark and sawdust for their own energy production. Altogether, there are about 30 wood residue steam boilers in the pulp and paper industry. The forestry companies are also working together with the municipal sector and supply wood fuel for the municipal power plants.

The Republic of Karelia is located in the North-West of Russia, it is included in the Northwest Federal District of Russian Federation. In Karelia there are three main towns, Petrozavodsk (283 000 inhabitants), Kostomuksha (32 500 inhabitants) and Sortavala (20 200 inhabitants). Town of Kostomuksha is situated in the North-western part of Karelia. Its territory covers about 4 000 km^2. Kostomuksha is located 35 km from the Finnish Vartius border station.

2 The aim of the study

The aim of this study is to analyze the feasibility of the biomass power plant in Kostomuksha. The pre-feasibility study covers *the assessment of energy wood resource potential (1) in the surroundings of Kostomuksha, the study of harvesting technology of wood fuel for the plant (2) and biomass plant assessment (3).*

In the assessment of wood energy resource potential (1) the objective is to estimate the forest chip potential in the surroundings of the plant. Energy wood consists of logging residues, non-industrial wood and stumps from final fellings, and unmerchantable trees from thinnings. The forest chip potential calculation follows the normal procedure used in Finland and in other Nordic countries. The availability of energy wood is based on the felling data from the area (stand size, tree species, volume of harvested timber, road network, topography and geographical information on the location of cutting areas and etc.). For the calculation of the suitability of the logging stands for logging residue harvesting (1), the recovery rate for logging residues from the logging stands (2) and the crown mass factors (3) have also to be known. Based on this data it is possible to calculate the potential of forest chips by the transport distance. This work is mainly done by Metla together with the local forest logging organisations. The assessment of forest energy resource potential will be done for the former Kostomukshsky, Kalevalsky, Yushkozersky and Muyezersky forest districts (forest administration has been changed since the study) in Northwest Karelia. This task is made by Metla.

In the study of harvesting technology of wood fuel for the plant the objective is to define the most suitable and cost efficient supply chain and appropriate machines for harvesting and transport of energy wood for the power plant and to define the harvesting costs of forest residue chips at the power plant. Up-to-date harvesting technology (methods and machines) used in Finland are studied in the assessment. The methods for logging residue harvesting are chipping at the roadside-method (1), comminution at plant-method (2) and bundling of the residues -method (3). The methods for small-wood harvesting from thinnings are chipping at the roadside -method (4) and comminution at the plant -method (5). The harvesting costs for different methods are calculated (euro/MWh) on the basis of stand data (stand size, tree species, volume of harvested timber and etc.) and machine specifications. Based on this data it is possible to select the most cost efficient harvesting machines and procurement chains for the prevailing conditions. A calculation model, developed in the Finnish Wood Energy Technology Programme (1999-2003) is used in the harvesting cost calculation. The harvesting costs are divided into organizational costs, felling and bunching of the trees, terrain transport, chipping or crushing and road transport costs. This task is implemented by VTT together with the local forest logging organisations.

The aim of biomass plant assessment is to evaluate the feasibility of the selected boiler plant investments. The boiler plants can be based on co-firing, or on heat and/or power production. The production costs of heat and/or electricity will be calculated in the assessments. The effect on greenhouse gases and other emissions will also be evaluated. The heat and power production costs are divided into investment, labour, maintenance, electricity and fuel costs. A sensitivity analysis will be employed to study the effect of these parameters on the energy production costs. The following results will be obtained among other things:

- production costs as a function of fuel price with investment cost as a variable
- energy production costs as a function of peak load hours
- breakdown of energy production costs; investment, fuel costs etc. and
- overall cost-effectiveness and feasibility of the boiler plant investment

3 Forest fuel resources assessment

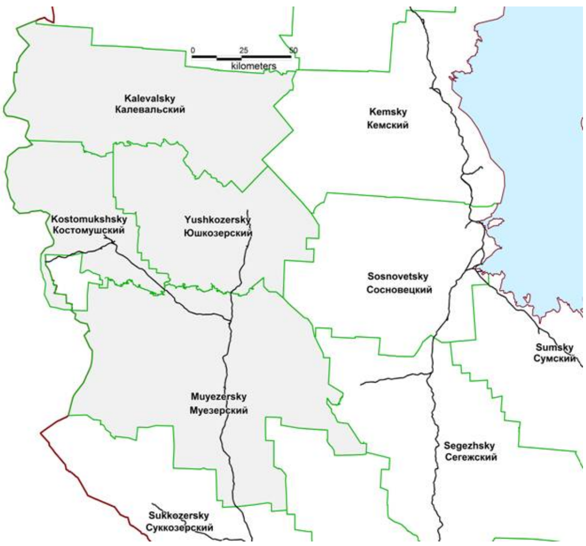
3.1 Actual and allowable cut in the study area

In order to estimate the availability of energy wood for a possible power plant, the following data were gathered:

- overall data of former Kostomukshsky, Muezersky, Kalevalsky and Yushkozersky forest districts (Figure 1),
- specific information on the cutting areas in the Kostomukshsky forest district,
- data from 7 forest leasers in the Kostomukshsky administrative district and
- sawmills in the Kostomukshsky administrative district.

The total actual cut was 1.14 million m^3 in the studey area in 2006 (Table 1 and Figures 2 - 3). The main share (89 %) of wood came from the final fellings (1.0 million m^3). The share of thinnings (20 000 m^3) from the total fellings was very low, only about 2 %. The other fellings consist of fellings e.g. for road construction and agricultural purposes.

The annual allowable cut from final fellings was 1.76 million m^3 (Table 2). Thus it would be possible to increase the cutting of wood by 55 % in the study area.



Kuva 1. Kostomukshsky, Muezerksy, Kalevalsky and Yuskozervsky districts in the study area.

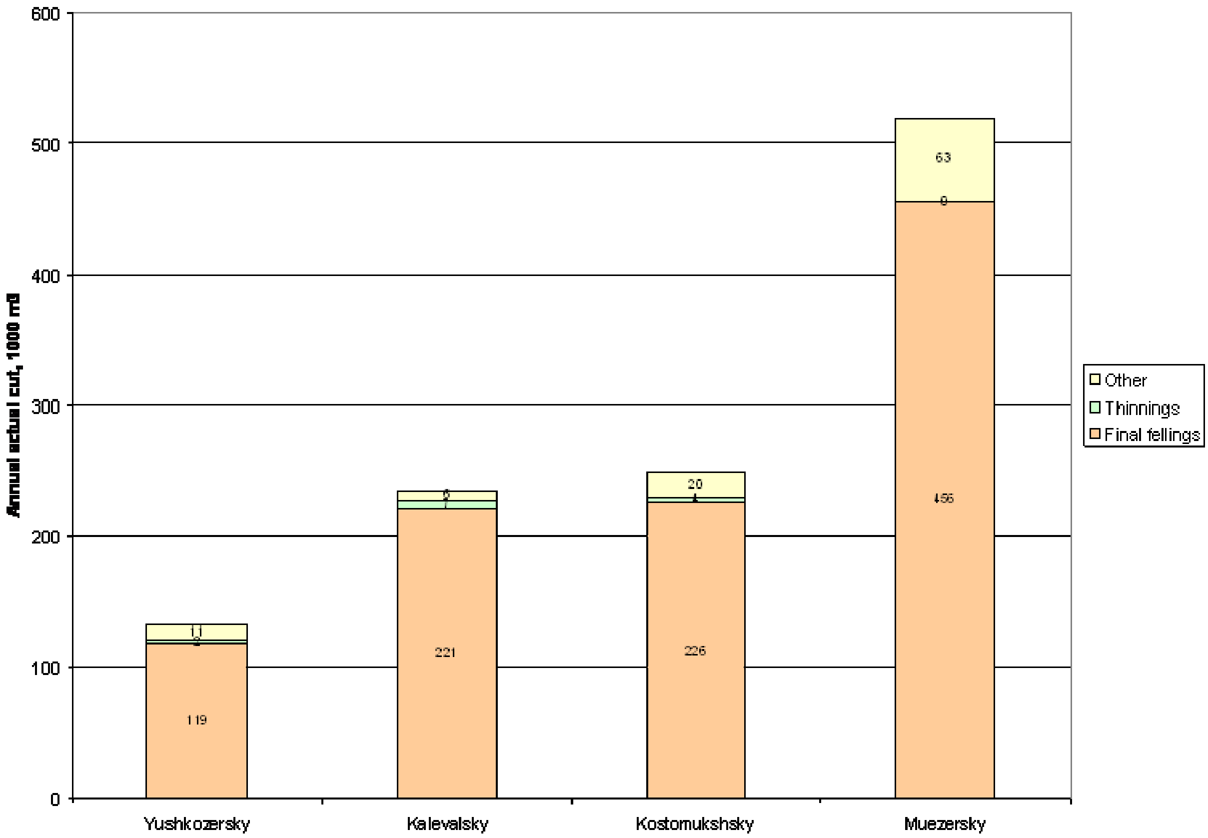


Figure 1. Annual actual cut in 2006 in Kostomukshsky, Muezersky, Kalevalsky and Yushkozersky forest districts.

Table 1. The actual fellings (1000 m3) in Kostomukshsky and neighbouring forest districts in 2006.

DISTRICT	**FINAL FELLINGS**	**THINNINGS**	**OTHER FELLINGS**	**TOTAL**
Yushkozersky	119.0	3.3	11.4	133.7
Kalevaljsky	221.0	9.0	6.0	236.0
Kostomukshsky	226.3	4.1	20.1	250.5
Muezersky	456.4	4.0	62.8	523.2
Total	1022.7	20.4	100.3	1143.4

Table 2. The allowable fellings (1000 m^3) in Kostomukshsky and neighbouring forest districts in 2006.

DISTRICT	FINAL FELLINGS	THINNINGS	OTHER FELLINGS	TOTAL
Yushkozersky	251.8	3.3	11.4	266.5
Kalevaljsky	373.3	9.0	6.0	388.3
Kostomukshsky	407.4	4.1	20.1	431.6
Muezersky	607.2	4.0	62.8	674.0
Total	1639.7	20.4	100.3	1760.4

Figure 2. Harvester at the final felling site in Kostomukshsky forest district.

3.2 Total energy wood potential

Energy wood potential from the actual cutting and allowable cutting is presented in Tables 3 and 4. The energy wood sources include final fellings and thinnings. The total energy wood potential from the actual cut was 332 200 m^3 (Table 3) and from the allowable cut 536 300 m^3 (Table 4). Energy wood includes non-industrial wood (65 % in actual cutting) (Figure 4), spruce stumps from final fellings (6 %), unused branches from final fellings (5 %), wood damaged during harvesting in final fellings and thinnings (12 %), energy wood from thinnings (3 %) and small wood from final fellings (9 %).

It should be noticed that sawmills use all their wood residues (102 000 m^3 in 2006) for their own purposes, and therefore they are not available for the power plant. Moreover, 64 000 m^3 of the non-industrial wood is already used as fuel in the villages.

Table 3. The total energy wood potential from the actual fellings (1000 m^3) in Kostomukshsky and neighbouring forest districts in 2006.

District	Non-industrial wood from final fellings	Spruce stumps from final fellings	Unused branches from final fellings	Damaged wood in harvesting of final felling and thinning	Energy wood from thinnings	Energy wood from other fellings	Total energy wood
Yushkozersky	24.8	0.0	1.9	4.7	1.5	3.0	35.9
Kalevaljsky	44.3	1.5	3.6	8.8	4.1	1.6	63.9
Kostomukshsky	37.1	10.6	4.1	9.5	1.9	5.4	68.6
Muezersky	109.5	8.0	7.7	17.1	1.8	19.6	163.7
Total	215.8	20.0	17.3	40.1	9.3	29.6	332.2

Table 4. The total energy wood from allowable fellings (1000 m^3) in Kostomukshsky and neighbouring forest districts in 2006.

District	Non-industrial wood from final fellings	Spruce stumps from final fellings	Unused branches from final fellings	Damaged wood in harvesting of final fellings and thinnings	Energy wood from thinnings	Energy wood from other fellings	Total energy wood
Yushkozersky	52.8	3.3	4.3	10.0	1.5	3.2	75.0
Kalevaljsky	75.7	12.2	6.8	14.9	4.1	1.8	115.5
Kostomukshsky	67.9	15.4	7.5	17.0	1.9	5.3	114.9
Muezersky	147.8	25.2	11.8	22.7	1.9	21.5	230.8
Total	344.2	56.0	30.3	64.6	9.4	31.7	536.3

Figure 3. Non-industrial wood (photo by Arvo Leinonen).

Forests in the study area are pine-dominant, which reduces the energy wood potential compared to spruce and broadleaved tree species dominant forests. The distribution of tree species (%) in each district is presented in the Table 5.

Table 5. The distribution of tree species in the Kostomukshsky district and neighbouring forest districts, %.

	Pine	**Spruce**	**Birch**
Yushkozersky	93.7	5.7	0.6
Kalevaljsky	84.4	14.3	1.3
Kostomukshsky	82.3	16.5	1.1
Muezersky	79.1	18.2	2.7

3.3 The techno-economic energy wood potential in the study area

The following assumptions were made in the calculation the techno-economic energy wood potential:

- the energy wood potential is based on the actual and allowable cut in 2006,

- the available forest fuel in the area consists of non-industrial wood from final fellings, logging residues (small wood + unused branches) from final fellings and mechanically damaged round wood from final and other fellings,
- spruce stumps from final and other fellings and energy wood from thinnings (energy wood from thinning type fellings and mechanically damaged wood from thinnings) were excluded due to small amounts and
- the techno-economic availability of forest fuel is 60 % of the potential in general. The figure 60 % is defined on the basis of prevailing conditions. The main logging residues resource in the study area is non-industrial wood (344 000 m^3). As mentioned earlier 20 % of this is used for fuel (firewood) in villages. Some of the non-industrial wood (20 %) is also used for road construction and maintenance. Based on these factors the utilization rate of non-industrial wood was estimated as 60 %. In Finland the harvesting rate of logging residues for fuel from final felling is about 60 - 70 %. Also in this study the utilization rate of logging residues was estimated as 60 %.

Based on these assumptions the techno-economic energy wood potential from the actual cut in the Kostomukshsky, Kalevalsky, Yushkozersky and Muyezersky forest districts is 179 100 m^3 (358 GWh) and from the annual allowable cut 280 000 m^3 (560 GWh) (Tables 6 and 7). The energy wood potential is assumed to come totally from final and other fellings. The main source is non-industrial wood and it’s share is 78 % from the total energy wood potential. The accumulation of available forest fuel and transporting distances on the study area are presented in Figure 5.

Table 6. Techno-economic potential of energy wood from fellings (1000 m3) in forest districts nearby Kostomuksha in 2006 based on the actual cut. It is assumed that one m^3 is 2 MWh.

District	Non-industrial wood from final fellings	Unused branches from final fellings	Damaged wood in final felling harvesting	Energy wood from other fellings	Total energy wood from fellings 1000 m^3	Total energy wood from fellings GWh
Yushkozersky	14.88	1.14	2.5	1.8	20.32	40.64
Kalevaljsky	26.58	2.16	4.9	0.96	34.64	69.28
Kostomukshsky	22.26	2.46	5.1	3.24	33.11	66.22
Muezersky	65.7	4,62	9.0	11.76	91.03	182.06
Total	129.48	10.38	21.5	17.76	179.11	358.22

Table 7. Techno-economic potential of energy wood from fellings (1000 m3) in districts nearby Kostomuksha in 2006 based on the allowable cut. It is assumed that one m^3 is 2 MWh.

District	Non-industrial wood from final fellings	Unused branches from final fellings	Damaged wood in final felling harvesting	Energy wood from other fellings	Total energy wood from fellings 1000 m^3	Available energy wood from fellings GWh
Yushkozersky	31.68	2.58	5.7	1.92	41.85	83.70
Kalevaljsky	45.42	4.08	8.6	1.08	59.17	118.34
Kostomukshsky	40.74	4.5	9.6	3.18	58.05	116.10
Muezersky	88.68	7.08	12.3	12.9	120.93	241.86
Total	206.52	18.18	36.1	19.02	280.00	560.00

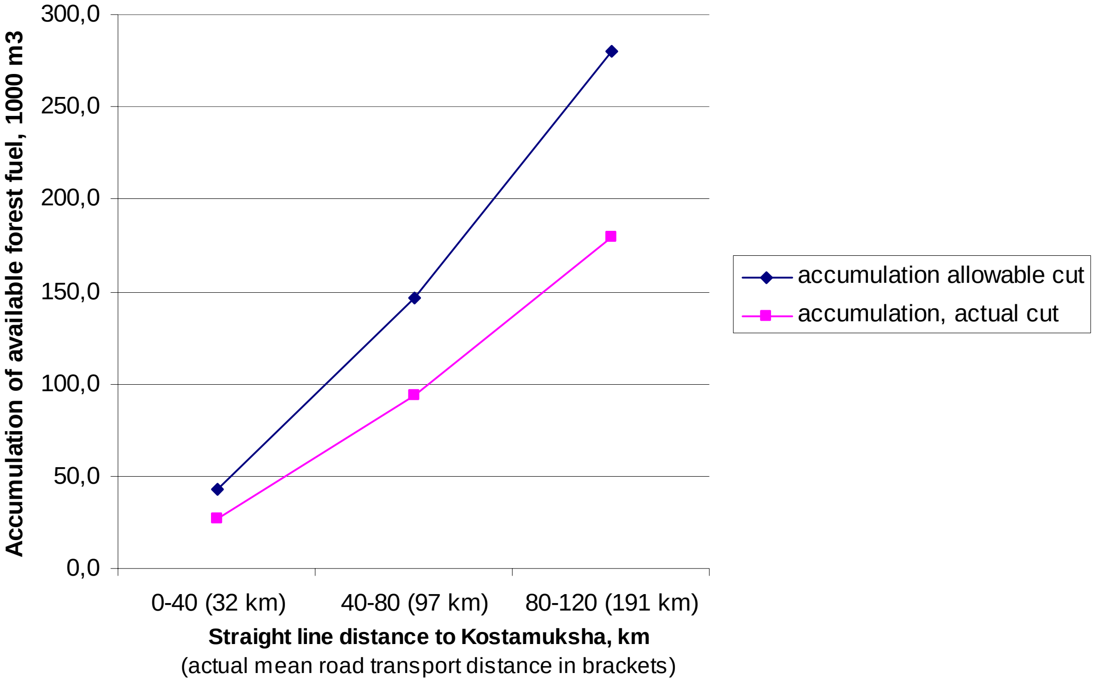


Figure 4. Accumulation of annually available forest fuel as a function of straight-line distance to Kostomukshsky.

3.4 Peat resources in the study area

The peat resources in Kalevalsky, Muezersky and Kostomukshsky administrative districts are remarkable (Table 8). The total peat resources suitable for peat production are 326 TWh. The main share (87 %) of the peat resources is located in Kalevalsky administrative district.

Table 8. Peat resources in Kalevala, Muezersky and Kostomukshsky administrative districts (Gerasimov 2008).

District	Number of peat fields	Area, ha	Stock of peat 1000 tons (moisture content 40 %)	Stock suitable for industrial exploitations, 1000 tons (moisture content 40 %)	Energy content of the peat, TWh (moisture content 40 %)
Kalevalsky		43834	104697	87135	282
Muezersky	195	4667	13721	13700	44
Kostomukshsky	72	8500	2230	-	-
Total				100835	326

3.5 Biomass resources in the region

The techno-economic potential of energy wood in former Kostomukshsky, Kalevalsky, Yushkozersky and Muyezersky forest districts is 358 GWh (179 100 m^3). The total peat resources suitable for peat exploitation in the study area are huge – altogether 326 TWh. The resources will last 326 years if the peat consumption would be 1 TWh per year.

4 Technical and economical assessment of energy wood procurement

4.1 Studied wood energy sources

Logging residues (LR)

Logging is defined as an operation during which timber is felled and extracted from forests (Dykstra & Heindrich 1996). In this study forest energy wood includes both logging residues and non-industrial round wood (Figure 5).

Logging residues mean in this study the branches and tree tops after delimbing. Volume of these equals to 8-10% of the felled stem volume. Lump stems include stems from improper cutting, forwarding or skidding, loading into truck, and tops of logs before transporting to central processing yard. Non-industrial wood includes round wood that is not suitable for forest industry because of its quality, size or tree species. It is often regarded as round wood of firewood quality (Gerasimov et al. 2006).

The logging residues harvesting is generally done only on final felling areas where cutting is done in a mechanized way. Logging residues from manually cut areas and from thinnings are not included in the study because of the high accumulating and forwarding costs. In the mechanized final felling, it is usually possible to process the trees from the strip road and pile the residues on one side of the strip road. This procedure improves the productivity of the forwarding of residues compared to manual felling, where residues are left spread out evenly over the felling area.

According to the norms for felling operations in Russia, all loose logging residues have to be accumulated and piled because of a high risk of forest fires. Most residues are usually used for strip road improvement. In addition, a significant amount of lower value wood is used for forest road construction. It has been estimated, by taking into account that a lot of felling operations take place in winter when the residues are not needed for strip roads, that about 60 % of logging residues from final fellings can be used for energy production (Ilavský et al. 2007).

Non-industrial wood (NIW)

Non-industrial wood comes from final fellings integrated in normal industrial wood supply chains for tree-length and full-tree harvesting methods. It includes stem wood that does not meet the standards for ordinary industrial wood (e.g. decayed, dry or damaged wood). Because forests are unmanaged in general, the proportion of non-industrial wood compared to industrial wood is substantially high.

Small wood (SW)

Small diameter wood is harvested from thinnings and from forest improvement cuttings. About 50 % of this wood is used by the forest industry and the rest is available for energy production. Small wood chips are a rather expensive fuel compared to logging residue chips. The biggest cost difference compared to logging residues takes place in the felling-bunching work phase. Productivity (about 5 m^3/h) of felling-bunching of small dimension trees is much lower than that of bigger trees in final fellings.

Logging residues are a side product of bucking and delimbing of trees at the stand or road-side, whereas small wood is the primary product that is to be harvested in special operations. Thinnings are primarily done for silvicultural reasons. The cost of the small wood harvesting from thinnings in Tikhvin district in Leningrad region is around 9 €/m^3 (Ilavský et al. 2007) and the cost of logging residue piling while doing delimbing and crosscutting of the stems is roughly 0.3 €/m^3 (on average in Finland), thus the cost of small wood chips is inevitably higher that the cost of logging residue chips. However, the quality of small wood chips is better than logging residue chips and this makes SW chips a suitable fuel for small installations with higher chip quality requirements.

4.2 Studied harvesting systems

The supply chains of LR and SW chips are strongly determined by the method and place of the comminution of wood. The comminution can take place in terrain, in a landing area, at a terminal or at a power plant. Therefore, the production chains are often named after the comminution place (Leinonen 2004). The production chains studied here are chipping on the roadside, crushing at a plant and bundling of residues in a logging site. In previous studies, these methods have proved to be the most effective energy wood supply methods (e.g. Gerasimov et al. 2006, Ilavský et al. 2007). However, currently these methods are not used widely in practise in the studied area.

With regard to logging residue procurement this study is limited to final felling areas where a harvester is used. If the residues are to be recovered for energy, the harvesters should pile the residues along strip roads instead of directly in front of the machine (Brunberg et al. 1994). Piles that are alongside strip roads are easier to recover compared to piles that are on the strip road and therefore can get easily run over by a forwarder. The piling increases productivity of terrain transport or chipping and reduces contamination of logging residues (Ranta 2002). The piling of residues does not necessarily decrease the profitability of felling However, a logging entrepreneur in Finland usually gains compensation for logging residue piling (Ranta 2002).

Procurement chains for the harvesting of small wood chips studied in this research were chipping on the roadside and crushing at a plante the studied. In the initial felling and piling work phase of the supply chain, only mechanized felling method was studied. Based on similar studies, a medium sized harvester equipped with an accumulating felling head was chosen for calculations. This type of machine is capable of felling and bunching several stems simultaneously.

Figure 5. Wood chips in Kostomukshsky (photo by Arvo Leinonen).

4.2.1 Chipping at roadside

LRs are accumulated from mechanically cut final felling areas where the dominating tree species is pine (*Pinus sylvestris*). The residues are piled at logging site during the delimbing of trees and crosscutting of stems (Figure 7). After cutting LRs are forwarded to the roadside storage with a medium size forwarder (12 ton load capacity). Chipping takes place on roadside where the residues are chipped and blown directly into a container of a chipper truck or into a separate chip truck (Hakkila 2004).

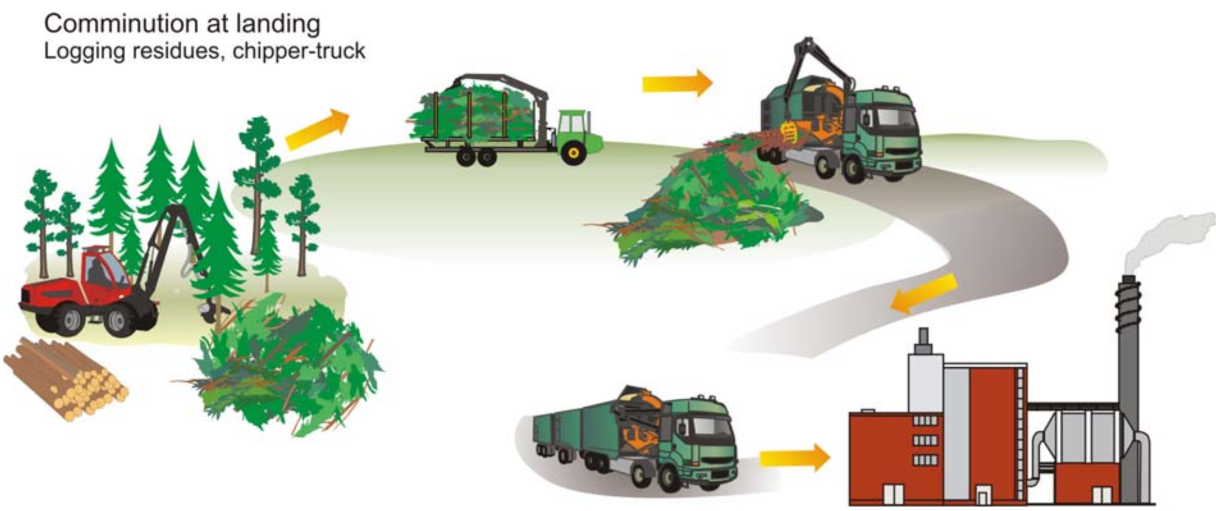


Figure 6. Chipping at the roadside method for logging residues harvesting (picture from VTT).

The weakness of the roadside chipping method is that the effectiveness of a chipper and a chip truck depend strongly on each other. The close linkage of chipping and road transport easily result in waiting and interruption, and thus reduces the operational efficiency. A considerable part of the time consumption of the chipper or chip truck may consist of waiting. A smooth interaction of chipping and road transport is the most vulnerable link of the supply chain. However, over 50 % of logging residues, harvested annually in Finland, are harvested with chipping on the roadside method (Kärhä et al. 2006).

4.2.2 Crushing at a plant

In the crushing at a power plant method (Figure 8) the terrain haulage is done with a forwarder just like in a roadside chipping method. A residue truck is equipped with a loader and therefore the driver of the truck can do the loading on the roadside and transport residues to the plant where they are comminuted. Crushing (or chipping) at a plant makes the chipper and chip truck independent of each other which makes organization much easier. Truck chippers can be replaced by effective stationary (or mobile) crushers suitable for comminuting all kinds of biomass, including stump and root wood and recycled wood. The larger the fuel flow is, the more obvious becomes the advantages of using this chain. Since the investment cost is high, only large plants can afford a stationary crusher (Hakkila 2004).

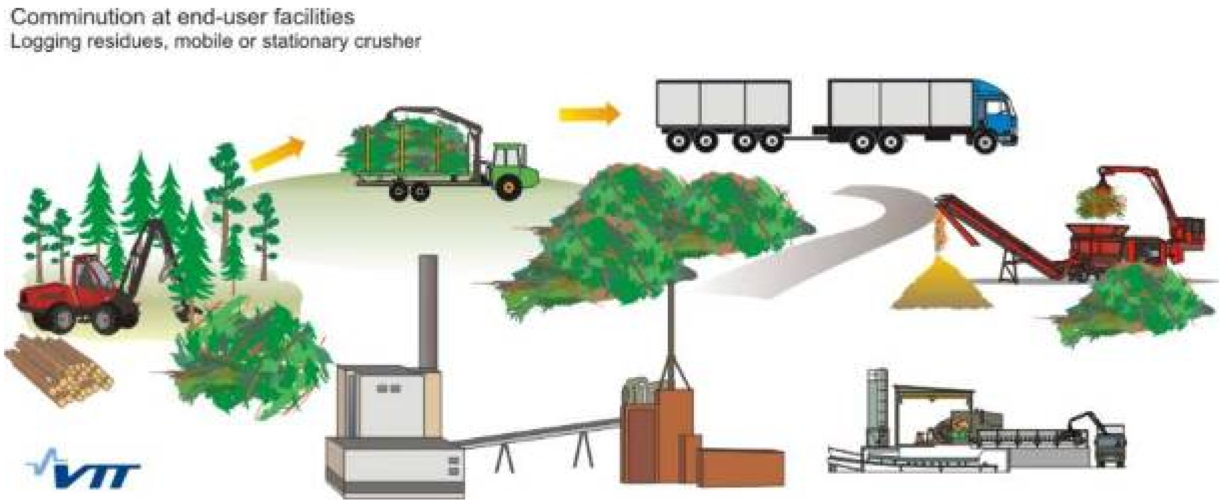


Figure 7. Logging residue harvesting with chipping at a plant method (picture from VTT).

When chipping is performed at a plant, truck transportation of residues takes place in the form of loose logging residues. The main weakness of this method is a relatively high road transport cost because of low bulk density of the loose residue load. This is the main reason why chipping is usually done already at a landing. Roughly 25 % of the annually harvested logging residues in Finland are chipped at a plant (Kärhä et al. 2004).

4.2.3 Bundling of logging residues

A significant amount of loose logging residues are generated during the final fellings. A low bulk density of loose residues makes the transport expensive. A bundling method was designed to reduce both the forwarding and the road transport costs, thus enabling longer transport distances and larger procurement areas (Figure 9).

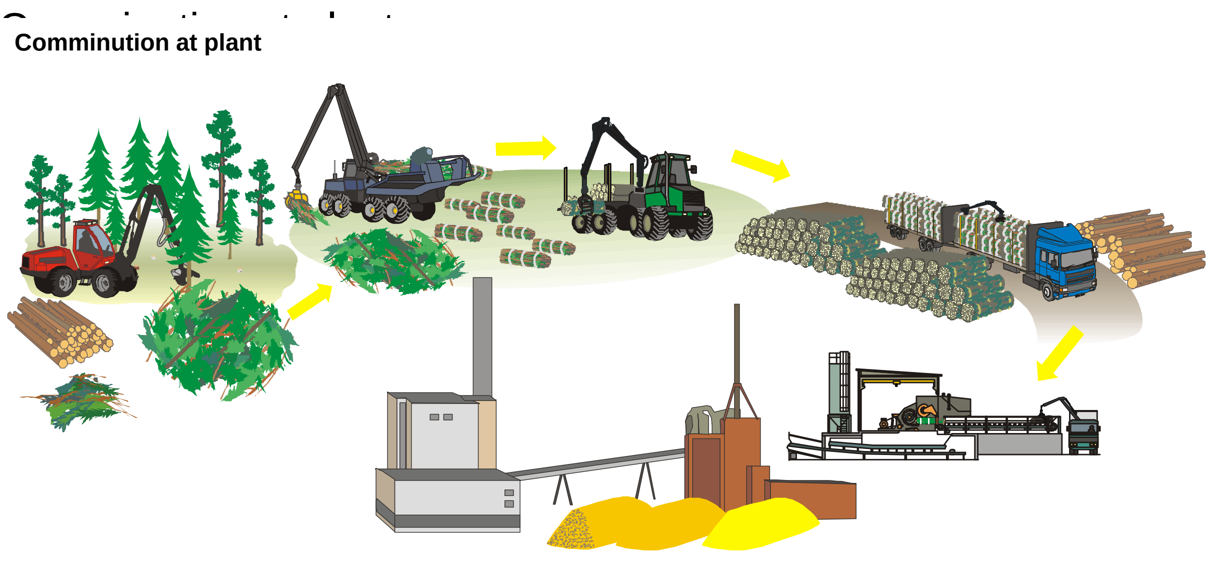


Figure 8. Logging residues harvesting with a bundling method (picture from VTT).

In bundling method the piled loose residues are bundled right after the logging with a special bundler, usually mounted on a conventional forwarder. In some models the same base machine can, after dismounting the bundling unit, be used for forwarding residue bundles to roadside. These bundles are then transported with a log truck to a power plant for end facility crushing. A bundle or as sometimes called, a residue log, contains 0.5-0.7 m^3 of biomass. The productivity of bundling varies substantially from 15 bundles per hour to 27 bundles per hour, depending primarily on the bundler (Kärhä et al. 2004). The forwarding productivity of logging residue logs in Finland is 20-30 m^3/h (Kärhä et al. 2004).

4.3 Wood chip harvesting cost calculation method and basic data

4.3.1 Energy wood procurement cost calculation method

The wood chip production costs were calculated with the cost calculation model of VTT. There were several phases in the calculation of the total wood chip production costs for power plant. Small wood from thinnings was not included in the techno-economic wood energy potential of energy wood in forest districts nearby Kostomuksha becaause of high production costs. However the results of the harvesting cost calculation of small wood harvesting for enrgy from thinnings have been presented in this report.

The annual hourly cost (€/h) for each machine in the harvesting chain were calculated first. In the hourly cost calculation the total annual costs (€) for every machine in the production chain were calculated first, after which the hourly machine cost were calculated when the annual total costs and the annual working hour for each machine are known.

After defining the hourly costs of the machines, *the machine costs per a volume unit* (€/m^3) for every machine in the harvesting chain can then be estimated by dividing the machine hourly cost with the productivity of each machine correspondingly. The total machine costs were calculated by summing all the machine costs in the harvesting chain.

The total wood chips cost (€/m^3) were calculated as a sum of the cost of wood resources (a stumpage price), costs of producing energy wood at each production stage (machine costs) and additional expenses (e.g. organization, administration, marketing, etc.). In the Kostomukshsky district, however, the logging companies have leased the logging sites and, therefore they do not have to pay any stumpage price for energy wood. The wood chip production costs are presented as a function of the road transport distance.

After defining the actual road transport distance of wood chips it was calculated the actual wood chip production costs at the power plant in Kostomukshsky.

The main cost factors of the machine hourly cost calculation are capital, labour and operating costs. They can be further divided into fixed and variable costs. Fixed costs (investment for the machine) do not depend on the utilization level but they are solely time dependent. Variable costs, however, depend very much on the utilization rate, i.e. how much the machine is used over a certain period of time. The variable costs consist of fuel, oil and maintenance costs. Labour costs consist of worker's wage.

Energy wood was assumed to be harvested from two types of fellings. Logging residues and non-industrial wood are harvested from regular final fellings, and small diameter wood from thinnings (mean stem volume 30 dm^3, dbh <10 cm) stands. The production costs were calculated by using the information presented in the following chapter and forest inventory data of Metla (Tables 1, 2 and 3) (Figure 10).

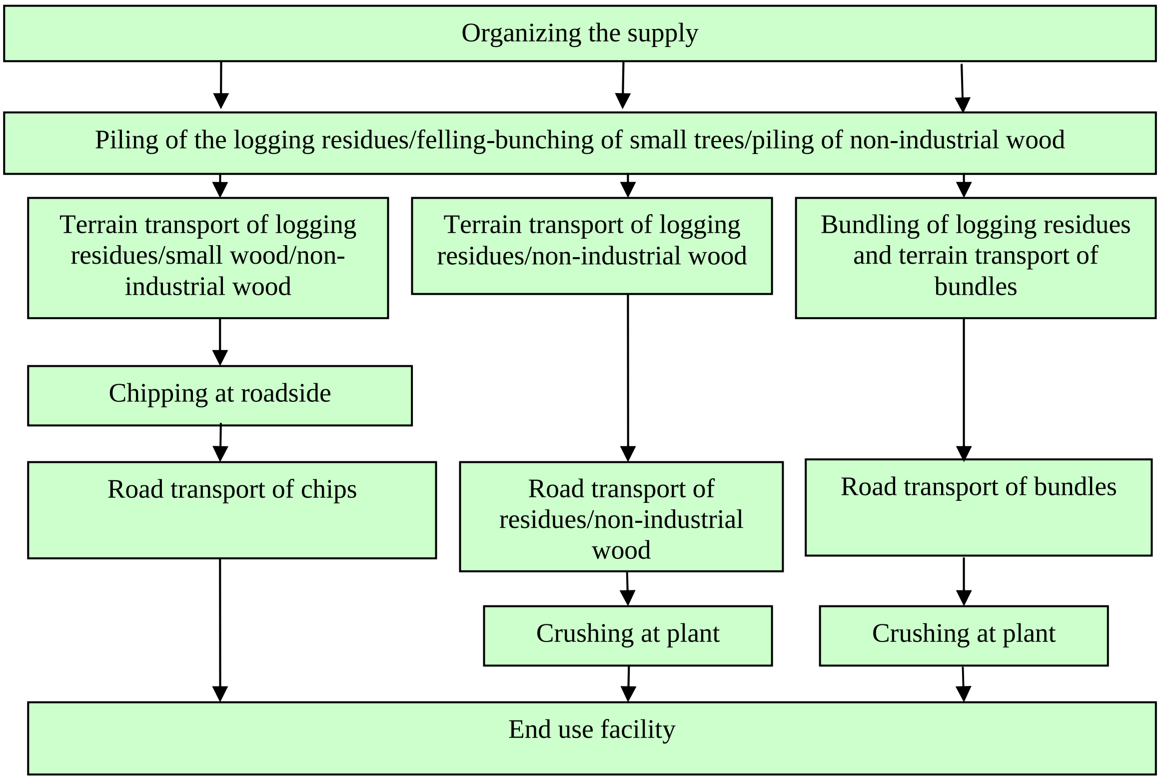


Figure 9. The studied logging residue, small diameter wood and non-industrial wood chip harvesting chains.

4.3.2 Basic data for wood chip cost calculation

Purchase prices of the machines were collected from manufacturers. Machines chosen for the study are conventional machines widely used in Finland for similar energy wood procurement operations. Other detailed information, used in calculations, is based on previous studies (e.g. Virkkunen 2008) and on interviews of forestry contractors in Leningrad region (Ilavský et al. 2007 and Gerasimov et al. 2006). The results presented in Wood Energy Technology Programme 1999-2003 (Hakkila 2004) have also been used in the evaluation of the machine productivities.

One euro corresponds to 41.6 rubles (January 2009).

4.3.2.1 Stand properties

Energy wood was assumed to be harvested from two types of fellings (final and thinning fellings). Forests in the Kostomukshsky, Kalevalsky, Yushkozersky and Muyezersky forest districts are clearly pine-dominant. The final felling stand properties of the Kostomukshsky forest district, that is the main perocurement district of the potential power plant, are presented in the following Table 9. The thinning stand properties are presented in Table 10.

Table 9. Characteristics of an average final felling stand in the procurement area (RW = Round wood, volumes under bark, min. top diameter 7 cm).

Variable	Unit	Value
Felling area (average stand)	ha	15
Roundwood accumulation	m^3 (solid)/ha	156
- Conifers	%, of RW accumulation	99
- Non-conifers (broadleaved)	%, of RW accumulation	1
Logging residue accumulation	m^3 (solid)/ha	25
Terrain transport distance	m	400
Initial moisture content	%	55
Recovery rate	%	60

Table 10. Characteristics of an average thinning stand in the procurement area.

Variable	Unit	Value
Felling area (average stand)	ha	15
Energy wood accumulation	m^3 (solid)/ha	30
Conifers	%, of RW accumulation	99
Non-conifers (broadleaved)	%, of RW accumulation	1
Terrain transport distance	m	400
Initial moisture content	%	55
Storage (at roadside)	months	8

4.3.2.2 Machines in the working phases

In the cost calculation it was assumed that energy wood is harvested as whole trees and seasoned on the roadside for about 8 months before further operations. Logging residues from final fellings and small wood from thinnings are transported to the roadside using a forwarder.

A stationary crusher was chosen for the comminution at plant method because most of the comminution can be done at the plant in Kostomukshsky as cost-effectively as with mobile chippers. If the load sizes of residue trucks can be increased, crushing becomes even more economical. In addition, having a terminal storage of wood fuel at the power plant removes the problem with a close linkage between road transport and chipping, and enables selection of the best fuel fraction for each season of the year.

The cost data for a stationary crusher is based on the studies of VTT. The studied terminal crusher is a slow rotating crusher with a crushing capacity of 325 GWh of forest fuels per year. The applied annual operating time is 2000 h. The service time of the wearing parts of the crusher is 10 years (rotors and engine) and for the other parts (frame and foundation) 20 years. The total investment cost is 780 000 € divided equally between the wearing parts, and the frame and foundation. The capital cost was calculated with the annuity method for 10 and 20 year periods, the depreciation value being 0 €. The applied interest rate is 15 %. The crusher is fed by an external machine with an hourly cost of 33 €/h. The applied electricity price for the crusher is 30 €/MWh and electricity consumption 3 kWh/MWh correspondingly. Insurances are 0.4 % of the total investment. Unexpected costs, costs for maintenance, administration, waiting times and margin (5 %) are included in the calculation. As a result, the total cost for comminuting forest fuels with the terminal crusher amounts to 1.17€/MWh. Based on the studies of VTT on crushing of forest fuel at a power plant, the cost of crushing with mobile crushers has been roughly double the cost of stationary ones.

Two types of trucks were studied: chip trucks (LRCT = logging residue chip truck, SWCT = small wood chip truck) are used in the roadside chipping method and logging residue or small wood trucks (LRT, SWT) are used in the chipping at a plant method. The latter truck type is designed for uncomminuted material transportation and the truck is equipped with a loader and an extendable load space to fit a loose residue or small wood load. The total weight of an each truck type was limited to 40 tons (payload about 20 tons) because of unpredictable forest road conditions in Russia (Table 11).

Table 11. Applied load sizes and material properties in road transportation for logging residue (LR), logging residue chips (LRC), small wood (SW) and small wood chips (SWC). (LRCT = logging residue chip truck, SWCT = Small wood chip truck).

Truck type	**Value**
Net load volume, Chip truck, LRCT, solid-m^3	28
Net load volume, Residue truck, LRT, soldi-m^3	19
Net load volume, Chip truck, SWCT, solid-m^3	28
Net load volume, Small tree truck, SWT, solid m^3	19
Chip load density, %	40
Loose material load density (LR, SW), %	18
Density, kg/solid-m^3 (40 w-%)	425
Transport moisture content, %	40

4.3.2.3 Machine productivity

Different logging site factors like a tree species, amount of residues, forwarding distance and road transport distance naturally have direct effects on these productivities (Table 12). The productivity is presented in effective hour. The share of effective hour from the work (machine utilisation rate) place time depends on the machine and varies from 60 % to 85 %. *The productivity of forwarding, chipping and road transport in Kostomuksha case is 10 – 20 % higher than in Finland harvesting logging residues for energy. The reason for that is the high share of stem wood (non-industrial wood) in logging residues from final fellings.*

Table 12. The applied productivities (productivity per effective hour) of different forest machines.

Type of machine	**Productivity, m^3/h**
Harvester	5[1]
Forwarder	7.9[1], 9.3[2], 13.1[3]
Bundler	11.2
Chipper	40, (100)[4]
Crusher	80

[1] 1st thinning, [2] Loose residues, [3] Bundles and [4] Loose-m^3

4.3.2.4 Machine investments and operation costs

Initial cost factors for different machines and calculated machine hour are presented in the following Table 13.

Table 13. Initial cost factors for the studied machines including salaries and calculated machine hourly cost for logging residues and small wood procurement chains for energy Kostomukshsky and neighbouring regions.

Type of machine **Logging residues (LR)**	**Purchase price (€)**	**Interest rate (%)**	**Depreciation (%)**	**Service time (a)**	**Calculated hourly cost (€/h)**
Forwarder (medium size)	250 000	15	25	6	45
Roadside chipper	400 000	15	20	8	143
Chip truck	240 000	15	23	7	41
Residue truck	260 000	15	23	7	45
Bundler	395 000	15	20	7	77
Stationary crusher	780 000	15		10/20	189
Type of machine **Small wood (SW)**	**Purchase price (€)**	**Interest rate (%)**	**Depreciation (%)**	**Service time (a)**	**Calculated hourly cost (€/h)**
Harvester (small)	350 000	15	25	5	63
Forwarder (medium size)	250000	15	25	6	45
Roadside chipper	400 000	15	20	8	148
Chip truck	240 000	15	23	7	41
Residue truck	260 000	15	23	7	45
Stationary crusher	780 000	15		10/20	189

4.3.2.5 Other costs

The other costs in the cost calculation consist of overhead costs. The overhead costs consist of compensation cost of piling logging residues in felling phase, organisational costs, covering costs of stockpiles and marketing costs (Table 14). Logging residues and small wood are transported after seasoning at the stand, and therefore the costs for covering and storage losses due to decaying and needle drop off are included in the calculation.

Table 14. Applied 'other costs' for logging residue and small wood harvesting. CR means chipping at a roadside method, CP chipping at a plant method and SW small wood.

Other costs	€/m^3
Compensation for piling	0.3
Organisational costs, CR	1.3
Organisational costs, CP	1.0
Organisational costs, bundles	0.7
Organisational costs, SW	1.5
Covering (not for bundles)	0.9
Marketing	3.46

4.3.2.6 Salaries and fuel price

Forest machine operators work often in two or even three shifts in Russia. In this study, the calculations based on two shifts. The given figures are averages in the Leningrad region. Annual transfer distance was 5 000 km for each machine. The applied piecework pay and the hourly pay for other working times varies from 7.0 €/h to 9.0 €/h and the shift work compensation was 20 % of the regular wages. The overheads (33 %) were added to all wages. The fuel price (0.68 €/l) was considered equal for both forest operations and for on-road operations. Forest machines are procured in three ways in Russia: to purchase with own funds, to purchase with a bank loan or to lease. The applied interest rate 15 % was the same as used for leased machines. Capital costs were calculated by using an annuity method.

4.4 Production costs of wood chips from final fellings

Table 15 and Figures 11 and 12 show the costs of wood chips produced from wood from final fellings with different methods. Wood chips made from non-industrial wood are included in this calculation. The cost figures below are the mean values of the supply chains of both logging residues and non-industrial wood. Harvesting costs are not included, however, because wood chips from final fellings are considered to be a by-product of round wood procurement.

Table 15. Production costs of wood chips from final fellings with different wood chip procurement methods.

Distance from logging site to end user, km	30	60	100	140	180
Costs, €/MWh					
Chipping at a roadside -method: Harvester, forwarder, chipper, chip truck					
Forwarding	2,75	2,75	2,75	2,75	2,75
Chipping	2,28	2,28	2,28	2,28	2,28
Road transport	2,18	3,08	4,04	5,02	6,01
Other costs	3,10	3,10	3,10	3,10	3,10
Total, €/MWh	**10,32**	**11,21**	**12,17**	**13,15**	**14,14**
Chipping at a plant -method: Harvester, forwarder, residue/log truck, stationary crusher					
Forwarding	2,75	2,75	2,75	2,75	2,75
Road transport	3,20	4,25	5,61	6,88	8,10
Crushing	1,21	1,21	1,21	1,21	1,21
Other costs	3,07	3,07	3,07	3,07	3,07
Total, €/MWh	**10,23**	**11,28**	**12,63**	**13,91**	**15,13**
Bundling-method: Harvester, bundler, forwarder, log truck, stationary crusher					
Bundling	3,55	3,55	3,55	3,55	3,55
Forwarding	1,60	1,60	1,60	1,60	1,60
Road transport	3,19	4,40	5,77	7,05	8,28
Crushing	1,17	1,17	1,17	1,17	1,17
Other costs	2,29	2,29	2,29	2,29	2,29
Total, €/MWh	**11,80**	**13,01**	**14,38**	**15,67**	**16,90**

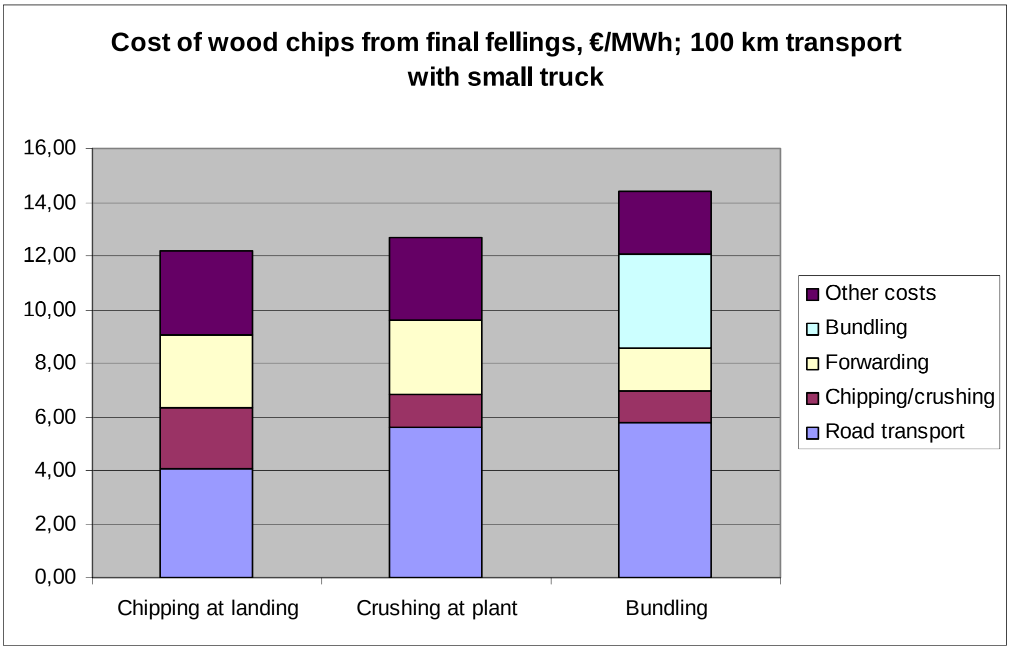


Figure 10. Procurement costs of wood chips from final fellings with three different supply chains if the average distance from the power plant is 100 km. The chip truck holds 70 loose-m³ of chips, the residue truck holds 105 loose-m³ of logging residues and the residue log truck holds 46 bundles, and the maximum weight of a log truck is 40 tons.

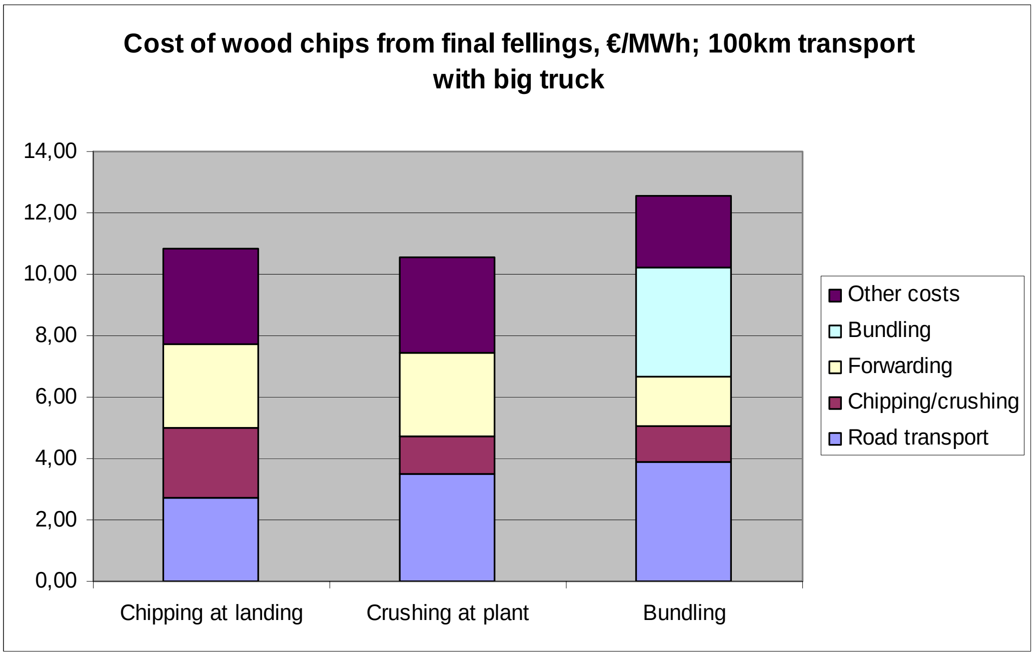


Figure 11. Procurement costs of wood chips from final fellings with three different supply chains if the average distance from the power plant is 100 km. The chip truck holds 115 loose-m³ of chips, the residue truck holds 145 loose-m³ of logging residues and the residue log truck holds 70 bundles, and the maximum weight of a log truck is 60 tons.

The chipping at the roadside method (CR) is slightly the most economic supply chain. Only in short distances (<45 km) it seems more economic to transport all wood chip material to the plant and do the crushing there. However, if larger trucks (60 ton) can be used, the crushing at a plant method (CP) becomes the cheapest chain up to maximum road transport distance of 100 km. If the residue truck has enough load space, transporting of loose residues appears to be very competitive compared to transporting of chips because in the studied areas the loose residues contain a lot of stem wood (such as lump stems). High bundling costs make the bundling method (B) the least economic in all distances.

4.5 Production costs of wood chips from thinnings

In the Northwest Russia most forests are unmanaged. This means that tending and thinning operations are badly neglected. The vast majority of round wood comes from final fellings. This is clearly seen in the Table 1. Because thinning operations are rare, it is very challenging to estimate the procurement costs of small diameter energy wood coming from thinnings. Some up to date information was given by local forestry companies (gathered by Metla). Otherwise calculations are based on experience and previous studies made by VTT.

In the calculation it is assumed that energy wood is harvested as whole trees and seasoned on the roadside for about 8 months before further operations. By the time of chipping the moisture content has decreased to 40 %. The wood chip harvesting costs are presented in the Figure 13. The wood chip production costs from thinnings are high - 20 €/MWh - using chipping at roadside or chipping at plant -methods. The wood chip production costs are 7 – 9 €/MWh higher those of wood chip production from final fellings. *Because of the high wood chip production costs and low potential the wood chips from thinnings is not included in the wood chip potential.*

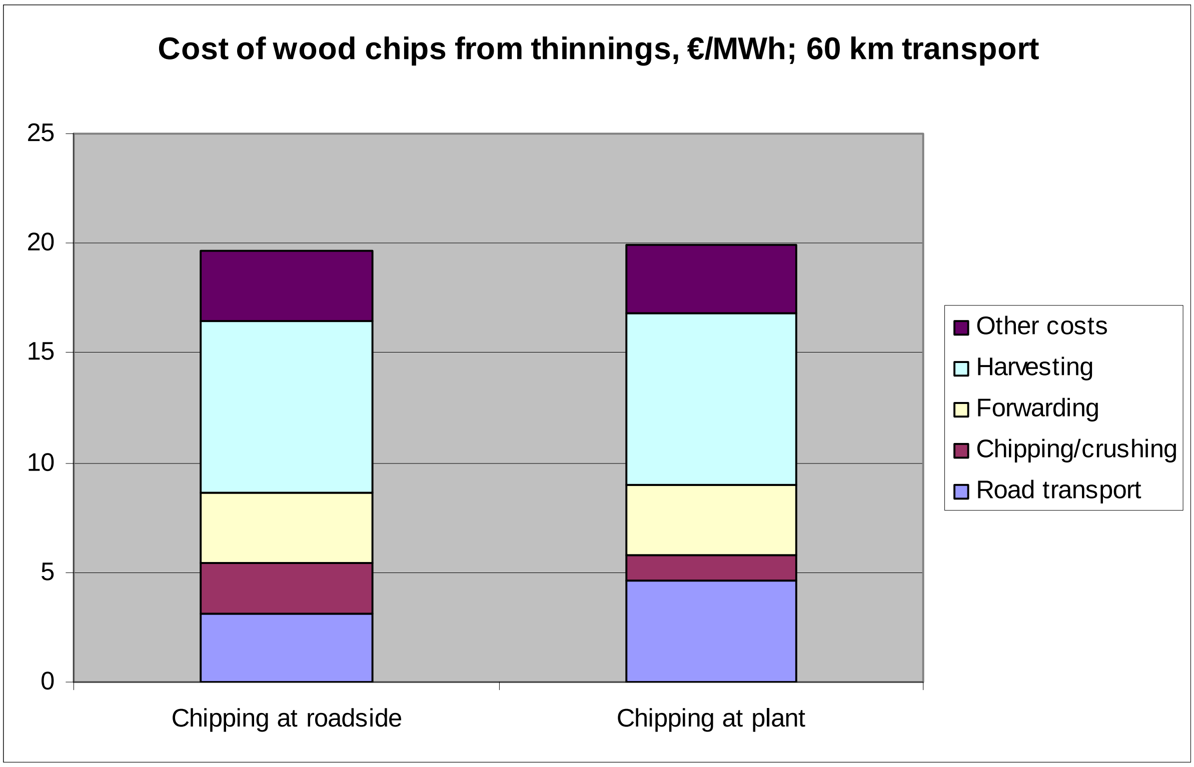


Figure 12. Procurement costs of wood chips from thinnings with chipping on the roadside and chipping at a plant supply chains. The applied transport distance is 60 km.

4.6 Wood fuel procurement costs for the Kostomukshsky power plant

4.6.1 The calculation method

Exact road network and felling site location data were not available for procurement cost calculations in the study area. For estimating the transport distances for energy wood in the area, a winding coefficient was used for attaining actual transporting distances (Villa 2007). The coefficient is based on the relation between straight line distance and road distance from logging company headquarters in each forest district to Kostomuksha. The applied coefficient in the study is 1.61.

For estimating the distribution of available forest fuels in the area, the area was split into transporting distance zones. The locations of the zones were measured with straight-line distances and converted to transporting distances by multiplying the average straight line distances of each zone with a winding coefficient.

Table 16. Road transport distances and forest fuel accumulation on the study area

Procurement zone, km	Middle point, km from Kostomuksha	Actual transporting distance to Kostomuksha, km	Share of forest fuel accumulation in the zone
0-40	20	32	15 %
40-80	60	97	37 %
80-120	100	161	48 %

4.6.2 Wood chip production costs for the power plant

Bundling method is feasible for harvesting branches and treetops and due to large share of large-size stemwood in the energy wood amount, bundling method calculations were not included in the total procurement cost calculations. The Figures 14 and 15 present the available amount of forest fuel from final fellings within transporting zones and average forest fuel procurement costs with chipping on roadside and chipping at plant methods.

A chipping at the roadside method has the lowest costs with all studied transporting distances. The average road transporting distance for utilizing all available forest fuel in the area is 118 km. If it is assumed that all forest fuel is procured with chipping on the roadside method, the weighted average cost of chips delivered at plant is 12.6 €/MWh.

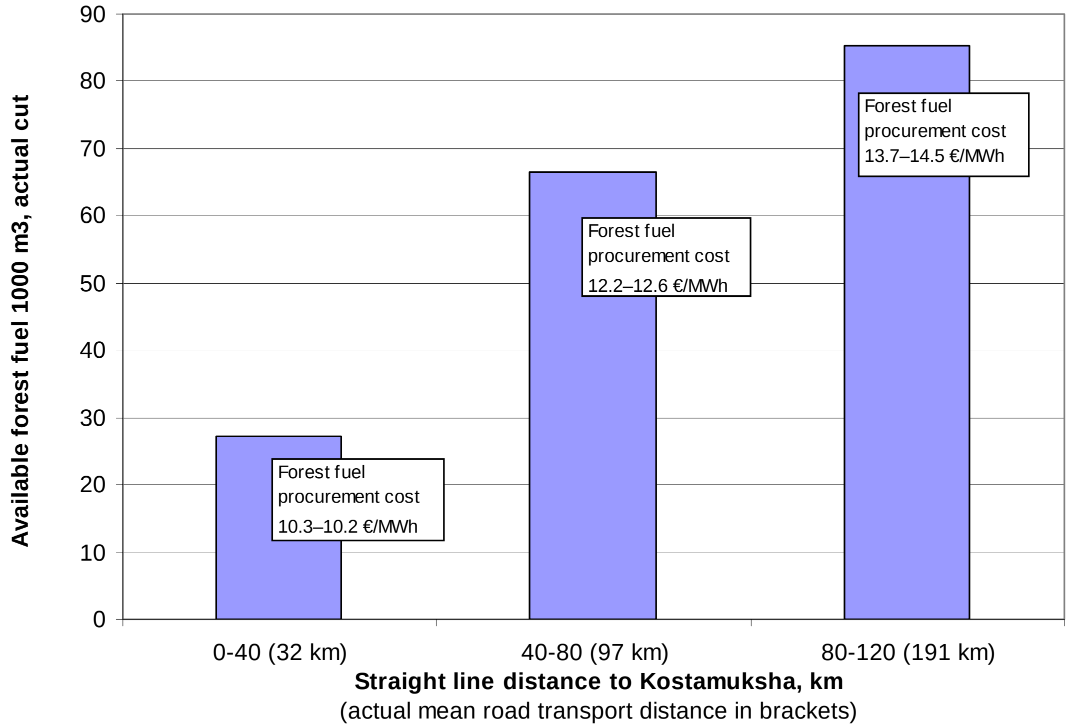


Figure 13. The availability of wood chips from final fellings and the average procurement costs with the chipping at a roadside and chipping at a plant methods based on the actual cut. The first figure in the column refers to the chipping at a roadside -method and the second figure refers to the chipping at a plant -method. The actual mean transport distance is in the brackets.

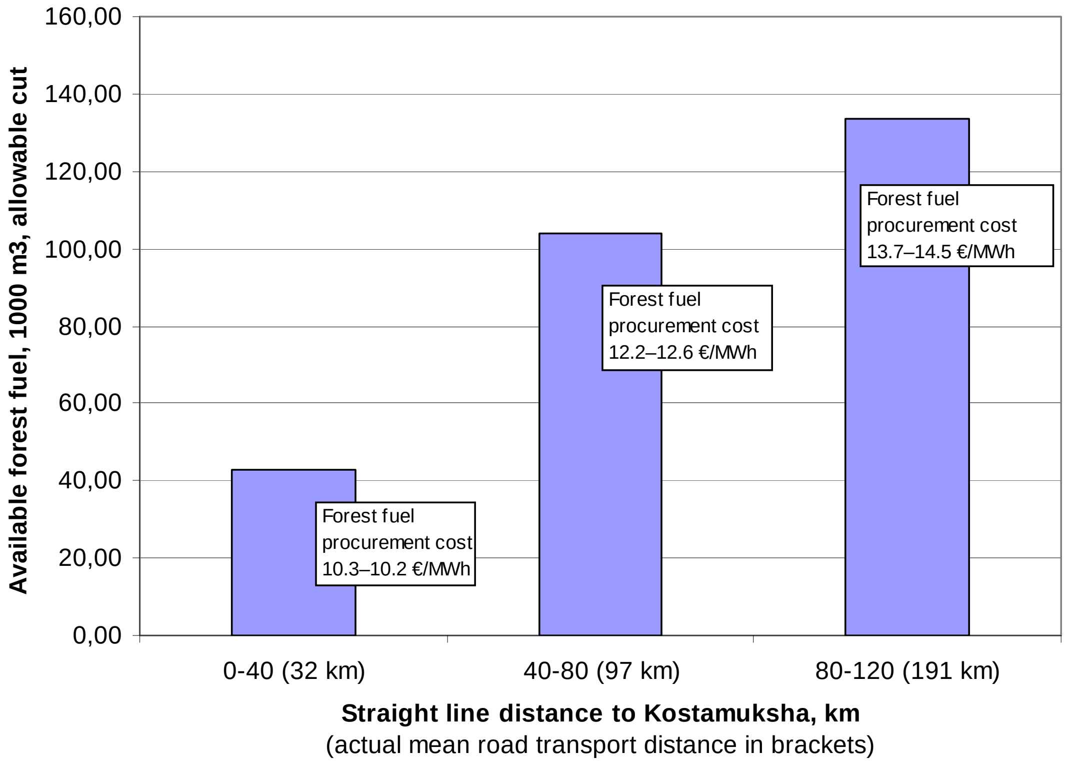


Figure 14. *Available forest fuel from final fellings and average procurement costs with chipping at roadside and chipping at plant -methods based on the allowable cut. The first figure in the column refers to the chipping at a roadside -method and the second figure refers to the chipping at a plant -method. The actual mean transport distance is in the brackets.*

5 Technical and economical assessment of the biomass power plant

5.1 Current situation

In Kostomuksha the energy system consist of a boiler house situated near iron pellet mill owned by JSC Karelskij Okatysh (KO) and of the heat transmission and distribution systems for the iron pellet mill and for the town of Kostomuksha. All heat is produced in the boiler house. Heat is distributed by KO for the iron mill premises and some industrial customers.

Nowadays (2008) there are four KVGM-100 hot water boilers and three GM-50 steam boilers for the heat production. Heavy fuel oil (Mazut) is the single fuel that is used to for energy production. The sulphur content of the heavy fuel oil is high – 3.5 %.

The energy system was mainly established at the end of 1970´s. Oil fired boilers have been repaired in every 8 - 12 years but no actual modernisation has been made. The electricity for the town of Kostomukshsky and for iron pellet mill is bought from the grid.

This study deals with a power plant situated in Kostomuksha, which will utilize local biomass fuels and coal. Possibilities to utilize local peat as fuel will also be discussed.

The aim of the study was to evaluate the feasibility of a biomass boiler plant investment in question. The effects of investment and fuel costs and some other factors on the total cost-effectiveness were calculated, as well as the effect on greenhouse gas and other emissions. The report summarises an overall feasibility evaluation touching on all relevant factors.

5.2 Energy demand in Kostomuksha

Table 17 presents the energy production capacities of existing oil fired boilers including iron pellet mill and other parties in year 2007. There is no electricity production in Kostomuksha area. Iron pellet mill has used 1.6 – 1.7 TWh of electricity per year. This means that the average electric power is 180 – 200 MW_e. Annual energy production was 743 GWh totally meaning average power of 85 MW_{th}.

In this pre-feasibility study it is assumed that heating energy demand will be at the same level in the future. A possible growth of energy demand is not included in this study.

Table 17. Heat production in Kostomuksha boiler plant in 2007

	MWh
Total energy production	743 000
Heat distributed	707 600
- Steam for own use	193 500
- Heat for town use	316 500
- Heat for own use	197 600
Consumption of Mazut oil (ton)	73 000

5.3 Power plant options

Because the energy demand at the site is quite large, totally more than 700 GWh/a, combined heat and power plant (CHP-plant) options will be analyzed in this study.

Based on energy demand of Kostomuksha town there are three different power plant options:

1) The power plant will produce heat and steam for the iron pellet mill and for the town and also electricity for the grid

Based on an energy demand of 743 GWh in year 2007 (Table 17), the following values for the plant are used:

- thermal output 140 MW,

- heat output 75 MW and steam output 25 MW and

- electric output 40 MW.

In the plant the fuel consumption will be 907 GWh/a, from which the share of biomass is about 40 % and the rest is coal or peat.

2) The power plant will produce heat and electricity for the Kostomuksha town

Based on the heat demand of the Kostomuksha town 317 GWh, the following values are used:

- thermal output 68 MW,

- heat output 50 MW and

- electric output 18 MW.

The fuel consumption in this power plant option is about 447 GWh/a, from which wood biomass share would be 80 % and the rest would be coal or peat.

3) Power plant is dimensioned on the basis of the biomass fuel potential

Based on at the available biomass resources 358 GWh/a, the following values are used:

- thermal output 54 MW,

- heat output 40 MW and

- electric output 14 MW

The best profit of combined heat and power generation will be achieved by combining both the heat demand of the pellet factory and the heat demand of the town. Because there is the existing infrastructure available (power plant site at the pellet factory, district heating network, etc.) the power plant option one was chosen as a base case assessment. Old oil fired boilers will be used for auxiliary boiler and for peak loads.

5.4 Base case assesment

5.4.1 Annual fuel use

In the cofiring CHP-plant the heat output is 75 MW, steam output 25 MW and electric power output 40 MW. The total thermal output of the boiler is 159 MW. Annual fuel demand of the plant will be 907 GWh.

Following assumptions were made in the calculation the annual wood fuel demand:

- wood fuel is the main fuel; wood fuel is mixed with other fuels, in base case with coal but it is also possible to mix wood fuel with peat,
- average efficiency of the co-fired biomass and coal boiler is 88 % and
- fuel characteristics of wood chips and other biomass are as listed in Table 18.

Table 18. Average fuel characteristics of wood biomass.

	Design value	Design range
Moisture content, %	40	30 – 50
Lower heat value, MJ/kg (dry basis)	19.0	18 – 21
Bulk density, kg/m3	300	250 – 350

By taking the typical overall biomass boiler efficiency, 88 % with relatively wet fuels, into account, the annual fuel input for the biomass boiler would correspond to 358 000 MWh in energy. The required annual amount of biomass in tonnes can be calculated from the fuel input. Assuming that the biomass characteristics will be like those in Table 18, the annual amount of biomass would be about 124 600 tonnes, see Table 19.

There are 358 GWh of forest based biofuels in Kostomukshsky administrative district. Annual energy demand of the site would be 904 GWh. That means that there is not enough biomass fuels and also other fuels like coal, Mazut or peat have to be used.

KO has its own coal mines so the coal is an obvious fuel option for the power plant. Heavy fuel oil, Mazut, can also be used similarly as it has been used earlier.

The annual fuel consumption of biomass and fossil fuel in combined heat and electricity producing power plant has been presented in Table 19. Coal and peat are alternative fuels.

Table 19. Annual fuel consumption of the co-fired biomass and coal boiler. Coal and peat are alternative fuels.

Fuel	Heat value, MJ/kg (on wet basis)	Annual consumption, tonnes/solid-m^3	Fuel input, TJ/GWh	Share of the total energy
Wood fuel	10.4	124 600/179 000	1 289/358	40 %
Coal	18.4	107400/	1976/549	60 %
Peat	10	198000/	1976/549	60 %

Table 20 summarizes the fuel options for the energy production. The wood fuel cost is calculated in this study. The peat fuel price is evaluated based on the peat harvesting and supply costs in Finland. The coal price is from the iron mill plant.

Table 20. Fuel options for the new combined heat and power (CHP) plant. Coal and peat are alternative fuels.

Fuel	**Fuel quantity**	**Fuel price €/MWh**	**Comments**
Biomass	358 GWh/a	13	
Peat	326 TWh	9	There is no peat harvesting in the region
Coal		7	
Heavy fuel oil		15	S-content 3.5 %

5.4.2 Energy production costs

Energy production costs for CHP-power plant option, producing electricity for the grid, heat and steam for the mill and district heat for the town, were evaluated. CHP-plant produces heat and steam 100 MW_{th} and electricity 40 MW_e. Fuel power of boiler is about 159 MW_{th}. Annual fuel demand will be 907 GWh.

Figures 16-19 below present the results of production cost calculations, including sensitivity analyses. The following parameters were fixed in the calculations:

- circulating fluidized boiler, steam temperature 530 ^oC and steam pressure 100 bar,
- investment costs: € 140 million,
- labour costs: 4.5 €/kW (electricity + heat),
- maintenance costs: 2 % of the investment cost,
- electricity costs: 30 €/MWh at the site; use in biomass energy production 25 kWh per produced MWh (in heat),
- other costs for fuel : 2.0 €/MWh,
- fuel prices: biomass 13 €/MWh, coal 7 €/MWh, heavy fuel oil 15 €/MWh,
- interest rate: 9 % and

- investment pay-back period: 20 years.

The listed parameters are assumed to be good average values. They can easily be changed for recalculations.

The importance of fuel price (coal and biomass together) and investment cost appears still more clearly in Figure 16, in which all relevant costs of energy production are specified. Fuel and investment costs together account for more than 80 % of the total energy production costs. The other factors are of minor importance. It should be noted that the boiler efficiency 88 % was assumed in calculating the final fuel cost per energy unit (10.7 €/MWh), whereas the biomass fuel price for the boiler plant was taken as € 13/MWh and the coal price was 7 €/MWh in these calculations.

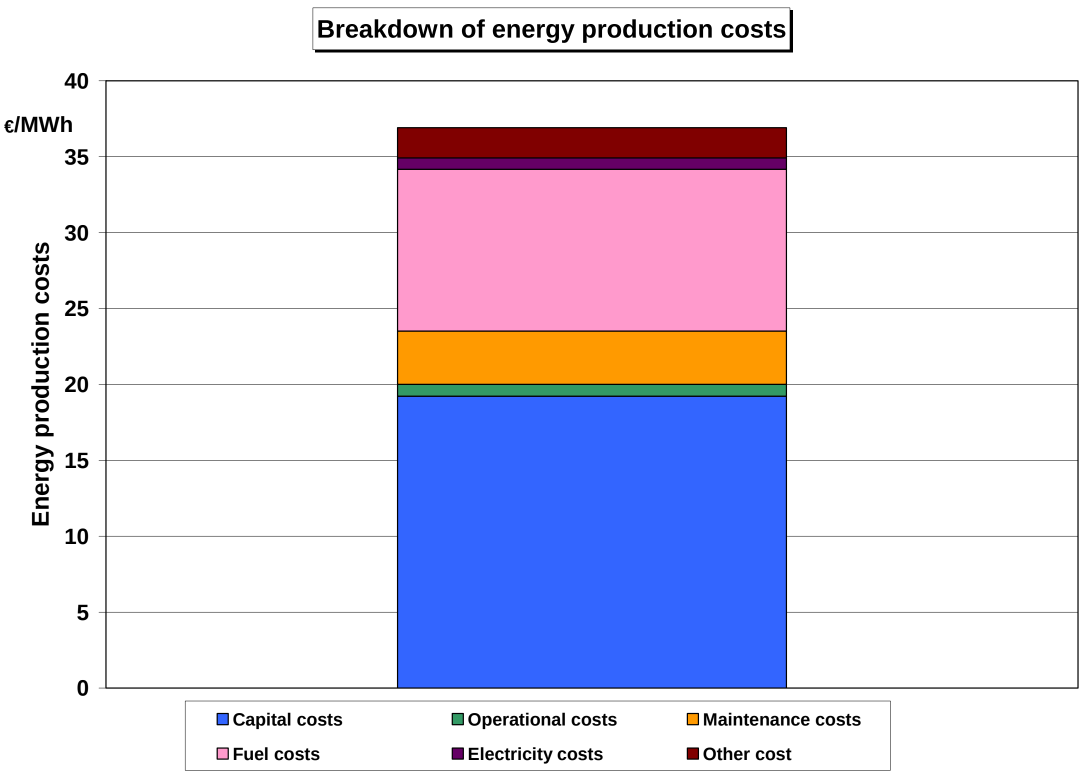


Figure 15. Breakdown of energy production costs in cofired biomass and coal plant. The base case investment cost is 140 milj. €, biomass price is 13 €/MWh and coal price is 7 €/MWh.

Figure 17 shows production costs as a function of investment cost with biomass fuel price as a variable. Since the final biomass fuel price is still not known precisely, the energy costs are presented also as a function of fuel price in Figure 17. As it can be seen, the biomass fuel price has not a significant effect on the total production costs. The investment cost affects heavily: if the investment cost (base € 140 million) is 20 % higher or lower, the effect on the production costs will be 4 - 5 €/MWh.

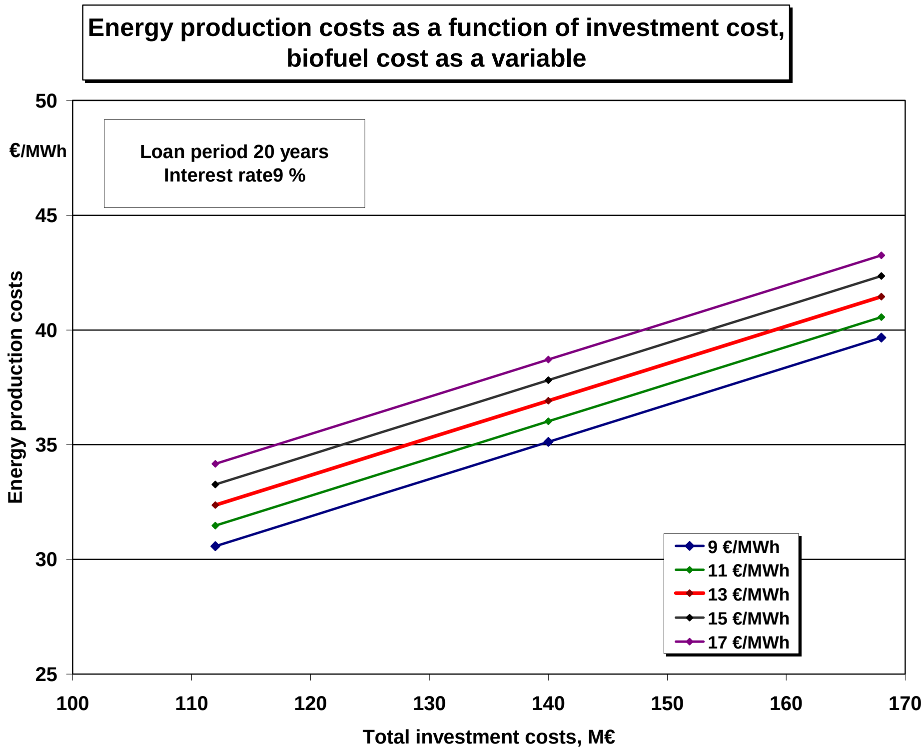


Figure 16. Energy production costs as a function of investment cost, biofuel cost as a variable. Coal price is 7 €/MWh.

Figure 18 shows the dependence of production costs on full load hours, investment cost as parameter. The unit costs in MWh depend quite strongly on the full load hours.

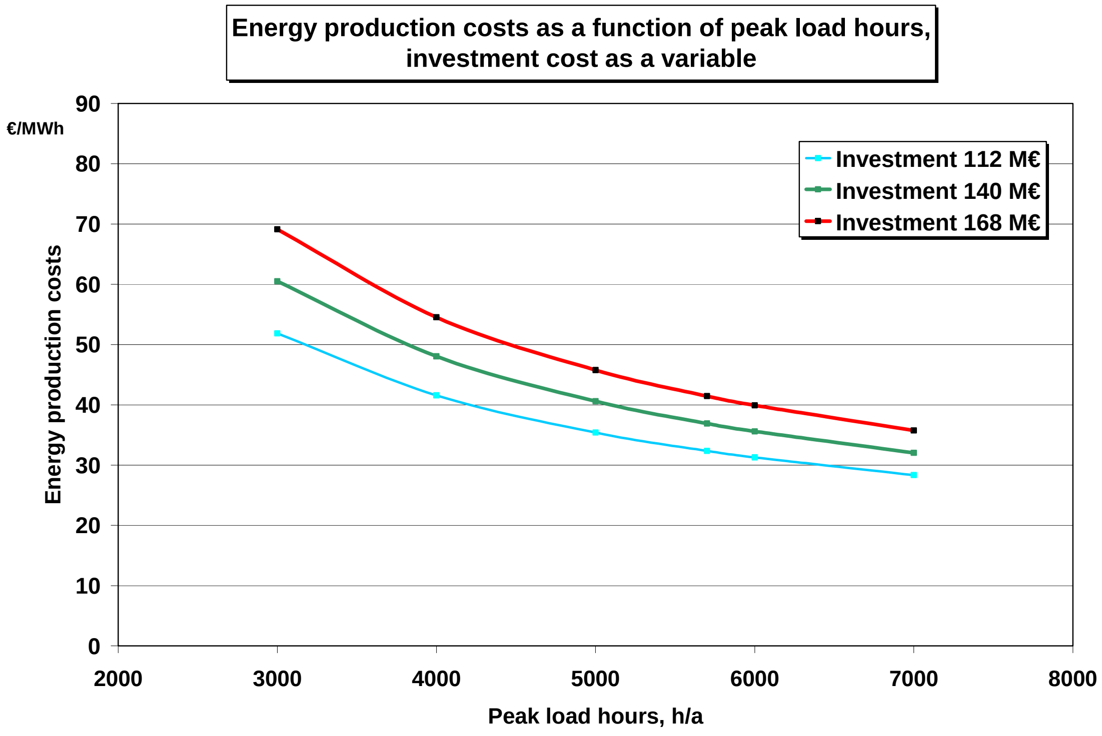


Figure 17. Energy production costs as a function of full load hours, investment cost as a variable. Wood Biomass price is 13 €/MWh and coal price is 7 €/MWh.

Figure 19 shows how the loan period and the interest of loan effects on energy production cost.

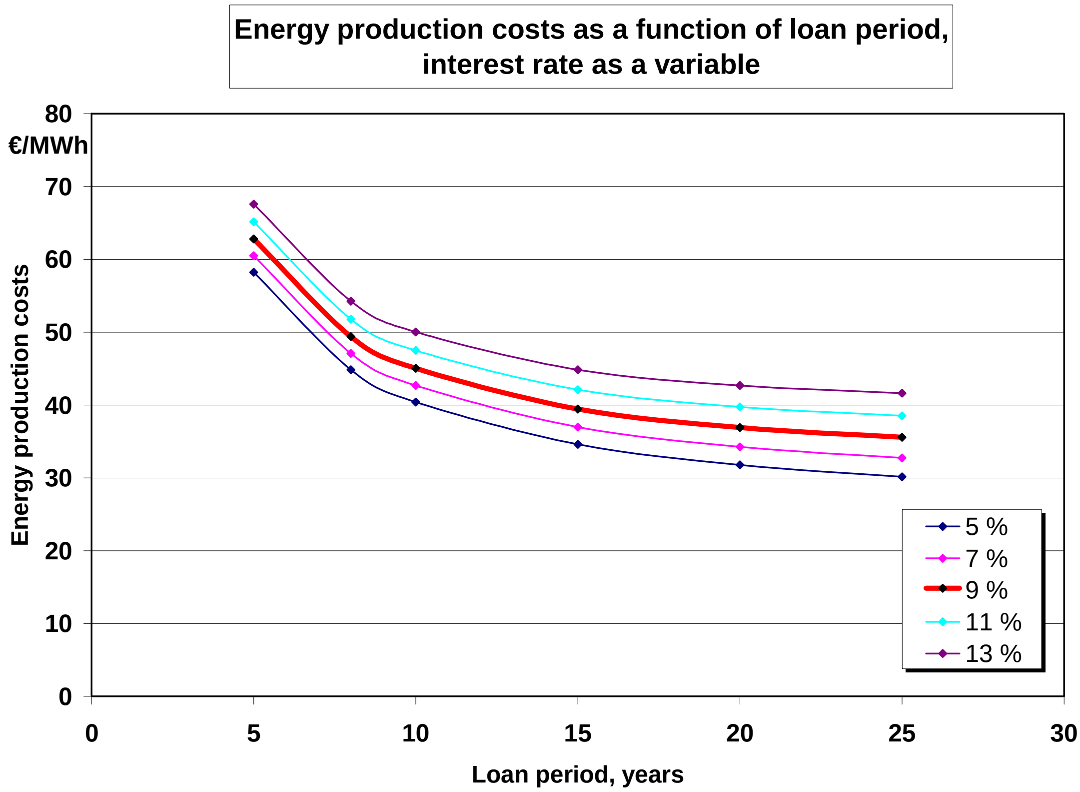


Figure 18. Energy production costs as a function of a loan period, interest rate as a variable. Investment cost for the plant is 140 million €, biomass price is 13 €/MWh and the coal price is 7 €/MWh

The annual energy costs can be calculated. If the annual energy production in form of heat is 798 000 MWh and the unit price of it € 36.9/MWh, the total annual costs are 29.4 M€.

5.5 Cost-effectiveness of the boiler plant investment

The overall cost-effectiveness of a co-fired biomass and coal power plant with the existing energy production system, based on the use of heavy fuel oil (Mazut) for energy production of same amount of electricity, purchased from electricity markets and produced with a CHP-plant are compared in this section (Table 21). It is assumed that the investment costs for old heavy fuel oil boilers plant are not included, and in the base case the price of heavy fuel oil € 15/MWh. The other cost factors are assumed based on general values for oil fired boiler plants. Figure 20 compares the energy production costs of co-fired biomass and coal CHP plant, equipped with the above mentioned oil fired system and the equal amount of electricity is purchased from the grid. Price of the electricity is assumed in base case to be 30 €/MWh.

Table 21. Energy production in cofired biomass and coal boiler and in Mazut fired boiler..

	Cofired boiler	**Mazut boiler**
Steam/heat production	570 000 MWh	570 000 MWh
Electricity production	228 000 MWh	
Purchased electricity		228 000 MWh
Total	798 000 MWh	798 000 MWh

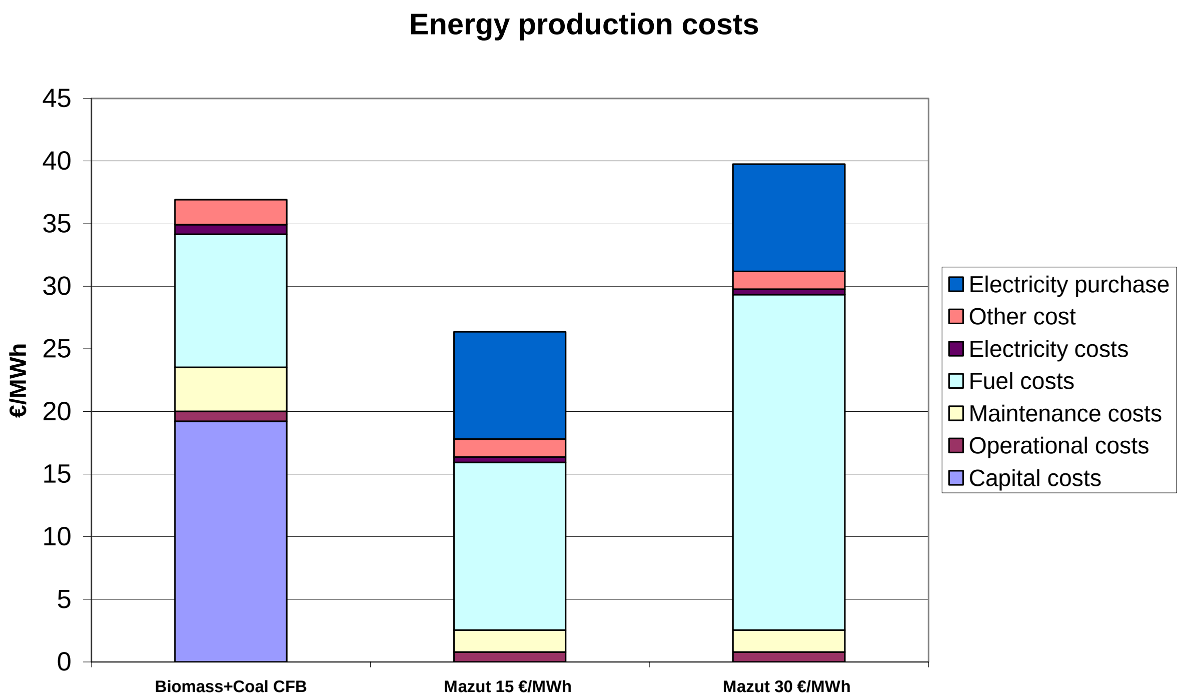


Figure 19. Breakdown of energy production costs in cofired biomass and coal and in heavy fuel oil boiler. Investment cost for the biomass plant is 140 Milj. €, wood biomass price is 13 €/MWh and coal price 7 €/MWh. The electricity price is 30 €/MWh.

The production costs of co-fired biomass and coal boiler are more expensive than those of oil fired boiler. In oil fired boiler the purchase of electricity is included in energy price. In Figure 20 we can see that the new co-fired biomass and coal CFB–boiler is not economic compared with existing system. Main reasons are that price of the Mazut oil is very low and so is the price of electricity. If the price of Mazut oil would double, then the new boiler plant will be able to compete with the existing energy system.

Figure 21 shows how the price of Mazut oil effects on the competitivity of the combined biomass and coal fired boiler plant. Same figure shows also how the electricity price effects on competitivity of a biomass boiler. In Figure 21 we can notice that the competitivity of cofired biomass and coal fired boiler increases when price of Mazut oil increases and also when the price of electricity increases.

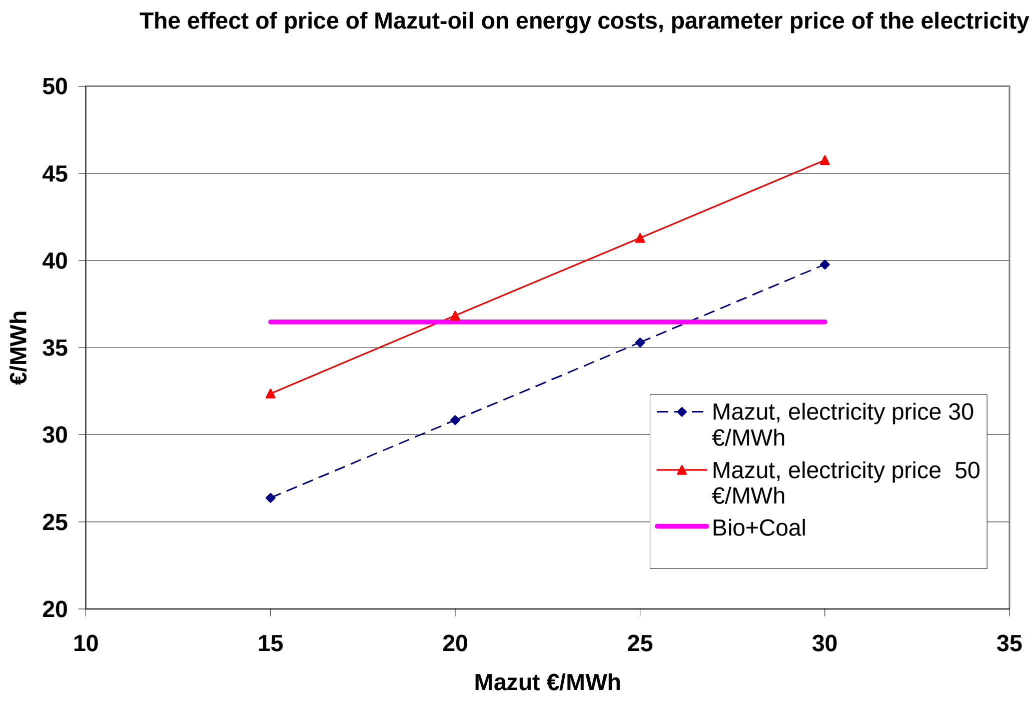


Figure 20. The effect of the price of Mazut oil on energy costs, parameter price of electricity, investment costs 140 million €, biomass price 13 €/MWh and coal price 7 €/MWh

5.6 Flue gas emissions

Table 22 shows the expected levels of gaseous emissions of a combined biomass and coal boiler. Emissions from a heavy fuel oil boiler with the same heat output are presented for comparison. It is assumed that the efficiency of an old oil fired boiler is 80 %, being somewhat lower than that of a combined biomass and coal fired boiler based on fact that existing boilers represent old boiler plant technology.

Table 22. Gaseous emissions of a co-fired biomass and coal and oil fired boilers.

Emissions	Specific emissions, mg/MJ		Annual emissions, tons	
	Biomass and coal	Oil	Biomass and coal	Oil
NO_X	110	115	360	300
SO_2	450	1500	900	4500
CO	90	100	290	260
Particle emissions	10	30	35	65
CO_2, g/MJ	72	80	235 000	205 000

It is assumed that there are no CO_2 emissions associated with wood combustion. This is not strictly true since there will be some CO_2 emissions due to fuel handling, transportation, etc. These emissions, however, are very low and no CO_2 emissions are therefore a good estimate.

From Table 22 we can notice that SO_2-emissions will be reduced remarkably. If we take the emissions from electricity generation in Russia into account, also the CO_2-emissions will be reduced. In Russia two thirds of electricity is produced with fossil fuels, 60 % of which is produced using natural gas and the rest with coal. Locally other gaseous emissions will stay at the same level as nowadays. Particle emissions will be reduced because of the efficient dust separator of a fluidized bed boiler.

5.7 Energy production costs using peat and biomass

As shown in Table 20 the peat resources in Karelia are quite huge. It was estimated that the price of peat is on the same level as in Finland, 9 €/MWh. In Russia the salary costs are lower than in Finland, but the average transport distance is quite long, more than 150 km. The weather conditions in Kostomukshsky region are also worse than on average in Finland which means there should be more peat land to produce the same quantity of peat.

If the peat replaces coal the average fuel costs would increase with 1.2 €/MWh when share of biomass fuels is about 40 % of total fuel energy. When the efficiency of the boiler is included the increment in energy production costs is 1.4 €/MWh.

Utilization of peat has following advantages:

- peat is local fuel,

- peat creates work opportunities for local people and

- peat use instead of coal decreases CO_2-emissions because the quality of coal is not good.

5.8 Direct employment effects of using local fuels in Kostomuksha

Table 23 shows estimates of direct employment effects if local fuels (wood and peat) would be utilized in the studied power plant in Kostomuksha town. The direct employment effects of wood and peat production would be 145 man-years. The direct employment effect of fuel at the power plant would be 46 man-years. All together the direct employment effects of wood and peat production and use would be about 191 man-years. The total employment effect (direct and indirect effects) would be 1.5 – 2.0 times higher than the direct employment effects. In the calculation the transport costs are not included in the figures. The presented employment effects are based on the study made in Finland (Halonen et al. 2003).

Table 23. The direct employment effects of wood and peat fuel production in Kostomuksha region.

Fuel	Fuel use, GWh	MWh/Man-year	Man-years in Kostomuksha
Forest chips	358	4 370	82
Peat	549	8 840	63

6 Conclusions

Current energy production in Kostomuksha

In Kostomuksha the energy system consists of a boiler house situated near the iron pellet mill owned by JSC Karelskij Okatysh (KO) and the heat transmission and distribution systems for the iron pellet mill and for the town of Kostomuksha. All heat is produced in the boiler house. Heat is distributed by KO for the iron mill premises and to some industrial customers.

There is no electricity production in Kostomuksha site. The iron pellet mill uses 1.6 – 1.7 TWh electricity annually. This means that 180 – 200 MW_e electric power is used on average. Annual total energy production was 743 GWh (2007), meaning 85 MW_{th} of average power. The annual amount of distributed heat and steam was 708 MW in 2007.

Potential of wood and peat biomass

The techno-economic forest fuel potential from the actual cut in the Kostomukshsky, Kalevalsky, Yushkozersky and Muyezersky forest districts is 179 100 m^3 (358 GWh) and from the allowable cut 280 000 m^3 (560 GWh). The wood fuel potential is assumed to come totally from final fellings.

The peat resources in Kalevala, Muezersky and Kostomukshsky administrative districts are remarkable. The total peat resources suitable for peat production are altogether 326 TWh. The main share (87 %) of the peat resources is located in Kalevalsky administrative district.

Logging residue chips production

The chipping on the roadside -method of logging residues chips has slightly the lowest procurement costs. Also the crushing at the power plant is very competitive method especially in short distances (< 45 km). The average road transporting distance for utilizing all available energy wood in the area is 118 km. If it is assumed that all energy wood is procured with chipping on the roadside method, the weighted average procurement cost of the fuel delivered at plant is 12.6 €/MWh.

In the roadside method the logging residues are transported to the roadside there it is stored. The logging residues are chipped at the roadside directly into a truck trailer and then transported to the power plant.

The biomass plant in the study

CHP-plant producing 100 MW_{th} heat and 40 MW_e electricity was assessed in the study. The fuel power of the boiler is about 159 MW. The annual fuel demand will be 907 GWh. The available wood fuel resources in the area are only 358 GWh. The share of wood fuel would be about 40 % of the total fuel need in the power plant. In the study the rest 60 % (548 GWh) of the fuel would be either coal or peat.

Energy production cost in biomass-coal fired plant

The energy production costs of combined biomass and coal fired boiler are more higher (37 €/MWh) than those of an oil fired boiler (27 €/MWh) when also the purchasing of electricity is included. Main reasons are that the price of the Mazut oil is very low and so is the price of electricity. If the price of Mazut oil (15 €/MWh) would double, the new boiler plant would be economical. In the study the investment costs for a combined biomass and coal fired plant are 140 Milj. €, the wood biomass price is 13 €/MWh and coal price 7 €/MWh. The electricity price is 30 €/MWh.

Biomass fuel plant

Peat resources in the district nearby Kostomuksha are remarkable. If the peat replaces coal the average energy costs will increase with 1.4 €/MWh. There are some benefits to use peat instead of coal. Peat is a local fuel and gives work opportunities for the local people.

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Appendix 1

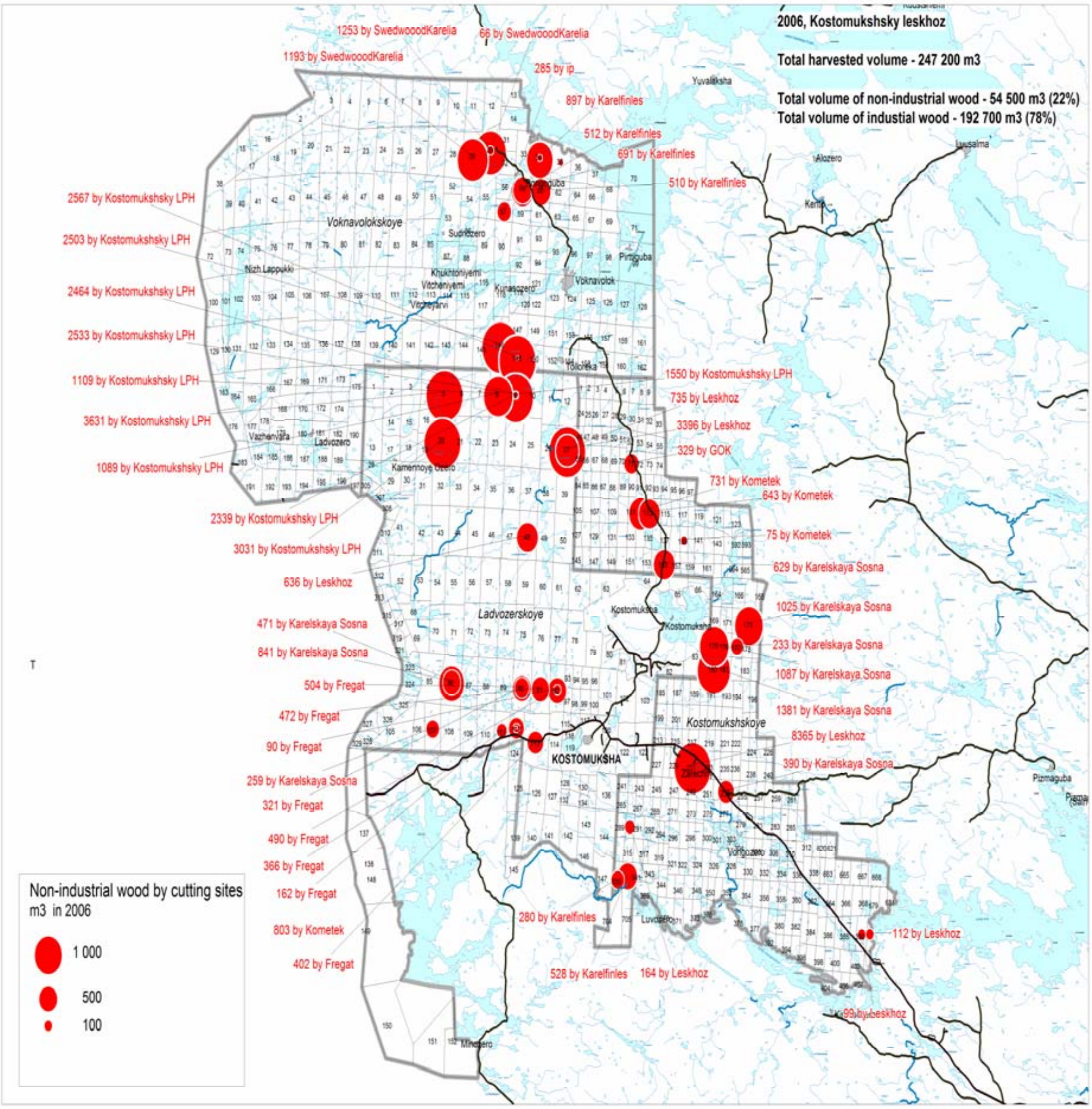

Figure 1. The cutting sites and total volume of non-industrial wood in 2006 in the Kostomukshsky forest district (leskhoz).

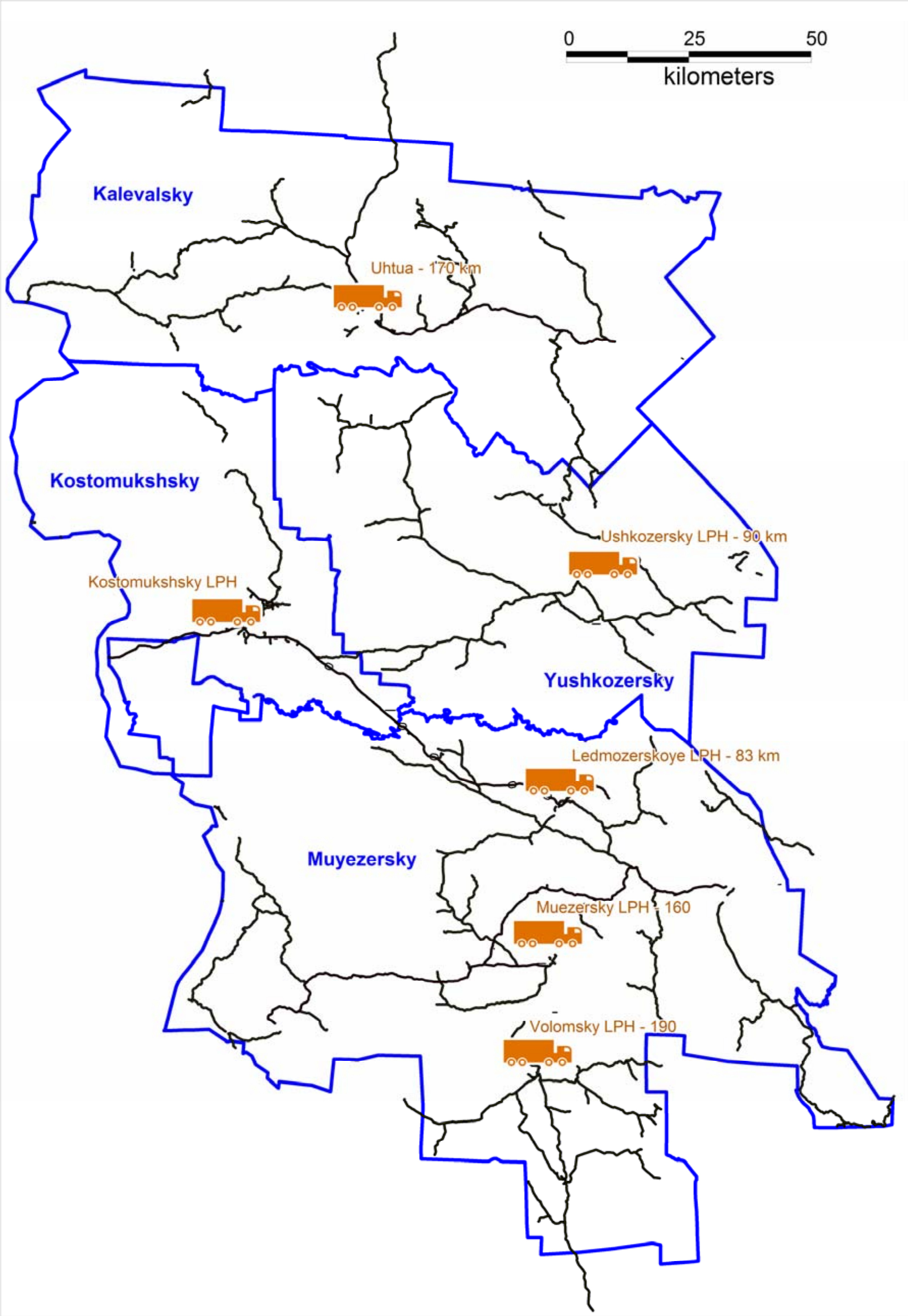

Figure 2. Average road transport distances from different logging company operation headquarters to Kostomuksha.